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Research article

Effect of fruit size on fruit quality, shelf life and microbial activity in cherry tomatoes

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Abstract: This study was conducted to investigate the effects of large, medium, and small fruit sizes on fruit quality, shelf life, and microbial activity in cherry tomatoes. Large (31.28 mm), medium (28.52 mm), and small (24.16 mm) tomatoes were harvested at light red maturity in Gangwon Province in the Republic of Korea. The quality of the tomatoes was measured at harvest time. Following harvest, the tomatoes were stored at 5 ℃; they were kept in boxes, acting as controls, or packed with a 20,000 cc oxygen transmission rate (OTR), acting as modified atmosphere packaging (MAP) to measure postharvest quality. The large tomatoes showed lower rates of respiration and ethylene production compared to the other sizes. The rate of fresh weight loss was the highest in the small tomatoes. A prolonged shelf life was observed in the large tomatoes. The rate of fungal incidence was lower in the large tomatoes compared with the medium and small ones. On the final day of storage, the large tomatoes retained the highest level of firmness and the concentrations of titratable acidity and vitamin C. However, the small tomatoes contained the highest level of soluble solids among the different sizes. Bacterial and fungal counts were the lowest in the large tomatoes. Based on the above results, large tomatoes may be better than smaller tomatoes for exporting over long distances.

Keywords: firmness; lycopene; *Solanum lycopersicum*; Unicorn; vitamin C

1. Introduction

Tomato is a perishable product that starts to deteriorate after harvest. It is important to maintain quality of tomatoes by selecting the best fruit sizes when exporting them over long distances. Tomato size, which can influence nutritional value, is an important factor for consumer choice. The size of fruits and vegetables is an important indicator of various qualities [1]. Smaller produce is often transferred to local markets or to processing houses, and the produce with the highest quality is packaged and marketed domestically or abroad [2].

There are many factors that can influence the size of tomatoes. First, low ambient-light conditions result in smaller tomatoes and reduced vitamin C content [3]. Second, excessive sodium and/or chloride (due to salinity) can reduce fruit size, and weight, and increase the levels of soluble solids within the fruit [4,5]. Finally, it has also been shown that water stress may decrease fruit size, thereby affecting the levels of soluble solids, acidity, and ascorbic acid within the fruit. Mineral imbalances, salinity and cultivar may influence fruit size [6]. Small fruit may weigh less, be less firm, have a shorter shelf life, and reduced market ability. All of these things result in a loss of market value for tomatoes.

Additionally, fruit size may be reduced due to nutritional and organoleptic traits [7]. This effect is problematic, because low light or salinity can affect intrinsic fruit composition. Variation in fruit size and shape is quantitatively inherited (polygenic) [8]. Progeny from cultivated species and crosses with wild relatives' segregate and the consequences can include small fruit size that is influenced by mutations of genetic loci [9]. The variation of the quantitative nature of fruit size can be inhibited by using Mendelian techniques to characterize and identify the gene mutations that can occur in cultivated fruit [10]. Microbial activity on the fruits usually increases during storage.

After harvest, respiration and ethylene production increase and deterioration begins. The deterioration of the fruit may also be caused by microbial activity that usually increases during fruit storage.

Consumers initially choose tomatoes based on external appearance (size and color), and afterwards by the internal quality of flavor. Grading tomatoes on the basis of size is necessary to maintain their quality, get optimum market value, export them over long distances without a significant reduction in quality, and store them for long periods of time to satisfy the demand from consumer. Modified atmosphere packaging (MAP) increase the quality and shelf life by maintaining optimum conditions [6]. There is no research relating fruit size with MAP, a factor that can influence the quality, shelf life and microbial activity of cherry tomatoes. This study was conducted to evaluate the effects of fruit size with MAP storage on the quality, shelf life, and microbial activity in cherry tomatoes.

2. Materials and methods

2.1. Tomato fruits and treatments

Sixty cherry tomato (*Solanum lycopersicum* cv. 'Unicorn') plants were supplied with a nutrient solution and were grown using the hydroponic nutrient film technique (NFT) from April to July in 2016, with EC 2.3 dS m^{-1} and pH 5.8–6.2 [11] in the Republic of Korea. The greenhouse was maintained to 20 °C/15 °C (day/night) and supplemented with quantum dot light-emitting diodes (LEDs) to maintain a light intensity (Photosynthetic Photon Flux Density) of 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

Tomatoes were harvested in the stage of light red maturity, from the 3rd to 7th trusses. Large (31.28 mm), medium (28.52 mm), and small (24.16 mm) size tomatoes were classified according to the available fruits in the trusses. The quality of large, medium, and small tomatoes was measured at harvest time at room temperature (20 °C).

Tomatoes were washed with 150 ppm sodium hypochlorite (NaClO) for 10 minutes before storage. Commercial-sized cartons (box) (20 fruits of each size, for a total of 60 fruits for the three sizes) were used as the control and 20,000 cc m^{-2}/day atm oxygen transmission rate (OTR) packaging film was used for the different treatments (10 fruits/ pack and five replicates for each size, for a total of 150 fruits for the three sizes). This material was considered to be modified atmosphere packaging (MAP) and tomatoes were kept at 5 °C with 85% relative humidity to measure the quality and shelf life of the fruits. On the final day of storage, after removing the seeds, some samples were kept at −24 °C to measuring the lycopene and vitamin C concentrations and to measure microbial activity.

2.2. Gaseous parameters

A PBI Dansensor (CheckMate 9900, Denmark) was used to measure the carbon dioxide and oxygen emitted by the fruit. Ethylene was measured by a GC-2010 Shimadzu chromatograph (Shimadzu Corporation, Japan) that was equipped with a BP20 (wax) column (30 mm × 0.25 mm × 0.25 µm; SGE Analytical Science, Australia). The detector and injector were programmed to operate at 127 °C and the ovens were set to 50 °C. The flow rate of the carrier gas (N_2) was 0.67 mL/s [12].

2.3. Quality parameters

The loss of fresh weight in tomatoes was measured by subtracting the final weight from the previous weight and converted to obtain % weight loss [12]. Visual quality was subjectively assessed on a scale of 1 to 5 (1 = very bad, 2 = bad, 3 = good, or marketable, 4 = very good, and 5 = excellent) by five panel members on the final day of storage. Shelf life was measured (≥ 3; good, or marketable) according to visual quality determinants such as mold growth, decay, shriveling, smoothness, shininess, and homogeneity. Fungus-affected tomatoes were counted and the amount of fungal activity was converted to a percentage.

A fruit hardness tester (Lutron FR 5105, Taiwan) with a 3 mm diameter stainless steel probe with a flat end was used to measure the firmness of the fruit. The skin color values of tomato fruits were measured using a chroma meter model CR-400 (Konica Minolta Sensing, Inc., Japan). The reported results include the levels of red (+ a*) and green (− a*), as well as yellow (+ b*) and blue (− b*) seen on the fruit [12]. In this research, the redness of the tomato fruits was measured as the value of a*/b*.

Lycopene content in the fruit was measured according to Islam et al. [13] with a UV spectrophotometer (Shimadzu Corporation, Tokyo, Japan) at 503 nm. A refractometer (Atago U.S.A. Inc., U.S.A.) was used to measure the soluble solids, and the results are presented as °Brix. The titratable acidity was measured by a fruit acid meter (G-Won Hi-tech, Korea) and the results are reported as % citric acid.

Vitamin C was also analyzed according to Islam et al. [14] using a Waters HPLC (Waters Associates, Milford, MA, USA) with a C_{18} column (4.6 cm × 250 mm, 5 µm, Agilent, USA) at 265 nm with 100% MeOH:0.1 M KH_2PO_4 1:9 mobile phase and 1.0 $mL \cdot min^{-1}$ flow rate.

2.4. Microbial activity

Bacterial colonies and fungal spores were evaluated according to Islam et al. [15]. Briefly, 3 cm^2 from each chilled, segmented tomato was rinsed with 10 ml of 0.1% peptone and shaken. About 0.1 mL of each rinsed solution was surface plated. Nutrient agar (NA) and potato dextrose agar (PDA) were used for bacteria and fungi, respectively. Plates were incubated for 48 h at 35 ℃ (bacteria) or for 5 days at 25 ℃ (fungi). Bacteria and fungi were identified based on colony and spore characterization, and by microscopic methods.

2.5. Statistical analysis

The significant differences of mean values were determined using Duncan's multiple range test (DMRT) of the one-way ANOVA by SPSS V. 16 (SPSS Inc., Chicago, USA).

3. Results and discussions

3.1. Gaseous parameters

Large tomatoes showed the lowest levels of respiration (Figure 1A) and ethylene (Figure 1B) production at harvest time, and they maintained their freshness better than the other sizes. This result is similar to the data reported by Kays and Paull [16]: Smaller fruits had higher rates of respiration and ethylene production due to their larger surface area to volume ratios compared with larger fruits. On the final day of storage, large tomatoes produced the least amount of carbon dioxide (respiration) and ethylene compared with smaller tomatoes (Figures 1 and 2). Additionally, during storage, large tomatoes produced less carbon dioxide, more oxygen and less ethylene compared with smaller fruits. Similarly, large guava fruits have been shown to have lower rates of respiration and ethylene production compared with smaller ones [17]. The lower ethylene content in large tomatoes can be a benefit, because lower levels of ethylene causes fruit to ripen and decompose at a slower rate.

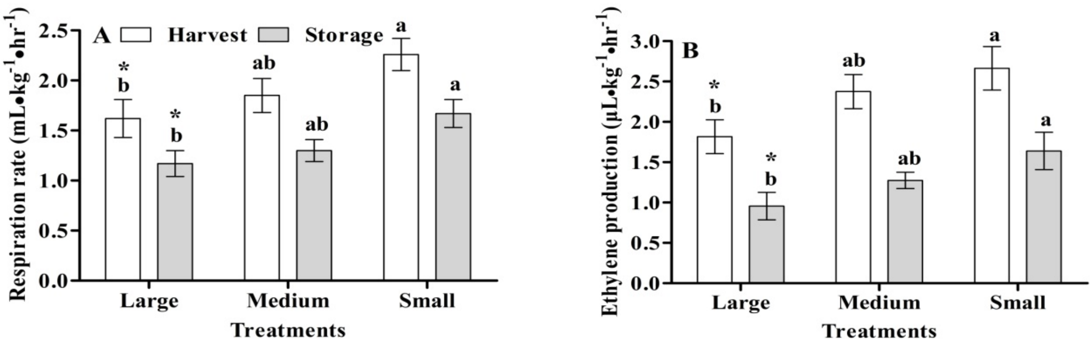

Figure 1. Changes of respiration (A) and ethylene production rate (B) of cherry tomatoes at harvest time (0 day at 20 ℃) and after box storage time (20th day at 5 ℃). Each data point is the mean of five replicates (two fruits in each box) ± standard error. *: significant at $p \leq 0.05$ of Duncan's multiple range tests (DMRT).

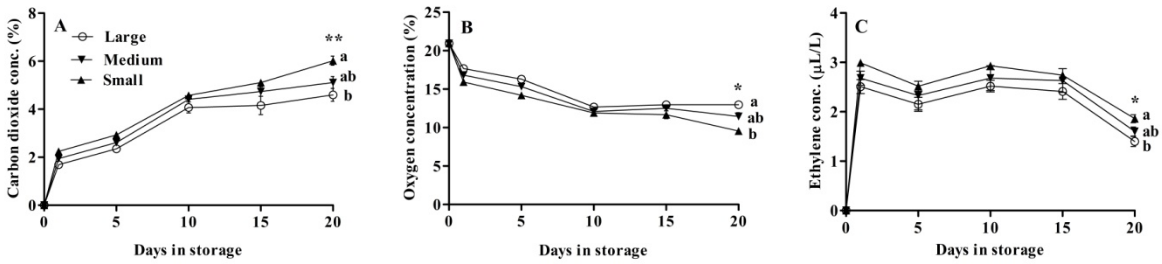

Figure 2. Changes of carbon dioxide (A), oxygen (B), and ethylene concentration (C) of cherry tomatoes during 5 °C MAP storage. Each data point is the mean of five replicates (10 fruits in each pack) ± standard error. *, **: significant at $p \leq 0.05$ and 0.01, respectively of Duncan's multiple range tests (DMRT).

3.2. Quality parameters

Tomatoes of different sizes (large, medium, and small) and weights were analyzed to determine their quality and shelf life. The large tomatoes showed the lowest fresh weight loss compared with the small ones (Table 1). Diaz-Perez et al. [18] also suggested that small carrots and peppers have been shown to have a higher amount of fresh weight loss compared with larger ones. Larger tomatoes have lower surface area to volume ratios, which confer relatively less water loss [19]. We saw the longest shelf life in the large tomatoes because they maintained a marketable visual quality (≥ 3) and freshness during the experiments. The large tomatoes had the longest shelf life due to lower rates of respiration and ethylene production. The small fruits had a shorter shelf life due to higher rates of respiration and ethylene production compared with the other fruits sizes on the final day of storage. The surface area to volume ratios affects the shelf life of vegetables and the rates of water loss [19]. The fungal incidence of large tomatoes was the lowest, and that helped in maintaining quality and extending their shelf life. The small tomatoes showed higher rates of fungal incidence compared with large tomatoes. Smaller size may increase sensitivity to fungal incidence, which mainly occurs during cuticle fluidity. The weak resistance of the small fruit is due to a relatively high flow of water and sugar to the fruits, and a lack of resistance [20].

Table 1. Fruit size, fruit weight, fresh weight loss, shelf life, and fungal incidence of cherry tomato.

	Fruit size (mm)	Fruit weight (g)	Fresh weight loss (%)		Shelf life (days)		Fungal incidence (%)	
	Harvest	Harvest	Box	MAP	Box	MAP	Box	MAP
Large	31.28a^{z}	16.56a	4.32b	0.17b	15a	19a	30.00b	37.50b
Medium	28.52b	12.65ab	4.69ab	0.19ab	14ab	17ab	40.00ab	60.00ab
Small	24.16c	8.16b	5.29a	0.22a	12b	16b	50.00a	72.73a
P value	***	***	**	*	**	*	**	**

*Note: z means separation of columns by Duncan's multiple range tests (DMRT) (n = 10). *, **, ***: significant at $p \leq 0.05$, 0.01, and 0.001, respectively of DMRT.

At the time of harvest, there were no significant differences in color, the amount of lycopene, soluble solids, titratable acidity, or vitamin C content among the different fruit sizes. This is because we selected tomatoes at the same developmental stage and sizes. However, after storage, the tomatoes of different sizes showed significant differences.

The small tomatoes were the firmest at the time of harvest compared with the other sizes. This may be due to better membrane integrity in smaller fruits [14]. Previous works reported that the large fruits were less firm than the small fruits at harvest time [1,2]. After storage, the large tomatoes were the firmest of the three different sizes. This may be related to the slower ripening due to the lower ethylene production as shown in Figure 2C. Less ethylene and less color development allow tomatoes to maintain a high level of firmness [21]. The large tomatoes maintained their firmness better than the other sizes, making them more desirable for long-time storage (Table 2).

Those tomatoes that changed color rapidly experienced a corresponding loss of quality. The small tomatoes had more rapid color development due to their higher levels of respiration and production of ethylene. Rates of respiration and ethylene production can influence the development of color in tomatoes. As a result, these factors lead the ripening of tomatoes [22,23]. Large tomatoes, which are the most desirable to export over long distances, change color very slowly and have lower rates of respiration and ethylene production compared to the medium and small fruits.

The levels of lycopene were influenced by size. The large tomatoes contained less lycopene than the other sizes, and this characteristic may happen due to their slower ripening. As a result, levels of lycopene were high due to an increased level of ripeness. As tomatoes ripen, levels of lycopene increase. This agrees with results from Brandt et al. [24], that the level of ripeness affects the lycopene content in tomatoes.

Table 2. Fruit firmness, color, and lycopene of cherry tomato at harvest time (0 day at 20 °C) and after storage (20th day at 5 °C).

	Firmness (N)			Color (a*/b*)			Lycopene (mg kg^{-1} FW)		
	Harvest	Box	MAP	Harvest	Box	MAP	Harvest	Box	MAP
Large	13.04b^{z}	8.05a	11.08a	0.55a	0.81b	0.70b	91.60a	112.27	100.94b
Medium	15.53a	7.28ab	9.36ab	0.55a	0.82b	0.71ab	92.14a	117.86	103.31ab
Small	15.85a	6.45b	9.17b	0.56a	0.86a	0.75a	91.93a	126.46	106.23a
P value	**	**	**	NS	*	**	NS	**	*

*Note: z means separation of columns by Duncan's multiple range tests (DMRT) (n = 10). NS, *, **: not significant, or significant at $p \leq 0.05$ and 0.01, respectively of DMRT.

Among the different sizes, the small tomatoes contained the most soluble solids on the final day of storage (Table 3). Smaller fruits contained more soluble solids [4]. Usually, the amount of soluble solids increases during the ripening of tomatoes because the organic acids convert to sugar [14]. The small tomatoes showed lower titratable acidity and vitamin C content than the other sizes, due to being riper on the final day of storage. As smaller fruits ripen more quickly, their acidity decreases compared with larger fruits. The large tomatoes had the highest vitamin C content because of lower levels of ethylene production. These results support the results from a previous study [3] that small tomatoes had reduced levels of vitamin C.

Table 3. Fruit soluble solids, titratable acidity, and vitamin C of cherry tomato at harvest time (0 day at 20 °C) and after storage (20th day at 5 °C).

	Soluble solids (°Brix)			Titratable acidity (% citric acid)			Vitamin C (mg 100 g^{-1} FW)		
	Harvest	Box	MAP	Harvest	Box	MAP	Harvest	Box	MAP
Large	5.53a^{z}	6.08b	5.98b	0.61a	0.40a	0.53a	17.31a	9.89a	12.34a
Medium	5.53a	6.10b	6.06ab	0.61a	0.39ab	0.52a	18.56a	8.16ab	11.95ab
Small	5.54a	6.47a	6.20a	0.62a	0.35b	0.46b	18.43a	6.15b	10.97b
P value	NS	*	*	NS	**	*	NS	**	*

*Note: z means separation of columns by Duncan's multiple range tests (DMRT) (n = 5). NS, *,**: not significant, or significant at $p \leq 0.05$ and 0.01 of DMRT.

3.3. Microbial activity

The lowest bacterial and fungal count occurred in large tomatoes after storage. The bacterial count at both harvest time and after storage was higher than the fungal densities (Table 4). The small tomatoes had the most bacteria and fungi probably due to high levels of ethylene and environmental conditions. Moreover, bacteria and fungi produce ethylene [25] and, as a result, tomatoes with higher levels of them ripen faster and lose their quality. In summary, ethylene increases the bacterial and fungal activity in small tomatoes.

Table 4. Count of the microbial activity associated with cherry tomato fruits extracts at harvest time (0 day at 20 °C) and after storage (20th day at 5 °C).

	Bacteria (× 10 colony ml^{-1})			Fungi (× 10 spores ml^{-1})		
	Harvest	Box	MAP	Harvest	Box	MAP
Large	193.00a^{z}	195.08b	200.67b	6.33a	6.70b	6.67b
Medium	194.67a	198.04ab	206.33ab	6.67a	6.59b	9.00ab
Small	195.33a	206.66a	211.67a	7.00a	7.76a	9.67a
P value	NS	*	*	NS	*	*

*Note: z means separation of columns by Duncan's multiple range tests (DMRT) (n = 5). NS, *: not significant, or significant at $p \leq 0.05$ of DMRT.

4. Conclusions

Tomatoes of different sizes (large, medium, and small) were examined to evaluate the quality, shelf life, and microbial activity associated with them. The large tomatoes were the firmest, and had the lowest rates of respiration and ethylene production on the final day of storage. The large tomatoes also had the longest shelf life, as well as the lowest occurrence of fungal and microbial activity. Therefore, it may be best to use larger cherry tomatoes when the fruit needs to be exported over long distances.

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Conflict of interest

The authors declare no conflict of interest.

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