Postharvest Heat Stress Application to Reduce Water Loss in Tomato During Storage

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ABSTRACT

Mature green tomatoes were treated by a single heat stress [hot air (HA) or hot water (HW)] and a double heat stress (combination of HA + HW or HW + HA) before storage at 15°C for 10 days. The rate of water loss of fruit was evaluated during storage after being treated by single heat stress namely HW at temperatures ranging from 35 to 45°C for periods of 5 to 60 min and HA at 40°C for 1 to 24 h. The double heat stress technique used either hot water followed by hot air (HW + HA) or hot air followed by hot water (HA + HW). The findings suggest that 6 h of hot air was beneficial in reducing the rate of water loss of fruit both in short term as well as long-term tomato storage. The use of hot air followed by hot water was also found effective in reducing water loss and preserving freshness of tomato during storage.

Keywords: Tomato, storage, heat treatment, water loss, hot water, hot air, double heat shock

1. INTRODUCTION

Many fruits and vegetables are highly perishable in nature. Their storage at room temperature favors decay, mass loss, softening, wilting, and off-flavor development (Irtwange, 2006). In recent years, however, there has been increasing interest in the use of postharvest heat treatments for maintaining freshness of many agricultural commodities including tomato during long-term storage (Paull and McDonald, 1994; Morimoto *et al*., 1997; Morimoto *et al*., 2003; ElAssi, 2004). It has been noted that postharvest exposure to temperature between 38 and 42°C is effective to increase storage life and improve flavors (Sabehat *et al*., 1996; Shellie and Mangan, 1996). Heat-stressed plant cells accumulate mitochondria-located small heat shock proteins (MT-sHSP) and the accumulation is corresponding with the thermotolerance of mitochondria. Under heat stress, mitochondrial metabolic pathways breakdown and function abnormally, thus diminishing cell viability (Sanmiyal *et al*., 2002). Recent studies with heat-stressed tomato fruits revealed a correlation between the accumulation of Heat Shock Proteins (HSPs) and the acquisition of cold tolerance (Sabehat *et al*., 1998; Kadyrzhanova *et al*., 1998).

The present study was intended to analyze the effect of prestorage heat treatments at various temperatures and duration on the rate of water loss of tomato during storage.

2. MATERIALS AND METHODS

2.1 Plant Material

Mature green tomatoes (*Lycopersicon esculentum* Mill. cv. Momotaro) of uniform color and size (about 8 cm in diameter), grown in the hydroponic system were used in this investigation.

2.2 Treatment Conditions

In this study, single and double heat stress techniques were used as treatments. In the single HW treatments, tomatoes were immersed in hot water at temperatures ranging from 35 to 45^{o}C for periods of 15 to 60 min. After the hot water treatment, the fruits were placed on absorbent paper to remove the excess surface water, weighed and then stored at 15^{o}C for 10 days. The water temperature during hot water treatment was maintained within the set temperature using a Fine Thermo-Indicator. In the single HA treatments, the fruits were divided into three groups based on different temperatures (5 to 45^{o}C and overturns 45 to 5^{o}C correspondingly; 40^{o}C for 1 to 24 h; 40^{o}C for 6 h). In the first group, tomatoes were treated at temperature 5 to 45^{o}C and overturns 45 to 5^{o}C correspondingly with 12 h intervals for 5 days in the storage chamber. In a second lot, the fruits were held in hot air at 40^{o}C for 1 to 24 h before storing them at 15^{o}C for 10 days. In the third group, tomatoes were treated with hot air (40^{o}C) for 6 h. The fruits were then kept at (i) 5 to 15^{o}C, and (ii) 40 to 15^{o}C in the storage chamber.

Similarly in the double heat treatments, tomatoes were divided into three groups. In the first group, the fruits were first immersed in hot water at 41 to 43^{o}C for 5 to 15 minutes and then kept in hot air at 40^{o}C for 6 h (HW + HA method) before storing them at 15^{o}C for 10 days. In the second group, tomatoes were first kept in hot air at 40^{o}C for 6 h and then immersed in hot water at 34 to 42^{o}C for 6 to 12 h (HA + HW method) prior to storage at 15^{o}C for 10 days. In the third group, short-term response of tomatoes was evaluated under HA + HW treatment. Here, tomatoes were first held in hot air at 40^{o}C and then immersed in hot water at 42^{o}C both for 6 h. The fruits were then kept at (i) 5 to 15^{o}C, (ii) 40 to 15^{o}C, and (iii) 5 to 45^{o}C and overturns 45 to 5^{o}C in the storage chamber. Untreated tomatoes (used as control) were held at normal room temperature for 24 h and then stored at 15^{o}C. The air humidity during HA treatment was 60% while during storage it was kept as nil. The experimental details are summarized in Table 1.

2.3 Water Loss Measurement

Among the major fruit responses, the fresh mass loss (%)/day was evaluated during the storage period for 10 days. Three tomatoes were used in each treatment. After treatment, fruits were stored in temperature controlled chamber (LHU-112M, Tabai-Espec Corp., Osaka, Japan), where the temperature and relative humidity were strictly controlled with accuracies of 0.1^{o}C and 2%, respectively. The rate of water loss (μmol g^{-1} s^{-1}) was measured in terms of fruit mass loss after the heat stress application in a storage chamber (Espec, LHU-113). Three tomatoes were enclosed in airtight transparent box using a CO_2 and H_2O Analyzer (LI-7000, LI-COR, Nebraska, USA) for 12 to 144 h in the storage chamber.

2.4 Statistical Analysis

Means and standard deviations were calculated from day-10 data and a t-test was also performed in order to see the significance level between the treatment means at $P < 0.05$.

3. RESULTS AND DISCUSSION

The response of tomato transpiration to a stepwise up- and down-regulation of the fruit temperature reveals a considerable direct effect of heat treatments. After the heat treatment (6 h at 35^{o}C + 6 h at 40) the fruit was significantly lower at both 35^{o}C and 25^{o}C than before the treatment (Fig. 1). The rate of water loss was reduced when temperature declined from 40 to 15^{o}C as compared to increase in temperature (15 to 40^{o}C) whereby a higher rate of water loss was noted (Fig. 2). Among various treatments, the fruits held under hot water had a weight loss (4.78% at 39^{o}C for 45 minutes, 4.88 and 4.82% at 41^{o}C for 30 and 45 minutes and 7.05, 8.26 and 10.17% at 45^{o}C for 20, 25 and 30 minutes) higher than untreated control (4.73%) after 10 days storage at 15^{o}C (Table 2). The non-significant differences between HW treated and control, except at exposure temperatures 35^{o}C for 15 minutes and 45^{o}C for 10 and 25 minutes, suggest that most of these treatments did not raise the internal temperature of the fruit significantly and the chemical composition remained unaffected. The tomatoes of all other single HW treatments at varying exposure temperatures and duration showed lower water losses than the untreated tomatoes. Regarding the prestorage use of hot air, tomatoes had a lower weight loss than both HW treatments and control when exposed to hot air at 40^{o}C for 1 to 24 h. Although statistically not significant, exposing tomatoes to hot air for 6 h minimized the rate of water loss to only 1.95%. It was followed by HA + HW treatment, which also showed lower water loss of fruit during storage when prestorage hot water application was done at 42^{o}C for 6 to12 h (Table 2).

In the single HW treatments, the rate of water loss increased by increasing the water temperature up to 45^{o}C for 20 to 30 minutes. This was mainly due to the effect of high temperature exposure that increased the water loss of the fruit. Water loss (transpiration) of fruit mostly depends, on the one hand, the transpiration driving force (vapor pressure deficit: VPD; including temperature effects), and, on the other hand, an overall resistance in the water vapor pathway (including dermal tissue effect, and air velocity effect) that determines the transpiration rate per unit diffusion area. The higher water loss at 45^{o}C might also be due to protein denaturation, disruption of protein synthesis and loss of membrane integrity. Such a denaturation of protein at elevated temperatures was found to be non-reversible (Bernstam, 1978; Inaba and Crandall, 1988). Dimitris *et al*. (2005) found out that, in treatments at higher temperature levels, the epicuticular waxes melt completely and may be removed that results in higher water loss in fruits. Regarding the use of HA treatments at 40^{o}C, the rate of water loss was lower than HW treatments (Table 2) whereby initial rate of water loss was almost the same at temperatures 5 to 25^{o}C but it declined from 25 to 35^{o}C and again accelerated from 35 to 45^{o}C (Fig. 3). However, the rate of water loss of fruit was reduced considerably when temperature declined from 45 to 5^{o}C.

Table 1. Experimental detail of various treatments used in tomato storage process

Method of heating	Exposure temperature	Exposure time	Procedure
Hot Water	35, 37, 39, 41, 43^{o}C	15, 30, 45 and 60 min	HW immersing at given temperatures and time and then shifted to storage chamber at 15^{o}C for 10 days
	45^{o}C	5, 10, 15, 20, 25 and 30 min	HW immersing at given temperature and time and then shifted to storage chamber at 15^{o}C for 10 days
Hot Air	40^{o}C	1, 2, 3, 6, 12 and 24 h	HA treatment at given temperature and time and then shifted to storage chamber at 15^{o}C for 10 days
	5, 15, 25, 35, 45^{o}C	12 h	HA treatment at 5 to 45^{o}C and overturns 45 to 5^{o}C correspondingly for 12 h each in the storage chamber
	40-15^{o}C	6h + 24-120 h	HA treatment at 40^{o}C for 6 h; shifted to storage chamber at 40^{o}C for 24 h and 15^{o}C for 5 days
	5-15^{o}C	6h + 48-96 h	HA treatment at 40^{o}C for 6 h; shifted to storage chamber at 5^{o}C for 48 h and 15^{o}C for 4 days
	15^{o}C	6h + 144 h	HA treatment at 40^{o}C for 6 h; shifted to storage chamber at 15^{o}C for 6 days
Hot Water + Hot Air	41^{o}C	5-10 min + 24h + 6h	HW immersing at 41^{o}C for 5 to10 min; placed in storage chamber at 15^{o}C for 24 h; exposed to HA at 40^{o}C for 6 h and then shifted to storage chamber at 15^{o}C for 10 days
	43^{o}C	15 min + 24h + 6h	HW immersing at 43^{o}C for 15 min; placed in storage chamber at 15^{o}C for 24 h; exposed to HA at 40^{o}C for 6 h and then shifted to storage chamber at 15^{o}C for 10 days
Hot Air + Hot Water	34,36, 38, 40, 42^{o}C	6h + 24h + 6-12h	HA treatment at 40^{o}C for 6 h; placed in storage chamber at 15^{o}C for 24 h; immersed in HW at 34,36, 38, 40, 42^{o}C for 6 to12 h and finally shifted to storage chamber at 15^{o}C for 10 days
	5, 15, 25, 35, 45^{o}C	6h + 24h + 6h + 12 h	HA treatment at 40^{o}C for 6 h; placed in storage chamber at 15^{o}C for 24 h; immersed in HW at 42^{o}C for 6 h and finally held under HA at 5 to 45^{o}C and overturns 45 to 5^{o}C correspondingly for 12 h each in the storage chamber

	40-15^{o}C	6h + 24h + 6h + 24-120 h	HA treatment at 40^{o}C for 6 h; placed in storage chamber at 15^{o}C for 24 h; immersed in HW at 42^{o}C for 6 h and finally held under HA at 40^{o}C for 24 h and 15^{o}C for 5 days in the storage chamber
	5-15^{o}C	6h +24h + 6h + 48-96 h	HA treatment at 40^{o}C for 6 h; placed in storage chamber at 15^{o}C for 24 h; immersed in HW at 42^{o}C for 6 h and finally held under HA at 5^{o}C for 2 days and 15^{o}C for 4 days in the storage chamber
	15^{o}C	6h + 24h + 6h + 144 h	HA treatment at 40^{o}C for 6 h; placed in storage chamber at 15^{o}C for 24 h; immersed in HW at 42^{o}C for 6 h and finally held under HA at 15^{o}C for 6 days in the storage chamber
Control	Room temperature	24 h	At room temperature for first 24 h and then stored at 15^{o}C

This pattern corresponds to the dynamic response, which reveals that the rate of water loss of fruit is reduced by dropping the temperature after heat application (Fig. 1). However, the variations found in two heating methods (HW and HA) under various temperatures and duration might be due to the reason that the internal heat resistance in tomato during water heating acts as a dominant factor in controlling the heat transfer than in hot air (Wang *et al*., 2001). Similarly, it has been established that the hot air treatment (HA) produces stronger stress than the hot water (HW) if the temperature is same (Baloch *et al*., 2006). In the present study, the rate of water loss was lower after 6 to 12 h hot air exposure as compared to 1 to 3 h. It suggests that the use of prestorage HA for 6 h is optimum to induce heat response, where the increased respiration consumes inconsiderable quantity of organic acids (Lurie and Klein, 1990). The short-term response of fruit also showed lower rate of water loss after HA treatment at 5 to 15 ^{o}C, 40 to 15^{o}C and a constant temperature of 15^{o}C for 144 h in the storage chamber (Figs. 4-5). In double heat stress, the rate of water loss was reduced to a large extent in most of the treatments during storage. It is evident from Table 2 that the application of HW + HA technique at 41^{o}C for 5 to 10 minutes showed relative mass losses of 44 and 48% during storage. Other treatment where the same technique was applied at 43^{o}C, however, showed more or less the same rate of water loss as found in single HW treatments. It might be due to the reason that the mass of fruit tissue was not uniformly treated when both water and air heating was used (Field, 1984). In HA + HW treatment, the combined use of hot air and water allowed the water loss of the fruits to be successfully reduced (2.55 and 2.78%) at 36 and 40^{o}C. Hence the reduction relative to the control was 46 and 41% respectively. The application of HA + HW (6 h hot air + 6 to 12 h hot water) at water temperature 42^{o}C was, however, found most effective in reducing the rate of water loss during storage (Table 2). After the hot water treatment, the fruits gained an average weight of 0.36 and 0.45% due to absorbance of water at 42^{o}C and then lost 2.34 and 2.32%, respectively at the end of 10 days storage at 15^{o}C. The short-term response of fruit (release of H_2O) was also evaluated using HA + HW treatment at 5 to 45^{o}C and overturns 45 to 5^{o}C in the storage chamber (Espec, LHU-113). Initially, the rate of water loss was lower than that of HA treatment but it accelerated from 25 to 45^{o}C and overturned in the same way from 45 to 5^{o}C (Fig. 3). Such a variation was mainly due to the difference in storage temperatures. In the previous experiment, tomatoes were kept under a constant temperature of 15^{o}C after HA + HW treatment but in the later trial, the fruit experienced a high temperature stress (15 to 45^{o}C) for around 60 h during storage. Therefore, the lower water loss of fruit held at a constant storage temperature of 15^{o}C was probably due to using hot air at 40^{o}C for 6 h before or after the fruits were immersed in hot water under a range of exposure temperatures and duration. Earlier, the use of hot air treatment at 35 to 40^{o}C has been reported to inhibit ethylene synthesis within hours in tomatoes (Biggs *et al*., 1988) and this inhibition is reversed when the fruit is removed from heat (Paull and Chen, 2000). Such a recovery needs protein synthesis and studies reveal that both mRNA and protein of ACC oxidase accumulate during recovery from 38 to 40^{o}C hot air treatment (Lurie *et al*., 1996). Moreover, it has also been reported that exposure of tomatoes under 35 to 40^{o}C could reduce damage during subsequent hot or cold treatment (Lurie and Klein, 1992; Lurie, 1998). These results are also in conformity with Ferguson *et al*. (1994) who demonstrated that exposure to elevated sublethal temperatures (<45^{o}C) induce thermotolerance, which protects fruit from a second exposure to a normally lethal temperature (45^{o}C or above).

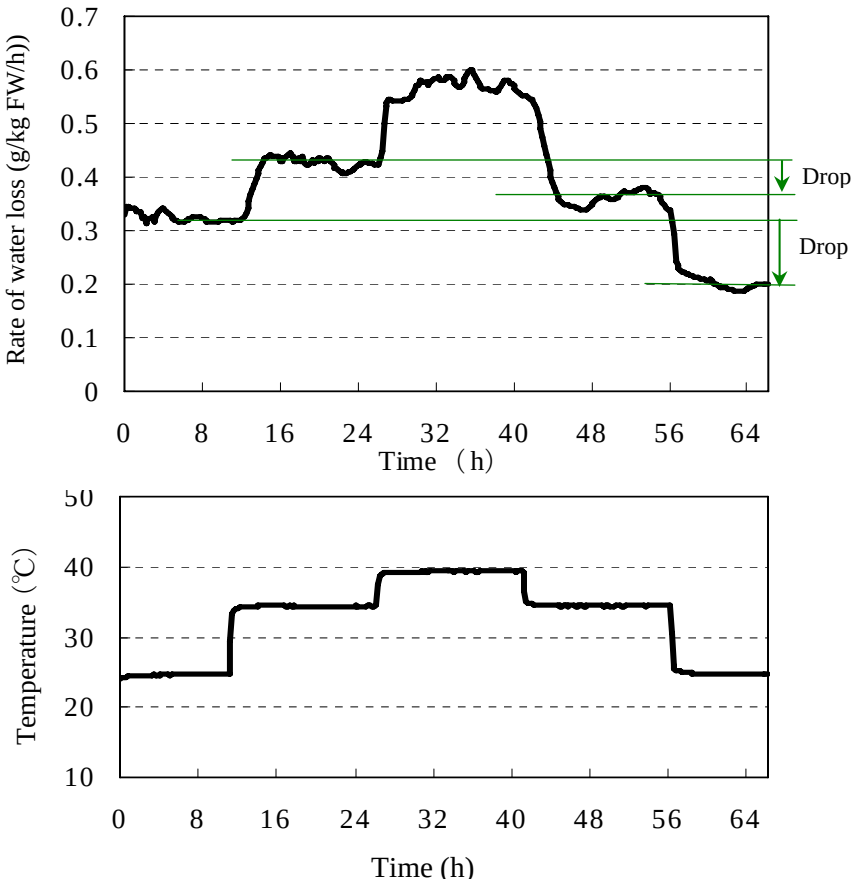

Fig. 1. Sharing different temperatures (25 to 40^{o}C and vice-versa) and response of the rate of water loss of tomato as affected by these temperatures

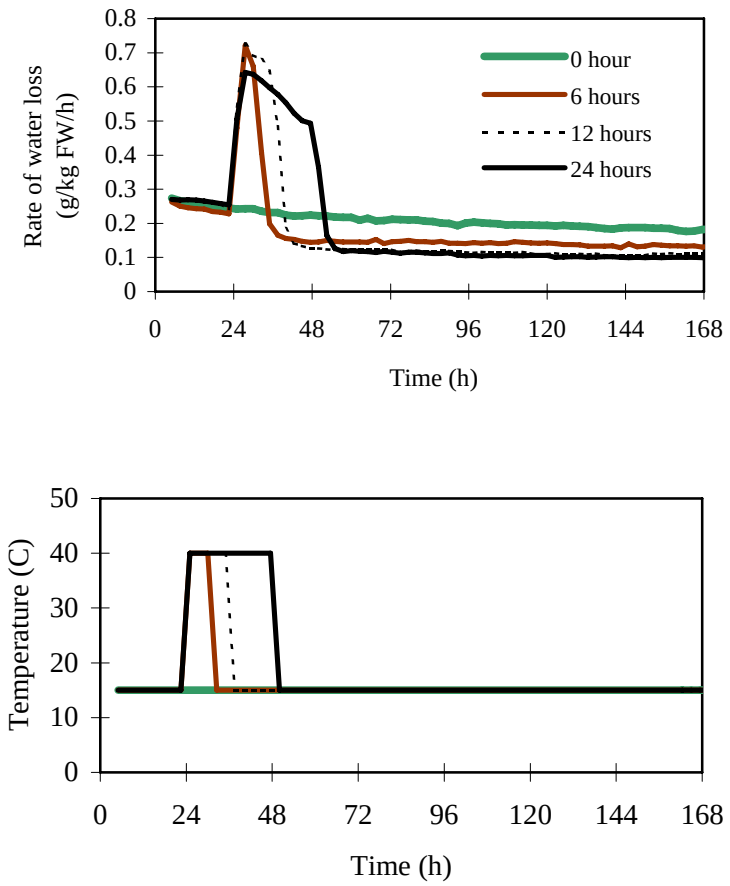

Fig. 2. Rate of water loss of tomato at different temperatures and duration (0, 6, 12 and 24 h heat treatment)

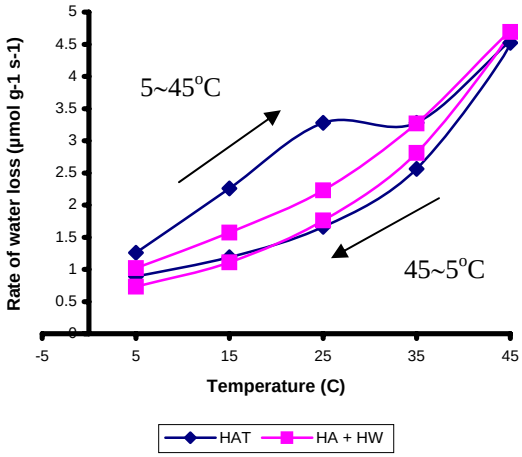

Fig. 3. Treatments (HA and HA + HW) showing water loss (µmol g^{-1} s^{-1}) in tomato as affected by different temperatures. The fruits were stored at 5 to 45°C and overturns 45 to 5°C for 12 h each

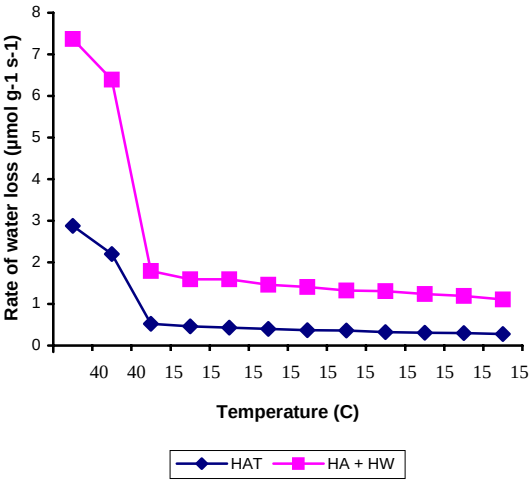

Fig. 5. Treatments (HA and HA + HW) showing water loss (µmol g^{-1} s^{-1}) in tomato as affected by different temperatures. The fruits were stored at 40 to15°C for 12 h each

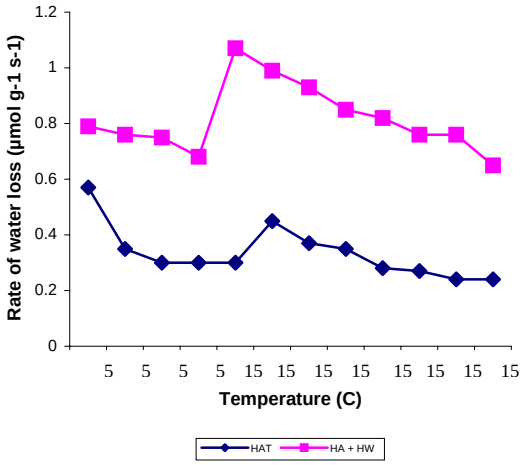

Fig. 4. Treatments (HA and HA + HW) showing water loss (µmol g^{-1} s^{-1}) in tomato as affected by different temperatures. The fruits were stored at 5 to15°C for 12 h each

Table 2. Response of tomatoes to various exposure times and temperatures during storage

Method of heating	Exposure temperature	Exposure time	Total reduction in weight (%) after 10 days storage at 15°C	t-value
Single Heat Stress Treatment				
Hot Water Treatment	35°C	15 min	3.49± 1.05	7.312*
		30 min	3.71± 1.00	0.287
		45 min	3.43± 0.18	0.188
		60 min	3.34± 0.31	0.338
	37°C	15 min	3.70± 1.27	0.377
		30 min	4.24± 0.62	0.853
		45 min	3.53± 0.37	0.112
		60 min	3.59± 0.02	0.338
	39°C	15 min	3.32± 0.23	0.151
		30 min	4.51± 1.09	1.215
		45 min	4.78± 1.26	1.580
		60 min	4.34± 0.08	0.978
	41°C	15 min	4.63± 2.45	0.670
		30 min	4.88± 2.49	1.069
		45 min	4.82± 2.39	1.147
		60 min	4.03± 0.67	1.206
	43°C	15 min	2.72± 0.83	1.767
		30 min	3.61± 1.55	0.301
		45 min	4.20± 1.98	0.316
		60 min	3.87± 0.49	0.316
	45°C	5 min	3.19± 0.55	0.707
		10 min	3.81± 1.34	5.391*
		15 min	4.34± 2.18	0.632
		20 min	7.05± 5.48	1.743
		25 min	8.26± 3.71	2.229*
		30 min	10.17± 9.95	1.937
Hot Air Treatment	40°C	1 h	3.60± 0.13	0.338
		2 h	3.85± 0.09	0.226
		3 h	2.99± 1.35	0.625
		6 h	1.95± 0.25	1.634
		12 h	2.52± 0.30	1.499
		24 h	3.09± 1.32	1.767
Control	Room temperature	24 h	4.73± 3.14	---

Double Heat Stress Treatments				
Method of heating	HW temperature	Exposure time	Total reduction in weight (%) after 10 days storage at 15°C	t-value
Hot Water + Hot Air Treatment	41°C	(5 min + 6h)	2.46± 0.91	0.834
		(10 min + 6h)	2.67± 0.86	0.377
	43°C	(15 min + 6h)	3.95± 1.42	1.093
Hot Air + Hot Water Treatment	34°C	(6h + 6h)	3.05± 0.46	0.936
		(6h + 12h)	4.88± 0.46	2.823*
	36°C	(6h + 6h)	2.55± 0.45	0.906
		(6h + 12h)	3.09± 0.26	2.188*
	38°C	(6h + 6h)	3.73± 0.07	2.451*
		(6h + 12h)	3.36± 0.11	4.601*
	40°C	(6h + 6h)	2.78± 0.16	0.482
		(6h + 12h)	3.95± 2.41	2.101
	42°C	(6h + 6h)	2.34± 0.14	2.603*
		(6h + 12h)	2.32± 0.19	3.204*
Control	Room temperature	24 h	4.73± 3.14	---

Values are average total reduction in weight ± SD (n=3)

***** Significantly different from control at 5% level of probability using t-test

In the present study, the double heat stress technique (HA + HW) not only reduced the rate of water loss during storage but also improved the moisture contents of fruit when immersed under hot water at varying temperatures. Previously, we found out that the combination of the stronger stress (HA) during the first stage and the smaller stress (HW) during the later stage is more effective to reduce the water loss of the fruit (Baloch *et al*., 2006).

4. CONCLUSIONS

Cold storage has been widely used as storage medium that preserves freshness of fruits. Heat treatments aid in improving freshness and shelf life of fruits thereby increasing value and acceptability to consumer. Hence, the prestorage use of HA at 40^{o}C for 6 h reduces water loss and allows a long-term storage of tomato. It is also useful in exporting fruits by less expensive sea transport rather than by air.

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