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

Mohammad Zahirul Islam[1], Mahmuda Akter Mele[1], Han Jong Lee[1], Kyoung Soo Lee[1], Sung Mi Hong[1], Min Jae Jeong[1], Il-Seop Kim[1], Soon-Kwan Hong[2], In-Lee Choi[1,3], Jun Pill Baek[1,3], and Ho-Min Kang[1,3]*

[1]*Department of Horticulture, Kangwon National University, Chuncheon 200-701, Korea*
[2]*Department of Bio-Health Technology, Kangwon National University, Chuncheon 200-701, Korea*
[3]*Agriculture 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/m^2.day.atm O_2 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 O_2 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/m^2.day.atm O_2 permeability film; for 24°C it is 40,000cc/m^2.day.atm O_2 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 O_2 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.

*Corresponding author: hominkang@kangwon.ac.kr
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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 × 8.2cm × 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 × 0.25mm × 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-

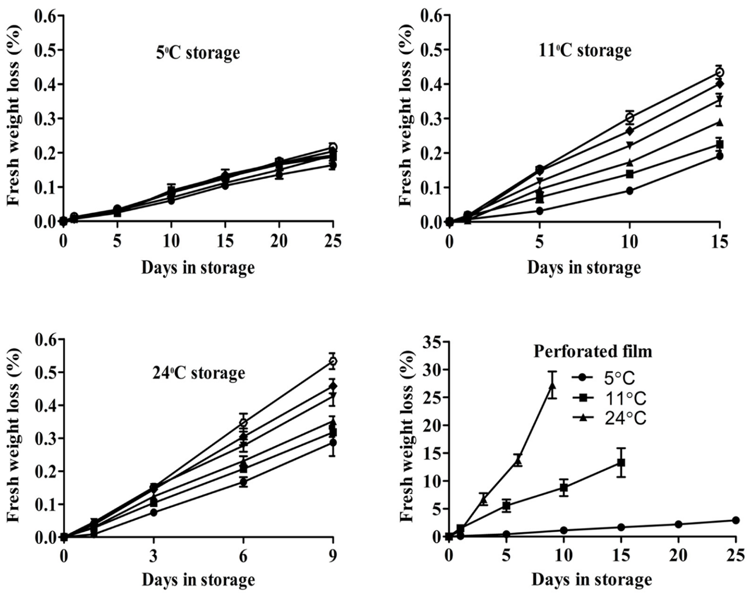

Fig. 1. Changes of fresh weight loss (%) of tomatoes at 5°C, 11°C, and 24°C storage temperature (●:10,000; ■:20,000; ▲:40,000; ▼:60,000; ◆:80,000; ○:$100,000cc/m^2$.day .atm O_2 permeability film and perforated film). Vertical bars represent ± SE of mean (n = 4).

ity, and vitamin C were performed by SPSS V.16 (SPSS Inc., Chicago, USA). Significant differences between mean values were determined using the Duncan's Multiple Range Test ($P = 0.05$) following one-way ANOVA.

Results and Discussion

The highest and the lowest fresh weight loss shown by perforated film and 10,000cc/m^2.day.atm O_2 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 overlaped 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 film proved the best visual quality at 5°C and 11°C. The utmost visible quality performed by the 40,000cc film, whereas the minutest visual quality was presented with the 10,000cc film at 24°C (Fig. 2). The visual quality exhibited more days at 5°C, followed by 11°C, and 24°C. The MAP helps to maintain the visual quality of fresh cut tomato (Gill et al., 2002). The visual quality as well as shelf life of perforated film showed the worst in all storage temperatures than MAP because more fresh weight loss and shriveling.

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) (Guan 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

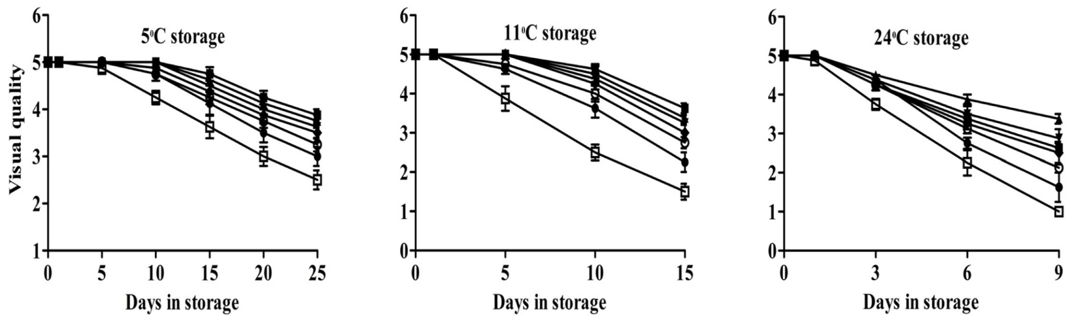

Fig. 2. Changes of visual quality of tomatoes at 5°C, 11°C, and 24°C storage temperature (□: perforated film, ●:10,000; ■:20,000; ▲:40,000; ▼:60,000; ◆:80,000; ○:100,000 cc/m^2.day.atm O_2 permeability film). Visual quality scores were 5: excellent, 4: very good, 3: good, marketable, 2: bad, 1: waste. Vertical bars represent ± SE of mean (n=4).

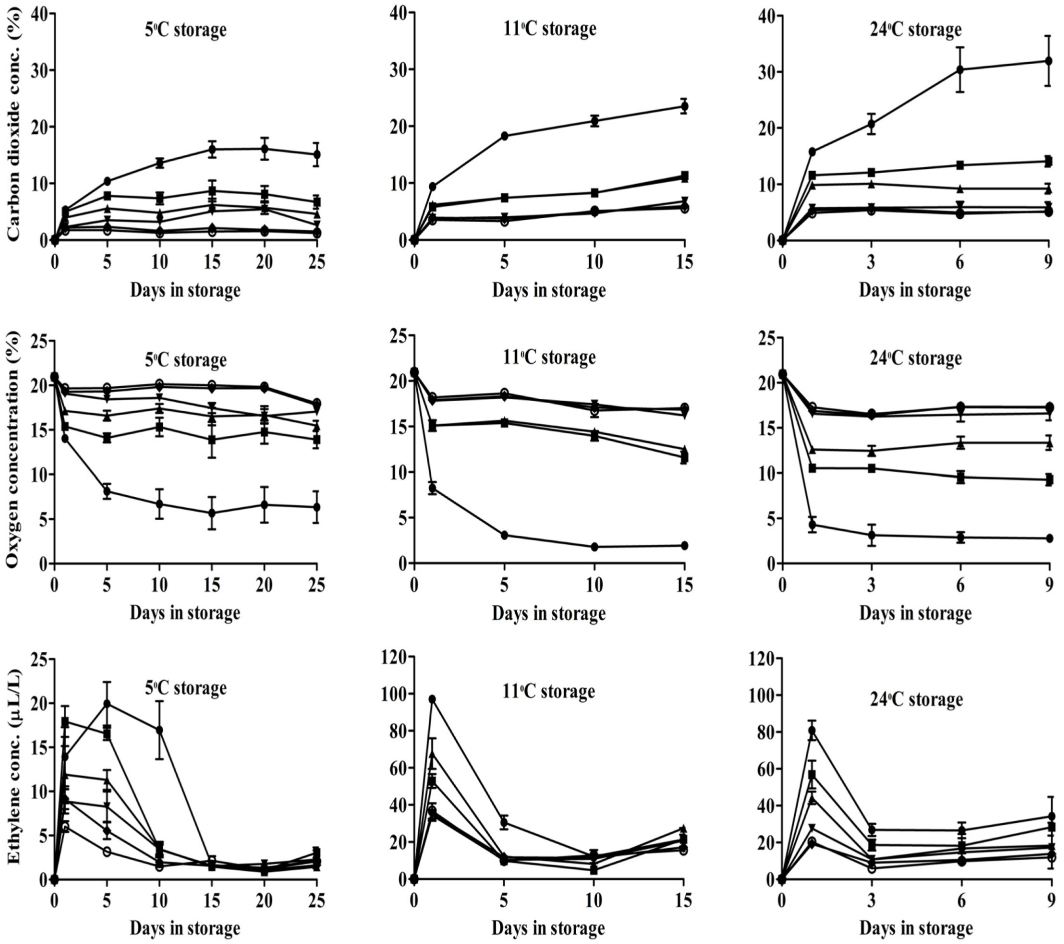

Fig. 3. Changes of carbon dioxide concentration (%), oxygen concentration (%), and ethylene concentration (μL/L) of tomatoes at 5°C, 11°C, and 24°C storage temperature (●:10,000; ■:20,000; ▲:40,000; ▼:60,000; ◆:80,000; ○:100,000 cc/m^2.day.atm O_2 permeability film). Vertical bars represent ± SE of mean (n=4).

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

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/m^2.day.atm O_2 permeability film).

	Firmness (N)			Soluble solids (°Brix)			Titratable acidity (% citric acid)			Vitamin C contents (mg/100gFW)		
Storage tempts.	5°C (25days)	11°C (15days)	24°C (9days)	5°C (25days)	11°C (15days)	24°C (9days)	5°C (25days)	11°C (15days)	24°C (9days)	5°C (25days)	11°C (15days)	24°C (9days)
Initial	21.59 ± 1.75			6.33 ± 0.08			0.61 ± 0.02			24.89 ± 0.69		
Perforated film	11.35b^z	16.05a	12.69c	7.08abc	6.85a	7.39a	0.63a	0.36ab	0.44ab	7.33b	7.13a	9.47a
10,000cc	10.76b	15.19a	13.90bc	7.07abc	6.51abc	5.87bc	0.57ab	0.38a	0.38ab	9.43a	9.13a	9.53a
20,000cc	13.26a	18.07a	16.78ab	7.25a	6.77ab	5.99bc	0.49b	0.36ab	0.30b	7.87ab	9.10a	9.83a
40,000cc	10.89b	17.29a	18.55a	7.20ab	6.54abc	6.24b	0.49b	0.29b	0.46a	8.30ab	8.93a	9.73a
60,000cc	10.04b	16.09a	17.33ab	6.73cd	6.42bc	6.02bc	0.54ab	0.30ab	0.36ab	6.87b	7.07a	9.13a
80,000cc	9.76b	16.72a	16.03bc	6.56d	6.37c	5.79bc	0.45b	0.34ab	0.42ab	8.73ab	9.10a	9.53a
100,000cc	9.50b	16.43a	15.29bc	6.51d	6.27c	5.55c	0.53ab	0.29b	0.35ab	8.33ab	8.33a	9.40a

^{Z}Mean separation within columns by Duncan's multiple range tests at $P < 0.05$.
Initial value indicated mean ± SE.

5°C than 11°C on the final storage day (Islam et al., 2012). Islam 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, O_2 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.

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방울토마토의 MA 저장성 향상을 위한 비천공 breathable 필름 구명

이슬람 모하메드 조히룰[1] · 밀리 마하무다 악터[1] · 이한종[1] · 이경수[1] · 홍성미[1] · 정민재[1] · 김일섭[1]
홍순관[2] · 최인이[1,3] · 백준필[3] · 강호민[1,3]*

[1]강원대학교 원예학과, [2]강원대학교 생명건강공학과, [3]강원대학교 농업생명과학연구원

적 요. 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°C, 11°C, 그리고 24°C에서 산소투과도가 각기 다른 비천공 breathable 필름(10,000; 20,000; 40,000; 60,000; 80,000; 100,000 cc/m^2.day.atm)과 천공필름으로 포장하여 저장하였다. 저장 중 생체중 감소율은 세가지 온도 모두에서 모든 비천공 breathable 필름처리구에서는 0.6%미만이었으나, 천공필름은 5°C는 2.93%, 11°C는 13.29%, 그리고 24°C에서는 27.24%에 달하였다. 포장내 이산화탄소와 산소 농도를 볼 때 5°C와 11°C에서 20,000 cc 필름, 24°C에서 40,000 cc 필름이 MA 조건에 근접한 수치를 보였다. 에틸렌 농도는 산소투과도가 가장 낮은 10,000 cc에서 모든 온도에서 가장 높았다. 저장 중 외관상 품질과 최종일에 측정한 경도와 당도는 5°C와 11°C의 20,000 cc 필름, 24°C의 40,000 cc 필름이 높은 수치를 나타내었다. 그러나 산도와 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°C와 11°C에서 20,000 cc 필름, 24°C에서는 40,000 cc 필름이 적합하였다.

추가 주제어 : 경도, 당도, 비타민 C, 외관 품질