A Heat Stress Application Technique for Reducing Water Loss of Fruits during Storage

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(Received June 1, 2005)

Hot air and hot water are being extensively studied as postharvest heat treatments for retaining freshness and extending shelf life of many fruits and vegetables during storage. In the present study, the best combination of several types of heat stress application methods that minimizes water loss of fruit during storage were investigated, aiming at the practical use. The heat stress application allowed the water loss of the fruit during storage to be successfully reduced. The combinatorial double heat shock treatment where the hot air was first applied for 6 h at 40°C followed by hot water dipping for 6–12 h at 40°C showed the best performance at the final stage in all other treatments including single hot air, hot water, hot water + hot air and control (non-heated) in minimizing the water loss of oranges during storage. This heat stress technique (HA + HW) is useful for successful storage of orange.

Keywords : double heat shock, heat stress, hot air, hot water, orange, storage, water loss

INTRODUCTION

During the past few years, the use of heat treatment technique attained much importance for maintaining freshness of fruits and vegetables during long-term storage (Lurie, 1998; Ferguson et al., 2000). This technique has been applied on a number of fruits and vegetables storage process (Mangan et al., 1998; Morimoto and Hashimoto, 2000; Morimoto et al., 2003; ElAssi, 2004). It is easy to apply, increases firmness and shelf life of fruits (Shellie and Mangan, 1994; Hofman et al., 2000), inhibits ethylene production (Lurie and Klein, 1992; McDonald and McCollum, 1996), controls insect pest and reduces chilling injury (Lurie and Klein, 1992; Paull and McDonald, 1994; Lurie and Sabeht, 1997). Thus, this technique substitutes a non-damaging physical treatment for chemical preservation (Lurie, 1998).

Among heat stress techniques, hot water treatment is generally used for fungal control and disinfestations of insects; vapor heat for insect control and hot air for both fungal and insect control (Lurie, 1998). These heat treatments are used in many countries on commercial scale. But there is still a need of such heating technology that is economically viable and has least thermal impact on product quality has been emphasized (Ferguson et al., 2000). It has been reported that applying heat stress at 40–50°C for 12–14 h at the first stage of the storage process could reduce the water loss (Morimoto et al., 2003). This is probably due to the production of Heat Shock Proteins (HSPs) in the living tissues that eventually attain thermal tolerance (Vierling, 1991) and may lead to the

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reduction of the water loss of fruits during storage (Paull and Chen, 2000). Morimoto et al. (1997 and 2003) found out the optimal treatment of hot air at 40°C for 12–24 h that minimizes the water loss of the fruit during storage. It is, therefore, imperative to find out an optimal heat treatment technique for minimizing the loss of water and maintaining quality of fruits during storage, aiming at the practical application.

In this study, as a next step, the optimal combinatorial uses of the hot air and the hot water were investigated for more effective and practical use of the heat treatment.

MATERIALS AND METHODS

Amanatsukan oranges (*Citrus natsudaidai*), abundantly produced in Ehime Prefecture of Japan, were used for the experiment. A total of 147 oranges were taken directly from the farm using 3 fruits in each treatment. The storage chamber used here is a thermo-hygrostat (Tabai-espec, LHU-112M), where the temperature and relative humidity are strictly controlled with the control accuracies of 0.1°C and 2%RH, respectively. The water loss of the fruit was estimated from the weight loss using an electronic balance. Different treatments scenarios were analyzed viz. Hot Air, Hot Water (conventional) and Double Heat Shock Treatments (Hot Air + Hot Water; Hot Air + Cold Water; and Hot Water + Hot Air). In single Hot Water Treatments (HWTs), an appropriate number of fruits were immersed separately in the water bath at 40, 41, 43 and 45°C with time intervals from 5 min to 12 h. The submerged fruit were then removed from the water, dried out individually and then shifted to the storage chamber where the temperature was kept constant at 15°C for 10 days. Similarly, in single Hot Air Treatments (HATs), the oranges were kept separately under hot air at 40°C with exposure time ranging from 30 min to 72 h before shifting to the storage chamber at 15°C for 10 days to achieve a desired effect. In case of Double Heat Shock Treatments (DHSTs), orange were first kept either in hot air and then in hot water (HA + HW method) or first held in hot water and then in hot air (HW + HA method) before placing into storage chamber. The treatments showing good time-temperature regime in single heat shock were selected for further evaluation under double heat shock method. Control (non-heated) fruit were placed under normal room temperature for first 24 h and then shifted to the storage chamber at 15°C. The experimental protocol is given in Table 1.

RESULTS

The data revealed that a substantial increase of water loss occurred especially in single HWTs during 10 days storage at 15°C (Table 2). Under varying temperatures, the overall rate of water loss was initially higher (7.25 and 7.64%) even under a short hot water exposure for 5 min at 43 and 45°C but it declined with the successive heating times of 10 and 15 min and expedited again from 30 to 60 min. Unlikely, 5.68% water loss after 5 min exposure was comparatively low but a higher water loss (7.13%) was noted after 10 min at 41°C (Table 2). The occurrence of lowest and the highest water loss both after 5 min exposure in HWTs might be the difference in exposure temperatures i.e. 41 and 45°C. The heating time 10–15 min at 43 and 45°C might be the transitional phase where the response of orange was fairly static in terms of water loss. As shown in Table 2 that among HATs, only 6–12 h hot air exposure displayed comparatively good results by reducing the water loss to 2.31 and 2.96%, respectively after 10 days storage. The rest of HATs (from 30 min - 18 h hot air exposure) showed more or less uniform rate of water loss (3.40 to 4.85%) as compared to 24, 48 and 72 h hot air treatment where a large amount of water was lost in the storage chamber (Table 2). A peer review of data further manifested that different combinations of HW + HA; HA + CW and HA + HW elucidated very interesting results. However, the maximum water reduction was always associated in treatments where HW was used as primary

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Table 1 Experimental protocol.

Method of heating	Exposure tempt	Exposure time	Procedure
Hot Water	41, 43, 45°C	5, 10, 15, 30, 45 and 60 min	HW dipping at given temperature and time and then shifted to storage chamber at 15°C for 10 days
Hot Air	40°C	30 min, 1, 2, 3, 4, 5, 6, 12, 18, 24, 48 and 72 h	HA treatment at given temperature and time and then shifted to storage chamber at 15°C for 10 days
Hot Water + Hot Air	41, 43, 45°C	5–15 min + 24 h + 24 h	HW dipping from 5–15 min at 41, 43 and 45°C; placed in storage chamber for 24 h; exposed to hot air at 40°C for 24 h and finally shifted to storage chamber at 15°C for 10 days
Hot Air + Hot Water	40°C	24 h + 24 h + 12 h	HA treatment at 40°C for 24 h; placed in storage chamber for 24 h; dipped in HW for 12 h at 40°C and finally shifted to storage chamber at 15°C for 10 days
Hot Air + Cold Water	40°C	24 h + 24 h + 12 h	HA treatment at 40°C for 24 h; placed in storage chamber for 24 h; dipped in CW for 12 h at 14°C and finally shifted to storage chamber at 15°C for 10 days
Hot Air + Hot Water	40°C	6 h + 24 h + 6–12 h	HA treatment at 40°C for 6 h; placed in storage chamber for 24 h; dipped in HW for 6–12 h at 40°C and finally shifted to storage chamber at 15°C for 10 days
Hot Air + Hot Water	42°C	6 h + 24 h + 6–12 h	HA treatment at 40°C for 6 h; placed in storage chamber for 24 h; dipped in HW for 6–12 h at 42°C and finally shifted to storage chamber at 15°C for 10 days
Hot Water + Hot Air	41°C	5 min + 24 h + 6 h	HW dipping for 5 min at 41°C; placed in storage chamber for 24 h; exposed to hot air at 40°C for 6 h and finally shifted to storage chamber at 15°C for 10 days
Hot Water + Hot Air	43, 45°C	15 min + 24 h + 6 h	HW dipping for 15 min at 43 and 45°C; placed in storage chamber for 24 h; exposed to hot air at 40°C for 6 h and finally shifted to storage chamber at 15°C for 10 days
Control (non-heated)	Room temperature	24 h	At normal room temperature for first 24 h and then shifted to storage chamber at 15°C for 10 days

heating medium at 41, 43 and 45°C for 5, 10 and 15 min (Table 2). In double heat shock treatments, where oranges were first kept under hot air for 24 h at 40°C and then dipped into hot water for 12 h at 40°C, the fruit absorbed an average of 1,453 mg and released a total of 3,576 mg of water. Similarly, the fruit absorbed 320 mg of water when first held under hot air for 24 h at 40°C and then placed under normal water for 12 h at 14°C. In this case, a total of 3,403 mg of water was lost from oranges in the storage chamber at 15°C. It is evident that the use of HA + HW (6 h hot air + 6–12 h hot water) both at 40°C demonstrated outstanding results by minimizing the rate of water loss (1.96 and 1.97%) after 10 days in the storage chamber. The same heat treatment, where oranges were first held under hot air for 6 h at 40°C and then placed under hot water for 12 h at 42°C, also showed lower water loss (total average of 2.26%) during storage. The other modified double heat shock treatment like HW + HA (5–15 min hot water at 41 and 43°C + 6 h hot air

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

Method of heating	Exposure temperature	Exposure time	Average total reduction in weight (%) after 10 days in storage chamber at 15°C
Single Heat Shock Treatment			
Hot Water Treatment	41°C	5 min	5.68 ± 3.57
		10 min	7.13 ± 0.88
		15 min	6.62 ± 0.23
		30 min	6.16 ± 1.25
		45 min	6.34 ± 1.45
		60 min	6.64 ± 2.0
	43°C	5 min	7.25 ± 1.05
		10 min	6.97 ± 0.80
		15 min	6.20 ± 2.07
		30 min	7.20 ± 0.49
		45 min	6.73 ± 2.17
		60 min	7.37 ± 0.42
	45°C	5 min	7.64 ± 0.72
		10 min	6.27 ± 1.21
		15 min	6.20 ± 0.61
		30 min	6.87 ± 2.04
		45 min	7.62 ± 2.96
		60 min	7.53 ± 1.55
Hot Air Treatment	40°C	30 min	4.15 ± 0.46
		1 h	3.40 ± 1.27
		2 h	4.51 ± 0.34
		3 h	4.34 ± 0.61
		4 h	3.41 ± 0.86
		5 h	4.69 ± 0.67
		6 h	2.31 ± 1.03
		12 h	2.96 ± 0.34
		18 h	4.85 ± 2.26
		24 h	6.87 ± 1.53
48 h	8.82 ± 1.55		
72 h	12.55 ± 1.55		
Double Heat Shock Treatments			
Method of heating	HW Exposure temperature	Exposure time	Average total reduction in weight (%) after 10 days in storage chamber at 15°C
Hot Water + Hot Air Treatment	41°C	(5 min + 24 h)	6.14 ± 2.92
		(10 min + 24 h)	8.16 ± 1.43
		(15 min + 24 h)	8.56 ± 0.75
	43°C	(5 min + 24 h)	8.73 ± 0.10
		(10 min + 24 h)	7.89 ± 1.05
		(15 min + 24 h)	7.06 ± 1.75
	45°C	(5 min + 24 h)	8.11 ± 0.61
		(10 min + 24 h)	7.66 ± 0.89
		(15 min + 24 h)	7.61 ± 3.74
HA + HW	40°C	(24 h + 12 h)	8.56 ± 0.51
HA + CW	14°C	(24 h + 12 h)	8.66 ± 0.63
Hot Air + Hot Water Treatment	40°C	(6 h + 6 h)	1.96 ± 0.49
		(6 h + 12 h)	1.97 ± 0.86
	42°C	(6 h + 6 h)	2.54 ± 0.59
(6 h + 12 h)		2.26 ± 0.72	
Hot Water + Hot Air Treatment	41°C	(5 min + 6 h)	2.69 ± 0.31
	43°C	(15 min + 6 h)	2.69 ± 0.59
	45°C	(15 min + 6 h)	3.09 ± 0.73
Control (Untreated)	Room temperature	24 h	6.56 ± 0.66

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

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Fig. 1 Average rate of water loss (%) / day in weight of orange during storage at 15°C using Single Hot Water and Double Heat Shock Treatments (HW + HA) at 41, 43 and 45°C for 5, 10 and 15 min after 10 days storage.

at 40°C) could not excel HA + HW at 40 and 42°C. The data also show that the rate of water loss (%) / day decreased progressively in almost all heat treatments than the non-heated control after 10 days. As shown in the figures, the use of HWT for 10 min at 41°C, HA + HW and HA + CW at water temperatures 40 and 14°C resulted in higher water loss than control (Figs. 1a and 4). The application of hot water for 5 min at 43 and 45°C showed same rate of water loss as noted for control (Figs. 1b, c) while all other heat treatments represented lower rate of water loss (%) / day after 10 days storage at 15°C (Figs. 2, 3, 5 and 6). In order to make the difference clear, standard deviation was calculated and then a t-test analysis was carried out. Significant differences were found in most of the treatments especially in single hot air treatment, double heat shock treatment (HA + HW) at 40 and 42°C than the non-heated (control) at 5% level of significance after 10 days storage. As far as the response of air temperature of the chamber and surface and center temperatures of the fruit is concerned, it was observed that the first rise of fruit temperature was almost same, however, a short delay about 10–20 min took place in the surface temperature, which revealed non-significant difference between the air and surface temperatures of the fruit (Fig. 7). So, the temperature of fruit followed the heat stress. Also, the rate of water loss decreased significantly by using heat stress technique for 12–24 h (Fig. 8). It was found out that after acquiring heat stress,

Fig. 2 Average rate of water loss (%)/day in weight of orange during storage at 15°C using Single Hot Water Treatment at 41, 43 and 45°C for 30, 45 and 60 min after 10 days storage.

the fruit showed lower amount of water loss than control. Therefore, the use of both short-term and long-term heat stress application is very helpful in reducing the rate of water loss of fruit during storage.

DISCUSSION

In the present study, no difference was noted in fresh weight as well as the weight taken just after HW heating but the higher water loss during 10 days storage explained certain physio-chemical changes occurred in the fruit throughout heating process that were subsequently exposed in the storage chamber. Keeping the variable response of fruit to various exposure temperatures and times, the process could be divided into three parts (1) Initial phase - higher water loss during the first 5 min exposure (2) Transitional phase - effective treated time with medium water loss around 10–15 min exposure, and (3) Heat damage phase - excessive water loss after 30 to 60 min exposure. Heating medium temperature and method always influence the process of thermal energy and it has been observed that the internal heat resistance in fruit during water heating was a more dominant factor in controlling the heat transfer rates than in hot air (Hansen, 1992). The overall higher water loss in HWTs at 43 and 45°C from 30–60 min might be the variation in the

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A1: HA 30 min, A2: 1h, A3: 2h, A4: 3h, A5: 4h, A6: 5h, A7: 6h, A8: 12h, A9: 18h, A10: 24h, A11: 48h, A12: 72h, B: Control

Fig. 3 Average rate of water loss (%) / day in weight of orange during storage at 15°C using Single Hot Air Treatment at 40°C from 30 min 72 h after 10 days storage.

A: HA+HW (24+12h), B: HA+CW (24+12h), C: Control

Fig. 4 Average rate of water loss (%) / day in weight of orange during storage at 15°C using Double Heat Shock Treatments (HA + HW and HA + CW) at water temperature 40 and 14°C after 10 days storage.

A: HA+HW (6+6h), B: HA+HW (6+12h), C: HA+HW (6+6h), D: HA+HW (6+12h), E: Control

Fig. 5 Average rate of water loss (%) / day in weight of orange during storage at 15°C using Double Heat Shock Treatments (HA + HW) at water temperature 40 and 42°C after 10 days storage.

thermal diffusivity (Wang et al., 2001). The other possible reason was that the thermotolerance decreases with continued exposure of fruit and temperature at 42°C is considered as the limit of induction of HS tolerance (Paull and Chen, 1990). Similarly, Ferguson et al. (1994) noted that continued exposure to 42°C, though allowed polypeptide synthesis, but also damaged the product quality. Our findings are also inline with Perdue et al. (1998) who exposed cherry fruit to heat treatment at 45°C for 15, 30, 45 and 60 min and found no induction of HSP70 polypeptides(s) because of the reason that 45°C is too high temperature for cherries to produce HSPs. While, as a

A: HW+HA (5 min+6h) at 41°C, B: HW+HA (15 min+6h) at 43°C, C: HW+HA (15 min+6h) at 45°C, D: Control

Fig. 6 Average rate of water loss (%)/day in weight of orange during storage at 15°C using Double Heat Shock Treatments (HW + HA) at water temperature 41, 43 and 45°C after 10 days storage.

Fig. 7 Response of inside air temperature of the chamber, surface and water temperatures of the fruit.

Fig. 8 Short-term response of the rate of water loss of fruit at 40°C hot air heat stress application and release.

whole, the lower water loss noted after HW exposure at 41°C for 5 min was probably due to “mild heat” that could cause less damage during subsequent hot or cold treatments (Klein and Lurie, 1992; Lurie, 1998). While observing symptoms, Paull and Chen (1990) reported failure of fruits to ripen fully or softening at a reduced rate at 45°C. Researchers like Shellie and Mangan (1996)

suggested vapor heat at 46°C for 4.5 h and hot water at 45°C for 42 min for increased sugar/acid ratio, firmness, colour development and reduce acidity in orange. The differences in HW results, found at 45°C in the present study with that of previous findings, might be the differences in cultivars that showed variable responses to heat treatment (Lurie and Sabehat, 1997). Under such conditions Grove et al. (2000) found HW as commercially non-viable treatment, which although reduced chilling injury but could not eliminate it due to variable fruit responses. It has also been reported that HW technique consume many hours in getting a desirable effect due to slow rate of heat transfer (Hansen, 1992). While, Klein and Lurie (1992) preferred hot water treatment due to its low capital investment and high commercial application.

In HATs, initially when the oranges were kept under hot air from 30 min to 5 h, it showed more water vapors on its surface, which might be due to higher respiration rate in the beginning under higher air temperature of 40°C (Lurie and Klein, 1992). It also showed that the heating process and high water thrashing could be instigated even after a shorter to few hours' hot air exposure. By comparing the results obtained in the HW and HATs, it is obvious that the mode of moisture loss in both the heating techniques was same i.e. higher initial water loss, fairly static during transitional phase and excessive water loss after the midpoint. In general, the rate of water loss was higher as after HAT for 72 h. It might be the result of longer heat stress at 40°C, whereas the less heating time (6–12 h) caused lower water loss in the storage chamber (Gaffney and Armstrong, 1990).

The best optimal temperature for orange storage was realized by making certain adjustments in exposure time using double heat shock technique. As shown previously that the rate of water loss was found to be minimum in DHSTs where oranges were first held under hot air for 6 h and then immersed under hot water for 6–12 h both at 40°C before placing into storage chamber at 15°C. The possible reason for such a lower water reduction in this treatment could be the use of optimum hot air exposure for 6 h in the beginning process and subsequent submergence of fruit into hot water that might have either compensated the loss of water that occurred during the hot air exposure or caused certain physio-chemical changes in the fruit to acquire double heat shock stress in storage chamber at 15°C. In the present study, the combination of HA + HW was found better than that of HW + HA might be due to the effect of the strength of heat stress. The hot air treatment (HA) produces stronger stress than the hot water (HW) if the temperature is same. The combination of the stronger stress (HA) during the first stage and the smaller stress (HW) during the latter stage is more effective to reduce the water loss of fruit. It seems that this phenomenon is the same as the decrease in water loss after the heat stress application (stronger stress). But, the inverse combination of the smaller stress (HW) during the first stage and the stronger stress (HA) during the second stage resulted in a higher water loss. Therefore, the combination of the first stronger stress (stress application) and the second non-stress (stress release) is effective to reduce the water loss of fruit during storage. In all DHSTs, the use of 6 h hot air exposure appeared as an appropriate time therefore by making certain adjustments in water temperatures and time, the technique could successfully be used for storage of other agricultural commodities.

CONCLUSION

The rate of water loss was generally lower than the non-heated control using single HWTs at 41°C (5, 30, 45 min), 43°C (15 min) and 45°C (10–15 min). Similarly, the HATs from 30 min–18 h also showed lower moisture loss than the untreated control during 10 days storage. The loss of water was reduced substantially by using the combinatorial DHSTs where the fruit was first placed under hot air for 6 h followed by hot water dipping for 6–12 h both at 40°C. This treatment showed the best performance in minimizing the water loss of orange during storage. Therefore, this new technique is useful for successful storage of orange.

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