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Effect of Temperature on the Quality and Storability of Cherry Tomato during Commercial Handling Condition

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Abstract. This study was carried out in order to investigate the effect of temperature of treatment and storage on the longevity of 'Unicorn' tomatoes of light red maturity stage during commercial handling conditions encountered while exporting over long distances. Tomato stored at 5°C and 11°C temperature with 85% relative humidity by pre-treating handling temperature that was using from field to before shipment as a winter temperature 5°C, spring temperature 11°C and summer temperature 25°C for 3 days. On the final storage day, 25°C/11°C (treated/stored) tomatoes showed the highest respiration and ethylene production rate; whereas the lowest respiration and ethylene production rate was found for 5°C/5°C treated and stored tomatoes. Tomatoes treated and stored at 5°C/5°C showed higher marketability, without evidence of fungal rot, decay or spots for 23 days. The fresh weight loss under all treatment conditions increased gradually during 5°C and 11°C storage temperatures. The higher firmness and soluble solids were determined from 5°C/5°C and 5°C/11°C treated and stored tomatoes repectively, than from others tomatoes on the final day of storage. In addition, 5°C/5°C tomatoes showed higher vitamin C contents than tomatoes stored at other temperatures, on the final day of storage. As the ripening and storage period progressed, the titratable acidity increased, but declined ($P < 0.05$) thereafter, due to over ripe tomatoes under all treatment conditions. These results show that 5°C/5°C treated and stored light red maturity stages of 'Unicorn' tomatoes are optimum to export because they show the highest storability and marketability. Moreover, the marketability of light red maturity stage of 'Unicorn' tomato maintained for 2 weeks in 25°C/11°C treated and stored temperature that might be the export temperature from Korea to Japan in summer season. This research result could be useful in helping tomato growers and exporters to get optimum market value by satisfying the buyer and consumer with a fresher product.

Key words : handling condition, tomato export, tomato quality, tomato storability

Introduction

The shelf life of tomatoes is very short under ambient conditions due to a high perishability. After harvesting tomatoes, quality deterioration begins by emitting gaseous compounds (carbon dioxide & ethylene), reducing physical properties (visual quality, weight and firmness), and chemical properties (vitamin C, soluble solids, titratable acidity). It mainly happens through inadequate storage facilities, and due to enzymatic activities. As a result, growers and/or exporters, wholesaler, retailer as well as nations incur heavy losses in revenue. Temperature is an important factor tomato to maintain postharvest quality and storability. At lower temperatures ripening is slowed; at temperatures over 27°C, bacterial growth and rotting may be accelerated, and above 30°C ripening may be inhibited (Kader, 2002). Polderdijk et al. (1993) showed that a temperature of 12°C is considered to be safe for storage for tomatoes. Znidarcic and Pozrl (2006) reported that tomatoes can be stored at ambient temperatures for periods of up to 7 days. However, longer period ripe tomatoes can be stored at a temperature of 10~15°C and 85~95% relative humidity (Castro et al., 2005).

Roberts et al. (2002) reported that during typical commercial handling, commodities are often shipped in mixed loads, meaning that shipping temperatures may be 5°C or lower, well below recommended temperatures for many crops, including tomatoes. Storage and ripening recommendations for tomatoes are well known, but quality

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problems associated with poor temperature management continue to occur during distribution (Cantwell et al., 2009). At the market interface, only produce that corresponds to the expectations of the consumer is acceptable (Tzortzakis et al., 2007). Consumers increasingly desire high quality (visual and nutritional) tomatoes for a longer market period, within convenient prices in both domestic as well as export markets. It is important to understand the growers and/or exporters, wholesaler, retailer as well as consumer's desire for quality throughout the commercial handling period. So, researchers should establish an optimum condition to reduce water loss, delay softening and extend shelf life, so as to not only prevent postharvest losses, but also generate additional revenue. The study was carried out to investigate the effect of temperature on the quality and storability of light red maturity stage of 'Unicorn' tomatoes during commercial handling when exporting over long distances.

Materials and Methods

Hydroponics grown light red maturity stage of fresh consumed tomatoes (*Lycopersicon esculentum* Mill. cv 'Unicorn') were harvested, washed and rinsed in chlorinated water (0.015% NaOCl), and stored at 5°C and 11°C with 85% relative humidity by pre-treating handling temperature that was using from field to before shipment as a winter temperature 5°C, spring temperature 11°C and summer temperature 25°C for 3 days.

Carbon dioxide concentration was measured by PBI Dan sensor (Check Mate 9900) and ethylene concentration was measured by GC (2010 Shimadzu) equipped with a wax column and a flame ionization detector (FID). The detector and injector operate at 127°C, oven was 50°C, and carrier gas (N_2) flow rate was 0.67 mL/s (Park et al., 2000). Two fruit per replicate of light red maturity stage were placed into a sealed 125 mL plastic container for 6 h. A 1 mL sample of the head space was withdrawn using a syringe, to measure the ethylene concentration. The percentage of marketability was subjectively assessed on fruits based on visual quality determinants likes mould growth, decay, shriveling, smoothness, shininess and homogeneity. Marketability was observed on a scale of 1 to 100 (01~39 = very bad, 40~59 = bad, 60~79 = good (marketable), 80~99 = very good, and 100 = excellent) during 5°C and 11°C storage. Five panel members were employed to assess the marketability of the tomatoes. 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. Firmness was measured using a Rheo meter (Sun Scientific Co. Ltd., Japan) with a maximum force of 10 kg and a 6 mm diameter round stainless steel probe with a flat end. During measurement, tomatoes were placed on a plastic ring to keep upright. Penetrating force (N) through the skin of the tomatoes flesh and deformation (mm) values were recorded. Vitamin C was measured by RQflex plus (Merck, Germany) with mg/100 g FW (Arvanitoyannis et al., 2005). Soluble solids was measured by Refractometer (Atago U.S.A. Inc., U.S.A.) and results were read directly in °Brix. The titratable acidity was measured by DL 22 Food & Beverage Analyzer (Metter Toledo Ltd., Korea), and results were reported as mg/g citric acid.

1. Statistical analysis

Graphs were produced using SigmaPlot 10 (Systat Software, Inc., USA) and statistic analyses were performed by SPSS V.18 (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

During postharvest handling temperatures (5°C, 11°C, and 25°C) treated period (0~3 days), the respiration rate was significantly decreased ($P < 0.05$). As the storage period (4~28 days) progressed, respiration rates were increased until the 23rd day, and significantly decreased ($P < 0.05$) thereafter. The highest to lowest respiration rates were produced by 25°C/11°C and 5°C/5°C tomatoes during storage period, respectively. As temperature as well as respiration rate increase, the fruit quality decreases. Respiration rate is one of the most important indicators of senescence in tomatoes, as are weight loss, pigment content, firmness and ethylene production (Meir et al., 1992). Hardenburg et al. (1986) reported that the respiration rate of mature green tomatoes increased by 100% when stored at 25 to 27°C compared to storage at

0°C. As assessing respiration rates during storage is beneficial to maintain quality (Wareham and Persaud, 1999), 5°C/5°C tomato treatment, and storage is appropriate because of lower respiration rates.

The ethylene production rate (8.28 μLC2H4/kg/h) of initial day was in agreement with Kader (2002) that tomatoes produce 1.0~10.0 μLC2H4/kg/h at 20°C. Burg (2004) reported that the optimal temperature for ethylene production by tomatoes tissue is 27°C. Higher temperatures produce higher ethylene production rates than lower temperatures. Until the 13th day the ethylene production rate was significantly decreased ($P < 0.05$) at different treatment and storage temperatures, and thereafter ethylene production rates increased and quality decreased. Due to concerns that naturally produced ethylene from the fruit delays ripening (Krishnamoorthy, 1982), 5°C/5°C tomato treatment, and storage is appropriate because of lower ethylene production rates.

It may be possible to extend tomato storability by lowering the respiration and ethylene production rates after harvesting, by taking appropriate action at the store house, during transportation, in port, at distribution period, in super market/outlet, in wholesale/retail shop and in the refrigerator. Our results agreed with those of Workneh and Osthoff (2010), in that ethylene was found to increase significantly with an increase in respiration rates in climacteric fruit, increasing the ripening process. In addition, our results also agreed with Krishnamoorthy (1982), that a rise in respiration rate is accompanied by increased ethylene production.

As storage period progressed, the fresh weight loss was significantly increased. Not only did different temperatures show different fresh weight losses, but results were almost linear (Fig. 2, left). 25°C/11°C treated and stored tomatoes showed higher fresh weight loss than other lower temperatures. Until the final storage day, our result did not exceed the maximum permissible weight loss 7% (Kays and Paull, 2004). During the storage period at 5°C/5°C, 5°C/11°C and 11°C/5°C, 11°C/11°C, the fresh weight loss did not influence the fruit appearance due to controlled humidity. It has been found that storage duration, storage temperature and treatment have significant effects on weight loss (Javanmardi and Kubota, 2006) because higher temperatures and longer storage times showed higher transpiration than lower temperatures and shorter times.

The marketability of light red maturity stage of 'Unicorn' tomatoes, were maintained for 2 weeks under 25°C/11°C conditions, which might be the export temperature from Korea to Japan during the summer season. In contrast, 5°C/5°C, 5°C/11°C, 11°C/5°C, 11°C/11°C tomatoes remained marketable for 3 weeks. All tomatoes had 100% marketability until the 8th day except for 5°C/5°C, 11°C/11°C and 25°C/11°C tomatoes, which showed 1~2% reduction. In light red tomatoes, 5°C/5°C treated tomatoes showed the highest marketability (60%) on the 23rd day. Cantwell et al. (2009) reported that at 5°C and 10°C, near ripe grape tomatoes remained of marketable quality for 18 and 12 days, respectively. Our results agreed with those of Roberts et al. (2002) in that no decay occurred from any treatments during ripening and storage for several days beyond the light red (red-ripe) maturity stage. In addition, there was no visible evidence of chilling injury (uneven color development) due

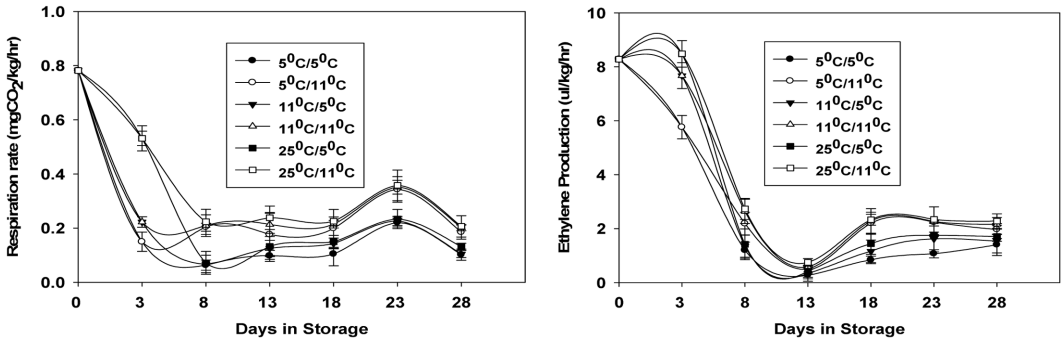

Fig. 1. The respiration rate and ethylene production rate of 'Unicorn' tomato at different treated (5°C, 11°C and 25°C for 0~3 days) and storage temperature (5°C and 11°C for 4~28 days). Vertical bars represent ± SD of means (n = 5).

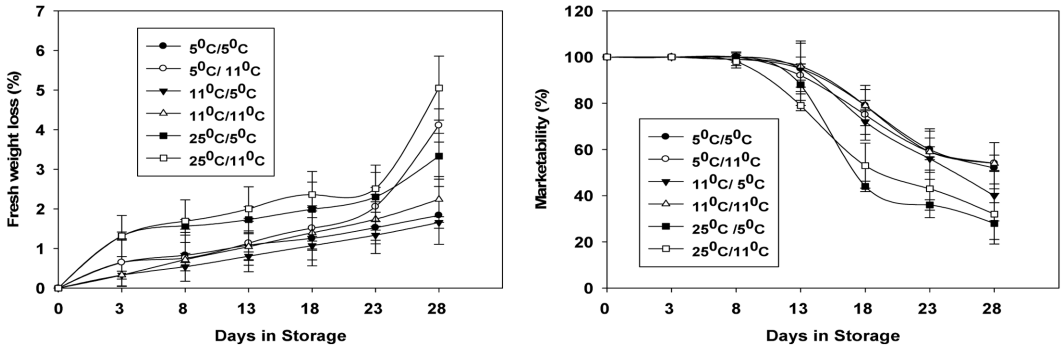

Fig. 2. The Fresh weight loss (%) and marketability (%) of Unicorn tomato at different treated (5°C, 11°C and 25°C for 0~3 days) and storage temperature (5°C and 11°C for 4~28 days). Marketability was scored on the scale of 1 to 100 (01~39 = very bad, 40~59 = bad, 60~79 = good, marketable, 80~99 = very good, and 100 = excellent) during storage period. Vertical bars represent ± SD of means (n = 5).

to treatment and storage at low temperatures for the light red maturity stage.

Firmness is an important aspect of fresh tomato quality and it decreases over time (Islam et al., 2011). It is primarily dependant on the storage temperature. As firmness is closely associated with the ripeness stage of the tomato (Kader, 1986), as ripeness and storage progressed, firmness significantly decreased ($P < 0.05$). High temperature treated tomatoes showed lower firmness, whereas low temperature treated tomatoes showed higher firmness. During 18 days of storage, the tomatoes of lowest firmness were those treated at 5°C/5°C, decreasing by almost 29% over the next 28. Moreover, the firmness of tomatoes treated at 25°C/11°C decreased by around 40%, and 28 days later, by around 43%. Our results agreed with Roberts et al. (2002) in that higher storage temperatures caused more rapid senescence. However, on the 23rd day our results showed the minimum acceptable firmness (16.82 N) was determined for 5°C/5°C tomatoes. If the firmness value of tomatoes is below this minimum acceptable value, they are very difficult to market.

During the postharvest handling temperature treatment period (0~3 days) the vitamin C content significantly decreased ($P < 0.05$) under all treatment conditions. For higher temperature treated tomatoes, the vitamin C losses were higher than for lower temperature treated tomatoes. As storage period and ripening progressed, vitamin C increased and significantly decreased ($P < 0.05$) thereafter under all treatment conditions. Our results agreed with those of Dalal et al. (1965) that an increase in ascorbic acid content took place with ripening, with either a continuing rise or a slight fall during the final stages of ripening. On the final day of storage, 5°C/5°C tomatoes showed higher vitamin C than other tomatoes. As vita-

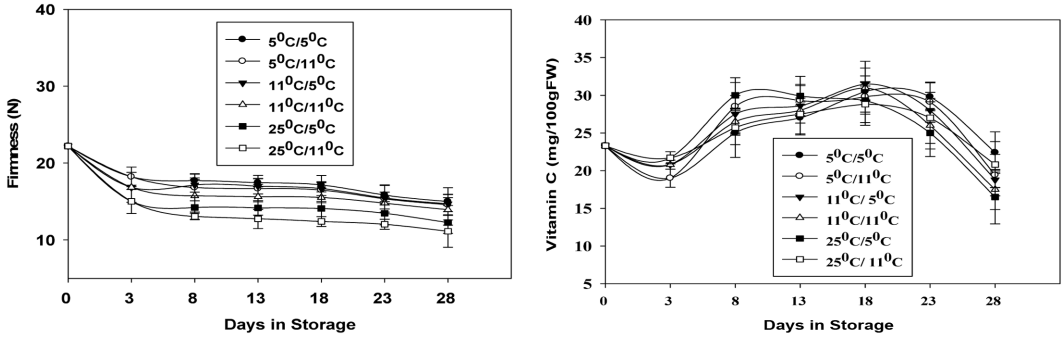

Fig. 3. The firmness and vitamin C of 'Unicorn' tomato at different treated (5°C, 11°C and 25°C for 0~3 days) and storage temperature (5°C and 11°C for 4~28 days). Vertical bars represent ± SD of means (n = 5).

min C losses are accelerated at higher temperatures (Lee and Kader, 2000) 11°C/11°C tomatoes showed about 22% more loss than 5°C/5°C tomatoes on the 28th day.

During the treated period (0~3 days) all tomatoes showed a sharp reduction in soluble solids, but it did not show any differentiation between higher and lower temperature effects. It was found that as the ripening and storage period progressed, soluble solids increased over a certain period, and decreased significantly ($P < 0.05$) afterwards for all tomatoes except 25°C/5°C and 11°C/5°C. However, 25°C/5°C and 11°C/5°C tomatoes, soluble solids significantly increased during the storage period. The highest soluble solids were observed in 5°C/11°C tomatoes followed by 5°C/5°C, 25°C/5°C, 11°C/5°C, 25°C/11°C, and 11°C/11°C, respectively, on the final day of storage. Our results are in agreement with those of Javanmardi and Kubota (2006) in that no significant changes in soluble solids for both room (25°C) and low (5°C) temperature treated tomatoes occurred up to the 3rd day. A previous report had indicated that total sugar levels showed a general increase, followed by stability, or a slight decrease during ripening (Baldwin et al., 1991), though our different temperatures showed a similar effect during the postharvest ripening and storage period.

During the treated period (0~3 days), 5°C treated tomatoes showed a higher citric acid content than others, and significantly decreased ($P < 0.05$) under all treatment conditions. The highest and lowest acidity value was recorded in 5°C/5°C and 11°C/11°C tomatoes, respectively, on the final storage day. Moreover, 11°C/11°C tomatoes showed about 18% more loss in titratable acidity than 5°C/5°C tomatoes on the 28th day. During the storage period (4~28 days) under all treatment conditions, titratable acidity increased gradually over a certain period, and declined ($P < 0.05$) thereafter. So, our result agreed with those of Castro et al. (2005) which reported titratable acidity of tomatoes during ripening and storage to slightly increase, and decrease afterwards. The titratable acidity content of 5°C/11°C, and 25°C/5°C tomatoes were fairly constant at 28th day. As sourness highly correlated with titratable acidity (Stevens et al., 1979), the lower titratable acidity content showed higher sweetness than higher titratable acidity contents.

During the treated period (0~3 days), 11°C treated tomatoes showed higher sugar/acid ratio. The sugar/acid ratio was higher due to increased sugar and decreased acid contents during the treatment and storage period. On the final day of storage, 5°C/11°C tomatoes showed higher

Table 1. The soluble solids (°Brix) of different treated (5°C, 11°C and 25°C for 0~3 days) and storage temperatures (5°C and 11°C for 4~28 days) of 'Unicorn' tomato.

Treatment	Initial	3 day	8 day	13 day	18 day	23 day	28 day
5°C/5°C	6.80^{az}	5.75^{a}	6.15^{ab}	6.93^{c}	7.07^{d}	7.03^{b}	6.93^{cd}
5°C/11°C	6.80^{a}	5.75^{a}	6.28^{b}	6.90^{c}	7.15^{d}	7.13^{b}	7.00^{d}
11°C/5°C	6.80^{a}	5.90^{a}	6.00^{a}	6.48^{a}	6.52^{a}	6.70^{a}	6.80^{c}
11°C/11°C	6.80^{a}	5.90^{a}	6.46^{c}	6.68^{b}	6.80^{bc}	6.57^{a}	6.30^{a}
25°C/5°C	6.80^{a}	5.70^{a}	6.08^{a}	6.60^{ab}	6.63^{ab}	6.65^{a}	6.85^{cd}
25°C/11°C	6.80^{a}	5.70^{a}	6.30^{b}	6.60^{ab}	6.85^{c}	6.60^{a}	6.33^{b}

^{z}Mean separation within columns by Duncan's multiple range test at $P < 0.05$.

Table 2. The titratable acidity (mg/g citric acid) of different treated (5°C, 11°C and 25°C for 0~3 days) and storage temperatures (5°C and 11°C for 4~28 days) of 'Unicorn' tomato.

Treatment	Initial	3 day	8 day	13 day	18 day	23 day	28 day
5°C/5°C	0.38^{az}	0.32^{a}	0.40^{c}	0.42^{b}	0.42^{a}	0.54^{c}	0.38^{b}
5°C/11°C	0.38^{a}	0.32^{a}	0.38^{bc}	0.43^{b}	0.45^{a}	0.53^{bc}	0.33^{ab}
11°C/5°C	0.38^{a}	0.30^{a}	0.30^{a}	0.37^{ab}	0.44^{a}	0.41^{a}	0.36^{ab}
11°C/11°C	0.38^{a}	0.30^{a}	0.33^{a}	0.38^{ab}	0.42^{a}	0.50^{abc}	0.31^{ab}
25°C/5°C	0.38^{a}	0.30^{a}	0.34^{ab}	0.43^{b}	0.48^{a}	0.53^{bc}	0.33^{a}
25°C/11°C	0.38^{a}	0.30^{a}	0.32^{a}	0.36^{a}	0.47^{a}	0.43^{ab}	0.36^{ab}

^{z}Mean separation within columns by Duncan's multiple range test at $P < 0.05$.

Table 3. The sugar/acid ratio of different treated (5ºC, 11ºC and 25ºC for 0~3 days) and storage temperatures (5ºC and 11ºC for 4~28 days) of 'Unicorn' tomato.

Treatment	Initial	3 day	8 day	13 day	18 day	23 day	28 day
5ºC/5ºC	17.89[az]	17.97[a]	15.38[a]	16.50[c]	16.83[f]	13.02[b]	18.24[b]
5ºC/11ºC	17.89[a]	17.97[a]	16.53[b]	16.05[b]	15.89[d]	13.45[d]	21.21[f]
11ºC/5ºC	17.89[a]	19.67[c]	20.00[f]	17.51[d]	14.82[c]	16.34[f]	18.89[c]
11ºC/11ºC	17.89[a]	19.67[c]	19.58[d]	17.58[e]	16.19[e]	13.14[c]	20.32[d]
25ºC/5ºC	17.89[a]	19.00[b]	17.88[c]	15.35[a]	13.81[a]	12.55[a]	20.76[e]
25ºC/11ºC	17.89[a]	19.00[b]	19.69[e]	18.33[e]	14.57[b]	15.35[e]	17.58[a]

[Z]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.

sugar/acid ratios whereas 25ºC/11ºC tomatoes showed lower (P <0 .05) sugar/acid ratios. As storage time and ripening progressed, sugar/acid ratios generally increased. However, our result agreed with those of Mohammed et al. (1999) in that there was a general increase in the sugar/acid ratio in each group, as storage time advanced.

Before exporting tomatoes, growers and/or exporters must confirm the appropriate handling temperature for optimum longevity. If there is a loss in quality, marketability will decrease. It is recommended that after harvesting until before exporting, the tomatoes growers and/or exporters can keep their tomatoes under appropriate temperatures for long distance exports. The light red maturity stage of 'Unicorn' tomato at 5ºC treated at the store house, during transport, and at sea/air port, and 5ºC storage temperatures from the port onwards are appropriate for long distance export because of the higher storability and marketability. Therefore, the findings of this work should be useful in helping to tomatoes growers and/or exporters to export their tomatoes different countries by using appropriate temperatures.

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유통중 온도관리가 방울토마토의 품질과 저장성에 미치는 영향

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적 요. 본 연구는 방울토마토 장거리 수출을 위한 적정 유통저장 조건을 확립하기 위하여, 온도관리가 방울토마토의 품질과 저장성에 미치는 영향에 따른 외관상 품질변화와 저장성에 미치는 영향에 대해 알아보고자 연구를 진행하였다. 소과종인 '유니콘' 품종을 대상으로, 저장 전 3일간 각각 5, 11, 25ºC에서 저장한 후, 각각 5ºC와 11ºC에서 25일간 저장하였다. 저장온도는 봄, 여름, 겨울철 외부 평균온도에 준하여 설정하였다. 저장 최종일에 25ºC/11ºC(저장 전 온도/저장온도) 처리구에서 높은 호흡률과 에틸렌 발생량을 나타냈고, 5ºC/5ºC 처리구에서 가장 낮은 호흡률과 에틸렌 발생량을 나타냈다. 5ºC/5ºC 처리구가 가장 높은 시장성을 나타냈고, 저장 23일간 외관상 품질의 부패 현상은 나타나지 않았다. 생체중 감소율은 저장 전 5ºC와 11ºC에서 저장된 처리구에서 대체적으로 느리게 증가하였다. 저장 최종일에 5ºC/5ºC 처리구와 5ºC/11ºC 처리구가 다른 처리구보다 높은 경도와 당도를 나타냈으며, 또한 5ºC/5ºC 처리구는 다른 처리구에 비해 높은 비타민 C 농도를 나타냈다. 저장 중 과숙 되어짐에 모든 처리구에서 titratable acidity가 대체적으로 증가하였으나, 과숙이 어느 정도 진행된 후에는 오히려 감소하는 경향이 보였다. 이상의 결과로, 5ºC 3일 저장 후, 5ºC로 25일 저장하는 것이 바람직하며, 담적색기의 과실을 저장 유통하는 것이 저장성과 시장성에 적합한 것으로 판단된다. 또한 여름철 25ºC 이상의 고온에서 저장 하였음에도 11ºC에서 저장하여 2주간의 저장이 가능하여, 여름철 일본 수출조건으로 적용 가능하다. 이와 같은 조건 조건의 유통조건이 이뤄진다면, 안정적인 시장경제와 소비자들에게 보다 신선한 품질의 방울토마토를 공급하는 데에 효과적일 것으로 생각된다.

주제어 : 처리조건, 토마토 수출, 토마토 품질, 토마토 저장성