International Journal of Horticultural Science and Technology
Vol. 2, No. 1; June 2015, pp 67-74

Diverse postharvest responses of tomato fruits at different maturity stages to hot water treatment

Siamak Kalantari, Mohsen Hatami*, Mojtaba Delshad
Department of Horticultural Sciences, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran

(Received: 21 August 2013, Accepted: 11 June 2014)

Abstract
Sensitivity of tomato fruits to chilling injury limits its storage and marketability. This study investigated the effect of hot water treatment (HWT) on reducing the consequences of chilling injury (CI) with respect to quality attributes of tomatoes during storage. Tomatoes were harvested at three ripening stages: mature green, pink, and red; dipped in hot water at 45°C for 15 min; and stored at three storage temperature conditions: 5°C, 13°C, and a simulated condition (SC: 3 days at 25°C and then at 5°C) representing the time between harvest and consumption by consumer. Quality analysis was carried out at the beginning of the experiment and every 10 days of storage 3 days of shelf life evaluation. Fruit color, lycopene content, weight loss, and CI were evaluated during the experiment. HWT reduced CI in mature green tomatoes but had little effect in pink and red fruits. It also caused delay in surface color development and reduced weight loss. During storage, heated mature green fruits often had significantly more lycopene content but low *a** compared with unheated ones, whereas in heated red fruits, both *a** and lycopene content were lower than unheated ones. This study showed that HWT could be used to reduce CI in mature green tomatoes, but not in pink and red fruits.

Keywords: chilling injury, color, heat treatment, maturity stage, postharvest.

Introduction

Application of nonfreezing temperatures (below ~10°C) results in chilling injury (CI) to the tissues of sensitive subtropical products like tomato (Saltveit, 2005). CI affects physiological activities of tissues and results in symptoms, such as failure to ripen, slow and abnormal coloring, surface lesions, electrolyte leakage, and susceptibility to decay (King and Ludford, 1983; Paull, 1990). Sensitivity to chilling injury varies among species of tomatoes, and symptoms associated with chilling injury often develop only after transfer of chilled fruits to ambient temperature (King and Ludford, 1983). CI also affects quality attributes like firmness and subsequent ripening of tomatoes during storage life.

Practically, tomato as a climacteric fruit has the capacity to be harvested at different stages of maturity and can be allowed to ripen during storage or handling (Cantwell and Kasmire, 2002; Wills and Ku, 2002). Early ripening results in fruits that are less sensitive to chilling injury and thus are more resistant to chilling damages (Rubatzky and Yamaguchi, 1997; Saltveit, 2005).

Heat treatment is a safe postharvest treatment for reducing CI of horticultural products (Lurie and Klein, 1992; Whitaker, 1994; Hakim *et al*., 1997). Heat may be applied to fruits and vegetables in several ways, but water is the preferred medium for

Corresponding author Email: mohsenhatami@ut.ac.ir

most applications because it is a more efficient heat transfer medium than air. This treatment has a number of advantages, which include relative ease of use, short treatment time, reliable monitoring of fruit and water temperatures, and the killing of skin-borne decay-causing agents (Fallik, 2004).

The objective of this study was to evaluate the effects of hot water treatment on the reduction of CI effects on tomatoes harvested at different stages of maturity.

Materials and Methods

Plant material and hot water treatment

Greenhouse-grown tomatoes (*Solanum lycopersicom* Mill. 'Banemi') were harvested on the same day at three ripening stages (mature green, pink, and red), based on their external color as described by the USDA standards (USDA, 1991). Fruits at each maturity stage were divided into two groups; one group was subjected to HWT. HWT was performed by dipping fruits in a large water bath at 45 ± 0.5°C for 15 min. Next, the fruits were air dried at room temperature for approximately 1 hour. Both heated and unheated fruits at each maturity stage were placed at 5°C, 13°C, respectively, or a simulated condition (SC: 3 days at 25°C and then at 5°C). The whole experiment was repeated three times. SC is almost similar to conditions normally occurring in the market chain, which is three days in plastic boxes under 25°C and then at 5°C as household refrigerator temperature: the period between harvest and consumption by consumers. The storage period to ripen was 40, 30, and 20 days for mature green, pink, and red fruits, respectively. Fruit characteristics were evaluated at 10-day intervals. Fruits were stored at room temperature for 3 additional days at the end of storage. All fruits (216 mature green, 180 pink, and 144 red fruits) were kept in plastic containers (54 containers as experimental units) during the experimental period, and on each sampling day, two fruits (as samples) from each container were randomly taken for quality analysis. On the same day, a piece of each fruit was frozen for required subsequent analyses.

Chilling injury (CI), weight loss, color values, and lycopene content

Chilling injury was assessed visually according to Lu *et al*. (2010) and Jing *et al*. (2009). After 10 days of storage period, fruits (12 tomato samples from each treatment) were transferred to room temperature for 3 days and then evaluated. Symptoms included skin lesions, severity of irregular coloring, pitting, cracking, and decay. Visual assessment was performed by three evaluators using a 0–3 scale: 0 = no injury (no signs), 1 = slight (<20% of surface area), 2 = moderate (20–50% of surface area), and 3 = severe (>50% of surface area). CI was calculated as follows: CI = (∑ (scale × N))/total fruit number, where N is the number of fruits on the corresponding scale.

The weight of three fruits, corresponding to each experimental unit, was measured at the beginning of the experiment and every 10 days during the storage period. Weight loss was expressed as the percent loss with reference to the initial total weight.

Surface color values were measured using a Minolta Chroma Meter (Model CR-400, Japan) at three random points of the fruits. $L*$ (lightness), $a*$ (green-red tonality), and $b*$ (blue-yellow tonality) values were recorded, and results were expressed as follows:

Hue angle $h = \tan^{-1} (b*/a*)$, saturation (or chroma) $C = (a*^2 + b*^2)^{1/2}$.

Lycopene content was determined according to Davies (1965), with minor modifications. One gram of the frozen pericarp was ground and homogenized in 4 mL of precooled hexane. The suspension was centrifuged at 1400g for 6 min (Sigma, D-37620 Osterode am Harz, Germany). The supernatant was collected, and the pellet was extracted twice with precooled hexane. Supernatants were pooled, and the absorbance was recorded at 473 nm by a spectrophotometer (UV/VIS Spectrometer, Model Lambda EZ201, USA). The concentration of lycopene (micrograms per gram of fresh weight) was calculated using the extinction coefficient ($Є^{1\%}$) of 3450: Lycopene content = $(A_{473} \times v \times 10^6)/(Є^{1\%} \times 100 \times m)$, where v is the total volume of the extract (8 mL), m is the sample weight (1 g), and A_{473} is the absorbance at 473 nm.

Statistical analyses

The experiment was performed according to a factorial design with maturity stages (mature green, pink, and red), storage temperatures (5°C, 13°C, and SC: 3 days at 25°C and then at 5°C), HWT (45°C and control), and sampling times (days 0, 10, 20, 30, 40, and 43 for mature green fruits; days 0, 10, 20, 30, and 33 for pink fruits; and days 0, 10, 20, and 23 for red fruits) as factors, based on a completely randomized design (CRD). Data were subjected to statistical analyses using the SAS (Version 9.1) software. Duncan's new multiple range test was used to compare the mean of treatments at $P = 0.05$.

Results and Discussion

Chilling injury

Results showed that the severity of CI was greater in mature green fruits than pink and red fruits and at 5°C and SC-stored tomatoes than those stored at 13°C. HWT reduced CI in mature green tomatoes ($P < 0.05$) as lower values of more pronounced symptoms of CI, such as discoloration, pitting, and susceptibility to disease, were observed in heated fruits than in unheated ones after 10 days of storage (Fig. 1). In pink fruits stored at 5°C and SC, effect of HWT was minimum, and in red fruits, there was no significant difference between heated and unheated fruits. HWT had minimum or no effect on reduction of CI in these fruits because of their more resistance to CI, exposure to cold storage for shorter time, or both. The same pattern of higher CI in mature green fruits than pink and red fruits was observed at the end of the storage period, but there was no significant difference between heated and unheated fruits at all three storage temperatures.

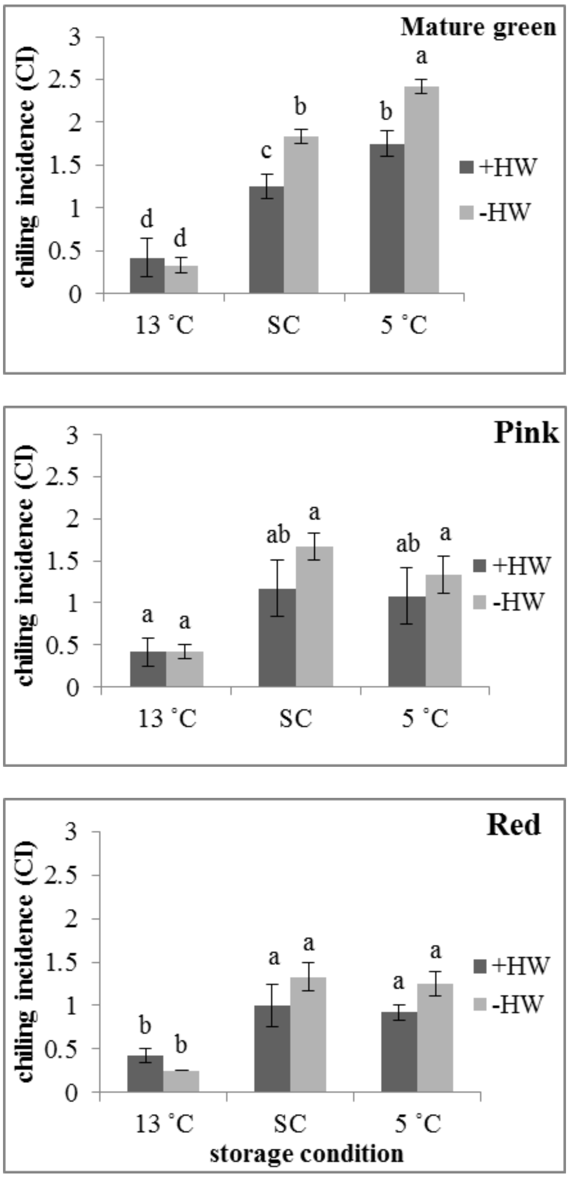

Fig. 1. Chilling incidence (CI) in heated (+HW) and unheated (−HW) tomatoes at three storage conditions after 10 days of storage followed by 3 days of shelf life. Each maturity stage was analyzed separately to compare the mean of treatments. The letters above the columns indicate the results of Duncan's multiple range test: treatments indicated by the same letter are not significantly different at α = 0.05.

Heat treatment can inhibit fruit softening because of CI. The reduction in fruit softening may be because of the inhibition of pectic hydrolysis, perhaps indicating a reduced level of cell wall–degrading enzyme activity, and to the inhibition of ethylene production (Lurie, 1998). Both decay and electrolyte leakage are indirect indicators of CI that can be significantly reduced by heat treatment (Bergevin *et al*., 1993; King and Ludford, 1983). Heat may also induce defense mechanisms in the outer layers of epicarp and biochemical changes in the fruit peel tissue, which enhanced fruit resistance to chilling damage (Fallik, 2004). Causes of lower CI at SC than 5°C can be related to placing at room temperature for the first three days where ripening has advanced and thereby resistance to CI has enhanced.

Weight loss

Weight loss was influenced by hot water treatment ($P < 0.01$). In mature green fruits, at all three storage conditions, heated fruits had lower rate of weight loss than unheated ones at all storage times (Fig. 2). In red fruits stored at 13°C and pink fruits stored at 5°C and SC, there was no significant difference between heated and unheated fruits.

Effect of HWT on reduction of water loss in mature green tomatoes was significantly higher than that in pink and red tomatoes. The rates of weight loss at the end of storage (40 days) at 13°C, 5°C, and SC for heated mature green fruits were 10.2, 9.2, and 9% and for unheated fruits were 11.3, 10, and 11.1%, respectively. During the last three days of the experiment (shelf life evaluation) and the first 10 days at SC, there was a severe weight loss because of placing at room temperature.

HWT causes a clear redistribution of the epicuticular wax layer and a significant reduction in cuticular cracks of mandarin (Schirra and D'Hallewin, 1997), thus improving physical barriers to reduction of water loss. Similar results were obtained for hot water rinsing and brushing (HWRB) so that natural openings and barely visible cracks in the epidermis of treated fruits were partially or entirely sealed with rearranged natural wax components present on the cuticle (Fallik *et al*., 1999). Another reason for vindicating lower weight loss in HW-treated fruits is lower rate of respiration. McDonald *et al*. (1999) showed that respiration rates of fruits treated at 27°C were considerably higher than those treated at 39, 42, or 45°C, probably because prestorage heat treatment protection was not afforded to them.

Color

Green and pink fruits stored at 13°C and pink fruits stored at 5°C developed a normal coloration during storage, whereas green fruits at 5°C developed only a "poor" pink color, indicated by a^* in Figure 2. Storage at 5°C inhibited red color development in both green and pink tomato fruits. HWT had a slightly negative effect on the red color development of both green and pink fruits as unheated fruits had relatively higher amount of a^* than heated ones during storage. Heat treatment could not prevent the consequences of CI both on undeveloped red coloration of tomato fruits stored at 5°C and on SC-treated tomatoes.

In this study, HWT has been applied on three mature different ripening stages of tomato fruits, whereas previous studies on application of HWT have been carried out only on mature green tomatoes. Whitaker (1994) and Lu *et al*. (2010) reported inhibitory effect of HWT, both on red color development (represented by a^* or hue angle) in mature green and on breaker stages of tomatoes. There are some conflicting reports about its inhibitory effect on color development (Lurie and Klein, 1992; Jing *et al*., 2009). Different results could be related to effects of different treating temperatures and dipping durations or cultivars. The results of application of heat treatment on mature

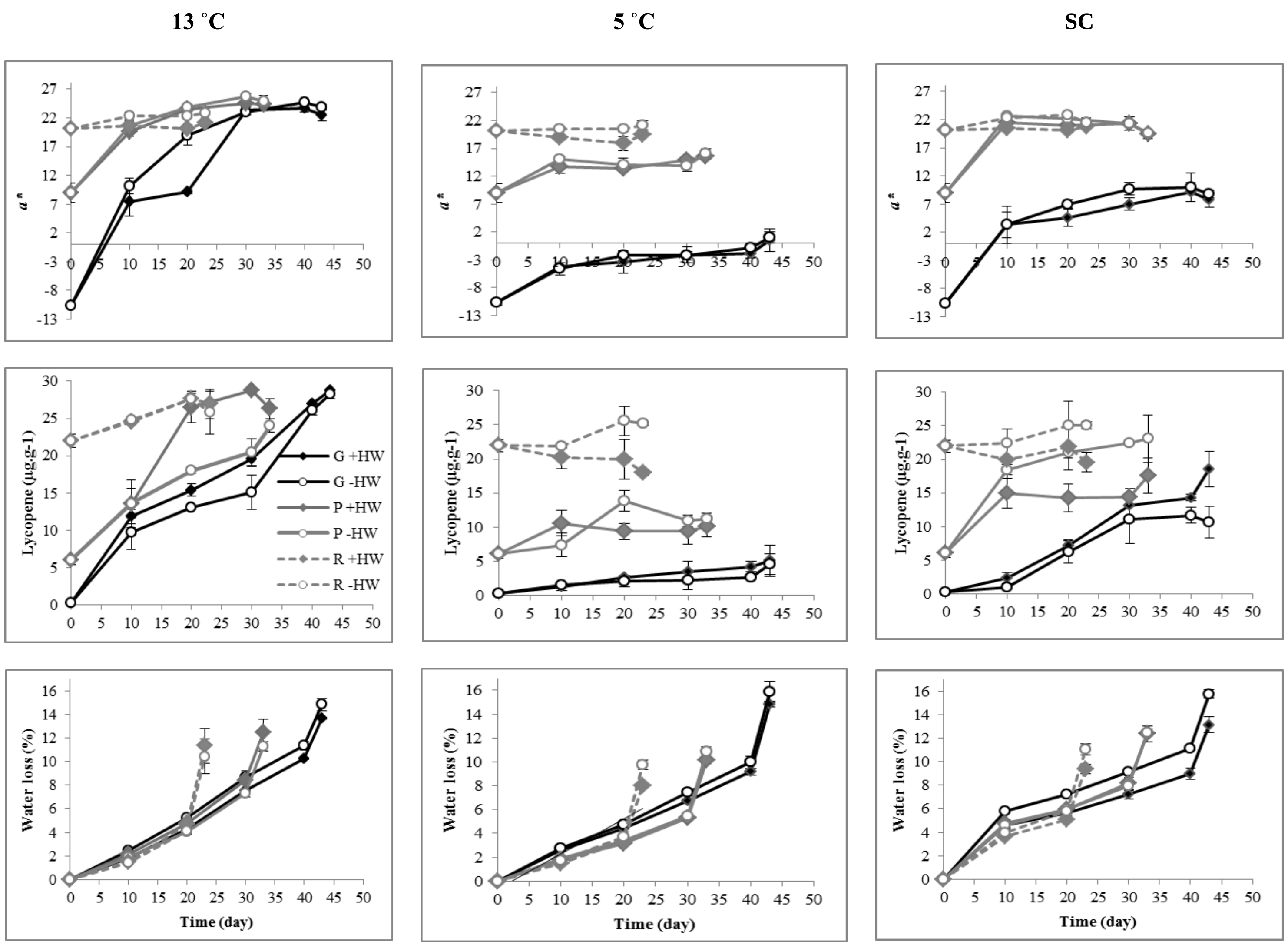

Fig. 2. Changes in *a value, lycopene content, and water loss in hot water–treated (+HW) and unheated (−HW) tomato fruits during 43, 33, and 23 days of storage for mature green (G), pink (P), and red (R) fruits, respectively, at 13°C, 5°C, and SC. Each value represents the mean of three replicates.**

green tomatoes can be validated by interpretation of Lu *et al*. (2010) who suggest that the synthesis of ethylene, which synchronizes the ripening processes of climacteric fruit, including color changes, is inhibited at temperatures ≥35°C.

Lycopene content

Effect of HWT on lycopene content of tomatoes depending on their maturity stages and their storage temperatures was different (Fig. 2). HWT enhanced lycopene content of green fruits in all three temperature conditions and also pink fruits stored at 13°C but had no positive effect on red fruits ($P < 0.05$). It is reasonable to conclude that heat treatment before storage at temperatures above 10°C stimulates lycopene development in mature green and pink fruits. Increased lycopene content of mature green fruits because of heat treatment was reported after storing at 12°C for two weeks (Lurie and Klein, 1992).

Lower lycopene contents were measured in heated compared with unheated red and pink fruits stored at 5°C and SC. It seems that temperatures below 10°C causes lycopene degradation in heated red and pink fruits.

In heated mature green and pink fruits, an increase in lycopene levels was observed during three days of shelf life evaluation in both low temperature conditions ($P < 0.05$). Increased lycopene content of heat-treated mature green tomatoes has been noticed after storage at low temperatures, such as 2°C for few days followed by few days at higher temperatures (Lurie and Klein, 1992; Hakim *et al*., 1997; Jing *et al*., 2009). It is concluded that low temperatures inhibit lycopene synthesis, this inhibition can be alleviated by the prestorage heat treatment, and the heated tomatoes developed lycopene pigment after being kept at higher temperatures (Lurie and Klein, 1992).

Heated mature green fruits often had significantly ($P < 0.05$) more lycopene content but low a^* compared with unheated ones, whereas in heated red fruits, both a^* and lycopene content were lower than in the unheated ones. Tomato color includes not only lycopene pigment but also other pigments, especially chlorophyll. The a^* value represents color range from green to red, and high temperature affects synthesis of chlorophyll and lycopene differently, probably because HWT has increased lycopene synthesis in mature green tomatoes but has not accelerated chlorophyll degradation. This contradiction was not found in pink and red fruits because of no or lower chlorophyll content. Sozzi *et al*. (1996) reported that the increase in temperature from 21 to 40°C in 48 hours decreased the degradation of chlorophyll in mature green tomatoes. According to McDonald *et al*. (1999), mature green tomatoes treated in 48°C water not only had the highest color rating (greatest a^*/b^* ratio) but also contained more chlorophyll than fruits from other heat treatments.

Conclusion

This study showed that HWT has a significant effect on the reduction of CI and on the postharvest behavior of tomato fruits. These effects can be described in the following ways: lower value of CI and weight loss were observed in heated fruits than unheated ones and also increased lycopene content of mature green fruits because of heat treatment.

The results of an HWT are different for the three maturity stages studied because of the observed higher resistance to chilling injury in the green tomatoes. Most of the studies on application of HWT for the purpose of controlling chilling injury have been done on mature green tomatoes. This study applied heat treatment on three ripening stages to compare the responses of each maturity stage to this treatment with the aim of technology transfer to the market. In addition, by providing different storage conditions, non-chilled, chilled, and consumer simulated condition (SC), nearly all possible scenarios for harvested tomato have been explored simultaneously with heat treatment. This may interpret disagreement with previous results, such as results obtained with respect to color and lycopene content.

Storage at 5°C and SC is not recommended for mature green fruits because of their susceptibility to CI and inhibitory effect of these conditions on coloring process. According to the obtained results, long postharvest life in tomato fruits is caused by two factors i.e., harvesting at primary stages of maturity and maintaining at low temperatures, but this condition could lead to chilling injury; so, HWT can be a useful and inexpensive procedure before storage of mature green tomatoes.

Inhibitory effect of heat treatment on reduction of water loss during storage could recompense low humidity of storage and thereby recompense part of the final storage expenditures. Corresponding to maturity stage, this study showed that hot water treatment is a proper postharvest treatment for tomato fruits and can be suggested as an efficient approach before storage.

References

1. Bergevin, M., G.P. L'Heureux, J.E. Thompson, and C. Willemot. 1993. Effect of Chilling and Subsequent Storage at 20˚C on Electrolyte Leakage and Phospholipid Fatty Acid Composition of Tomato Pericarp. Physiol. Plant. 87:522–527.
2. Cantwell, M.I. and R.F. Kasmire. 2002. Postharvest Handling Systems: Fruit Vegetables, pp. 407–423. In: A.A. Kader (ed.) Postharvest Technology of Horticultural Crops. University of California, Agriculture and Nature Resources, Davis.
3. Davies, B.H. 1965. Analysis of Carotenoid Pigments, In: T.W. Goodwin (ed.) Chemistry and Biochemistry of Plant Pigments. Academic Press, New York, USA. 530.
4. Fallik, E., S. Grinberg, S. Alkalai, O. Yekutieli, A. Wiseblum, R. Regev, H. Beres, and E. Bar-Lev. 1999. A Unique Rapid Hot Water Treatment to Improve Storage Quality of Sweet Pepper. Postharvest Biol. Technol. 15:25-32.
5. Fallik, E. 2004. Prestorage Hot Water Treatments (Immersion, Rinsing and Brushing). Postharvest Biol. Technol. 32:125-134.
6. Hakim, A., E. Kaukovirta, E. Pehu, and I. Voipio. 1997. Effect of Hot Water, Immersion Time, and Length of Storage on Chilling Injury of Tomato Fruit. J. Veg. Crop Prod. 3:17-27.
7. Jing, Y., F. Mao-run, Z. Yu-ying, and M. Lin-chun. 2009. Reduction of Chilling Injury and Ultrastructural Damage in Cherry Tomato Fruits after Hot Water Treatment. Agr. Sci. China 8:304-310.
8. King, M.M. and P.M. Ludford. 1983. Chilling Injury and Electrolyte Leakage in Fruit of Different Tomato Cultivars. J. Amer. Soc. Hort. Sci. 108:74-77.
9. Lu, J., M.T. Charles, C. Vigneault, B. Goyette, and G.S.V. Raghavan. 2010. Effect of Heat Treatment Uniformity on Tomato Ripening and Chilling Injury. Postharvest Biol. Technol. 56:155-162.
10. Lurie, S. 1998. Postharvest Heat Treatments of Horticultural Crops. Hort. Rev. 22:91-121.
11. Lurie, S. and J.D. Klein. 1992. Ripening Characteristics of Tomatoes Stored at 12˚C and 2˚C Following a Prestorage Heat Treatment. Sci. Hort. 51:55-64.
12. McDonald, R.E., T.G. McCollum, and E.A. Baldwin. 1999. Temperature of Hot Water Treatments Influences Tomato Fruit Quality Following Low-temperature Storage. Postharvest Biol. Technol. 16:147-155.
13. Paull, R.E. 1990. Chilling Injury of Crops of Tropical and Subtropical Origin, pp. 17-36. In: C.Y. Wang (ed.) Chilling Injury of Horticultural Crops. CRC Press, Boca Raton, FL, USA.
14. Rubatzky, V.E. and M. Yamaguchi (eds.). 1997. World Vegetables: Principles, Production, and Nutritive Values. Chapman & Hall, New York, USA.
15. Saltveit, M.E. 2005. Postharvest biology and handling, pp. 305–324. In: E. Heuvelink (ed.) Tomatoes. CAB International, Wallingford.
16. Schirra, M. and G. D'Hallewin. 1997. Storage Performance of Fortune Mandarins Following

Hot Water Dips. Postharvest Biol. Technol. 10:229-237.

17. Sozzi, G.O., O. Cascone, and A.A. Fraschina. 1996. Effect of a High-Temperature Stress on Endo-β-mannanase and α- and β-galactosidase Activities during Tomato Fruit Ripening. Postharvest Biol. Technol. 9:49-63.

18. USDA, 1991. United States Standards for Grades of Fresh Tomatoes. United States Department of Agriculture, Agricultural Marketing Service, P. 13.

19. Whitaker, B.D. 1994. A Reassessment of Heat Treatment as a Means of Reducing. Postharvest Biol. Technol. 4:75-83.

20. Wills, R.B.H. and V.V.V. Ku. 2002. Use of 1-MCP to Extend the Time to Ripen of Green Tomatoes and Postharvest Life of Ripe Tomatoes. Postharvest Biol. Technol. 26:85-90.