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ORIGINAL PAPER

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EFFECTS OF HARPIN AND MODIFIED ATMOSPHERE PACKAGING (MAP) ON QUALITY TRAITS AND BIOACTIVE COMPOUNDS OF SWEET CHERRY FRUITS THROUGHOUT COLD STORAGE AND SHELF LIFE

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ABSTRACT

This study was conducted to investigate the effects of pre-harvest Harpin treatments and post-harvest MAP treatments on fruit quality attributes and bioactive compounds of '0900 Ziraat' cherry cultivar throughout cold storage and shelf life of the fruits. Weight loss and decay ratios were significantly reduced with Harpin and MAP treatments. In general, lower L* and chroma values were measured in Harpin-treated fruits. As compared to control fruits, higher firmness, titratable acidity and vitamin C contents were measured in MAP and Harpin + MAP treated fruits throughout the cold storage and shelf life. On the other hand, lower solible solids content (SSC) values were observed in the same treatments. At harvest and shelf life measurements, higher total monomeric anthocyanin (TMA) and total phenolics (TPs) were measured in Harpin-treated fruits than in control fruits. Although lower anthocyanin contents were obtained from MAP-treated fruits throughout the cold storage, higher values were observed throughout shelf life. Throughout cold storage and shelf life, MAP-treated fruits had lower total phenolics and total antioxidant activity (according to FRAP and TEAC assay) values than the control and Harpin-treated fruits. It was concluded that Harpin and MAP treatments could be used reduce weight losses and decays throughout the cold storage.

Key words: anthocyanin, decay, firmness, phenolics, *Prunus avium*, weight loss

INTRODUCTION

Potential storage of fruits without any or significant losses in quality attributes is a critical issue influencing marketing period of the fruits. Post-harvest storage potential of the fruits varies with physical and biochemical characteristics of the fruits. Cherries have quite short storage durations because of fruit characteristics. Therefore, it is quite significant in cherries to prolong post-harvest life of the fruits with minimum losses in quality attributes [Sen et al. 2014].

Either pre-harvest or post-harvest treatments are used in various fruit species to reduce quality losses throughout the storage periods. Pre-harvest treatments usually improve fruit quality; pre-storage treatments preserve fruit quality attributes and provide significant contributions to prolong storage durations and shelf life. Therefore, pre-harvest growth regulators (1-MCP, methyl jasmonate, putrescine, aminoethoxyvinylglycine, gibberellin etc.), post-harvest growth regulators and some other post-harvest technologies (modified atmosphere packaging, caotings etc.) are commonly used [Lurie 2010, Lopez-Lauri 2016].

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Modified atmosphere treatments restrict gas exchange thorough packaging material and thus recess metabolic activities of the products. In brief, they create a modified atmosphere within the packaging material. The modified atmosphere in packages directly influences respiration rates of the fruits and vegetables, reduce ethylene synthesis and ethylene-sensitivity of the fruits and retards ripening process [Cantin et al. 2008].

In recent years, researchers mostly focused on natural growth regulators without any risks for human and animal health and with low environmental impacts. Harpin protein is a natural growth regulator [Choi et al. 2013]. It is used to promote plant growth and development [Akbudak et al. 2007, Chen et al. 2008], to stimulate plant defense mechanism [Qiao et al. 2010], to improve plant resistance to pests and pathogens and to improve pre and post-harvest fruit quality [Chai et al. 2004, Tubajika et al. 2007, Li et al. 2012]. To reduce the losses throughout the storage durations, post-harvest Harpin treatments were used in apples [De Capdeville et al. 2003], pears [Wang et al. 2011], melons [Bi et al. 2005], oranges [Lucon et al. 2010] and grapevines [Tubajika et al. 2007]. However, there is limited information about the effects of pre-harvest Harpin treatments (while the fruits are still on tree) on fruit quality attributes and bioactive compounds of cherries throughout storage durations and shelf life of the fruits. The present study was conducted to investigate the effects of pre-harvest Harpin treatments and post-harvest MAP treatments on fruit quality attributes and bioactive compounds of '0900 Ziraat' cherry cultivar throughout cold storage and shelf life of the fruits.

MATERIALS AND METHODS

Plant material and experimental design. The study was carried out in 2015 on fruits harvested from 5-year-old '0900 Ziraat' sweet cherry trees (*Prunus avium*) grafted on 'MaxMa 14 (*P. mahaleb* × *P. avium*) rootstock in Suşehri, Sivas Province, Turkey (40°10'09.67"N latitude, 38°06'37.14"E longitude and 952 m altitude). The trees were planted at 3.5 × 4 m spacing and trained by Spanish Bush system. Standard cultural practices such as irrigation, fertilization, disease control were regularly applied during experimental period.

The study was laid out in a randomized complete-block design. A total of 18 trees with homogeneous fruit load were selected and they were separated into 3 blocks with 6 trees per block based on proximity in orchard and crop load. In each block, 1% Harpin (Messenger Gold, AMC-TR, Turkey) was sprayed (10 June, 2015, at yellow straw color) on three trees until run-off with a low pressure hand sprayer and three tree in each block was served as control treatment (sprayed only with water, pH = 6.50).

As 500 fruits from each tree, about 1500 fruit for each replication (block) were harvested randomly. The fruits were harvested at commercial maturity of color grade 4 according to the color scale developed by CTIFL (Centre Technique Interprofessionnel des Fruit et Legumes, Paris, France), in which 1-light pink and 7-dark mahogany. Fruits were placed 5 kg capacity plastic boxes. Then, fruits were immediately transported via a cooled truck to the postharvest laboratory of the Department of Horticulture at Ordu University where they were selected for uniform size, disease-free, with no mechanical damage and healthy greenish stems. Fruits were hydro-cooled and put into plastic boxes (fruit pulp temperature at 1–2°C).

A total of 150 fruits from each replication were used to determine quality characteristics at harvest – 26 June, 2015, (75 fruit for instant analysis; 75 fruits after 3 days at room temperature). For cold storage, treatments were designed as control (obtained from the trees that were not treated with Harpin and storing without MAP treatment), MAP (storing fruits, which were obtained from the trees that were not treated with Harpin, in MAP), Harpin (storing fruits, which were obtained from the trees that were treated with Harpin, without MAP treatment) and Harpin + MAP (storing fruits, which were obtained from the trees that were treated with Harpin, in MAP treatment). MAP bags (5 kg) for the sweet cherry were Xtend® (815-CH97/a, StePac, Turkey). The fruits were stored in plastic boxes (39 × 29 × 21 cm, Plastas, Turkey) each of which contains 225 fruits. For each repetition 3 boxes (675 fruits) were used.

Fruits were stored in the same storage together, at 0 ±0.5°C and 90 ±5% RH for 7, 14 and 21 days and

analyzed at the end of each storage period (3, 10 and 17 July 2015). Analyses were also performed after three days at room temperature (23°C and 90 ±5% RH) simulating a shelf-life period. In each analysis date, 3 plastic fruit box (1 plastic box for each replicate) were analyzed for each treatment. Of the fruits in each plastic box, half was used for cold storage analyses and the other half was used for shelf life analyses.

Weight loss and decay ratio. Fruit weights were determined using a digital scale (±0.01 g) (Radwag PS 4500/C/1, Poland). Weight loss was determined by the difference between the initial and final weights of each replicate during cold storage and expressed as percent. The fruit decay was visually evaluated during the storage and shelf life. Sweet cherry fruits that showed any sign of surface mycelia development were considered as decayed with naked eye. Decay ratio was expressed as a percentage of infected sweet cherry fruits. Weight loss and decay ratio was replicated three times for each replication.

Color characteristics and firmness. Color characteristics (L*, chroma and hue angle) were measured at opposite sides of each fruit with a colorimeter (Konica-Minolta, model CR–400, Japan). Chromatic analyses were conducted in accordance with the CIE (Commission Internationale de l'Eclairage) system. Values of L^*, a^* and b^* were used to define a three-dimensional color space. The chroma value was calculated with the Eq. (1), and the hue angle with the Eq. (2). Color characteristics were determined for 20 fruits in each replication.

$$C^* = (a^{*2} + b^{*2})^{1/2} \quad \text{Eq. (1)}$$

$$h^\circ = \tan^{-1} b^*/a^* \quad \text{Eq. (2)}$$

Texture analyzer, TA-TX Plus (Stable Microsystems, Godalming, UK), fitted with a 2.0 mm penetrometer probe, a 50 N load cell, operating at a penetration speed of 10 mm s^{-1} and a penetration depth of 3 mm, was used to measure flesh firmness (N mm^{-1}). The maximum force needed for penetrating the fruit 3 mm deep was 5 N. Flesh firmness results were the average of 10 measurements in each replication.

Solible solids content (SSC), titratable acidity and vitamin C. For SSC, titratable acidity and vitamin C measurements, 90 fruits were selected from each replicate and fruits were divided into 3 groups each of with 30 fruits. Stones of each fruit were removed and fruit juices were extracted with an electrical fruit juice extractor (HR1855/70, Philips, Turkey). A digital refractometer (PAL-1, McCormick Fruit Tech., Yakima, Wash., USA) was used to determine SSC (%). For titratable acidity, 10 ml extract was diluted with 10 ml distilled water, and then titrating to pH 8.2 using 0.1 mol L^{-1} sodium hydroxide, expressed in malic acid equivalent (g malic acid 100 g^{-1}). For vitamin C content, sufficient amount of extract was taken and resultant volume was completed to 5 ml with the addition of 0.5% oxalic acid. Ascorbic acid test strip (Catalog no: 116981, Merck, Germany) was taken from reclose tube, dipped into the solution for 2 seconds and reflectometer set (Merck RQflex plus 10) was started. The test strip was then shaken off to remove excess liquid over it, waited for 8 seconds and reading was performed until the end of 15th second. The resultant value was expressed as mg 100 g^{-1}.

Total phenolics (TP), total antioxidant capacity and total monomeric anthocyanin (TMA). For bioactive compounds, 90 fruits were selected from each replicate. Then stones of these fruits were removed, and the pulp was homogenized with a food blender. The homogenates were placed into 3 different tubes and stored at –20°C for bioactive analyses. Samples were thawed at room temperature (≈21°C) and homogenized in a food-grade blender. The resultant slurry was centrifuged (12.000 × g) at 4°C for 30 min to separate the juice from the pulp. The freshly obtained juice was diluted with distilled water, divided into multiple sample aliquots and refrozen at –20°C until used in phenolics, anthocyanin and antioxidant assay procedures.

Total phenolics (TP). Total phenolics content was measured according to the procedure described by Singleton and Rossi [1965]. Briefly, fruit pulp were extracted with a buffer containing acetone, water and acetic acid (70 : 29.5 : 0.5 v/v) for 2 hours at dark. Samples were replicated four times. Extracts were combined with Folin-Ciocalteu's phenol reagent and water, and incubated at room for 8 minutes followed by the addition of 7% sodium carbonate. After 2 h, the absorbance at 750 nm was measured in an automated UV-Vis spectrophotometer (Model T60U, PG Instruments). Gallic acid was used as the standard.

The results were expressed as micrograms (µg) gallic acid equivalent (GAE) g^{-1} fresh weight (FW).

Ferric ions (Fe^{+3}) reducing antioxidant power assay (FRAP). Portions of 120 µL were taken from the samples, 0.2 M of phosphate buffer (PO_4^{-3}) (pH 6.6) was added to obtain a volume of 1.25 mL and then 1.25 mL of 1% potassium ferricyanide ($K_3Fe(CN)_6$) solution was added. After vortexing, they were incubated at 50°C for 1 h. Afterwards, 1.25 mL of 10% TCA (trichloro acetic acid) and 0.25 mL of 0.1% $FeCl_3$ were added to the samples. The absorbances of the extract solution were read on an UV-Vis spectrometer at 700 nm. The results were expressed as µmol Trolox equivalents (TE) per kilogram of FW (µmol TE g^{-1} FW) [Benzie and Strain 1996].

Trolox equivalent antioxidant capacity (TEAC) assay. 10 mmol L^{-1} ABTS (2.2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid) was dis- solved in acetate buffer and prepared with potassium per sulfate as described in Ozgen et al. [2006]. The mixture was diluted using an acidic medium of 20 mM sodium acetate buffer (pH 4.5) to an absorbance of 0.700 ±0.01 at 734 nm for longer stability. For the spectrophotometric assay, 2.90 mL of the $ABTS^+$ solution and 100 µL of fruit extract were mixed and incubated at room temperature and dark conditions for 10 min. The absorbance at 734 nm was then determined. The results were expressed in µmol trolox equivalent (TE) g^{-1} FW.

Total monomeric anthocyanin. Total anthocyanin levels were measured by the pH differential method described in Giusti et al. [1999]. Sample extracts were combined in a 1 : 20 ratio (v : v) with potassium chloride and with sodium acetate buffers (pH 1.0 and 4.5, respectively) in separate vessels. After an equilibration period (15 min), the raw absorbance of each solution was measured at 533 and 700 nm. A corrected absorbance value was calculated as ((A520 – A700) pH 1.0 – (A520 – A700) pH 4.5). The anthocyanin content was calculated using the molar absorptivity (ϵ) and molecular weights (MW) of cyanidin 3-glucoside (ϵ = 26.900; MW = 449.2). Results were expressed as micrograms (µg) of cyanidin 3-glucoside equivalents (µg cy-3-glu g^{-1} FW).

Statistical analysis. The percentage values were transformed using the arcsin of the square root before analysis of variance (ANOVA). The normality of the data was confirmed by the Kolmogorov-Smirnov test and the homogeneity of variances by the Levene's test. Data for physical, mechanical and biochemical parameters were subjected to ANOVA by using SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA) software. When the F test was significant, means were compared with Tukey's range test. The level of significance was set as 5%.

RESULTS

Losses were observed in fruit weights of all treatments throughout cold storage. As compared to control fruits, lower weigh losses were observed at all measurement periods of MAP treatments. On the other hand, weight loss in only Harpin-treated fruits were not different from the control fruits on 7th day of storage, but fruit weight values were significantly lower than the control fruits on 14 and 21st days of storage (tab. 1).

Table 1. Effects of MAP and 'Harpin' treatments on weight loss of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during storage at 0°C and 90% RH

Treatments	Weight loss (%)		
	7 day	14 day	21 day
Control	1.06 a	2.04 a	4.31 a
Harpin	0.94 a	1.45 b	3.45 b
MAP	0.29 b	0.53 c	0.78 c
Harpin + MAP	0.25 b	0.56 c	0.83 c

n = 9 for the weight loss (three replications × three different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Increasing decay rates were observed in fruits with the progress of storage duration. As compared to control fruits, significantly lower decay ratios were observed in all treatments on 14 and 21st day of storage. Significantly lower decay ratios were also observed in MAP and Harpin + MAP treated fruits than only Harpin-treated ones. During the shelf life, significantly lower decay ratios were observed in MAP-treated fruit than in control fruits. In only Harpin-treated fruits, lower decay ratios were observed on 7th day than the control fruits (tab. 2).

The fruits treated with Harpin at harvest had significantly lower chroma and hue angle values that the control fruits. The L* values of Harpin-treated fruits were also significantly lower on 14 and 21st day of storage than the control fruits. Harpin + MAP treated fruits had significantly lower chroma values than the control fruits on 21st day of storage. Hue angles of Harpin-treated fruits were significantly lower than the control fruits on 7 and 14th day of storage. In shelf life measurements made at harvest, lower hue angle values were measured in Harpin-treated fruits than in control fruits. L* and hue angle values of MAP-treated fruits, chroma value of Harpin, MAP and Harpin + MAP treated fruits were significantly higher than the control fruits on 7th day of shelf life (tabs 3–5).

Table 2. Effects of MAP and 'Harpin' treatments on decay ratio of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Decay ratio (%)			
	Harvest	7 day	14 day	21 day
Control		nd.	0.58 a	1.31 a
Harpin		nd.	0.31 b	0.71 b
MAP		nd.	0.12 c	0.33 c
Harpin + MAP		nd.	0.15 c	0.28 c
	Harvest + 3 days at room temperature	7 + 3 day	14 + 3 day	21 + 3 day
Control	nd.	2.13 a	4.27 a	6.43 a
Harpin	nd.	1.11 b	4.00 a	6.89 a
MAP		0.69c	2.44 b	2.67 b
Harpin + MAP		0.22 d	0.67 c	2.44 b

nd: not determined. n = 9 for the decay ratio (three replications × three different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 3. Effects of MAP and 'Harpin' treatments on L* values of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	L*			
	Harvest	7 day	14 day	21 day
Control	33.12 a	32.84 a	32.55 a	31.96 a
Harpin	32.97 a	31.61 a	30.68 b	30.26 b
MAP		33.14 a	32.83 a	32.26 a
Harpin + MAP		31.94 a	30.69 b	30.46 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	32.70 a	31.29 b	31.13 a	30.12 a
Harpin	32.23 a	30.51 b	30.47 a	29.38 a
MAP		32.42 a	31.74 a	30.61 a
Harpin + MAP		31.01 b	30.58 a	29.78 a

n = 120 for the L* (three replications × twenty fruits × two different measurements for each fruit). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 4. Effects of MAP and 'Harpin' treatments on chroma values of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Chroma			
	Harvest	7 day	14 day	21 day
Control	37.93 a	34.86 b	34.69 a	33.87 a
Harpin	35.83 b	34.42 b	33.38 a	32.89 ab
MAP		37.43 a	35.03 a	34.32 a
Harpin + MAP		35.27 b	34.36 a	31.92 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	33.76 a	29.47 b	29.17 a	28.18 a
Harpin	33.01 a	32.21 a	28.22 a	27.07 a
MAP		32.60 a	30.44 a	27.65 a
Harpin + MAP		32.21 a	29.73 a	27.19 a

n = 120 for the chroma (three replications × twenty fruits × two different measurements for each fruit). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 5. Effects of MAP and 'Harpin' treatments on hue angle values of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Hue angle			
	Harvest	7 day	14 day	21 day
Control	22.87 a	22.68 a	21.83 a	19.22 b
Harpin	20.33 b	19.95 b	19.24 b	18.89 b
MAP		22.10 a	21.48 a	20.75 a
Harpin + MAP		20.08 b	19.68 b	19.20 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	19.22 a	16.75 b	16.34 a	11.91 a
Harpin	18.17 b	16.51 b	15.72 a	12.93 a
MAP		18.53 a	16.31 a	12.97 a
Harpin + MAP		16.83 b	15.83 a	12.72 a

n = 120 for the hue angle (three replications × twenty fruits × two different measurements for each fruit). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 6. Effects of MAP and 'Harpin' treatments on firmness of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Firmness (N)			
	Harvest	7 day	14 day	21 day
Control	5.82 a	3.54 b	3.59 b	2.73 b
Harpin	5.90 a	3.59 b	3.55 b	2.69 b
MAP		4.54 a	4.32 a	3.55 a
Harpin + MAP		4.60 a	4.35 a	3.48 a
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	3.71 a	3.09 b	2.85 b	2.49 b
Harpin	3.76 a	3.06 b	2.76 b	2.52 b
MAP		3.52 a	3.33 a	2.89 a
Harpin + MAP		3.61 a	3.36 a	2.96 a

n = 30 for the firmness (three replications × ten fruits for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 7. Effects of MAP and 'Harpin' treatments on SSC of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	SSC (%)			
	Harvest	7 day	14 day	21 day
Control	10.79 a	11.51 a	12.52 a	13.14 a
Harpin	11.17 a	11.53 a	12.50 a	12.96 a
MAP		11.13 b	11.47 b	11.70 b
Harpin + MAP		11.17 b	11.32 b	11.53 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	10.97 a	12.79 a	13.21 a	13.95 a
Harpin	11.37 a	12.60 a	12.77 a	13.73 a
MAP		11.55 b	11.67 b	12.03 b
Harpin + MAP		11.47 b	11.70 b	11.93 b

n = 9 for the SSC (three replications × three different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 8. Effects of MAP and 'Harpin' treatments on titratable acidity of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Titratable acidity (g malic acid 100 g^{-1})			
	Harvest	7 day	14 day	21 day
Control	1.38 a	1.35 a	1.20 b	1.04 b
Harpin	1.43 a	1.32 a	1.19 b	1.02 b
MAP		1.33 a	1.25 a	1.19 a
Harpin + MAP		1.36 a	1.24 a	1.15 a
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	1.35 a	1.17 a	1.06 b	0.91 b
Harpin	1.38 a	1.16 a	1.03 b	0.92 b
MAP		1.19 a	1.16 a	1.05 a
Harpin + MAP		1.17 a	1.15 a	1.06 a

N = 9 for the titratable acidity (three replications × three different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 9. Effects of MAP and 'Harpin' treatments on vitamin C of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Vitamin C (mg 100 g^{-1} FW)			
	Harvest	7 day	14 day	21 day
Control	11.57 b	10.69 b	10.16 b	8.19 b
Harpin	12.50 a	10.83 b	10.47 b	9.48 a
MAP		12.27 a	11.40 a	9.53 a
Harpin + MAP		12.33 a	11.68 a	9.70 a
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	10.12 a	8.20 b	7.51 b	6.99 b
Harpin	10.20 a	8.23 b	7.32 b	7.04 b
MAP		10.13 a	9.50 a	7.00 b
Harpin + MAP		10.73 a	9.76 a	7.32 a

n = 9 for the vitamin C (three replications × three different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 10. Effects of MAP and 'Harpin' treatments on total monomeric anthocyanin of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Total monomeric anthocyanin (µg cy-3-glu g^{-1} FW)			
	Harvest	7 day	14 day	21 day
Control	8.41 b	14.22 a	17.24 a	23.87 a
Harpin	10.46 a	13.87 a	17.60 a	25.39 a
MAP		10.51 b	14.11 b	16.29 b
Harpin + MAP		10.93 b	15.90 b	16.49 b
	Harvest + 3 days at room temp.	7+3 day	14+3 day	21+3 day
Control	12.84 b	15.64 b	19.79 b	27.28 b
Harpin	17.22 a	14.90 b	20.94 b	28.88 b
MAP		19.22 a	30.40 a	33.84 a
Harpin + MAP		18.86 a	27.36 a	32.53 a

n = 12 for the total monomeric anthocyanin (three replications × four different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 11. Effects of MAP and 'Harpin' treatments on total phenolics of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	Total phenolics (µg GAE g^{-1} FW)			
	Harvest	7 day	14 day	21 day
Control	591.3 b	768.4 b	787.1 b	894.3 a
Harpin	717.8 a	822.8 a	852.3 a	909.5 a
MAP		776.7 b	806.7 b	856.2 b
Harpin + MAP		722.8 b	798.3 b	827.8 c
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	708.3 b	812.9 b	917.2 a	975.1 a
Harpin	796.2 a	833.7 a	908.3 a	958.8 a
MAP		809.5 b	846.2 b	894.5 b
Harpin + MAP		730.3 c	818.7 c	878.4 b

n = 12 for the total phenolics (three replications × four different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 12. Effects of MAP and 'Harpin' treatments on antioxidant activity (according to FRAP) of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	FRAP (µmol TE g^{-1} FW)			
	Harvest	7 day	14 day	21 day
Control	1.77 a	1.81 b	2.52 a	2.84 a
Harpin	1.85 a	2.08 a	2.36 a	2.96 a
MAP		1.85 b	2.03 b	2.39 b
Harpin + MAP		1.81 b	1.93 b	2.22 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	1.96 a	2.54 a	2.61 a	3.14 a
Harpin	2.12 a	2.57 a	2.62 a	3.19 a
MAP		2.12 b	2.19 b	2.65 b
Harpin + MAP		2.04 b	2.20 b	2.58 b

n = 12 for the antioxidant activity according to FRAP (three replications × four different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Table 13. Effects of MAP and 'Harpin' treatments on antioxidant activity (according to TEAC) of sweet cherry fruits (*Prunus avium* L. cv. '0900 Ziraat') during cold storage and shelf life

Treatments	TEAC (μmol TE g^{-1} FW)			
	Harvest	7 day	14 day	21 day
Control	1.85 b	1.96 b	2.51 a	3.33 a
Harpin	2.26 a	2.45 a	2.55 a	3.18 a
MAP		1.92 b	2.15 b	2.59 b
Harpin + MAP		2.02 b	2.19 b	2.52 b
	Harvest + 3 days at room temp.	7 + 3 day	14 + 3 day	21 + 3 day
Control	2.09 b	2.62 a	2.93 a	3.82 a
Harpin	2.39 a	2.64 a	2.98 a	3.99 a
MAP		2.10 b	2.42 b	2.89 b
Harpin + MAP		2.11 b	2.51 b	2.95 b

n = 12 for the antioxidant activity according to TEAC (three replications × four different measurements for each replication). Means in columns with the same letter do not differ according to Tukey's test at $P < 0.05$

Harpin treatments did not have significant effects on fruit flesh firmness at harvest, throughout cold storage and shelf life; but MAP treatments had significant effects on flesh firmness values. Combined Harpin and MAP treatments did not created significant changes in this effect (tab. 6).

SSC and titratable acidity values of Harpin-treated fruits at harvest were not different from control fruits; but vitamin C contents were significantly higher. In general, lower SSC and higher vitamin C contents were observed in MAP-treated fruits in all measurements throughout cold storage and shelf life. MAP-treated fruits had higher titratable acidity values than the control fruits on 14 and 21st day of cold storage and shelf life (tabs 7–9).

Significantly higher total phenolics (TP) and total monomeric anthocyanin (TMA) values than the control fruits were measured in Harpin-treated fruits at harvest and shelf life measurements. As compared to control fruits, the lowest TMA values throughout cold storage were observed in MAP-treated fruits. However, the greatest TMA values throughout shelf life were measured in MAP-treated fruits. On 7 and 14th of cold storage, TPs values of Harpin-treated fruits were significantly higher than the value of other treatments. On 21st day of cold storage, TPs values of MAP-treated fruits were significantly lower. On 7th day of shelf life, TPs values of Harpin-treated fruits were significantly higher than the other treatments. On the other hand on 14 and 21st days of shelf life, MAP-treated fruits had significantly lower TPs values than the control and Harpin-treated fruits (tabs 10–11).

At harvest and shelf life measurements, Harpin-treated fruits had significantly higher antioxidant activity (according to TEAC) than the control fruits. In general both on cold storage and shelf life measurements, MAP-treated fruits had significantly lower antioxidant activity (according to FRAP and TEAC) than the control fruits. According to both FRAP and TEAC tests, antioxidant activity of Harpin-treated fruits was significantly higher than the other treatments only on 7th day of cold storage (tabs 12–13).

DISCUSSION

Cherries are sensitive fruits and have short post-harvest life. Significant losses and various problems are experienced in marketing of cherries. The present study was conducted to provide contributions to overcome these problems. Significant decreases were observed in weight loss and decay ratios with Harpin and MAP treatments. Harpin treatments might have strengthened defense mechanisms of the plants and stimulated plant growth and development; MAP treatments on the other hand might have slowed down respiration rates. It was reported in previous studies that Harpin treatments reduced the incidence of diseases during the storage of apples [De Capdeville et al. 2003], pears [Wang et al. 2011], melons [Bi et al. 2005], oranges [Lucon et al. 2010] and

grapevines [Tubajika et al. 2007]. Wang et al. [2011] reported that pre-harvest Harpin treatments increased lignin accumulation in melons and activated defense mechanism-related enzymes and metabolites and reduced post-harvest diseases. MAP treatments create low-oxygen and high carbon dioxide and humidity atmosphere around the products. Such a case reduces fruit respiration rates and water loss, thus prolongs storage life [Guilbert et al. 1996]. It was reported in previous studies that MAP treatments reduced weight loss throughout the storage of cherries [Giacalone and Chiabrando 2013] and plums [Kaynaş et al. 2010, Peano et al. 2010, Guillen et al. 2013].

In present study, Harpin treatments did not have significant effects on fruit flesh firmness, SSC and titratable acidy values measured at harvest and end of storage. Wang et al. [2011] reported that pre-harvest Harpin treatments increased SSC/TA ratio and vitamin C contents of melons and partially improved fruit quality. Present findings revealed that MAP treatments were effective in preservation of flesh firmness during the cold storage and lower SSC and higher titratable acidity values were observed at the end of storage. Complying with the present findings, MAP treatments were found to be effective in preservation of flesh firmness in plums [Kaynaş et al. 2010] and cherries [Giacalone and Chiabrando 2013]. However, present findings about the effects of MAP treatments on SSC and titratable acidity values were different from the findings of previous studies. Cantin et al. [2008] reported insignificant effects of MAP treatments on SSC and decreased titratable acidity values. Khan and Sing [2008] reported lower SSC and titratable acidity with MAP treatments; Kaynaş et al. [2010] reported higher SSC and titratable acidity values.

Harpin treatments yielded higher vitamin C contents, total monomeric anthocyanin, total phenolics and antioxidant activity than the control fruits at harvest. These findings comply with the results of Wang et al. [2011] indicating higher vitamin C contents of melons and preserved physico-chemical and sensory characteristics with Harpin treatments. The role of Harpin on various cellular reactions such as activation of genetic reaction related to defense mechanisms [Qiao et al. 2010], activation of reactive oxygen forms [Sang et al. 2012], translocation of effector cytoplasm proteins and depolarization of cell membrane, photosynthesis and production of phenolic compounds and increased enzyme activity [Choi et al. 2013] may have effected in the emergence of this effect. In the present studies vitamin C contents of cherry fruits were better preserved with MAP treatments throughout the storage and shelf life. Serrano et al. [2006] reported decreased losses in antioxidant activity, total phenolics and vitamin C contents of broccoli with MAP treatments; Giacalone and Chiabrando [2013] indicated that MAP treatments did not have any negative impacts on phenolic compounds and antioxidant activity. Khan and Singh [2008] reported that MAP-treated plums had lower antioxidant activity than the control fruits. Rocha et al. [1995] indicated the reason of decreasing antioxidant activity of MAP-treated fruits as increased cytochrome oxidase, oxidase and peroxidase enzyme activities.

CONCLUSION

It was concluded based on present findings that pre-harvest Harpin treatments had positive effects on fruit quality at harvest and MAP treatments could be used as an effective tool in prevention of weight loss, decays and other quality losses throughout the cold storage of the fruits.

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