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Nutrient and salinity concentrations effects on quality and storability of cherry tomato fruits grown by hydroponic system

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ABSTRACT: This study was conducted to investigate the effects of nutrient and salinity concentrations on the quality of deep-flow technique hydroponic system cultivated cherry tomatoes (*Lycopersicon esculentum* Mill 'Unicorn'). The conditions were: (1) control (NS-1 × nutrient Solution, Electrical Conductivity – EC: 2.5 mS·cm⁻¹); (2) 2 × NS (2 × NS-Double NS, EC: 5 mS·cm⁻¹); (3) NS + 4.23 mM NaCl (NaCl-Sodium Chloride, EC: 5 mS·cm⁻¹); and (4) NS + 13.70 mM Sea Water – SW (EC: 7.5 mS·cm⁻¹). NS + 13.70 mM SW treatment showed the lowest fresh weight loss. Visual quality as well as shelf life was the longest in NS (1 × nutrient solution) treated tomato fruits. The longest

shelf life at 5 °C, 11 °C, and 24 °C were 21, 16, and 8 days, respectively, in NS (1 × nutrient solution) treated tomato fruits. The highest firmness was recorded in NS (1 × nutrient solution) treated tomato fruits, which was retained after storage. Moreover, NS + 13.70 mM SW treatment increased the cherry tomato fruit's quality, especially soluble solids and sugar contents. These results indicate that salinity concentration has effect the soluble solids and sugar of cherry tomato fruits. In addition, nutrient concentration influenced the shelf life and firmness of cherry tomato fruits.

Key words: firmness, lycopene, soluble solids, sugar, titratable acidity.

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INTRODUCTION

Currently, salinity treatment of tomato cultivation is taking place in Korea and Japan for enhancing soluble solids. Salinity influenced size and number of marketable fruits, but increased fruit quality by increasing total soluble solids (TSS) and sugar content (Del Amor et al. 2001). TSS is a vital quality criterion for tomato paste processing, serves and price setting for producer (Cuartero and Fernández-Muñoz 1998). Increasing salinity improved various aspects of tomato fruit quality, such as proportion of extra fruits (visual quality), soluble solids, and titratable acidity, but decreased fruit size (Magán et al. 2008). TSS was higher in the plants subjected to the salinity treatments (Borghesi et al. 2011). Regardless of the salinization time treatments, tomato fruits of salt-treated plants showed significant upturns in concentration of sugars, total soluble solids and total acid content, since fruit pH decreased (Del Amor et al. 2001). Hydroponically produced tomatoes with sodium chloride enriched nutrient solution had higher consumer preference, expanded sweetness and flavor, but also produced a harder tomato fruit (Petersen et al. 1998). Yield reduction occurred in the flowering and fruiting stages of salinity-treated tomato fruits, due to reduction of fruit number in lieu of fruits size, but salinity increased fruit quality that depends on developmental stage and application time (Zhang et al. 2017).

The high-quality tomato, which has higher soluble solids, should be needed in the high-end market. Saline cultural condition helps unification some fruit quality of many crops. We used three distribution temperatures (5 °C, 11 °C, and 24 °C). Typically during cold supply chains used to export produce to Hong Kong and Japan by ship, 5 °C and 11 °C is considered the standard temperature, for local distribution of produce, 24 °C is ideal. This study was conducted to demonstrate the performance of nutrient and salinity concentrations on quality of deep-flow cultivated cherry tomato 'Unicorn' in different storage temperatures (5 °C, 11 °C, and 24 °C).

MATERIAL AND METHODS

Cherry tomatoes (*Lycopersicon esculentum* Mill. cv. 'Unicorn') were grown with a deep-flow technique (DFT) hydroponic system in a greenhouse during the winter

in Gangwon province. Nutrient solution was supplied based on the Japanese Horticultural Experiment Station, which was adjusted to 2.5 dS·m⁻¹ EC and 5.8 – 6.2 pH (Sato et al. 2006). The treatments were: (1) control (NS-1 × Nutrient Solution, Electrical Conductivity – EC: 2.5 mS·cm⁻¹); (2) 2 × NS (2×NS-Double NS, EC: 5 mS·cm⁻¹); (3) NS + 4.23 mM NaCl (NaCl-Sodium Chloride, EC: 5 mS·cm⁻¹); and (4) NS + 13.70 mM Sea Water – SW (EC: 7.5 mS·cm⁻¹). For all treatments, the nutrients were supplied in DFT system that included PVC (polyvinyl chloride) trays, which were 4 m long, 0.15 m wide and 0.20 m deep and regulated by an electric pump set at a rate of 60 L·min⁻¹. Fruits were treated from third to seventh trusses in tomato plants. Light red maturity stage of tomatoes was harvested to measure harvest time (20 °C) quality and the rest of them were stored in commercial size carton box (34 cm × 24 cm × 13 cm) at 5 °C, 11 °C, and 24 °C temperatures with 85% relative humidity (Islam et al. 2013) to measure the quality of cherry tomato.

Minerals were quantified according to Simsek and Aykut (2007) and Islam et al. (2016) by using inductively coupled plasma-atomic emission spectroscopy (Integra XL Dual, GBC, and Melbourne, Victoria) following acidic digestion.

The respiration and ethylene production were measured by a PBI Dansensor (Check Mate 9900, Denmark) and a GC-2010 Shimadzu (Shimadzu Corporation, Japan), respectively. A GC-2010 Shimadzu was equipped with a wax column BP 20 (30 m × 0.25 mm × 0.25 µm, SGE Analytical Science, Australia), and a flame ionization detector. Detector and injector were set at 127 °C, the ovens were set at 50 °C, and 0.67 mL·s⁻¹ was the carrier gas (N₂) flow rate (Islam et al. 2016). Gas samples were removed after three hours at the harvest time (20 °C) and six hours on the final storage day (24 °C, 11 °C and 5 °C) from a closed 125 mL jar containing two cherry tomatoes.

During the storage period, tomatoes' fresh weight loss was measured by subtracting sample weights from their earlier recorded weights; results are mentioned as percentage of weight loss (Mele et al. 2017). Tomatoes' visible quality was subjectively analyzed by quality determinants (freshness, mold growth, decay, shriveling, smoothness, shininess, and similarity). The observed visual quality scale was scored from 1 to 5 (5 = excellent; 4 = very good; 3 = marketable, good; 2 = bad; and

→

1 = waste) and five panel members assessed the visual quality of the tomatoes during storage (Islam et al. 2016). Penetrometer (DFT-01, TR snc, Italy) was used to measure fruit firmness (N). A Chroma Meter CR 400 Model (Konica Minolta Sensing, Inc., Japan) was used to measure the tomatoes' skin color. Tomatoes a^* and b^* value indicate the degree of redness and yellowness, respectively, in Minolta Chroma Meter (Mele et al. 2017). Redness of tomatoes were noted as a^* / b^* values. Lycopene content was measured by UV-Spectrophotometer (Shimadzu Corporation, Tokyo, Japan; Fish et al. 2002). Soluble solids were assessed by Refractometer (Atago U.S.A. Inc., U.S.A.); results are mentioned in °Brix. Titratable acidity was analyzed by DL 22 Food Analyzer (Mettler Toledo Ltd., Korea); results are mentioned as percentage of citric acid. Sugars analysis was conducted by a Waters HPLC (Waters Associates, Milford, MA, USA) and the column was C_{18} (4.6 cm × 250 mm, 5 µm, Agilent, USA) at 265 nm. The mobile phase flow rates 0.50 mL·min⁻¹ with 50 mg·L⁻¹ Ca-EDTA (Calcium di-sodium ethylene diamine tetra-acetate) in HPLC grade water solution (Radi et al. 2003).

SPSS V. 16 (SPSS Inc., Chicago, USA) was used to perform the statistical analysis of data. Differences between conditions were analyzed by a DMRT following a one-way ANOVA.

RESULT AND DISCUSSIONS

Salinity-treated tomato fruits showed higher sodium (Na) content compared with NS (1 × nutrient solution) and, as a result, those treated tomato fruits were smaller. This finding is supported by Mitchell et al. (1991), who demonstrated that decreased fruit growth due to salinity could be caused

by lower mineral uptake during the fruit's development. Ca appears to have a major role in tomato fruit firmness (Islam et al. 2016). Our results showed that NS (1 × nutrient solution) treated tomato fruits highly accumulated Ca²⁺ content (Table 1). High EC had adverse effect on crop growth and yields (Fallovo et al. 2009) and less Ca²⁺ accumulates in high EC sweet pepper fruit (Tadesse et al. 1999b). As a result, total Ca²⁺ content remained low in salinity and double-strength nutrient-solution-treated tomato fruits. The diminished uptake of Ca²⁺ content likely occurred due to Ca²⁺ and K⁺ uptake competition by root (Kirkby 1979) and osmotic adjustments that affect water uptake by root (Tadesse et al. 1999b). Na⁺ reduces Ca²⁺ transport and mobility in the plant, which influences the quality in vegetative and reproductive organs, and salinity directly affects nutrient uptake like Na⁺ reducing K⁺ uptake and Cl⁻ reducing NO₃⁻ uptake (Grattan and Grieve 1998).

Tomatoes treated with NS + 13.70 mM SW had a higher respiration and ethylene production than the control at harvest time (20 °C; i.e., the light red stage). Tomato fruits grown in saline conditions had higher respiration and ethylene production than those in the control condition (Hobson 1988). Moreover, high EC condition increased the respiration in sweet pepper due to osmotic adjustment that cannot retain water and turgor (Tadesse et al. 1999a). The NS + 13.70 mM SW treated tomato fruits affirmed a higher respiration and ethylene production after storage, which can ripen the fruit and raise its quality. Given that the NS + 13.70 mM SW treated tomato fruits are smaller than those in other treatments, it can increase the respiration and ethylene production (Table 2).

The NS (1 × nutrient solution) treated tomatoes resulted in diminished fresh weight losses due to less moisture loss in the fruit. The fresh weight loss increased as increasing ionic strength due to higher respiration and transpiration.

Table 1. Mineral content of cherry tomato fruits treated by nutrient and salinity concentrations.

Treatments	CaO	K ₂ O	MgO	NaO	P ₂ O ₅	Fe	Mn	Cu	Zn
	(%)					(ppm)			
Control (1 × NS)	0.127a ^c	2.443ab	0.133b	0.130b	0.637a	0.183ab	0.030a	0.033a	0.067a
2 × NS	0.097b	2.687a	0.100c	0.137b	0.617ab	0.183ab	0.037a	0.027a	0.073a
NS + 4.23 mM NaCl	0.107ab	2.580a	0.147ab	0.420a	0.527ab	0.133b	0.037a	0.027a	0.060a
NS + 13.70 mM SW	0.087b	2.100b	0.167a	0.403a	0.287b	0.190a	0.023a	0.033a	0.060a
P values	***	**	***	***	**	*	NS	NS	NS

^aMean separation within columns by Duncan's multiple range tests (DMRT) (n = 5). NS, *, **, ***: not significant, and significant at p ≤ 0.05, 0.01 and 0.001, respectively.

Table 2. Respiration and ethylene production of cherry tomatoes at harvest time (20 °C) and after storage at 5 °C, 11 °C, and 24 °C.

Treatments	Respiration (CO ₂ mL·kg ⁻¹ ·hr ⁻¹)				Ethylene production rate (μL·kg ⁻¹ ·hr ⁻¹)			
	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)
Control (1 × NS)	2.28b ²	0.19b	0.24b	0.33b	1.32b	0.25b	0.39b	0.48b
2 × NS	2.30b	0.21ab	0.27ab	0.35ab	1.35ab	0.31b	0.42ab	0.49b
NS + 4.23 mM NaCl	2.31ab	0.23ab	0.28ab	0.36ab	1.40ab	0.37ab	0.50ab	0.63ab
NS + 13.70 mM SW	2.38a	0.27a	0.33a	0.40a	1.49a	0.52a	0.58a	0.76a
P values	*	*	*	*	*	**	*	**

²Mean separation within columns by Duncan's multiple range tests (DMRT) (n = 5). *, **: significant at p ≤ 0.05 and 0.01, respectively.

Given that smaller size fruits have large surface areas, they produce more respiration, transpiration (water vapor), and ethylene (Kays and Paull 2004), thus salinity and double-strength-treated smaller tomato fruits lose fresh weight during storage (Figure 1). The longest shelf life was observed in tomato fruits in NS (1 × nutrient solution) treatment because of maintaining freshness and marketable visual quality (≥ 3). The shelf life of NS (1 × nutrient solution), 2 × NS, NS + 4.23 mM NaCl, and NS + 13.70 mM SW-treated tomatoes were, accordingly, 21, 20, 19, 18 days at 5 °C, 16, 15, 14, 13 days at 11 °C, and 8, 7, 6, 5 days at 24 °C (Figure 2). Salinity considerably shortened shelf life by increasing ethylene production in tomato fruits (Mizrahi 1982). The NS (1 × nutrient solution) treated tomato showed the highest marketable fruit and marketable fruits weight whereas the NS + 13.70 mM SW treated tomato fruits had shown the lowest due to high salinity concentration (Table 3).

In previous research, salinity reduced the strawberry yield due to decreased water content in the fruit (Awang et al. 1993) and high ionic strength in nutrient solution decreased sweet pepper fruit size because of reduced water content that inhibits cell division and cell elongation (Tadesse et al. 1999a). In our experiment, both salinity and double-strength of the nutrient solution decreased the marketable fruit and marketable fruits weight of tomato.

Color is an important fruit quality parameter, as it impacts seller, buyer, and consumer choices. At the harvest time, color did not show significant difference across the treatment conditions as we selected consistent maturity stage (light red) throughout this experiment; however, color did exhibit significant difference after storage. The highest color development was recorded by the NS + 13.70 mM SW treated tomato fruits because of the increased respiration and ethylene production, which may help to ripen the fruit quickly (Table 4). This finding is in line with Borghesi et al.

(2011), who suggested that increased salinity enhanced the color development in tomato fruits. In addition, high EC in nutrient solution increased in sweet pepper color because it helps ripening process and maturation (Tadesse et al. 1999b).

The highest firmness was recorded in the NS (1 × nutrient solution) treated tomato fruits at harvest time due to high Ca content (Table 4) and the highest firmness retained by tomato after storage because of less ethylene production that induce polygalacturonase synthesis activity (Grierson and Tucker 1983). Fruit softening mainly occurs due to middle lamella degradation of cortical parenchyma cells walls with upsurge pectin release (Perkins-Veazie 1995). The NS (1 × nutrient solution) treated tomato fruits perhaps demonstrate slow degradation and retain the firmness as it contains the maximum Ca content. Among the salinity treatments, the NS + 4.23 mM NaCl treated tomato fruits performed the highest and the NS + 13.70 mM SW treated tomato fruits obtained the lowest firmness. Higher salinity restricted to deposit of Ca-pectate and Ca-phosphate in the tissue, limiting cell wall development (Minamide and Ho 1993) and increment salinity reduces Ca²⁺ uptake and xylem transport in tomatoes (Adams and Ho 1993). In the current study, the NS + 13.70 mM SW treated tomato fruits showed the lowest Ca²⁺ assimilation because higher Na content suppressed Ca²⁺ uptake, as a result, fruits cannot maintain firmness. High ionic strength of nutrient solution showed less firmness due to suppressed to Ca²⁺ uptake (Tadesse et al. 1999a).

The maximum lycopene content was confirmed in the NS + 13.70 mM SW treated tomato fruits likely due to higher respiration and ethylene production. Salinity-treated tomato fruits increase lycopene content because salinity treatment stimulates respiration and ethylene production, which accelerates ripening (Woo and Kang 2006).



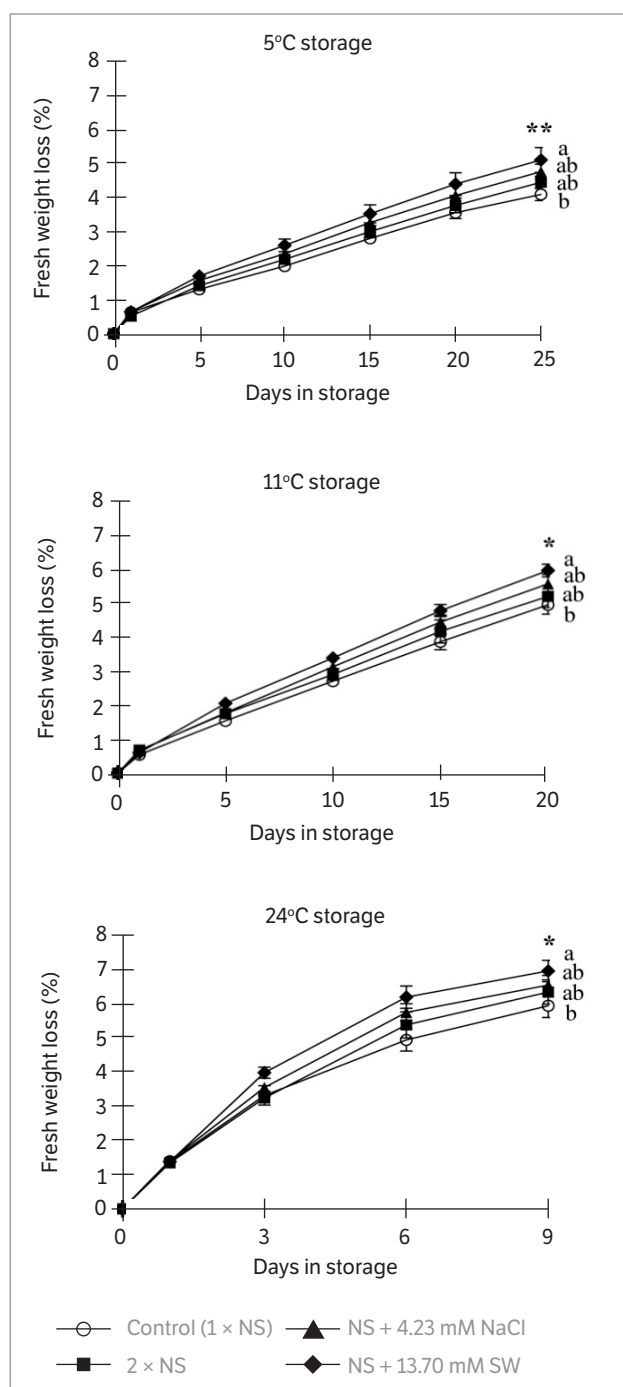


Figure 1. Changes of cherry tomatoes fresh weight loss at 5 °C, 11 °C and 24 °C. Each data point is the mean of ten single fruit replicates \pm standard error. *, **: significant at $p \leq 0.05$ and 0.01 , respectively, of Duncan's multiple range test (DMRT).

Soluble solids and titratable acidity are important factors for the taste and flavor of tomato fruits. In previous research, increasing salinity improved soluble solids of tomatoes (Magán et al. 2008). Likewise, in this study, higher salinity improved soluble solids (Table 5). Escalation in acidity of

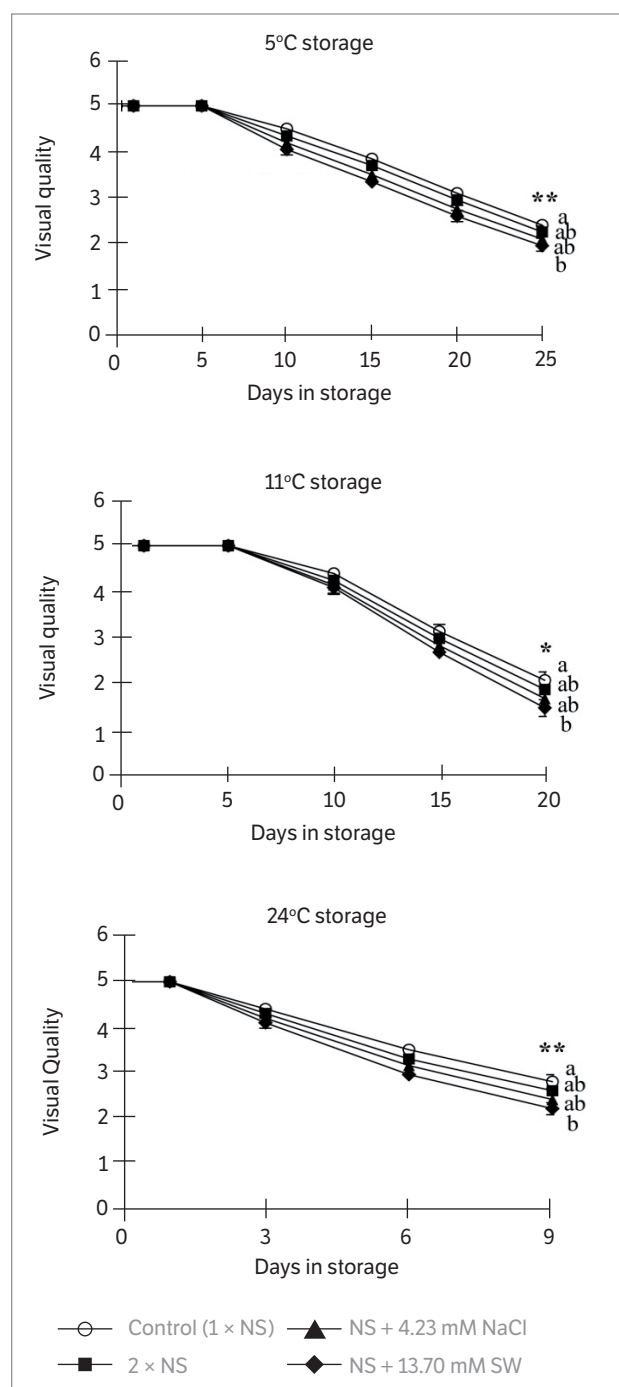


Figure 2. Changes of cherry tomatoes visual quality at 5 °C, 11 °C and 24 °C. Scale of visual quality: 5 = excellent; 4 = very good; 3 = marketable, good; 2 = bad; and 1 = waste. Each data point is the mean of ten single fruit replicates \pm standard error. *, **: significant at $p \leq 0.05$ and 0.01 , respectively, of Duncan's multiple range test (DMRT).

the fruit could be due to the higher Na^+ and / or Cl^- contents in the fruit given that these are the only ions that increase with salinity (Del Amor et al. 2001). Tomato fruits soluble sugar accumulation increased (Mitchell et al. 1991) due to

Table 3. Marketable fruits (%) and marketable fruits weight (g/fruit) of cherry tomato treated by nutrient and salinity concentrations.

Treatments	Marketable fruits (%)	Marketable fruits weight (g/fruit)
Control (1 × NS)	93.20a ²	13.17a
2 × NS	92.81a	11.22ab
NS + 4.23 mM NaCl	92.67a	11.94ab
NS + 13.70 mM SW	92.21a	9.60b
P values	NS	*

²Mean separation within columns by Duncan's multiple range tests (DMRT) (n = 5). NS, *: not significant, and significant at p ≤ 0.05, respectively.

Table 4. Color, firmness, and lycopene of cherry tomatoes at harvest time (20 °C) and after storage at 5 °C, 11 °C and 24 °C.

Treatments	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)
	Color (a* / b*)			
Control (1 × NS)	0.81a ²	0.89b	0.98b	0.99b
2 × NS	0.82a	0.93ab	1.03ab	1.04ab
NS + 4.23 mM NaCl	0.83a	0.95ab	1.02ab	1.04ab
NS + 13.70 mM SW	0.84a	0.98a	1.06a	1.08a
P values	NS	*	**	**
Treatments		Firmness (N)		
Control (1 × NS)	18.90a	13.68a	14.59a	12.91a
2 × NS	17.83ab	12.55ab	13.18ab	11.71ab
NS + 4.23 mM NaCl	18.32ab	13.08ab	13.78ab	12.03ab
NS + 13.70 mM SW	16.42b	11.12b	11.91b	10.73b
P values	*	**	*	*
Treatments		Lycopene (mg/kg FW)		
Control (1 × NS)	115.07b	163.44b	168.84b	171.36b
2 × NS	117.35b	168.27ab	174.58ab	178.33ab
NS + 4.23 mM NaCl	120.48ab	172.98ab	183.92ab	187.16ab
NS + 13.70 mM SW	137.89a	197.92a	186.48a	196.07a
P values	**	*	**	*

²Mean separation within columns by Duncan's multiple range tests (DMRT) (n = 10). NS, *, **: not significant, and significant at p ≤ 0.05 and 0.01, respectively.

Table 5. Soluble solids and titratable acidity of cherry tomatoes at harvest time (20 °C) and after storage at 5 °C, 11 °C and 24 °C.

Treatments	Soluble solids (°Brix)				Titratable acidity (% citric acid)			
	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)
Control (1 × NS)	7.66b ²	7.77b	7.87b	8.24b	0.65b	0.54b	0.46b	0.39b
2 × NS	7.79ab	7.87ab	8.09ab	8.95ab	0.70ab	0.58ab	0.50ab	0.47ab
NS + 4.23 mM NaCl	7.82ab	7.94ab	8.14ab	9.96ab	0.71ab	0.61ab	0.51ab	0.49ab
NS + 13.70 mM SW	8.01a	8.15a	9.30a	9.63a	0.76a	0.65a	0.56a	0.55a
P values	**	*	**	***	NS	*	*	*

²Mean separation within columns by Duncan's multiple range tests (DMRT) (n = 10). NS, *, **, ***: not significant, and significant at p ≤ 0.05, 0.01 and 0.001, respectively.

raised soluble solids and reduced water content in salinity condition (Adams and Ho 1989).

The fructose and glucose were significantly higher in the NS + 13.70 mM SW treated tomato fruits compared with

NS (1 × nutrient solution) treated tomato at harvest time and after storage (Table 6). Salinity increases sugar and acid content by decreasing the amount of water in tomato fruits, which helps to improve overall taste (Adams and Ho 1989).

Table 6. Fructose and glucose of cherry tomatoes at harvest time (20 °C) and after storage at 5 °C, 11 °C and 24 °C.

Treatments	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)
		Fructose (g/100g FW)		
Control (1 × NS)	0.56b ²	1.01b	1.03b	1.74b
2 × NS	0.72ab	1.24ab	1.26ab	2.02ab
NS + 4.23 mM NaCl	0.79ab	1.32ab	1.43ab	2.22ab
NS + 13.70 mM SW	0.88a	1.59a	1.68a	2.57a
P values	*	**	*	*
Treatments	Harvest	5 °C (25 days)	11 °C (20 days)	24 °C (9 days)
		Glucose (g / 100g FW)		
Control (1 × NS)	1.40b	1.75b	2.38b	3.98b
2 × NS	1.69ab	2.98ab	3.44ab	4.46ab
NS + 4.23 mM NaCl	1.81ab	3.01ab	3.67ab	4.79ab
NS + 13.70 mM SW	2.11a	3.33a	5.89a	5.96a
P values	*	***	***	***

²Mean separation within columns by Duncan's multiple range tests (DMRT) (n = 5). *, **, ***: significant at p ≤ 0.05, 0.01 and 0.001, respectively.

CONCLUSION

The highest firmness and shelf life was demonstrated in the NS (1 × nutrient solution) tomato fruits because Ca²⁺ content that can suppress respiration and ethylene production. Moreover, the NS + 13.70 mM SW treated tomato fruits performed the highest lycopene, soluble solids, fructose and glucose because these treated tomato fruits developed red color quickly as suppressed to uptake Ca²⁺ content.

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