Available online at www.sciencedirect.com
SCIENCE DIRECT®

Postharvest Biology and Technology 38 (2005) 106–114

Postharvest Biology and Technology

www.elsevier.com/locate/postharvbio

A combination of hot water treatment and modified atmosphere packaging maintains quality of advanced maturity ‘Caldesi 2000’ nectarines and ‘Royal Glory’ peaches

Athena Malakou, George D. Nanos *

Laboratory of Pomology, School of Agricultural Sciences, University of Thessaly, Fitoko str., 38446 Volos, Greece

Received 9 October 2004; accepted 9 June 2005

Abstract

Advanced maturity nectarines cv. Caldesi 2000 [*Prunus persica* var. nectarina (Ait.) Maxim.] and peaches cv. Royal Glory [*Prunus persica* (L.) Batch] were treated in 46 °C hot water containing 200 mM NaCl for 25 min, sealed in low thickness PE bags and stored at 0 °C for 1 and 2 weeks. Quality was evaluated initially and after each storage period plus 1 day shelf life. Hot water treatment (an acceptable treatment to reduce spoilage from fungi) did not cause any fruit damage based on external observations, specific conductivity and total phenol content evaluations, but reduced firmness loss (possibly in combination with MA packaging) especially in the white-flesh nectarines and kept the cellular membranes functioning better. PE bags were of low thickness and MA conditions inside the bags were found inadequate (O_2 levels >15%, CO_2 levels <5%) to significantly affect the ripening process during cold storage, but could be harmful after 10 h at room temperature (O_2 levels <3%, CO_2 levels >13%). Mass losses were kept low in PE bags. Juice soluble solids concentration, pH and acidity were not affected by the hot water treatment before and after cold storage. Hot water combined with MA packaging during storage resulted in good quality fruit after 1 week duration for postharvest handling.

Keywords: Stone fruit; Heat treatment; Low oxygen; High carbon dioxide

1. Introduction

Peach fruit are harvested relatively mature but hard enough to withstand postharvest handling through the marketing chain. These fruit have considerably lower edible quality than tree-ripened fruit so peach consumption in the USA and Europe has decreased or remained stable, respectively, over the last few years. Fruit quality can be improved by delaying harvest at least until physiological maturation is completed on the tree (Bonghi et al., 1999). Peaches and nectarines containing 11% soluble solids concentration (SSC) or higher are in high demand by consumers, as fruit have developed considerable taste and aroma (Claypool, 1977). These fruit will be highly perishable, so rapid cold storage to the lowest safe temperature and sup-

---

* Corresponding author. Tel.: +30 24210 93181;
fax: +30 24210 93144.
E-mail address: gnanos@agr.uth.gr (G.D. Nanos).

0925-5214/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2005.06.003

plementary treatments such as modified atmosphere or prestorage heat treatment will be necessary to retard ripening (mainly softening) during the 1–2 weeks postharvest life necessary for distribution to distant markets (McDonald et al., 1999). Thus, Kader (1999) proposed 10% as the minimum SSC to harvest peaches and nectarines for acceptable flavour to allow high quality and handling for long distance markets.

Heat treatment causes changes in fruit ripening, such as inhibition of ethylene synthesis and action of cell wall degrading enzymes, due to changes in gene expression and protein synthesis (Paull and Chen, 2000). Heat treatment increased postharvest life by delaying softening in plums (Tsuji et al., 1984), pears (Maxie et al., 1974), and tomatoes (Biggs et al., 1988), improving the flavor of a number of fruit (Shellie and Mangan, 1998) without affecting soluble solids concentration in apples (Klein and Lurie, 1990), nectarines (Lay-Yee and Rose, 1994) or strawberries (Garcia et al., 1995). In addition, titratable acidity was reduced in apples (Klein and Lurie, 1990) or remained unaffected in tomatoes (Lurie and Sabehat, 1997) and grapefruit (Miller and McDonald, 1992) after hot air treatments.

Hot water treatments are also used as alternative methods to control postharvest diseases. Ripe fruit are highly susceptible to disease infection, and therefore some means of controlling it are necessary. Peaches subjected to 46 °C hot water treatment for just 2–8 min were found to have substantially decreased disease susceptibility (Margosan et al., 1997).

Controlled or modified atmospheres are used as supplementary to fruit cold storage to limit water loss, delay ripening and suppress diseases. MA packaging during marketing of highly perishable commodities has similar results. Different modified atmosphere packaging systems were studied in ‘Elegant Lady’ and ‘O’ Henry’ peach cultivars (Zoffoli et al., 1997). CO_2 levels varied from 10 to 25% and O_2 levels from 1.5 to 10%. The rate of fruit softening was slowed and flesh browning (due to chilling injury) was reduced in high CO_2 packages. ‘Yumyeong’ peaches that were MA packed and stored at 0 °C for 4 weeks showed less flesh mealiness and higher electrical conductivity during shelf life than peaches stored unpacked (Choi and Koo, 1997). Heat-treated nectarines were individually plastic wrapped in order to prevent decay. Wrapping alone reduced ethylene production by 75% and respiration rate by 12%, but did not significantly influence softening (Anthony et al., 1989).

Our work examines the effect of a pre-storage hot water treatment combined with MA cold storage on the quality of relatively ripe-harvested peaches and nectarines, as an attempt to delay ripening during handling and transportation to distant markets of these perishable, high quality fruit.

2. Materials and methods

2.1. Plant material

Nectarines cv. Caldesi 2000 [*Prunus persica* var. nectarina (Ait.) Maxim.] and peaches cv. Royal Glory [*Prunus persica* (L.) Batch] were harvested from the University Experimental Farm in Thessaly, Central Greece. Fruit were harvested at mature ripe stage (Tables 3 and 4) late June in 2001 and 2002 and an attempt was made to avoid soft fruit or relatively immature ones. Ground color was impossible to use for sorting in peaches as 100% of the fruit surface was red. The nectarines’ ground skin color was yellow with a slight appearance of green. Fruit were immediately transported to the Pomology Laboratory, sorted, randomized and separated in to 7-fruit replicates.

2.2. Fruit treatment

Half of the fruit of each cultivar were completely immersed in 46 °C water containing 200 mM NaCl for 25 min before cold storage, while the control fruit were kept at room temperature. NaCl lessens the possible damage from hot water treatment to fruit (loss of red color, skin browning) by minimizing the entry of potentially injurious hot water into the fruit (Obenland and Aung, 1997). Fruit flesh temperature was monitored with thermocouples inserted next to (but not touching) the endocarp. Temperature was logged every minute with a data logger. Afterwards, four replicates per treatment were immersed in fungicidal solution (Captan, 6 g L^{-1}) to avoid interference of fungal growth with MA conditions developing in packages.

After drying, 7-fruit replicates were put in MA packages using 35 μm thick PE bags, constructed from three layers of similar thickness with LDPE-HDPE-LDPE

(Vileda, Milan) (permeability in mol s^{-1} mm^{-2} Pa^{-1} for O_2 6.85×10^{-19}, for CO_2 6.99×10^{-19} and for H_2O 4.6×10^{-16}) and 2–3 h later were stored in an industrial refrigerator at 0–1 °C and 90–95% RH for 1 and 2 weeks. PE bags were equipped with small tubing and were sealed properly in order to measure MA conditions upon exit from storage.

2.3. Modified atmosphere evaluation

Thirty minutes after removal from cold storage and 9 h later (when the bags were cut open), MA conditions were evaluated in the packages by withdrawing air and quantifying O_2 and CO_2 concentrations using a paramagnetic and an infrared gas analyzer, respectively (Bishop model 280 Combo, David Bishop Instruments Ltd., England). The analyzer was standardized using air and a mixture of 1% O_2 and 5% CO_2 (balance N_2).

2.4. Quality evaluations

After heat treatment, the quality of six 7-fruit replicates of heated fruit and six more of control fruit were evaluated. Quality was also evaluated after 1 and 2 weeks cold storage plus one day shelf life at 22 °C and 50–55% RH. Initially and at each removal (+1 day shelf life) the mass of each replicate was measured and mass loss expressed as percent loss from initial was calculated.

Observations on skin browning and pitting were taken before any other quality evaluation. Flesh firmness was measured on both cheeks of each fruit after skin removal with an Effegi penetrometer equipped with an 8.9 mm diameter plunger. Initial and total conductivity was evaluated in fruit pieces as described previously (Hong et al., 2000). Specific conductivity was calculated as the fraction of initial conductivity to total after corrections for temperature during each measurement. Two repetitions per replicate were conducted and their mean value was used for statistical analysis.

Soluble solids concentration (%) (Atago refractometer, model N-1E, Jencons Scientific Ltd., Japan), pH and titratable acidity were measured in the juice from the rest of the fruit. Titratable acidity was calculated as g malic acid/100 mL of juice, after titration with 0.1 N NaOH to an endpoint of pH 8.2. Two repetitions per replicate were conducted and their mean value was used for statistical analysis.

Finally, juice total phenols were determined with the Folin–Ciocalteau method using a spectrophotometer (model Spectronic 301, Milton Roy Co., USA) and gallic acid dilutions for standard curve development (Swain and Hillis, 1959). The results were expressed in mg gallic acid/100 mL of juice. Two repetitions per replicate were conducted and their mean value was used for statistical analysis.

2.5. Statistical analysis

Analysis of variance was calculated over two factors, treatment and time in storage for each year and cultivar using the SPSS statistical package (SPSS 10.0, Chicago, USA). Overall least significant differences (LSDs) were calculated for the 0.05 level of significance.

3. Results and discussion

3.1. Fruit temperature during heat treatment

Heat treatment caused a gradual increase of the fruit flesh temperature from 24 °C to 43 °C after 25 min in hot water. After the fruit's removal from the hot waterbath, the flesh temperature gradually decreased and reached 30 °C after 50 min, with room temperature at 22 °C.

3.2. Modified atmosphere development

In nectarines, both in 2001 and 2002, hot water treatment did not affect O_2 and CO_2 concentrations inside the modified atmosphere (MA) fruit packages compared to control MA packed fruit, 0.5 and 9.5 h after removal from 0 °C storage for 1 or 2 weeks (Table 1).

In 2001, packages of peaches treated with hot water had higher O_2 concentrations and lower CO_2 concentrations compared to control fruit 0.5 and 9.5 h after 2 weeks cold storage, but heat treatment did not affect MA conditions after 1 week cold storage (Table 2). This possibly means that after 2 weeks cold storage, hot water treatment kept fruit less ripe inside MA packages. But, in 2002 (with less mature peach fruit), hot water treatment slightly (not significant) reduced O_2 concentrations and increased CO_2 concentrations

Table 1
Changes in O_2 and CO_2 concentrations inside MA packages of control and heat-treated ‘Caldesi 2000’ nectarines (46 °C hot water for 25 min) 0.5 and 9.5 h after refrigerated storage at 0 °C and MA for 7 and 14 days

Treatment	Time (days)	O_2 (%)		CO_2 (%)	
		0.5 h	9.5 h	0.5 h	9.5 h
Year 2001					
Control	7	16.6	5.2	3.9	13.7
	14	17.2	4.9	3.8	14.1
Heated	7	15.7	4.9	4.2	13.3
	14	17.1	3.8	3.7	14.0
Significance					
Treatment		NS	NS	NS	NS
Time		*	NS	NS	NS
LSD treat × time		1.34	2.42	0.98	2.02
Year 2002					
Control	7	19.2	7.33	2.20	13.3
	14	15.8	3.20	4.98	15.5
Heated	7	17.0	3.70	4.33	15.8
	14	17.4	6.70	3.88	12.5
Significance					
Treatment		NS	NS	NS	NS
Time		*	NS	NS	NS
LSD treat × time		1.99	3.51	1.93	3.69

Table 2
Changes in O_2 and CO_2 concentrations inside MA packages of control and heat-treated ‘Royal Glory’ peaches (46 °C hot water for 25 min) 0.5 and 9.5 h after refrigerated storage at 0 °C and MA for 7 and 14 days

Treatment	Time (days)	O_2 (%)		CO_2 (%)	
		0.5 h	9.5 h	0.5 h	9.5 h
Year 2001					
Control	7	17.7	3.3	2.9	14.4
	14	17.7	8.6	3.0	10.0
Heated	7	18.2	5.4	2.4	12.3
	14	19.3	12.0	1.7	7.2
Significance					
Treatment		*	**	**	**
Time		NS	***	NS	***
LSD treat × time		1.24	2.68	0.83	2.41
Year 2002					
Control	7	17.2	5.9	3.7	13.8
	14	18.1	3.3	2.9	15.4
Heated	7	16.3	4.0	4.5	15.4
	14	15.4	1.7	4.8	17.4
Significance					
Treatment		NS	NS	NS	NS
Time		NS	NS	NS	NS
LSD treat × time		2.62	2.95	2 33	3.58

in fruit MA packages compared to non-heated fruit (Table 2).

A heat treatment, depending on temperature and length of exposure, can decrease or increase the climacteric respiratory peak as well as advance or delay it after treatment, while the result also depends on the physiological stage of the tissue (Klein and Lurie, 1990). Respiration rates of apples and tomatoes were enhanced initially during high air temperature treatment at 35–40 °C for one or two days, but after longer times at high temperatures the rate decreased (Lurie and Klein, 1990, 1991). With increasing keeping time at 35 °C a greater proportion of respiration is from the cyanide insensitive pathway (Inaba and Chachin, 1989). The shift to alternative oxidative phosphorylation may reflect the thermoregulatory role of this pathway in order to maintain cellular homeostasis (Breidenbach et al., 1997). When heated fruit return to ambient temperature, the respiration is often lower than in unheated fruit.

In 2001, 30 min after removal of nectarines from cold storage, O_2 concentrations after 2 weeks cold storage were 9% higher than after 1 week cold storage. This difference was observed only in heat-treated fruit. In 2002, 30 min after removal of nectarines from cold storage, O_2 concentrations after 1 week cold storage were higher than after 2 weeks cold storage, and the difference was observed only with control fruit (Table 1). O_2 and CO_2 concentrations in MA packages with nectarines kept for 9.5 h at room temperature did not differ after 1 or 2 weeks of cold storage (Table 1).

There were no differences in O_2 and CO_2 concentrations 30 min after removal from cold storage of MA packed peaches between the first and second week evaluations for control or hot water treated fruit during both experimental years (Table 2). Differences between the two weekly evaluations were also unimportant 9.5 h after removal from cold storage in 2002, but MA packages of heated fruit had higher O_2 and lower CO_2 concentrations than control fruit in 2001 (Table 2).

Nectarines cv. Fantasia packed in plastic film 35 μm thickness (slightly less than in our study) had 18.5% O_2 and 0.5% CO_2 after 5 days and 11% O_2 and almost 0% CO_2 after 10 days cold storage (Retamales et al., 1997). Packages of plastic film with double thickness (70 μm) had 5.2% O_2 and 9.5% CO_2 after 5 days cold storage and after 10 days 2.5% O_2 and 8% CO_2. In another study, peaches packed in semi-permeable PE bags had lower respiration and ethylene production rates and better quality than the unpacked controls (Roig et al., 2003).

CO_2 concentrations were very high and O_2 concentrations very low in our packages after keeping them for more than 9.5 h at 22 °C (shelf life) probably due to a very high respiration rate with the danger of causing anoxia in the fruit, as 1% O_2 is recommended as the minimum safe concentration at low temperatures (Kader, 1997). Thus, the retailer or consumer should keep the packages in refrigerated shelves or cut open the plastic bag if it is kept for more than 10 h at room temperature.

The plastic bag used for peach and nectarine packages in our experiments was of relatively high permeability. Thirty min after fruit removal from cold storage, gas sampling (for total air bag volume of around 1 L) showed mean values of 3.9% CO_2 and 17% O_2. The respiration rate for peaches and nectarines is around 4–6 mL kg^{-1} h^{-1} CO_2 at 0 °C (Hardenburg et al., 1986). Cold room temperature was 0–1 °C and each bag contained a mean fruit mass of 770 g. Thus, during the first week of cold storage 760 mL CO_2 should have been produced and this same amount for the second week. On the contrary, we found almost one-twentieth of the above quantity, since plastic film permeability at low temperatures was so high that it would not permit any CO_2 concentration increase above 3–4% at low temperatures. This CO_2 level is not expected to affect the respiration rate in addition to a very high O_2 concentration. We suggest that the plastic bags used in our study were of appropriate permeability for use during commercial postharvest handling, where periodic increases in temperature may occur due to inappropriate handling. Of course, relatively ripe stonefruit (like the ones used in this study) should be handled carefully and maintained as close to 0 °C as possible through the postharvest chain.

3.3. Mass loss

Hot water treatment did not affect mass losses in peaches and nectarines during both cold storage durations and years of study (data not shown).

During 2001, peaches softened relatively fast during MA cold storage. They also lost about 3.3% of their mass during the first week of storage plus 1 day shelf-life and losses remained stable thereafter. During 2002, when peaches remained firmer, mass losses were reduced to 0.5% after 1 week and 1.5% after 2 weeks of MA cold storage plus 1 day shelf-life. Nectarines lost around 1.6% of their mass after 2 weeks of MA cold storage in 2001 and 2.7% in 2002. In general, most mass losses occurred during the first week of MA cold storage. Mass losses also seemed to positively correlate with flesh softening rates for both cultivars studied. Other researchers kept peaches at 0 °C and 80–90% RH for 8 weeks and mass losses were substantial at 3.5% per week of cold storage, but this was due to continuous loss of water due to the cooling unit operation and the development of internal breakdown (Robertson et al., 1990).

3.4. Skin browning and pitting

The fruit of both cultivars and for both years did not show any external measurable injury (skin browning or pitting) due to hot water treatment evaluated initially and after each storage period. This was expected as it previously has been found that 46 °C for 25 min in the presence of 200 mM NaCl was not injurious to a number of nectarine cultivars tested with less mature fruit (Obenland and Aung, 1997).

3.5. Flesh firmness

Flesh firmness of heat-treated nectarines was higher than control fruit both after 1 and 2 weeks cold storage during both years of the study (Table 3). This delay in fruit flesh softening is possibly the result of inactivation of cell wall hydrolytic enzymes, mainly polygalacturonase. Lurie (1998) reports that fruit exposed to 38 or 40 °C hot air softened slower than control fruit. On the other hand, flesh firmness of nectarines treated with 46 °C hot water (+NaCl) for 25 min was similar to control fruit (Obenland and Aung, 1997). Thus, there is a possibility that MA packaging used in our study may

Table 3
Changes in flesh firmness, juice pH, SSC, acidity, specific conductivity and total phenolics in control and heat-treated ‘Caldesi 2000’ nectarines (46 °C hot water for 25 min) after refrigerated storage at 0 °C and MA for 7 and 14 days plus 1 day shelf life

Treatment	Time (days)	FF (N)	pH	SSC (%)	Acidity (g/100 mL)	Specific conductivity	Total phenolics (mg/100 mL)
Year 2001							
Control	0	33.7	3.52	13.9	0.614	0.243	482
	7	23.5	3.54	13.7	0.536	0.376	395
	14	22.0	3.63	13.7	0.813	0.562	409
Heated	0	32.3	3.51	13.7	0.622	0.252	473
	7	27.7	3.55	13.7	0.509	0.299	443
	14	27.9	3.68	13.8	0.755	0.486	480
Significance							
Treatment		*	NS	NS	NS	***	NS
Time		***	***	NS	***	***	NS
LSD treat × time		4.1	0.04	0.50	0.056	0.040	88
Year 2002							
Control	0	36.8	3.46	12.6	1.490	0.343	330
	7	22.6	3.56	13.0	0.879	0.519	328
	14	20.9	3.62	12.6	0.593	0.475	337
Heated	0	34.7	3.45	13.0	1.430	0.329	369
	7	38.2	3.51	12.9	0.902	0.387	339
	14	29.8	3.61	12.6	0.539	0.324	312
Significance							
Treatment		***	NS	NS	NS	***	NS
Time		***	***	NS	***	***	NS
LSD treat × time		4.3	0.05	0.54	0.080	0.047	37

have supplemented the hot water treatment in reducing nectarine fruit softening.

Flesh firmness of heat-treated peaches was similar to control fruit (except after 1 week cold storage in 2001) (Table 4).

Based on previous research with yellow flesh peaches, fruit below 27 N is susceptible to damage during postharvest handling (Crisosto et al., 2001). This level was also used as critical for white flesh ‘Snow King’ peaches and a flesh firmness of 13 N was accepted for optimum eating quality (Garner et al., 2001). In 2001, flesh firmness decreased during the first week of MA cold storage at 0 °C and to a lesser extent over the second week of storage plus 1 day at 22 °C, but kept above 20 N for nectarines and 17 N for peaches (Tables 3 and 4). During 2002, similar results were observed for nectarines (Table 3), but flesh firmness of peaches was only slightly reduced during storage (Table 4). As a result, during 2002, yellow flesh peaches kept better, as far as flesh firmness is concerned, than white flesh nectarines.

3.6. Soluble solids concentration

In 2001, juice soluble solids concentration (SSC) of nectarines and peaches at harvest was very high, thus fruit were of excellent quality (Tables 3 and 4). Hot water treatment did not affect SSC after 1 or 2 weeks cold storage (Tables 3 and 4).

In 2001, SSC of control or heat-treated fruit was not affected by duration of cold storage, as peaches and nectarines contain only low amounts of starch at advanced maturity and MA cold storage reduced respiration, which could modify SSC during storage (Tables 3 and 4). Similar results were reported for ‘Snow King’ peaches, where SSC remained stable during storage at controlled atmospheres (5% CO_2 and 3% O_2) and 0 °C for 18 days (Garner et al., 2001).

During 2002, SSC of nectarines was neither affected by hot water treatment nor from duration in cold storage (Table 3). But peaches, in 2002, showed a reduction in SSC due to heat treatment and further progressive reduction with storage time (especially the heat-treated

Table 4
Changes in flesh firmness, juice pH, SSC, acidity, specific conductivity and total phenolics in control and heat-treated ‘Royal Glory’ peaches (46 °C hot water for 25 min) after refrigerated storage at 0 °C and MA for 7 and 14 days plus 1 day shelf life

Treatment	Time (days)	FF (N)	pH	SSC (%)	Acidity (g/100 mL)	Specific conductivity	Total phenolics (mg/100 mL)
Year 2001							
Control	0	41.5	4.30	15.3	0.229	0.223	241
	7	21.0	4.40	15.9	0.328	0.526	377
	14	17.3	4.52	15.4	0.300	0.436	258
Heated	0	42.2	4.32	15.2	0.220	0.241	253
	7	26.9	4.37	15.6	0.325	0.443	401
	14	19.3	4.60	15.4	0.281	0.466	292
Sianificance							
Treatment		*	NS	NS	NS	NS	NS
Time		***	***	NS	***	***	***
LSD treat × time		4.6	0.07	0.6	0.031	0.058	44
Year 2002							
Control	0	44.9	4.16	12.6	0.808	0.260	241
	7	43.4	4.21	12.6	0.453	0.214	243
	14	40.4	4 24	12.4	0.406	0.213	270
Heated	0	45.2	4.15	12.4	0.890	0.244	234
	7	40.7	4.26	12.2	0.417	0.191	307
	14	41.7	4.29	11.8	0.411	0.207	274
Significance							
Treatment		NS	NS	***	NS	**	*
Timp		**	***	***	***	***	**
LSD treat × time		3.4	0.08	0.27	0.050	0.017	30

ones) (Table 4). This could possibly be due to the complete depletion of fruit from starch, variability between fruit or slight fruit damage, although the latter is not supported from our observations and data presented below.

3.7. Juice pH and acidity

In 2001, hot water treatment of nectarines and peaches slightly increased juice pH compared to control fruit only after 2 weeks cold storage (Tables 3 and 4). Juice pH of nectarines and peaches increased with duration in cold storage (mainly after 2 weeks cold storage) in control and hot water treated fruit in both years (Tables 3 and 4).

In 2001, nectarines and peaches had lower juice acidity values at harvest than in 2002 (Tables 3 and 4). Hot water treatment did not affect juice acidity of nectarines and peaches in any of the two storage periods and years of study (Tables 3 and 4). In 2001, there was no clear influence of storage time on juice acidity of nectarines and peaches either with control or heat-treated fruit (Tables 3 and 4). During 2002, results were clear and expected. Acidity for both nectarines and peaches gradually and uniformly decreased with storage time for control and hot water treated fruit (Tables 3 and 4). In general, fruit juice acidity has been found to decrease and pH to increase with duration in storage. Similar results were found during ripening or 0 °C storage for more than 8 weeks (Robertson et al., 1990).

3.8. Specific conductivity

In 2001, hot water treatment resulted in reduced specific conductivity (an index of electrolyte leakage) compared to control fruit in nectarines after 1 and 2 weeks of cold storage plus 1 day at room temperature (Table 3) and in peaches (Table 4) only through the first week of storage without any changes during the following storage week. Similar results were found in 2002.

In 2001, specific conductivity of nectarines increased gradually and uniformly over the 2 weeks of storage and of peaches after the first week of storage and remained stable thereafter (Tables 3 and 4). This increase in specific conductivity was observed in control and hot water treated nectarines and peaches, and it is possibly the result of further ripening or gradual membrane malfunction due to chilling injury.

In 2002, specific conductivity in nectarines increased during the first week of storage and remained stable thereafter. In peaches, specific conductivity decreased with storage time. These results were found both for control and hot water treated fruit (Tables 3 and 4).

Specific conductivity is thought to be a good indicator of damage due to hot water treatment. In our study, the increase of specific conductivity due to cold storage was delayed by the 46 °C hot water treatment (combined with MA packaging), suggesting that membranes were kept more rigid, functioning better and ripening was delayed as also shown by the flesh firmness results.

Specific conductivity is also thought to be a good parameter to follow over prolonged storage. Its increase in nectarines (for both years of our study) and in peaches during 2001 with storage time is possibly due to ripening (as supported by the flesh softening results) or due to cold storage stress.

3.9. Total phenol content

Hot water treatment was expected to cause an increase in total phenols in fruit juice due to heat stress or damage. But this increase was not observed in our experiments. Hot water treatment of peaches and nectarines only slightly increased juice total phenol content compared to control fruit after 1 or 2 weeks of cold storage, but these differences were not significant except with peaches during 2002 (Tables 3 and 4).

Juice total phenol content of nectarines was not affected by duration of cold storage in either of the 2 years of study or in any of the treatments (Table 3).

In peaches during 2001, total phenol content of control and hot water treated fruit increased after 1 week cold storage compared to the initial value (Table 4). After 1 more week in cold storage, total phenol content decreased compared to the content of 1 week cold stored fruit. This decrease was found both with control and hot water treated fruit, but it was more pronounced in control fruit resulting in values similar to the initial (before storage) values of the fruit. In 2002, peaches behaved similarly as far as storage time was concerned (Table 4).

Thus, duration in cold storage did not have any major effect on total phenol content in peaches and nectarines. From our results, it is clear that nectarines contained almost double the total phenols of peaches. Total phenols correlate with bruising appearance (Kader and Chordas, 1984), but also with internal browning of peaches and nectarines after extended cold storage, an expression of chilling injury (Lee et al., 1990). In our experiments, storage duration was too short for the fruit to express any chilling injury symptoms. Also, flesh browning due to chilling injury in peaches and nectarines has not been observed in Greece (G.D. Nanos, unpublished data).

Specific conductivity and total phenol content are good indices to evaluate hot water injury. These two parameters were not negatively affected due to hot water treatment in our experiments. As mentioned before, no external injury to the fruit was observed, thus the hot water treatment used herein was not injurious to peaches and nectarines. Similarly, no damage was observed to six nectarine cvs from exposure to 46 °C hot water (+200 mM NaCl) for 25 min (Obenland and Aung, 1997).

4. Conclusions

Hot water treatment at 46 °C for 25 min of relatively ripe peaches and nectarines was found not to damage the fruit, to delay softening and probably substantially reduce fruit losses from fungal growth (see also Margosan et al., 1997 for results of a 46 °C hot water treatment for just 2.5 min on peach fruit infection from major diseases). Keeping the fruit in sealed low thickness PE bags resulted in reduced mass losses and modification of atmosphere with levels not expected to substantially affect the ripening process. A combination of hot water treatment and MA packaging was successful in keeping the high quality of relatively ripe peaches and nectarines during postharvest handling for up to 1 week. This method can now be tested on a commercial scale for its effectiveness.

References

Anthony, B.R., Phillips, D.J., Badr, S., Aharoni, Y., 1989. Decay control and quality maintenance after moist air heat treatment of individual plastic-wrapped nectarines. J. Am. Soc. Hort. Sci. 114, 946–949.

Biggs, M.S., Woodson, W.R., Handa, A.K., 1988. Biochemical basis of high temperature inhibition of ethylene biosynthesis in ripening tomato fruit. Physiol. Plant 72, 572–578.

Bonghi, C., Ramina, A., Ruperti, B., Vidrih, R., Tonutti, P., 1999. Peach fruit ripening and quality in relation to picking time and hypoxic and high CO_2 short-term postharvest treatments. Postharvest Biol. Technol. 16, 213–222.

Breidenbach, R.W., Saxton, R.J., Hansen, L.D., Criddle, R.S., 1997. Heat generation and dissipation in plants: Can the alternative oxidative phosphorylation pathway serve a thermoregulatory role in plant tissue other than specialized organs? Plant Physiol. 114, 1137–1140.

Choi, J.H., Koo, S., 1997. Effect of MA storage on wooliness of 'Yumyeong' peaches. Postharvest Hortic. Ser. 3, 132–138.

Claypool, L.L., 1977. Plant nutrition and deciduous fruit crop quality. HortScience 10, 45–47.

Crisosto, C.H., Slaughter, D., Garner, D., Boyd, J., 2001. Stone fruit critical bruising thresholds. J. Am. Pomol. Soc. 55, 76–81.

Garcia, J.M., Aguilera, C., Albi, M.A., 1995. Postharvest heat treatment in Spanish strawberry (*Fragaria * ananassa* cv. Tulda). J. Agric. Food Chem. 43, 1489–1492.

Garner, D., Crisosto, C.H., Otieza, E., 2001. Controlled atmosphere storage and aminoethoxyvinyl-glycine postharvest dip delay post cold storage softening of 'Snow King' peach. HortTechnology 11, 598–602.

Hardenburg, R.E., Watada, A.E., Wang, C.Y., 1986. The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S.D.A. Agric. Handbook No. 66.

Hong, J.H., Mills, D.J., Coffman, C.B., Anderson, J.D., Camp, M.J., Gross, K.C., 2000. Tomato cultivation systems affect subsequent quality of fresh-cut fruit slices. J. Am. Soc. Hort. Sci. 125, 729–735.

Inaba, M., Chachin, K., 1989. Electrolyte leakage as an indicator of high temperature injury to harvested mature green tomatoes. J. Am. Soc. Hort. Sci. 113, 96–99.

Kader, A.A., Chordas, A., 1984. Evaluating the browning potential of peaches. Calif. Agric. March–April, 14–15.

Kader, A.A., 1997. A summary of CA requirements and recommendations for fruit other than pome fruit. In: Kader, A.A. (Ed.), Proceedings of the 7th Intl. Controlled Atmosphere Res. Conf. 13–18 July, pp. 1–35.

Kader, A.A., 1999. Fruit maturity, ripening and quality relationships. Acta Hort. 485, 203–208.

Klein, J.D., Lurie, S., 1990. Prestorage heat treatment as a means of improving poststorage quality of apples. J. Am. Soc. Hort. Sci. 115, 265–269.

Lay-Yee, M., Rose, K.J., 1994. Quality of Fantasia nectarines following forced air heat treatments for insect disinfestation. HortScience 29, 663–666.

Lee, C.Y., Kagan, V., Jaworski, A.W., Brown, S.K., 1990. Enzymatic browning in relation to phenolic compounds and polyphenoloxidase activity among peach cultivars. J. Agric. Food Chem. 38, 99–101.

Lurie, S., 1998. Postharvest heat treatments. Postharvest Biol. Technol. 14, 257–269.

Lurie, S., Klein, J.D., 1990. Heat treatment of ripening apples: differential effects on physiology and biochemistry. Physiol. Plant 78, 181–186.

Lurie, S., Klein, J.D., 1991. Acquisition of low temperature tolerance in tomatoes by exposure to high temperature stress. J. Am. Soc. Hort. Sci. 116, 1007–1012.

Lurie, S., Sabehat, A., 1997. Prestorage temperature manipulations to reduce chilling injury in tomatoes. Postharvest Biol. Technol. 11, 57–61.

Margosan, D.A., Smilanick, J.L., Simmons, G.F., Henson, D.J., 1997. Combination of hot water and ethanol to control postharvest decay of peaches and nectarines. Plant Dis. 81, 1405–1409.

Maxie, E.C., Mitchell, F.G., Sommer, N.F., Snyder, R.G., Rae, H.L., 1974. Effects of elevated temperatures on ripening of 'Bartlett' pears *Pyrus communis* L. J. Am. Soc. Hort. Sci. 99, 344–349.

McDonald, R.E., Mc Collum, T.G., Baldwin, E.A., 1999. Temperature of water treatments influences tomato fruit quality following low temperature storage. Postharvest Biol. Technol. 16, 147–155.

Miller, W.R., McDonald, R.E., 1992. Postharvest quality of early season grapefruit after forced air vapor heat treatment. HortScience 27, 422–424.

Obenland, D.M., Aung, L.H., 1997. Sodium chloride reduces damage to nectarines caused by hot water treatments. Postharvest Biol. Technol. 12, 15–19.

Paull, R., Chen, N.S., 2000. Heat treatment and fruit ripening. Postharvest Biol. Technol. 21, 21–37.

Retamales, J., Reinaldo, L., Herrera, P., Camus, J.M., 1997. High CO_2 modified atmosphere can be effective in preventing wooliness in nectarines. Postharvest Hortic. Ser. 3, 46–53.

Robertson, S.A., Meredith, F.I., Horvat, R.S., Senter, S.D., 1990. Effect of cold storage and maturity on the physical and chemical characteristics and volatile constituents of peaches cv Crest Haven. J. Agric. Food Chem. 38, 620–624.

Roig, I., Vendrell, M., Lara, I., 2003. Use of CA, MA, shocks of CO_2 and heat treatments to improve storage of two peach cultivars grown in Lleida. Spain. Acta Hortic. 600, 289–295.

Shellie, K.C., Mangan, R.L., 1998. Navel orange tolerance to heat treatments for disinfecting Mexican fruit fly. J. Am. Soc. Hortic. Sci. 123, 288–293.

Swain, T., Hillis, W.E., 1959. The phenolic constituents of *Prunus domestica* I The quantitative analysis of phenolic constituents. J. Sci. Food Agric. 10, 63–68.

Tsuji, M., Harakawa, H., Komiyama, Y., 1984. Changes in shelf life and quality of plum fruit during storage at high temperatures. J. Jpn. Soc. Hortic. Sci. 52, 469–473.

Zoffoli, J.P., Rodriguez, J., Aldunce, P., Crisosto, C.H., 1997. Development of high concentration carbon dioxide modified atmosphere packaging systems to maintain peach quality. Postharvest Hortic. Ser. 3, 37–45.