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ORIGINAL PAPER

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EFFECT OF CHILLING EXPOSURE AND VAPOR HEAT TREATMENT DURATION ON THE QUALITY OF SWEET ORANGE DURING SIMULATED MARKETING

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ABSTRACT

Sweet orange fruits were exposed to vapor heat treatment (50°C) in water bath for 0, 5, 10, 15 and 20 min in plastic covered structure. The data were recorded on different physico chemical factors immediately after the storage and after seven days simulated marketing under ambient condition (20°C). Low temperature storage enhanced weight loss, surface pitting, disease incidence, total soluble solids accumulation, TSS/Acid ratio but decreased reducing sugars, acidity and ascorbic acid content. Chilling exposure up to 45 days had no significant effect on weight loss and TSS. However, increased weight loss (2.63%), TSS (11.75), TSS/Acid ratio (8.45 ºBrix), disease incidence (8.93%) and lowest reducing sugars (3.90) were noted in sweet orange exposed to chilling temperature for 75 days. Among the VHT durations, the highest weight loss (2.29%) was found in VHT for 0 min while the highest TSS (11.81 ºBrix), TSS/Acid ratio (8.10) and disease incidence (6.22%) and least reducing sugars (4.12%) were found in VHT 20 for min. Vapor heat treatment ranging from 5–10 min resulted in lowest weight loss (1.79%), TSS (10.81 ºBrix) TSS/Acid ratio (7.33), disease incidence (1.00%) and highest reducing sugars (4.75%) in sweet orange fruits. However, non-reducing sugars were least affected by both LTSs and VHTs. It is concluded that the chilling exposure (5°C) beyond 45 days aggravated the decline of fruit physio-chemical quality characteristics. Whereas, VHT with 5–10 min maintained the sweet orange fruit quality during simulated marketing; however, VHT of 15–20 min adversely affected the sweet orange fruit quality attributes.

Key words: low temperature storage (LTS), simulated marketing time, storage, orange fruit, vapor heat treatment (VHT)

INTRODUCTION

Citrus is one of the major fruit crops of Pakistan and is grown in more than 52 countries of the world. Pakistan stands among the top 14 citrus growing countries of the world [Ahmed et al. 2006]. The citrus fruit is harvested in limited period resulting in market glut, which increases postharvest losses. The fruits and vegetable lose their quality rapidly after harvest [PHDEB 2008]. The major constraints in the postharvest management of fruit and vegetables in developing countries include inefficient handling and

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transportation; poor storage, processing, and packaging technologies and poor infrastructure [Rosa 2006].

Cold storage retards metabolic processes that lead to ripening and senescence of fruits and vegetables during storage. Therefore, most fruits and vegetables are stored at low temperatures to extend their shelf life. However, tropical and subtropical fruits suffer injuries by storage at lower temperature [Kader and Arpaia 2002]. Lower temperature results chilling injury by stimulating physiochemical reactions in commodities such as alterations in structure of membrane, ethylene synthesis and variations in respiration rates. Storage of citrus fruit below a critical temperature causes chilling injury [Purvis 2004]. The symptoms of chilling injury in citrus fruits include surface pitting, staining and necrosis of the peel and fruit weight loss [El-Hilali et al. 2003].

Chilling injury is an economically important postharvest problem that adversely affects the overall quality and marketability of many harvested fruits and vegetables native to tropics and subtropics [Mohammed and Barthwaite 2000]. It decreases consumer acceptability and, hence, commercial losses. Chilling injury symptoms may appear during storage but are usually pronounced after shifting the produce to ambient conditions [Wang 2004]. Chilling injury result in degradation of the cells structures that releases metabolites which encourage microbial growth. Thus, fruits show increase susceptibility to decay when exposed to very low temperature [Mulas and Schirra 2007] or for extended duration [Tripathi and Dubey 2003]. Various post-harvest techniques have been used to control chilling injury and disease in citrus. Imazalil application controls postharvest rots but is prohibited in many countries [Erkan et al. 2005].

Heat treatments have proved to stimulate chilling resistance [Toivonen and Hodges 2011] as well as control postharvest decay in diverse group of fruits [Schirra et al. 2000]. Application of heat treatments to the commodities is performed by hot water, vapor/moist heat or dry forced hot air [Erkan et al. 2005] to control post harvest storage losses. However, the influence of heat treatment effect may depend on heat treatment methods, temperature and duration. While lower than optimum heat treatment may fail to induce chilling tolerance or suppress pathogens, heat damage to the tissues of sensitive species can be caused if the temperatures are too high or if the durations are too long [Erkan et al. 2005]. Therefore, this study was designed to evaluate the efficacy of vapor heat treatment duration on chilling injury and fruit quality during post-storage simulated marketing.

MATERIALS AND METHODS

The sweet orange fruits (cv. Blood Red) were exposed to vapor heat treatment (50°C) in a water bath for 0, 5, 10, 15 and 20 min in plastic covered structure. After the completion of the vapor heat treatment, the fruit were blown with gentle breeze from a fan to remove the surface water. The fruits were then packed in cardboard packages having 4 holes on each side for ventilation and exposed to chilling temperature (5°C) for 0, 15, 30, 45, 60 and 75 days. The fruits were collected at each storage interval and transferred to room temperature. The fruits were analyzed for physico-chemical quality attributes either immediately after the chilling exposure or after seven days simulated marketing at room temperature (20°C). The difference either negative or positive was analyzed as positive number and presented as increase or decrease in a given parameter. Biochemical quality attributes such as Total Soluble Solid (TSS), Acidity, TSS/Acid ratio, Reducing Sugar and Ascorbic Acid content were determined [AOAC 2000].

Weight loss with 15 days interval was calculated as percentage by using the following formula.

$$\text{Percent weight loss} = \frac{\text{Fresh fruit weight} - \text{Weight after interval}}{\text{Fresh fruit weight}} \times 100$$

For disease incidence 50 fruit in each treatment and replication with no disease symptoms were collected at the end of each storage interval and the data is presented as percent disease incidence during the 7 days incubation at market temperature (20°C).

Statistical analysis

This study was conducted in two factorial completely randomized design (CRD) repeated three times. In order to find out the treatments differences and interactions the data pertaining to various attributes was analyzed by analysis of variance technique. Least significant difference (LSD) test was used where the differences were significant. Statistix 8.1 was used for analysis of variance and least significant difference test.

RESULTS AND DISCUSSION

Weight loss

The weight loss in sweet orange fruit after 7 days post chilling simulated marketing time reveals that weight loss was significantly affected by the duration of chilling exposure as well as the vapor heat treatment and their interaction (tab. 1, fig. 1). The weight loss increased non-significantly with increase in chilling exposure for 45 days but significantly with 60 days (2.21%), which escalated further to the higher of 2.63% when fruit were exposed for 75 days to 5°C. The vapor heat treatment duration also significantly affected the weight loss during post chilling simulated marketing. The weight loss during simulated marketing was more in control fruits (2.29%) as compared to fruits exposed to VHT for 5 min (1.79%). The losses in VHT for 0 min and VHT for 20 min were statistically at par with each other. Heat treatments beyond 5 min resulted in non significant increase in weight loss to 1.82% in VHT for 10 min and further enhanced to non significant weight losses of 1.95% in VHT for 15 min. Whereas the highest weight loss of 2.20% was observed in VHT for 20 min.

Table 1. Effect of vapor heat treatments on weight loss, disease incidence, TSS and acidity in citrus fruits during storage at chilling temperature and additional simulated marketing time

Storage durations (days)	Weight loss (%)	Disease incidence (%)	TSS (°Brix)	Acidity (%)
0	1.77 c	0.00 d	10.93 c	1.55 a
15	1.79 c	0.53 d	11.02 bc	1.51 b
30	1.81 c	0.93 d	11.13 bc	1.47 bc
45	1.84 c	4.13 c	11.23 bc	1.45 cd
60	2.21 b	6.27 b	11.43 ab	1.42 de
75	2.63 a	8.93 a	11.75 a	1.39 e
$LSD_{0.05}$	0.182	0.962	0.497	0.036
Vapor heat treatments (VHT)				
VHT 0	2.29 a	2.11 b	11.23 bc	1.46
VHT 5	1.79 c	1.00 c	10.81 c	1.47
VHT 10	1.82 bc	2.44 b	10.82 c	1.48
VHT 15	1.95 b	5.56 a	11.58 ab	1.46
VHT 20	2.20 a	6.22 a	11.81 a	1.46
$LSD_{0.05}$	0.166	0.878	0.454	NS
Interaction (VHT × storage duration)				
Significance	*	*	NS	NS
$LSD_{0.05}$	0.408	2.151	–	–

Means in column followed by similar letter(s) do not differ significantly; * – significant at 5% level of probability; NS – non-significant, VHT – vapor heat treatments

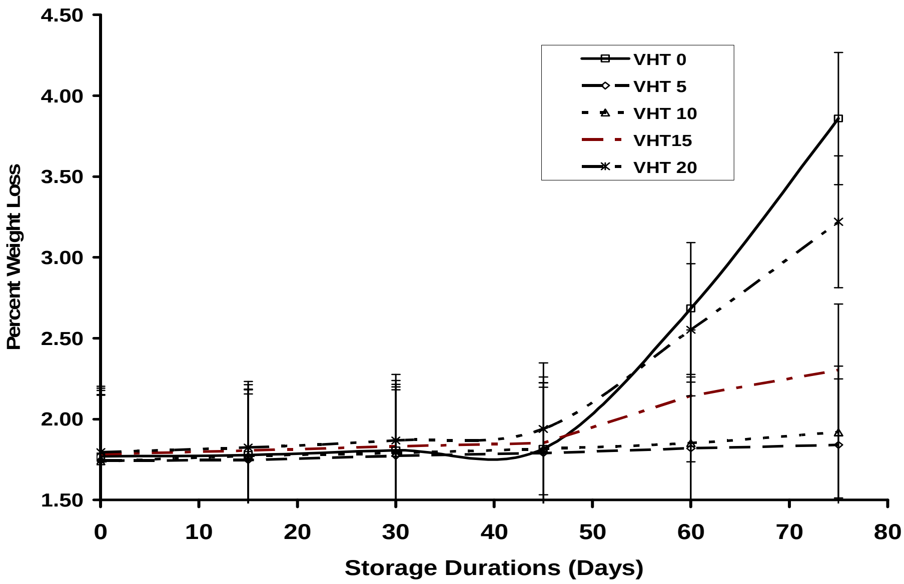

Fig. 1. Effect of vapor heat treatments (VHT) on weight loss in citrus fruits during storage at chilling temperature and additional simulated marketing time. The error bars represent LSD at $p \leq 0.05$

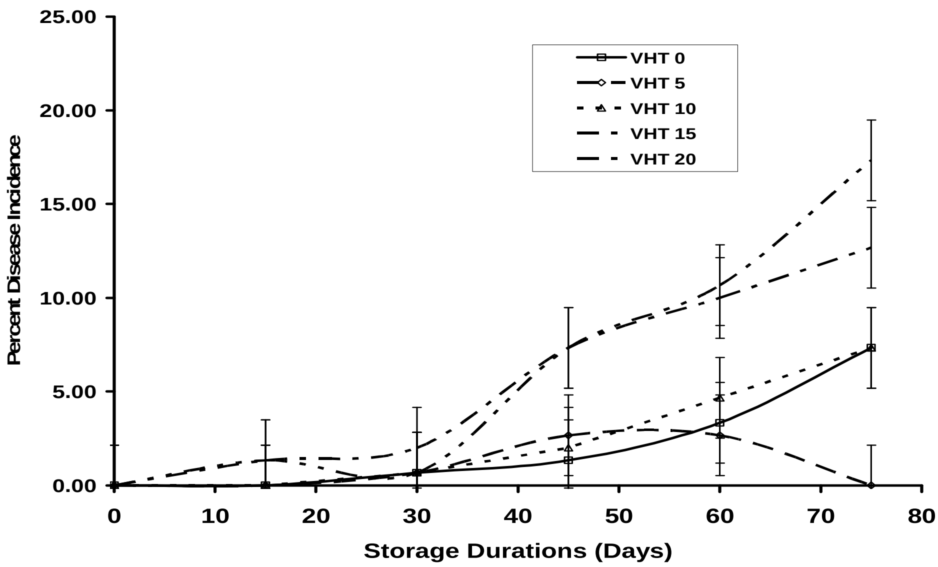

Fig. 2. Effect of vapor heat treatments (VHT) on disease incidence in citrus fruits during storage at chilling temperature and additional simulated marketing time. The error bars represent LSD at $p \leq 0.05$

Citrus fruits are mildly chilling sensitive [Lafuente et al. 2005] and are adversely affected by the low storage. The symptoms of chilling injury are surface lesions, pitting, sunken area, water soaking of tissue, water loss, internal browning, mealiness and browning in the flesh, tissue breakdown, accelerated senescence and ethylene production, shortened storage or shelf life, loss of flavor, increased decay and increased weigh loss during marketing at warmer temperature [Valero and Serrano 2010]. The non-significant weight loss in sweet orange at 45 days of chilling exposure but significant increase with 60 and 75 days chilling exposure indicates that sweet orange fruit are mildly chilling sensitive and are damaged with extended exposure to chilling temperature [Rezakhani and Pakkish 2014]. The increased weight loss with chilling injury could be due to its adverse effects on the epicuticular wax that may cause microscopic cracks in fruits skin. The increased microscopic cracks, ultimately lead to increased moisture/weight loss in fruit. The lowest weight loss in fruit treated with modest VHT of 5 or 10 min may be due to redistribution of epicuticular wax that may plug the skin cracks and arrest the weight loss [Schirra et al. 2000]. Modest heat treatments may also activate heat shock proteins (HSPs) which render cold tolerance to fruits stored at chilling temperature. On the other hand, extended VHTs may cause the degradation of epicuticular waxy layer that result in widening the fissures on fruit skin leading to increased weight losses [Erkan et al. 2005].

Disease incidence

Disease incidence during post-chilling simulated marketing time was significantly affected by chilling exposure, VHT duration and their interaction (tab. 1, fig. 2). The means for chilling exposure indicate no significant increase in disease incidence with chilling exposure for 30 days but significant ($P < 0.05$) increased was recorded with 45 days (4.13%) that finally reached the highest (8.93%) with 75 days exposure to chilling temperature. Heat treatment significantly affected the disease incidence in sweet orange fruit during post chilling marketing time. Disease incidence in control fruit (2.11%) decreased to 1% with VHT for 5 min but increasing VHT duration to 10 min triggered a significant increase in disease incidence (2.44%) that increased further to 5.56% and 6.22% with increasing VHT duration to 15 and 20 min respectively.

Generally, disease prevalence proliferates with increased chilling exposure storage duration in fruits [D'hallewin and Schirra 2001] and chilling exposure increase susceptibility to decay during the simulated marketing time. Chilling injury causes biochemical lesion such as increased respiration and ethylene production [Wang 2004], membrane damage that increased susceptibility to decay [Ding et al. 2001]. Thus, it is likely to observe increased disease incidence with increasing chilling exposure [Valero and Serrano 2010] as leakage of the cell metabolites [Valero and Serrano 2010] proved favorable site for pathogen attack.

The effectiveness heat treatments to inhibit disease incidence is well documented [Porat et al. 2000]. It is believed that heat treatment inhibit disease incidence either by accelerating wound healing process or scoparones (having antifungal properties) synthesis [Schirra et al. 2000]. In addition, heat/thermo treatment may kill spores and minimize incipient infection [Fruk et al. 2012]. However, it was observed that only brief exposure e.g. 5 min at 50°C is sufficient to decrease disease incidence and lengthy VHT duration may cause the fruit to become even more susceptible than control [Joyce et al. 2003]. The harmful effects of lengthy VHT may by due to damage to the rind tissue e.g. increasing cuticular cracks and, thus, allowing an entry route for the fungal pathogens responsible for decay.

Total soluble solids

Exposing the sweet orange fruits to chilling temperature and heat treatment durations significantly affected the total soluble contents (tab. 1). Total soluble solids increased non-significantly from the lowest (10.9 ºBrix) for 0 days to 11.2% with 45 days of chilling exposure but significantly to 11.43 and 11.75 ºBrix with chilling exposure for 60 and 75 days respectively. Different VHT durations also had a significant effect on the TSS content of the sweet orange fruit during simulated marketing time. The highest total soluble solids (11.8 ºBrix) was recorded in VHT for 20 min, which was significantly higher than control (11.2 ºBrix). The difference in TSS content of VHT for 5–10 min was, however statistically at far with control. While heat treatments effects have been found to be inconsistent on soluble solids in citrus fruits, modest VHT (5–10) min may arrest the increase in TSS during post-chilling period and the longer VHT duration may reverse such inhibition. It indicates that normal postharvest increase in TSS [Mohla et al. 2005] is further enhanced during the post-chilling marketing time.

The metabolic activities in harvested fruit continue to occur during storage and the rate depends on the storage temperature and duration [Sevillano et al. 2009]. Heat treatments in modest range slow down the ripening process in fruit by reducing respiration rate and ethylene production [Serrano et al. 2004] that helps in maintaining the TSS. Whereas, enhanced heat treatments trigger the weight loss in fruits during post chilling period [Hazbavi et al. 2015] that results in increased TSS due to higher weight/moisture losses.

Acidity (%)

The acidity of the fruit decreased with increasing chilling exposure and the highest acidity (1.55%) was observed in control fruits (0 days chilling exposure) followed by 15 days chilling exposure (tab. 1). The lowest acidity (1.39%) was recorded in sweet orange fruits exposed to chilling temperature for having 75 days. The means for VHT durations illustrate that the percent acidity of sweet orange was non-significantly affected by heat treatments. However, the least acidity (1.46%) was rerecorded in VHT for 0, 15 and 20 min. The decline in organic acid is commonly observed during storage [Rehman et al. 2014] and may proceed even at low chilling temperature [Kader 2008]. The sweet orange fruit is rich in citric acid which is consumed in respiration [Karadeniz 2004]. Thus, the decline in acidity during storage can be attributed to normal respiratory metabolism. However, increased loss of acidity after simulated marketing with increasing chilling exposure indicate that chilling stress increase the rate of respiration that result in decline of acidity [Hussain et al. 2004]. The influence of heat treatment was not significant on acidity. Heat treatments are found to inhibit respiration and ripening of fruits [Serrano et al. 2004]. Thus, it is observed to have a less decline in acidity with heat treatments. However, no significant effect of heat treatments was observed in this experiment.

TSS/Acid Ratio

The TSS/Acid ratio increased significantly during simulated marketing time from the lowest of 7.05 with 0 days chilling exposure to 8.45 in fruits exposed to 75 days chilling (tab. 2). The VHT effect was also significant. Whereas the VHT for 20 min had the highest TSS/Acid ratio, it was non significant with control, VHT 15 and VHT 20 min but significantly higher than VHT for 5 or 10 min. Vapor Heat Treatment of 5–10 min had lowest TSS/Acid of 7.33.

The TSS/Acid ratio is a function of TSS and acidity [Naglaa 2010]. During the fruits storage, respiration and transpiration continue [Maguire et al. 2001]. During storage and simulated marketing, the TSS increases [Abu-Goukh and Bashir 2003] due to hydrolysis of sugars [Soltani et al. 2010], while acidity declines due to consumption of organic acids in respiration [Fawole and Opara 2013]. Since, chilling increase the rate of respiration during marketing [Luengwilai et al. 2012] the TSS increases while organic acids decline, resulting in increased TSS/Acid ratio. The lower TSS/Acid ratio with modest VHTs might be the manifestation of induced chilling tolerance [González-Aguilar et al. 2000] or slowing down the ripening process [Serrano et al. 2004].

Reducing sugar (%)

The chilling exposure significantly affected the reducing sugar content of the sweet orange fruit during simulated marketing time (tab. 2). The highest reducing sugar (4.93%) on 0 days storage decrease with increasing chilling exposure and were significantly lower with 30 days (4.57%) exposure to chilling temperature. The reducing sugars decline to the lowest of (3.90%) with 75 days of chilling. Chilling injury results in increased respiration [Arendse 2014]. Since, the reducing sugars are consumed in respiratory metabolism, therefore, it is likely to observe rapid decline in reducing sugars

Table 2. Effect of vapor heat treatments on TSS/Acid ratio, reducing sugars and ascorbic acid in citrus fruits during storage at chilling temperature and additional simulated marketing time

Storage durations (days)	TSS/Acid ratio	Reducing sugars (%)	Ascorbic acid (mg 100 g^{-1})
0	7.05 e	4.93 a	40.36 a
15	7.30 de	4.89 a	38.18 b
30	7.56 cd	4.57 b	34.13 c
45	7.79 bc	4.41 bc	31.58 d
60	8.03 b	4.20 c	27.14 e
75	8.45 a	3.90 d	24.24 f
$LSD_{0.05}$	0.400	0.297	0.978
VHT 0	7.75 a	4.58 a	33.89 a
VHT 5	7.37 b	4.72 a	33.64 ab
VHT 10	7.33 b	4.75 a	32.89 b
VHT 15	7.94 a	4.24 b	31.75 c
VHT 20	8.10 a	4.12 b	30.85 d
$LSD_{0.05}$	0.365	0.271	0.893
Significance	NS	NS	NS

Means in column followed by similar letter(s) do not differ significantly; * – significant at 5 % level of probability; NS – non-significant; VHT – vapor heat treatments

with increasing chilling exposure, especially during simulated marketing [Bajwa et al. 2003]. Whereas the VHT for 5–10 min was at par with control, VHT for 15–20 min enhanced the decline in reducing sugars. Modest heat treatments (VHT 5–10 min) stabilized the metabolic activities of the stored fruit by reducing respiration rate and ethylene production that retained the fruit quality attributes [Serrano et al. 2004].

Ascorbic acid (%)

The ascorbic acid content of the sweet orange fruits was significantly affected by the duration of exposure to chilling temperature and heat treatments (tab. 2). Highest ascorbic acid (40.36 mg 100 g^{-1}) were recorded in fruits exposed to 0 days chilling, continued to decline significantly with incremental increase in chilling exposure and finally reached the lowest (24.24 mg 100 g^{-1}) with 75 days exposure to chilling temperature. The VHT duration also significantly affected the ascorbic acid content of the sweet orange fruit. The highest ascorbic acid (33.89 mg 100 g^{-1}) recorded in control fruit decreased not significantly with VHT for 5 but significantly to 32.89 with 10 min and decreased further to 31.75 and 30.85 with 15 and 20 min respectively. There was about 40% reduction in ascorbic acid content of the sweet orange fruits with 75 days chilling exposure. Ascorbic acid normally decreases with increase in storage duration [Sapeia and Hwaa 2014]. The incremental decrease in ascorbic acid with increase in chilling exposure indicates that chilling enhance the loss of ascorbic acid during post chilling marketing time [Ansari and Feridoon 2007]. It is also evident that both chilling exposure and extended VHT enhanced the decline in ascorbic acid after removal from the chilling temperature (simulated marketing time) [Ansari and Feridoon 2007]. Since, ascorbic acid is labile vitamin, it may be sensitive to heat treatment and hence it declined even with modest heat treatments [Singh et al. 2014].

CONCLUSIONS

Physical-chemical quality changes that occur in ambient condition preceded at a relatively slower rate at low temperature storage (LTS); however, enhanced during post-chilling incubation at warmer temperature (simulated marketing).

1. The storage of sweet orange fruits for 45 days proved to be critical. The changes associated with chilling such as weight loss, loss of reducing sugars and ascorbic acid are more prevalent when chilling exposure is extended beyond 45 days.

2. Chilling injury in sweet orange fruits triggered the weight loss, surface pitting, disease incidence, total soluble solids accumulation, TSS/Acid ratio but decreased reducing sugars and ascorbic acid content.

3. The chilling injury symptoms in sweet orange fruits are more prominent after shifting the chilled fruits to ambient conditions during simulated marketing time.

4. Mild vapor heat treatment (5 and 10 min) may slow down the chilling induced changes except the loss of ascorbic acid. However, extended VHT durations (15 and 20 min) may decline the fruit quality both visually and chemically.

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