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Impact of Hot Water and Modified Atmosphere Packaging Treatments on the Postharvest Quality of Pomegranate Fruit (*Punica granatum* cv. 'Hicaznar')

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ABSTRACT

Hot water (HW) and modified atmosphere packaging (MAP) treatments were evaluated to maintain postharvest quality of pomegranate fruit (*Punica granatum* cv. 'Hicaznar'). Pomegranates were subjected to hot water (HW) treatment (at 50 °C for 3 min) and packaged with or without MAP bags. Fruit was then kept at 6 °C for 6 months and at 20 °C for 7 days after cold storage period. The untreated and unpackaged fruit was served as a control treatment (C). MAP and HW+MAP treatments was more effective in reducing weight loss, fungal decay and husk scald, compared to HW and C treatments. The lightness and red color intensity of husk and aril (higher values of L* and C* and lower values of h°) were maintained better in the packaged fruit with MAP (MAP + HW+MAP treatments). The unpackaged fruit from HW and C treatments became unmarketable while those from MAP and HW+MAP treatments were still marketable after 6 months of cold storage and shelf life period. Although fungal decay incidence was low in HW-treated fruit, relatively high scald incidence and weight loss had adverse effect on overall visual acceptability of HW-treated fruit. Hot water dipped pomegranate fruit cv. 'Hicaznar' (50 °C for 3 min) could be kept in MAP bags for 6 months at 6 °C and for 7 days 20 °C without adverse effect on quality.

Keywords: MAP, Shelf life, Cold storage, Chilling injury, Husk scald

1. Introduction

Pomegranate (*Punica granatum* L.) production and export of Turkey has been reached over 500 thousand tons and 200 thousand tons, respectively (TSI 2018). 'Hicaznar' is the dominated cultivar and produced in mostly the Mediterranean and Aegean regions. Major destination markets of Turkish pomegranate export are the European Union countries beside to Russian Federation and other Middle East countries. Commercial storage of pomegranates is advised to prolong until late March (Selçuk & Erkan 2015) when price of pomegranate fruit in European markets reaches the highest level (Rymon 2012). Postharvest quality of pomegranate fruit is often impaired by the visible shriveling symptoms, chilling injury, husk scald, fungal decay beside to deterioration in aril color and taste of pomegranate fruit during long-term cold storage (D'Aquino et al. 2010; Selçuk & Erkan 2015; Porat et al. 2016; Candir et al. 2018; 2019).

Postharvest heat treatments such as curing, intermittent warming and hot water (HW) dips (45 °C to 55 °C for 1 to 5 min) have been studied to reduce chilling injury and fungal decay and improve nutritive and functional properties of pomegranates (Artés et al. 2000a; Mirdehghan & Rahemi 2005; Mirdehghan et al. 2006; 2007; Ramezanian & Rahemi 2010; Moradinezhad & Khayyat 2014). Modified atmosphere packaging (MAP) has been reported to be effective in maintaining the external and internal quality of pomegranate fruit by controlling weight loss, fungal decay and husk scald, and during cold storage period (Artés et al. 2000b; Nanda et al. 2001; D'Aquino et al. 2010; Selçuk & Erkan 2014; 2015; Porat et al. 2016). Combination of hot water, salicylic acid and MAP were reported to be more effective in reducing decay and chilling injury of pomegranate fruit cv. 'Sheshi-kab' in compared to individual application of each treatment (Moradinezhad et al. 2013). In this study, we investigated the combined effects of HW and MAP treatments on postharvest quality characteristics of pomegranate fruit cv. 'Hicaznar' during cold storage and shelf life period.

2. Material and Methods

Pomegranates (cv. 'Hicaznar') were taken from the local commercial orchard where the trees were planted at 5 m × 5 m spacing and were 9-year-old. Fertilizers (160 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1}, and 140 kg K_2O ha^{-1}) were applied under drip irrigation system. The orchard with loamy-clayey and slightly alkaline of soil was located in Antakya-Hatay in the Eastern Mediterranean region of Turkey (36°12′59′′ N, 36°25′43′′E, at altitude of 88 m). The typical Mediterranean climate prevails in this region with annual 1.126 mm precipitation, 69% average annual relative air humidity and annual average temperatures ranged from 8.2 °C to 27.7 °C.

Fruit was hand-harvested when titratable acidity (TA) and soluble solids content (SSC) were <1.85% and >17%, respectively during the 2015-2016 season and were then immediately transported to the storage and laboratory facilities of the Horticultural Department at Hatay Mustafa Kemal University. Pomegranate fruit in uniform size and maturity without defects and blemishes was subjected to the following treatments: (1) Fruit was dipped in hot water (at 50 °C for 3 min) and stored in 52 × 36 × 30 cm plastic boxes (HW); (2) fruit dipped in hot water was packaged with MAP (HW+MAP); (3) fruit without hot water dip was packaged in modified atmosphere packages (MAP); (4) fruit was dipped in water at 24 °C for 3 min and stored in plastic boxes (W) and (5) Control fruit without HW and MAP treatments was stored in plastic boxes (C). Hot water dip temperature was chosen according to the findings of previous studies conducted on 'Hicaznar' and 'Sheshi-kab' pomegranate cultivars (Kipri & Dündar 2011; Moradinezhad & Khayyat 2014). In MAP and HW+MAP treatments, the 5 kg Life Pack® (Patent No.: 2007 45625, Aypek Ambalaj Co., Bursa) bags were used as MAP. The HW and W treated fruits were allowed to dry on a paper towel at room temperature for 1 hour before packaging and storage. Packaged fruits were cooled to 6 °C for 24 hours before sealing the MAP bags and then stored together with the fruits from other treatments at 6±0.5 °C and 90±5% RH for 6 months. Fruit was also kept at 20 ± 1 °C and 70 ± 5% relative humidity for 7 days after 2, 4 and 6 months of cold storage period.

Postharvest quality was evaluated by two months intervals. Weight loss was determined as percentage by weighting of each fruit at harvest and after every 2 months. Check Point model O_2/CO_2 analyzer (PBI-Dansensor America Inc., NJ) was used to monitor headspace O_2 and CO_2 concentration of the bags. Husk color was measured at three points on the equatorial region of each individual fruit using the CIE L*a*b* color space with a CR-300 Minolta Chroma Meter (Osaka, Japan). Arils color was determined according to Artés et al. (1998). Chroma (C*) values were calculated as $C^* = (a^{*2}+b^{*2})^{1/2}$ and hue angle values as (h°) $h° = \tan^{-1}(b^*/a^*)$. The juice was obtained by squeezing of arils of five fruit per replicate through cheesecloth with hand press and used to determined total soluble solids (TSS) content and titratable acidity (TA). The TSS content was measured using a Atago Model ATC-1E refractometer. The five mL of juice was titrated with 0.1 N NaOH to a pH of 8.1 to determine TA (citric acid equivalents). The panelists evaluated overall visual quality using a 5 point scale, where: 1=very poor; 2=poor (limit of marketability); 3= good; 4= very good; 5=excellent (Selçuk & Erkan 2015), and taste using a hedonic scale , where 1= disliked to 9= liked. The fruit was examined visually for fungal decay and chilling injury and husk scald symptoms according to Defilippi et al. (2006). Fungal decay and scald incidence was calculated as a percentage of the fruit affected by decay or and scald. Severity of scald was assessed using a 6 point scale, where 1=no scald, 2=<10%, 3=11 − 250%, 4=25 − 50%, 5=50 − 75 and 6=75 − 100% of the surface affected.

The data were analyzed using SAS software (SAS 2019) according to a completely randomized design with five treatments, and three replications for each treatment. Each replication contained the 5 kg of fruit. Fisher's least significant difference (LSD) test was performed at a $P<0.05$ level for mean separation using the SAS Proc GLM procedure.

3. Results and Discussion

3.1. Headspace O_2 and CO_2 concentration

Figure 1a and 1b presents changes in O_2 and CO_2 concentrations, respectively, inside the MAP bags. Effects of treatments × storage period interaction on the changes in headspace O_2 and CO_2 concentration were significant ($P<0.05$). In both treatments, except for a slight increase in O_2 concentration and a slight decrease in CO_2 concentration after 4 months, O_2 concentrations inside MAP decreased while CO_2 concentration increased during cold storage period. After 6 months of cold storage, final headspace O_2 and CO_2 levels were 15.30% and 7.77% in MAP treatment and 16.73% and 6.57% in HW+MAP treatment, respectively. MAP treatment resulted in a lower O_2 and a higher CO_2 levels than HW+MAP treatment during cold storage. The MAP bag tested in this study ensured a proper modified atmosphere for pomegranate fruit cv. 'Hicaznar' since previous studies suggested 13.50-17.60% of O_2 and 4.40-8.10% of CO_2 (Selçuk & Erkan 2014; 2015), 13.63% of O_2 and 7.85% of CO_2 (Candir et al. 2018) and 15.30% of O_2 and 7.45% of CO_2 (Candir et al. 2019) for pomegranate fruit for long term storage at 6 °C. HW treatment did not have any improving effects on the headspace gas concentration inside MAP.

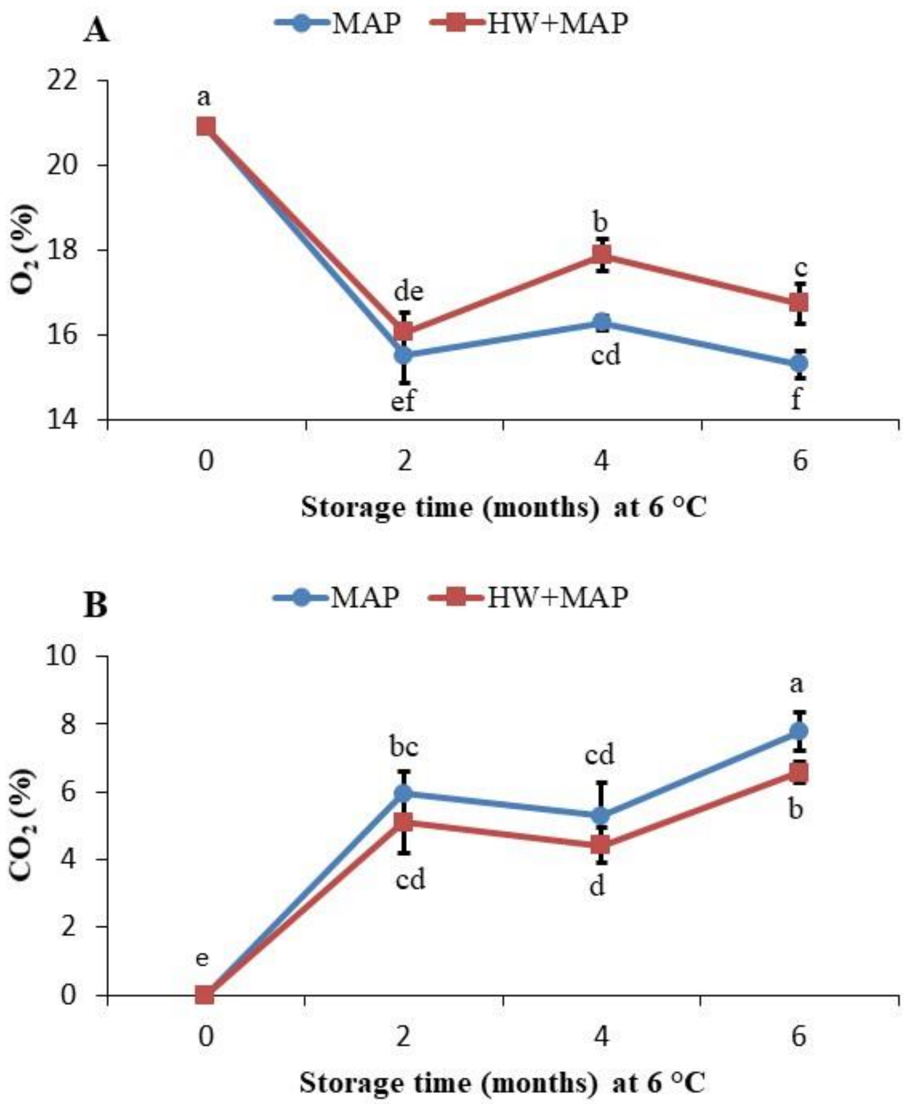

Figure 1- Changes in headspace O_2 (A) and CO_2 (B) concentration (%) inside the MAP containing hot water treated- or not treated pomegranate fruit cv. Hicaznar during storage at 6 °C. HW: Hot water; MAP: Modified atmosphere packaging

3.2. Weight loss

Effects of treatments × storage period and treatments × shelf life period interactions on the changes in weight loss were significant ($P<0.05$). MAP and HW+MAP treatments resulted in a significant reduction in weight loss during cold storage and shelf life period, compared to HW, C and W and treatments (Figure 2). Percent weight loss in MAP and HW+MAP treatments ranged from 9.09% to 9.64% after cold storage and from 11.91% to 12.52% after shelf life period. HW treatments also lead to reduction in weight loss, but it was not as much as MAP and HW+MAP treatments. The 18.51 and 20.27% of weight loss occurred in HW treated-fruit after cold storage and shelf life period, respectively. HW dip contributed a slight effect in controlling weight loss in HW+MAP treatment. Percent weight loss were highest in C and W treatments and reached to 20.36% and 22.11% respectively, after 6 months of storage and exceeded 20% occurred during shelf life period following cold storage. No shriveling was observed in MAP packaged fruit with or without HW dip. In case of the unpackaged fruit of C, W and HW treatments, the husk became hard and darkened, indicating severe shriveling at the end of cold storage and shelf life period. MAP have been suggested to minimize weight loss of pomegranate fruit during cold storage (Artés et al. 2000b; Nanda et al. 2001; D'Aquino et al. 2010; Selçuk & Erkan 2014, 2015, 2016; Porat et al. 2016). In agreement with our results, Mirdehghan & Rahemi (2005) found a lower weight loss occurred in pomegranate fruit from HW treatment at 50 °C than control fruit during 3 to 4 months of cold storage. In contrast to our findings, Moradinezhad & Khayyat (2014) reported that HW treatment alone had no significant effect on weight loss in cold stored pomegranate fruit, compared to control.

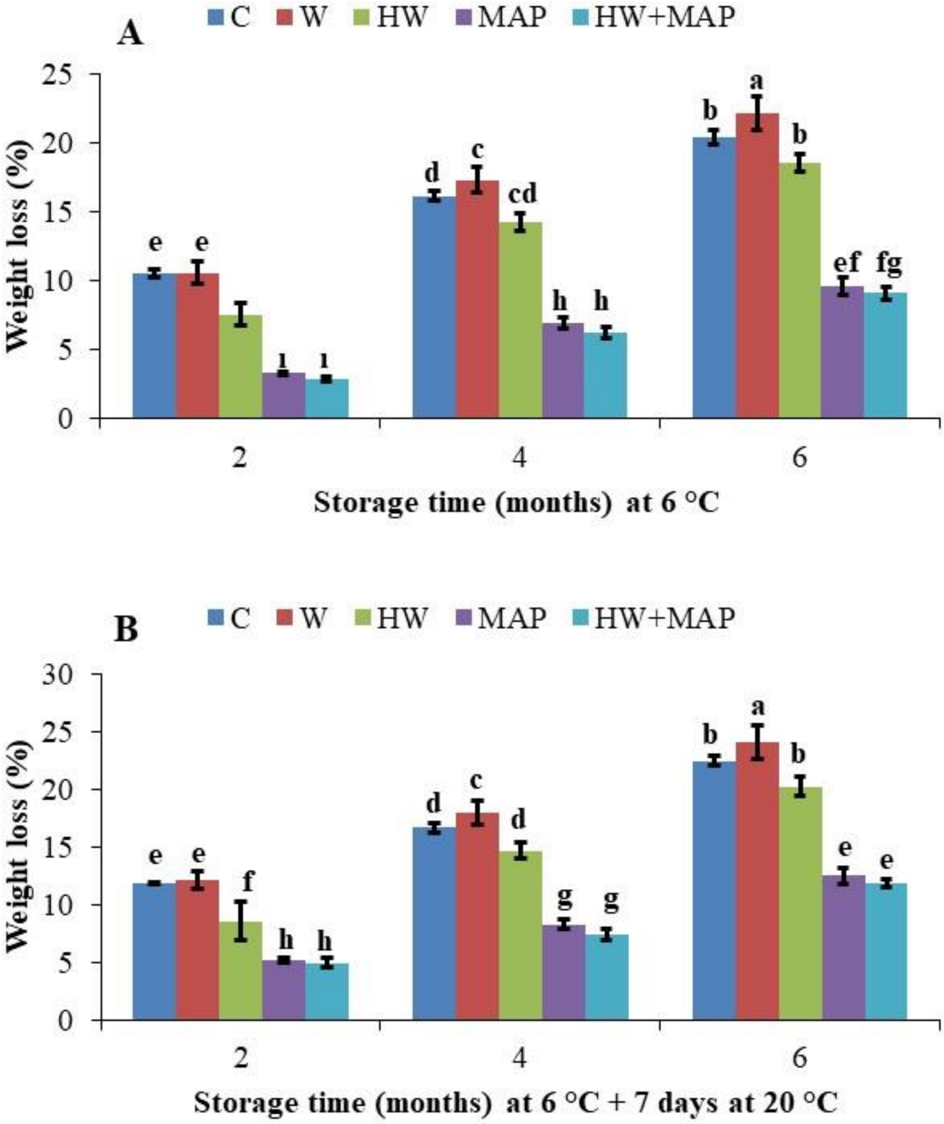

Figure 2- Effects of how water and MAP treatments on the changes in weight loss of Hicaznar pomegranate fruit during storage at 6 °C (A) and subsequent shelf life period for 7 days at 20 °C (B). C: Untreated; W: Water; HW: Hot water; MAP: Modified atmosphere packaging

3.3. SSC and TA

Treatments × storage period and treatments × shelf life period interactions significantly affected on changes in SSC and TA. ($P<0.05$). A decrease in SSC and TA occurred in all treatments after cold storage and shelf life period, compared to the values at harvest (Table 1). Pomegranates are non-climacteric fruit and the consumption of acids and sugars by pomegranate fruit via respiration process lead to decrease in SSC and TA during postharvest period (Kader et al. 1984; D'Aquino et al. 2010; Selçuk & Erkan, 2015, 2016). SSC was similar among the treatments during cold storage period and shelf life period following 2 and 4 months of storage (Table 2). However, control and water treated fruit had higher SSC than the fruit of HW, MAP and HW+MAP treatments after shelf life period following 6 months of storage due to a concentration effect of water loss on sugars (Selçuk & Erkan 2015). In compared to C treatment, TA was maintained better in HW, MAP and HW+MAP treatments throughout cold storage period, but there is no significant difference in TA among treatments after shelf life period. In pomegranate fruit, TA and SSC were reported not to be affected significantly by HW (Mirdehghan & Rahemi 2005; Ben Abda et al. 2010; Kipri & Dündar, 2011; Ramezanian & Rahemi 2010; Sepahvand et al. 2013; Moradinezhad & Khayyat 2014), MAP (Artés et al. 2000b; D'Aquino et al. 2010; Selçuk & Erkan 2015; 2016) or HW+MAP (Moradinezhad et al. 2013) treatments according to the results some studies. In contrast, other studies showed that TA was maintained better in pomegranate fruit dipped in hot water (Mirdehghan et al. 2006) or packaged MAP (Nanda et al. 2001; Selçuk & Erkan 2014; Candir et al. 2018; 2019) in comparison to control during cold storage and shelf life period. In our study, HW+MAP treatment did not have additive beneficial effect in maintaining SSC and TA, compared to individual application of each treatment.

Table 1- Effects of how water and MAP treatments on some quality parameters of Hicaznar pomegranate fruit during 6 months of storage at 6 °C

Treatments[1]	*SSC (%)*	*TA (%)*	*Husk color L**	*Husk color C**	*Husk color h°*	*Aril color L**	*Aril color C**	*Aril color h°*
At harvest	*17.62a*[2]	*1.38a*	*43.90a*	*49.68a*	*25.11g*	*32.70a*	*24.51e*	*29.73a*
2 months of cold storage at 6 °C								
C	17.30abc	1.20cd	42.32 bc	44.92cde	27.99bcd	31.39a	27.84cd	27.04b
W	16.87cde	1.12ef	41.46 cd	44.29def	27.90bcd	27.76a	26.99d	25.66bcd
HW	17.40ab	1.23bc	41.64 cd	44.97cd	25.60 fg	31.60a	27.89cd	27.02b
MAP	17.33ab	1.24bc	43.79 a	49.38a	25.65 fg	32.62a	26.70d	26.13bc
HW+MAP	17.23abc	1.25b	43.79 a	49.71a	25.82 fg	31.53a	26.62d	26.23bc
4 months of cold storage at 6 °C								
C	17.23abc	1.06g	40.61 d	43.03fgh	28.87 b	28.28cd	30.35a	25.22cde
W	16.70def	0.98h	40.57 d	43.17fg	28.77 b	24.81e	27.78cd	26.08bcd
HW	17.23abc	1.16de	41.19 cd	43.0efg	27.35cde	29.05cd	28.62bc	26.34bc
MAP	17.07bcd	1.13e	43.07 ab	46.74b	26.22efg	32.75a	28.34bc	26.27bc
HW+MAP	17.07bcd	1.16de	43.22 ab	46.14bc	27.22 de	31.15ab	28.73bc	25.72bcd
6 months of cold storage at 6 °C								
C	16.57ef	1.01h	40.80 d	42.22ghı	31.20 a	25.57c	30.69a	24.55de
W	16.73def	1.00h	40.78 d	41.16ı	30.93 a	20.33de	29.41ab	24.12e
HW	16.50ef	1.07g	41.31 cd	41.48hı	30.84 a	25.10c	27.56cd	24.87cde
MAP	16.33f	1.08fg	43.74 a	47.40b	26.49 ef	29.71b	26.84d	25.08cde
HW+MAP	16.67def	1.06g	42.99 ab	45.05cd	28.59 bc	28.00b	27.40cd	25.43cde

[1] C: Untreated; W: Water; HW: Hot water; MAP: Modified atmosphere packaging,[2] Means (n=3) followed by different letters within a column are significantly different according to Fisher's LSD test at P<0.05

Table 2-Effects of how water and MAP treatments on some quality parameters of Hicaznar pomegranate fruit after shelf life period for 7 days at 20 °C following 2, 4 and 6 months of storage at 6 °C

Treatments[1]	*SSC (%)*	*TA (%)*	*Husk color L**	*Husk color C**	*Husk color h°*	*Aril color L**	*Aril color C**	*Aril color h°*
At harvest	*17.62a*[2]	*1.38a*	*43.90ab*	*49.68a*	*25.11c*	*32.70a*	*24.51d*	*29.73d*
Shelf life for 7 days at 20 °C after 2 months of cold storage								
C	17.27abc	1.20cd	43.17bcd	44.83cd	25.69c	25.58ef	27.05bc	30.83c
W	17.10c	1.23cd	43.13bcd	44.98cd	25.64c	21.27g	27.17bc	31.05bc
HW	17.20bc	1.24c	43.75ab	45.44bc	25.59c	26.65d	26.20c	29.47de
MAP	17.17bc	1.31b	44.11a	46.87b	23.82c	30.51b	27.68bc	29.46de
HW+MAP	17.17bc	1.25bc	43.83ab	45.85bc	24.55c	28.81c	26.98bc	29.06def
Shelf life for 7 days at 20 °C after 4 months of cold storage								
C	17.35abc	1.01f	42.58de	41.52fg	29.06b	25.96de	31.24a	31.27bc
W	17.10c	1.06f	42.73cde	41.44fg	29.02b	21.78g	30.84a	31.93ab
HW	17.23bc	1.13e	43.43abc	42.46ef	24.26c	26.43de	27.13bc	28.70efg
MAP	17.20bc	1.25bc	43.70ab	45.14cd	25.41c	30.24b	26.59bc	28.09g
HW+MAP	17.13c	1.17de	43.88ab	45.42bc	25.44c	28.33c	27.75bc	29.07def
Shelf life for 7 days at 20 °C after 6 months of cold storage								
C	17.00c	1.02f	38.89f	39.74h	32.03a	22.14g	30.24a	32.47a
W	17.53ab	1.02f	38.97f	39.87h	32.41a	20.08h	30.48a	31.91ab
HW	15.53d	1.03f	39.66f	40.53gh	31.38a	24.90f	28.01b	29.79d
MAP	14.98e	1.03f	42.67cde	43.81de	27.78b	28.67c	26.67bc	28.15fg
HW+MAP	15.27de	1.01f	41.96e	43.84de	29.33b	28.82c	27.62bc	29.29de

[1] C: Untreated; W: Water; HW: Hot water; MAP: Modified atmosphere packaging, [2] Means (n=3) followed by different letters within a column are significantly different according to Fisher's LSD test at P<0.05

3.4. Husk and aril color

Husk and aril color were significantly affected by treatments × storage period and treatments × shelf life period interactions (P<0.05). Husk color L* (lightness) and C* (intensity) values were lower while h° values were higher after 6 months of cold storage and shelf life period, compared to the initial values (Table 1 and 2). Similar changes in husk color of cold stored pomegranate fruit have been previously reported (Fawole & Opara 2013; Selçuk & Erkan 2013; 2014; 2015; 2016; Candir et al. 2018; 2019). A significantly higher water loss resulted in loss of husk color lightness (lower L* values) in the unpackaged fruit from C, W and HW treatments. In comparison to the unpackaged fruit (C, W and HW treatments), the lightness and red color intensity of husk (higher values of L* and C* and lower values of h°) were maintained better in the packaged fruit with MAP (MAP + HW+MAP treatments) as reported in previous studies (Artés et al. 2000b; D'Aquino et al. 2010; Selçuk & Erkan 2013; 2014; 2015; 2016; Candir et al. 2018; 2019). Stand-alone MAP treatment was found to be effective in maintaining husk color. HW treatment was not successful in preventing husk color loss as C and W treatments. Therefore, we concluded that there is no improvement in husk color due to HW or HW+MAP treatments. Consistent with our findings, Kipri & Dündar (2011) reported no significant effect of HW treatments at 50 °C to 55 °C for 1-2 min on husk color. Sepahvand et al. (2013) found no significant differences in husk color a* and b* values between HW-treated and control pomegranate fruit cv. 'Malas Saveh', but HW treatments resulted in lower husk color L* values than control treatment after storage and shelf life period.

Aril color L* and h° values decreased and aril color intensity (C*) increased after 6 months of storage, compared to values at harvest (Table 1), indicating resulting in more intense aril color. Arendse et al. (2014) found similar changes in aril color L*, C* and h° values of pomegranate fruit cv. 'Wonderful' kept at 5 °C for 5 months. They reported that anthocyanin synthesis and accumulation is continued in the cold stored pomegranate fruit. Fruit from C and W treatments had darker (lower L*) and more intense (higher C*) aril color than those from HW, MAP and HW+MAP treatments after cold storage and shelf life period. Aril color h° values were similar among the treatments after 6 months of cold storage. However, C and W treatments resulted in higher h° values than HW, MAP and HW+MAP treatments during shelf life period following 6 months of cold storage (Table 2). This indicates discoloration of aril color in C and W treatments. Previous studies reported that aril color was not affected by HW treatment (Ben Abda 2010; Kipri & Dündar 2011). However, we found that stand-alone HW treatment and combination with MAP treatment was successful in maintaining aril color as MAP treatment did. Candir et al. (2019) reported a delay of discoloration of aril color in pomegranate fruit packaged with MAP compared to unpackaged control fruit during prolonged cold storage.

3.5. Husk scald, fungal decay, visual quality and taste

Husk scald, fungal decay visual quality and taste were significantly affected by treatments × storage period and treatments × shelf life period interactions ($P<0.05$). Husk scald symptoms and fungal decay were not observed until 6 months of storage and subsequent shelf life period, except for control treatment (Table 3 and 4). After 4 months of storage plus 7 days at 20 °C, scald incidence of 17.78% was observed only on control fruits. Incidence of husk scald was lower in MAP and HW+MAP treatments than HW, C and W after 6 months of cold storage and shelf life period. Severity of scald was low since only <10% of the skin's surface area covered with and scald symptoms. Fungal decay incidence was significantly reduced by HW, MAP and HW+MAP treatments compared to C and Win both cold storage and shelf life period. How water dip at 50°C for 3 min was found previously effective in reducing chilling injury of pomegranate fruit packaged with low-density polyethylene bags during 10 weeks of cold storage (Moradinezhad & Khayyat 2014). In our study, chilling injury symptoms were not observed in any of treatments. We found that stand-alone HW treatment was not effective as MAP and HW+MAP treatments in controlling husk scald. There is no improvement in preventing husk scald when combined HW treatment with MAP treatment. Ben-Arie & Or (1986) suggested that oxidation of phenolic compounds on the husk of pomegranates may resulted in husk scald when stored at >5 °C. Lower scald incidence was reported in 'Wonderful', 'Primosole' and 'Hicaznar' pomegranates stored in MAP bags for 12 to 16 weeks in comparison to unpackaged control fruit (D'Aquino et al. 2010; Porat et al. 2016; Candir et al. 2019). According to D'Aquino et al. (2010), lower O2 levels in MAP bags may reduce or delay oxidation of phenolic compounds on the husk and consequently could control scald incidence in pomegranate fruits packaged with MAP bags.

Table 3- Effects of how water and MAP treatments on the incidence of husk scald and fungal decay and visual quality and taste of Hicaznar pomegranate fruit after 6 months of storage at 6 °C

Treatments[1]	*Husk scald(%)*	*Severity of scald [3]*	*Fungal decay (%)*	*Visual quality [4]*	*Taste [5]*
At harvest	*0.00d[2]*	*1.00b*	*0.00c*	*5.00a*	*9.00a*
		2 months of cold storage at 6 °C			
C	0.00d	1.00b	0.00c	4.87a	7.00cde
W	0.00d	1.00b	0.00c	5.00a	7.17cd
HW	0.00d	1.00b	0.00c	4.93a	7.67bc
MAP	0.00d	1.00b	0.00c	5.00a	8.50ab
HW+MAP	0.00d	1.00b	0.00c	5.00a	7.08cde
		4 months of cold storage at 6 °C			
C	0.00d	1.00b	0.00c	2.20e	6.17e
W	0.00d	1.00b	0.00c	2.73d	6.17e
HW	0.00d	1.00b	0.00c	1.53f	6.50de
MAP	0.00d	1.00b	0.00c	4.77a	7.00cde
HW+MAP	0.00d	1.00b	0.00c	4.73a	7.00cde
		6 months of cold storage at 6 °C			
C	41.48a	2.12a	37.78a	1.00g	6.42de
W	37.78a	2.11a	41.48a	1.00g	6.44de
HW	23.71b	2.12a	0.00c	1.00g	6.39de
MAP	13.34c	2.14a	0.00c	3.59b	6.89cde
HW+MAP	12.2c	2.15a	7.78b	3.15c	6.72de

[1] C: Untreated; W: Water; HW: Hot water; MAP: Modified atmosphere packaging,[2] Means (n=3) followed by different letters within a column are significantly different according to Fisher's LSD test at $P<0.05$, [3] Assessed based on a 1–6 scale, (1=no scald; 2=<10%; 3=11-25%; 4=25-50%; 5=50-75%; 6=%75-100 of the fruit surface affected), [4]Evaluated based on a 5 point scale, where: 1=very poor; 2=poor (limit of marketability); 3=good; 4=very good; 5=excellent. [5]Evaluated based on a hedonic scale of 1=disliked extremely to 9=liked extremely

Table 4- Effects of how water and MAP treatments on the incidence of husk scald and fungal decay and visual quality and taste of Hicaznar pomegranate fruit after shelf life period for 7 days at 20 °C following 2, 4 and 6 months of storage at 6 °C

Treatments[1]	*Husk scald(%)*	*Severity of scald [3]*	*Fungal decay (%)*	*Visual quality [4]*	*Taste [5]*
AT	*0.00d*	*1.00b*	*0.00b*	*5.00a*	*9.00a*
Shelf life for 7 days at 20 °C after 2 months of cold storage					
C	0.00d	1.00b	0.00b	4.87ab	8.17b
W	0.00d	1.00b	0.00b	4.73ab	6.20de
HW	0.00d	1.00b	0.00b	4.87ab	7.50c
MAP	0.00d	1.00b	0.00b	5.00a	6.00ef
HW+MAP	0.00d	1.00b	0.00b	4.93ab	6.33de
Shelf life for 7 days at 20 °C after 4 months of cold storage					
C	17.78c	2.27a	0.00b	4.27c	6.38de
W	0.00d	1.00b	0.00b	2.48f	6.61d
HW	0.00d	1.00b	0.00b	2.85ef	5.89ef
MAP	0.00d	1.00b	0.00b	4.57bc	7.38c
HW+MAP	0.00d	1.00b	0.00b	3.53d	7.22c
Shelf life for 7 days at 20 °C after 6 months of cold storage					
C	40.00a [2]	2.43a	36.67a	1.00g	5.28g
W	37.50a	2.38a	40.00a	1.00g	4.45hı
HW	36.67a	2.37a	0.00b	1.00g	4.06ı
MAP	27.41b	2.23bc	2.22b	3.20de	5.44fg
HW+MAP	28.34b	2.33ab	0.00b	2.93e	4.97gh

[1] C: Untreated; W: Water; HW: Hot water; MAP: Modified atmosphere packaging, [2] Means (n=3) followed by different letters within a column are significantly different according to Fisher's LSD test at P<0.05, [3] Assessed based on a 1–6 scale, (1=no scald; 2=<10%; 3=11-25%; 4=25-50%; 5=50-75%; 6=%75-100 of the fruit surface affected), [4] Evaluated based on a 5 point scale, where: 1=very poor; 2=poor (limit of marketability); 3=good; 4=very good; 5=excellent, [5] Evaluated based on a hedonic scale of 1=disliked extremely to 9=liked extremely

HW and HW+MAP treatment was more effective in reducing decay, compared to MAP treatment. Effectiveness of HW treatment and its combination with MAP treatment in controlling fungal decay of pomegranate fruit was previously reported (Ben Abda et al. 2010; Kipri & Dündar 2011; Moradinezhad et al. 2013; Moradinezhad & Khayyat 2014). MAP treatment did not affect decay incidence in pomegranate fruits cv. Mollar de Elche (Artés et al. 2000b) and Wonderful (Porat et al. 2016) during cold storage and shelf life period. In contrast, Candir et al. (2019) observed lower decay percentage in 'Hicaznar' pomegranates packaged with MAP bags than control.

The unpackaged fruit from HW, C and W treatments became unmarketable while those from MAP and HW+MAP treatments were still marketable after 6 months of cold storage and 7 days at 20 °C. Higher incidence of fungal decay, weight loss and husk scald impaired visual quality in the fruit of C and W treatments. Although fungal decay incidence was low in HW-treated fruit, relatively high scald incidence and weight loss had adverse effect on overall visual acceptability of HW-treated fruit. Taste of fruits received lower scores as storage time extended in all treatments. The taste of fruits was rated as acceptable (>5) after 6 months cold storage plus shelf life period except for W and HW treatments. MAP, HW+MAP and control treatments received higher taste score than W and HW treatments after shelf life period following 6 months of cold storage.

4. Conclusions

MAP and HW+MAP treatments was effective in reducing weight loss, husk scald and fungal decay, and maintaining husk and aril color and overall visual quality at 6 ± 0.5 °C and 90 ± 5% relative humidity for 6 months of cold storage and the subsequent shelf life period at 20 ± 1 °C and 70 ± 5% relative humidity for 7 days. Although HW treatment reduced weight loss and fungal decay, was not effective as MAP and HW+MAP treatments to maintain quality parameters.

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