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Original Article

Iron, Iodine and Selenium Effects on Quality, Shelf Life and Microbial Activity of Cherry Tomatoes

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Abstract

Tomatoes have high nutritional and economical value and its deterioration start after harvest. They need proper treatments to increase and maintain quality as well as shelf life. The objective of this study was to determine the effect of iron, iodine and selenium on quality, shelf life and microbial activity of cherry tomatoes. Iron (1 mg/L), iodine (1 mg/L) and selenium (1 mg/L) were supplied with nutrient solution for five weeks prior to harvest. Then, cherry tomatoes were stored at 5 °C to assess quality, shelf life and microbial activity. The highest Ca content ($p < 0.05$) revealed in selenium-treated cherry tomatoes. Lower respiration and ethylene production were showed in selenium-treated cherry tomatoes both harvest time and after storage compared with iron and iodine treatments. At harvest time and after storage, the respiration were 1.29 ($p < 0.05$) and 0.62 mL/kg/hr ($p < 0.01$), respectively in selenium-treated cherry tomatoes. Moreover at harvest time and after storage in selenium-treated cherry tomatoes, the ethylene production was 2.11 and 0.87 μL/kg/hr ($p < 0.01$), respectively. The lowest fresh weight loss, the longest shelf life ($p < 0.01$), the least fungal incidence rate and microbial activities were found in selenium-treated cherry tomatoes. The longest shelf life of selenium-treated cherry tomatoes was 22 days. Selenium-treated cherry tomatoes' firmness increased (16.82N) at harvest time ($p < 0.05$) and it was significantly retained (12.70N) after storage ($p < 0.01$). Color development and lycopene content were more suppressed by selenium treatment after storage than iron and iodine treatments. Titratable acidity, vitamin C and soluble solids increased in selenium-treated cherry tomatoes after storage. Based on results, selenium-treated cherry tomatoes have significant potential to increase and maintain quality and shelf life.

Keywords: bacteria; firmness; fungi; respiration rate; *Solanum lycopersicum*

Introduction

Tomato (*Solanum lycopersicum*) is widely cultivated fruits and according to FAO (FAOSTAT, 2014), tomatoes harvested area was 7070 hectares, the production was 499960 tonnes, and yield was 707157 hectogram/hectare (calculated data) in Korea. Tomato has economical and nutritional values, and its pulp and seed obtain oil (Giuffrè and Capocasale, 2015; Giuffrè and Capocasale, 2016).

Iron, iodine and selenium are trace elements and plants need low concentrations (Broadley *et al*., 2012) that may have beneficial effects on quality, shelf life and microbial decontamination of cherry tomatoes. These elements are needed for plants as well as animals and humans. As plant can uptake these elements, so human can get from edible parts of plants. Close to 80% iron is localized in the chloroplast of growing leaves, stored in the stomata of plastids, and a deficient plant revealed a lower photosynthesis (Broadley *et al*., 2012).

Iodine can have a positive effect on the physiological, biochemical and molecular nature of plants (Kabata-Pendias, 2011) but plants' reaction to physiological and biochemical from iodine is unclear (Smolen *et al*., 2014). The basic role of iodine in the biosynthesis of thyroid hormones - thyroxin and triiodothyronine is monitoring plants' physiological and biochemical processes (Smolen *et al*., 2015). Globally, two-third of the population suffers from diseases because of insufficient iodine and selenium intake (Kabata-Pendias, 2011). Iodine and selenium may be easily transported through plants xylem (White and

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Broadley, 2009) and SeO_4^{2-} form may be redistributed through plants' phloem (White *et al.*, 2007).

Selenium is associated with the oxygen-sulfur-tellurium group and plants usually enable transfer from soil to the food chain although it has not been validated as an essential plant nutrient (Edelstein *et al.*, 2016). It regulates antioxidants and reactive oxygen species (ROS), inhibits uptake of heavy metal, rebuilds cell membrane and chloroplast structures, maintains the photosynthetic system, regulates minerals uptake and distributes in the antioxidative systems, makes ion balance, and increases cell integrity (Feng *et al.*, 2013). Selenium treatment increases selenium content in peaches, pears and cherry tomatoes (Pezzarossa *et al.*, 2012; Pezzarossa *et al.*, 2014).

There is insufficient research on iron, iodine and selenium in the hydroponic system of nutrient film technique (NFT) relative to use in large-scale production of cherry tomatoes. This study was conducted to determine the effect of iron, iodine and selenium on quality, shelf life and microbial activity of cherry tomatoes in the hydroponic system of NFT.

Materials and Methods

Fruit material and treatments

Cherry tomatoes (*Solanum lycopersicum* cv. 'Unicorn') were grown hydroponically at summer in 2016 with EC 2.3 dS m^{-1} and pH 5.8-6.2 supplied nutrient solution based on the Japanese horticultural experiment station in the Republic of Korea. The plastic house was equipped with electrical fan to maintain maximum 32 °C temperature. The following treatments were used: (1) control (non-treatment); (2) 1 mg L^{-1} iron (Fe) from Fe-EDTA ($C_{10}H_{13}FeN_2O_8$) (Smolen *et al.*, 2014); (3) 1 mg L^{-1} iodine (I) from potassium iodide (KI) (Li *et al.*, 2017); and (4) 1 mg L^{-1} selenium (Se) from sodium selenate (Na_2SeO_3) (Pezzarossa *et al.*, 2014). They were applied for five weeks prior to harvest in nutrient solution of 10 plants in each treatment. The 31.17 mm sizes cherry tomatoes harvest time quality was measured at room temperature (20 °C). Harvested rest of tomatoes were kept at 5 °C with 85% relative humidity (Islam *et al.*, 2013) to measure fruit quality, shelf life and microbial activity.

Mineral contents

Minerals were measured according to Simsek and Aykut (2007) and Islam *et al.* (2016). Inductively coupled plasma-atomic emission spectroscopy (Integra XL Dual, GBC, and Melbourne, Victoria) were used to measure minerals content.

Fruit physiology parameters

A PBI Dansensor (CheckMate 9900, Denmark) was used to measure carbon dioxide and oxygen. Ethylene was measured with a GC-2010 Shimadzu chromatograph (Shimadzu Corporation, Japan) (Mele *et al.*, 2017).

Fruits quality parameters

Fresh weight loss of cherry tomatoes was measured on the basis of Mele *et al.* (2017) by subtracting present to previous weight loss and converting to percentage. Visual quality was observed on the scale of 1 to 5 (1 = very bad, 2 = bad, 3 = good, marketable, 4 = very good, and 5 = excellent) during 5 °C storage for 25 days and five panel members were designated to assess visual quality and fungus of the cherry tomatoes (Islam *et al.*, 2016). Shelf life was measured according to visual quality (≥3; good, marketable) and determinants such as mold growth, decay, shriveling, smoothness, shininess, and homogeneity. Number of fungus-contaminated cherry tomatoes was counted and they were converted to fungal incidence percentage.

A fruit hardness tester (Lutron FR 5105, Taiwan) was used to measure firmness. Skin color values of the cherry tomatoes were measured using a chroma meter model CR-400 (Konica Minolta Sensing, Inc., Japan). Lycopene content was measured according to Fish *et al.* (2002).

A refractometer (Atago U.S.A. Inc., U.S.A.) was used to measure soluble solid. Titratable acidity was measured by a fruit acid meter (G-Won Hi-tech, Korea). Vitamin C was analyzed according to Islam *et al.* (2016) with Waters HPLC (Waters Associates, Milford, MA, USA) and the column was C_{18} (250 mm × 46 mm, 5 μm, Agilent, USA) at 265 nm.

Count of bacteria and fungi

A chilled (4 °C) cherry tomato slice (3 cm^2) was poured in 10 ml of 0.1% peptone for sterile and shaken. Nutrient agar (NA) and potato dextrose agar (PDA) were used for bacteria and fungi accordingly.

Plates were incubated for two days at 37 °C for bacteria and five days at 25 °C for fungi. After finishing incubation, bacteria and fungi were identified based on colony characterization and microscopic methods.

Statistical analysis

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).

Results and Discussion

Mineral contents

Higher CaO, K_2O, MgO, and P_2O_5 content was found in selenium-treated cherry tomatoes compared with other treatments (Table 1). Selenium increased cytosolic Ca in Arabidopsis plants (Pilon-Smits and Quinn, 2010), and it increased Ca, K, Mg, Na, and P in *Lycopersicon* root and hypocotyl (Colak *et al.,* 2014). Ca increase firmness, cell-wall thickness and shelf life of cherry tomato fruits (Islam *et al.*, 2016). Therefore, selenium-treated cherry tomatoes increase quality and shelf life.

Fruits physiology parameters

The lowest respiration rate and ethylene production were found for selenium-treated cherry tomatoes, followed by iodine, iron and control tomatoes at harvest time and after storage (Fig. 1). Selenium maintained cherry tomatoes, lettuce and chicory quality by suppressing respiration rate and ethylene production at harvest time and during storage (Malorgio *et al.*, 2009; Pezzarossa *et al.*, 2014; Zhu *et al.*, 2017). The lowest respiration rate and ethylene production are desirable to maintain quality and increase shelf life of cherry tomatoes.

Table 1. Mineral content of cherry tomato fruits which treated by iron, iodine and selenium

Parameter	%					mg kg^{-1}			
	CaO	K_2O	MgO	NaO	P_2O_5	Fe	Mn	Cu	Zn
Control	0.107b^z	2.103b	0.130b	0.133b	0.447b	0.127b	0.040a	0.037a	0.097a
Iron	0.123ab	2.367ab	0.140ab	0.150ab	0.513ab	0.163a	0.043a	0.067a	0.093a
Iodine	0.113ab	2.303ab	0.150ab	0.137b	0.540ab	0.150ab	0.047a	0.030a	0.100a
Selenium	0.130a	2.540a	0.153a	0.163a	0.653a	0.157ab	0.050a	0.033a	0.103a
p-value	*	*	*	**	**	**	NS	NS	NS

Note: ^{z}Mean separation of columns by Duncan's multiple range tests (DMRT) (n=10). NS, *, **; not significant, or significant at p < 0.05, and 0.01, respectively.

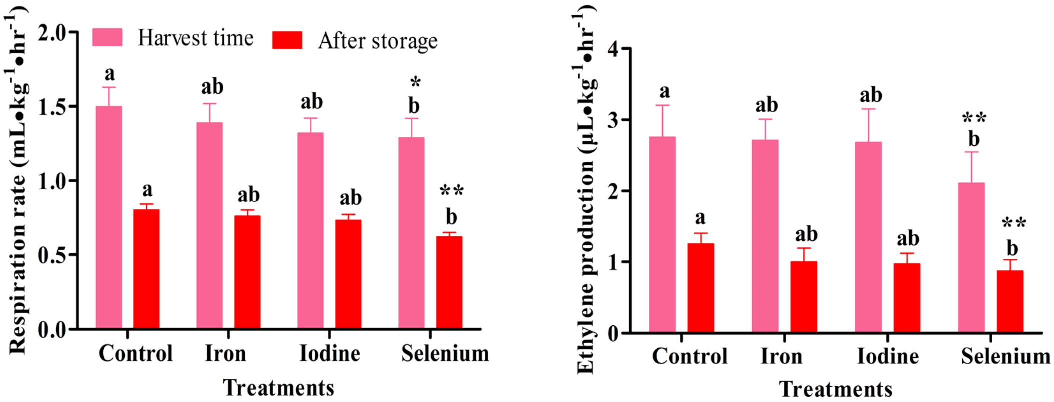

Fig. 1. Respiration and ethylene production rate of cherry tomatoes at harvest time (0 day at 20 °C) and after storage (25th day at 5 °C). *, **; significant at p< 0.05 and 0.01 of Duncan's multiple range tests (DMRT). Each data point is the mean of five double fruit replicates ± standard error

Fruits quality parameters

Selenium-treated cherry tomatoes revealed the lowest fresh weight loss compared with control and it is related to Zhu *et al.* (2017). Fresh weight loss may be influenced by respiration, transpiration, and moisture loss of cherry tomatoes (Islam *et al.*, 2016). The highest visual quality and longest shelf life were attributed to selenium-treated cherry tomatoes in maintaining marketable visual quality (≥ 3). Lettuce and chicory of selenium treatment improved shelf life by decreasing ethylene production (Malorgio *et al.*, 2009). Fungal incidence of selenium-treated cherry tomatoes was the lowest (Table 2) that can extend shelf life by maintaining quality. Selenium decreased fungal incidence in harvested cherry tomatoes by affecting intracellular ROS and plasma membrane of pathogens (Wu *et al.,* 2016).

Highest firmness was revealed in selenium-treated cherry tomatoes at harvest time and after storage (Table 3). Firmness was higher in selenium-treated peaches, pears and cherry tomatoes compared with control at harvest time and after storage (Pezzarossa *et al.*, 2012; Zhu *et al.*, 2016) and occurred because of less ethylene production (Malorgio *et al.*, 2009) that prevented softening of cherry tomatoes.

Color, lycopene, titratable acidity, vitamin C and soluble solids did not reveal significant differences at harvest with treatments, as selected cherry tomatoes were similar maturity-stage fruits (light red). Parameters revealed significant differences after storage in red maturity-stage cherry tomatoes. Color development and lycopene content of selenium-treated cherry tomatoes were lowest after storage (Table 3). Selenium effectively delays ripening because of less ethylene biosynthesis, controlling ROS level and oxidative damage (Pezzarossa *et al.*, 2012; Zhu *et al.*, 2017).

Highest titratable acidity and vitamin C content were observed in selenium-treated cherry tomatoes after storage (Table 4), and this result is related with Zhu *et al.* (2016). Soluble solids content was higher in selenium-treated cherry tomatoes compared with control after storage and may occur because of the breakdown of disaccharide (sucrose) into monosaccharide (fructose and glucose). Soluble solids content was highest in selenium-treated peaches, pears and cherry tomatoes after storage (Pezzarossa *et al.*, 2012; Zhu *et al.*, 2016).

Table 2. Fruit fresh weight loss, visual quality, shelf life and fungal incidence of cherry tomato after storage (25th day at 5 °C)

Parameter	Fresh weight loss (%)	Visual quality	Shelf life (days)	Fungal incidence (%)
Control	3.90b^z	2.20b	17b	26.50a
Iron	3.55ab	2.50ab	20ab	24.00ab
Iodine	3.20ab	2.35ab	18ab	21.50ab
Selenium	2.81b	2.70a	22a	18.00b
P value	**	**	**	*

Note: ^{z}Mean separation of columns by Duncan's multiple range tests (DMRT) (n=10). *, **; significant at p< 0.05 and 0.01, respectively.

Table 3. Fruit firmness, color, and lycopene of cherry tomato at harvest time (0 day at 20 °C) and after storage (25th day at 5 °C)

Parameter	Firmness (N)		Color (a*/b*)		Lycopene (mg kg-1FW)	
	Harvest	Storage	Harvest	Storage	Harvest	Storage
Control	14.10b[z]	10.27b	0.65a	0.97a	90.62a	106.09a
Iron	15.09ab	10.88ab	0.66a	0.93ab	90.09a	102.70ab
Iodine	15.86ab	11.03ab	0.65a	0.92ab	90.27a	102.39ab
Selenium	16.82a	12.70a	0.66a	0.91b	90.52a	98.87b
P value	*	**	NS	*	NS	*

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

Table 4. Fruit titratable acidity, vitamin C and soluble solids of cherry tomato at harvest time (0 day at 20 °C) and after storage (25th day at 5 °C)

Parameter	Titratable acidity (% citric acid)		Vitamin C (mg 100 g-1FW)		Soluble solids (°Brix)	
	Harvest	Storage	Harvest	Storage	Harvest	Storage
Control	1.04a[z]	0.80b	17.56a	10.09b	6.68a	8.27b
Iron	1.04a	0.81ab	17.70a	11.86ab	6.69a	8.42ab
Iodine	1.03a	0.84ab	17.52a	12.47ab	6.67a	8.35ab
Selenium	1.04a	0.89a	17.94a	14.37a	6.69a	8.57a
P value	NS	*	NS	***	NS	*

Note: [z]Mean separation of columns by Duncan's multiple range tests (DMRT) (n = 5). NS, *, ***; not significant, or significant at $p< 0.05$, and 0.001, respectively.

Table 5. Count of the microbial activity associated with tomato fruits at different treatments of cherry tomato at harvest time (0 day at 20 °C) and after storage (25th day at 5 °C)

Parameter	Bacteria (× 10 spores/ml)		Fungi (× 10 spores/ml)	
	Harvest	Storage	Harvest	Storage
Control	200.00a[z]	206.67a	6.00a	8.00a
Iron	196.67ab	201.67ab	4.67ab	6.33ab
Iodine	195.00ab	199.33ab	4.33ab	5.67ab
Selenium	188.33b	193.33b	3.33b	4.33b
P value	*	*	*	*

Note: [z]Mean separation of columns by Duncan's multiple range tests (DMRT) (n=10). *; significant at $p< 0.05$.

Count of bacteria and fungi

All treatments revealed distinctive effectiveness in diminishing bacteria and fungi occurrence either at harvest time or after storage compared with control. Lowest bacterial and fungal count was revealed in selenium-treated cherry tomatoes at harvest time and after storage. Bacteria at harvest time or after storage were higher than fungal densities (Table 5). Selenium effectively reduced gray mold of cherry tomatoes caused by *Botrytis cinerea* and control from severe damage to the conidia plasma membrane and loss of cytoplasmic materials from the hyphae (Wu *et al*., 2016).

Conclusions

Effects of iron, iodine and selenium on quality, shelf life and microbial activity of cherry tomatoes were examined in this study. Selenium-treated cherry tomatoes revealed the lowest respiration rate and ethylene production that slowed the ripening process. The least fresh weight loss and the longest shelf life was revealed in selenium-treated cherry tomatoes among treatments. Tomatoes firmness was increased at harvest time and it retained after storage with selenium treatment. Fungal incidence and microbial activities were also lower in selenium-treated cherry tomatoes compared with iron and iodine treatments. Therefore, selenium treatment may be a useful tool to maintain quality and shelf life for cherry tomatoes by reducing microbial activities.

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