Turkish Journal of Agriculture and Forestry

Volume 36 | Number 5 Article 5

1-1-2012

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TÜBİTAK

Research Article

Turk J Agric For
36 (2012) 563-575
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doi:10.3906/tar-1111-34

Combined treatment of modified atmosphere packaging and 1-methylcyclopropene improves postharvest quality of Japanese plums

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Received: 22.11.2011 ● Accepted: 02.04.2012

Abstract: Two Japanese-type plum (*Prunus salicina* Lindell) cultivars, 'Autumn Giant' and 'Black Beauty', were harvested at commercial maturity stage and either packed in nonperforated modified atmosphere packaging (MAP) or treated with a 500 ppb dose of 1-methylcyclopropene (1-MCP) alone or given a combination of 1-MCP and MAP. After these treatments, the plum samples were stored at 0 °C for 60 days. Treatment with either 1-MCP or modified atmosphere packaging (MAP) alone or with the 1-MCP+MAP combination reduced fruit softening, ethylene production, respiration rate, weight loss, and flesh browning, and resulted in higher flesh firmness, titratable acidity, and total soluble solids as compared to the control fruit at the end of the storage period. No decay was observed in either cultivar during the entire storage period. Furthermore, the combined treatment of MAP and 1-MCP had a clear advantage over the other treatments in reducing weight loss, retarding softening, increasing shelf life, and maintaining higher overall fruit quality for both cultivars of Japanese-type plums, especially after storage at 0 °C plus 7 days of storage at 20 °C.

Key words: 1-MCP, ethylene, flesh browning, modified atmosphere packaging, *Prunus salicina*, storage

Introduction

The consumption of Japanese-type plums (*Prunus salicina* Lindell) has recently been increasing in Turkey due to high consumer demand. Japanese-type plums are generally consumed all over the world, but softening is a major obstacle for the marketing and eating quality of these plums.

The marketing quality of plums can be maintained up to 2 months in cold storage at 0 °C (Abdi et al. 1997; Guerra and Casquero 2008; Singh et al. 2009). However, plums are very susceptible to low temperature and chilling injury (CI) occurs at this temperature (Abdi et al. 1997; Crisosto et al. 1999; Crisosto et al. 2004; Candan et al. 2008; Manganaris et al. 2008). Cold injury, weight loss, and fungal decay are the dominant factors limiting the storage life of fruit and vegetables (Özdemir et al. 2010). Flesh browning is one of the main CI symptoms in plums and the CI severity depends mainly on the variety and storage temperature (Crisosto et al. 1999; Candan et al. 2008). Crisosto et al. (1999) reported that CI in plums occurs more rapidly at 5 °C than at 0 °C.

During storage, plum softening develops due to ethylene accumulation around or in the fruit. Plums show a climacteric pattern in respiration, and ethylene is responsible for hastening ripening and senescence (Valero et al. 2003; Ozkaya and Dundar

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2010). Similar to other climacteric fruit, an increase in total soluble solids (TSS) content and a decrease in titratable acidity (TA) and flesh firmness occur during ripening. In addition, decay and off-flavors develop, and shelf life is shortened by ethylene during the postharvest period (Giovannoni 2001). To reduce these problems, plums are stored in a cold and controlled atmosphere for a certain duration at around 0 °C. However, the benefits of the cold storage may be diminished due to development of flesh browning (Menniti et al. 2004a; Larrigaudiere et al. 2009).

1-Methylcyclopropene (1-MCP) can maintain postharvest quality of many horticultural commodities by preventing ethylene damage, especially in ethylene-sensitive crops. Many researchers have shown that 1-MCP has the potential to maintain the postharvest quality of many fruit and vegetables (Watkins 2002; Blankenship and Dole 2003). Similarly, some storage studies on plums with 1-MCP have also shown a reduction in respiration rate and ethylene production, resulting in a better retention of flesh firmness (Abdi et al. 1998; Martinez-Romero et al. 2003; Menniti 2004b). Besides plum, studies with 1-MCP on different commodities have reported positive responses on postharvest fruit quality. Some of these commodities include flowers (Serek et al. 1995; Sisler et al. 1996), apples, bananas, oranges, strawberries, and tomatoes (Sisler and Serek 1997; Golding et al. 1998; Fan and Mattheis 1999; Fan et al. 1999; Ku et al. 1999; Porat et al. 1999; Watkins et al. 2000). Blankenship and Dole (2003) reported that cultivar, growing conditions, maturity stage, and storage duration all affect the results of 1-MCP in bananas and some green vegetables. The effects of 1-MCP on postharvest quality and storage duration of various horticultural crops have been compiled and summarized by Watkins (2006).

Modified atmosphere packaging (MAP) technology has been successfully used to maintain the postharvest quality and to prolong the storage period of many fruit and vegetables. By creating higher carbon dioxide (CO_2) and lower oxygen (O_2) concentrations in the surrounding atmosphere of the commodities, decay, respiration rate, ethylene production, and enzymatic activity can be controlled, resulting in an increase in postharvest quality (Brecht 1995; Kader and Watkins 2000; Mattheis and Felman 2000; Rocha et al. 2004). MAP may also prevent weight loss and fruit shriveling by creating a higher relative humidity in the surrounding environment of the products (Weichmann 1987; Zagory et al. 1989). Wargo et al. (2003) reported that the success of MAP depends on several factors such as the physical properties of the film and the respiration rate of the product. There are a lot of research publications on the effects of either 1-MCP or MAP individually on plums; however, there are no published data yet on the effects of 1-MCP and MAP combinations on Japanese-type plums. Therefore, the aim of our study was to investigate the efficacy of 1-MCP treatment alone and in combination with MAP on postharvest quality of 'Autumn Giant' and 'Black Beauty' plums during storage at 0 °C and shelf-life conditions at 20 °C.

Materials and methods

Fruit source

The fruit used in this experiment were harvested from 'Autumn Giant' and 'Black Beauty' plum trees grafted on 'Myrobolan 29C' rootstock and planted in alternating rows at a distance of 5 × 5 m in 2001 in Antalya, Turkey. After harvest, the fruit were immediately transported to the postharvest laboratory and cold storage unit of Akdeniz University in Antalya, Turkey. Plums were harvested at the firm-ripe stage from the same trees for 2 consecutive years (2006-2007). MAP studies were carried out using polyethylene (PE) with a thickness of 30 μm, an O_2 permeability of 1614.32 mL $(m^2 \text{ day atm})^{-1}$, and a CO_2 permeability of 546.24 mL $(m^2 \text{ day atm})^{-1}$ at 0 °C. The fruit were placed in small plastic crates and covered with PE bags as described above and closed tightly. All fruit samples were stored at 0 °C and 90%-92% relative humidity. 'Autumn Giant' and 'Black Beauty' plum cultivars were stored for 60 days with evaluations performed every 10 days. Following storage, the fruit were kept for 7 days at 20 °C to evaluate the shelf-life performance of the plums.

1-MCP application

1-MCP was applied on the day of harvest to 3 replicate units of fruit. 1-MCP powder (Smartfresh, 0.14% active ingredient) was weighed into test tubes

to provide final gas concentrations of 500 ppb per dose. Water was added to the tubes, the tubes were shaken and placed in each container with the fruit, and an airtight lid was closed. After 24 h at 5 °C (cold application), the containers were vented. Untreated control fruit were kept under identical conditions without a 1-MCP application.

Fruit storage and sampling

After the 1-MCP application, plums were packed either with or without MAP and stored at 0 °C with 90%-92% relative humidity. After 10, 20, 30, 40, 50, and 60 days of storage, 60 pieces of fruit from each experimental unit were transferred to an evaluation room; 30 of the plums were analyzed while the rest were kept at 20 °C for an additional 7 days before being analyzed.

CO_2 and O_2 concentration, ethylene production, and respiration rate determination

CO_2 and O_2 concentrations inside the MAP were monitored using a gas analyzer (Servomex 1420 O_2 analyzer and Servomex 1410 CO_2 analyzer). Ethylene and CO_2 production were measured at 20 °C prior to storage by placing each lot and replication of 20 plums in a 5-L glass jar hermetically sealed with a rubber stopper for 15 min. Then 1 mL of the sealed atmosphere was withdrawn with a gas-tight syringe, and the ethylene was quantified using a Thermo Finnigan gas chromatograph equipped with a flame ionization detector and a 3-m-long stainless steel column with an inner diameter of 3.5 mm containing activated alumina of 80/100 mesh. The column temperature was 90 °C, and the injector and detector temperatures were 150 °C. For respiration rate determination, another sample of 1 mL of the same atmosphere was withdrawn and the CO_2 was quantified using the same gas chromatograph with a thermal conductivity detector and a 3-m-long stainless steel column with an inner diameter of 3.3 mm containing Chromosorb 102. The column temperature was 55 °C, and the injector and detector temperatures were 110 °C.

Assessment of fruit quality

Weight loss during storage was determined by measuring the fruit weight before and after the storage period and was expressed as the percentage of weight loss with respect to the initial weight. Flesh firmness was determined using a hand-held penetrometer (Effegi FT 011, Milan, Italy) with an 8-mm-long measuring plunger on the pared equatorial surface on 3 sides of the fruit and was expressed as N. The total soluble solids were determined with a digital refractometer and expressed as a °Brix using the combined juice collected from the all fruits in a replicate. The fruits were squeezed and stirred and then a representative sample was taken to measure TSS. Titratable acidity (TA) was determined by titrating 5 mL of fruit juice in 25 mL of distilled H_2O with 0.1 N NaOH to pH 8.1, and calculating the result as grams of malic acid per 100 g fresh weight (Serrano et al. 2003). Changes in the shriveling, external appearance, and eating quality (overall quality) of plums during cold and room temperature storage were evaluated by a formal panel of 5 people familiar with plums. Overall quality was rated subjectively into one of 5 categories: 4 (excellent), 3 (good), 2 (fair), 1 (poor), and 0 (very poor). CI was expressed as flesh browning and decay incidence, expressed as the percentage of fruit affected, was assessed visually by cutting fruit samples (3 replicates with 10 pieces of fruit in each replicate) after removing them from cold storage and storing them for 7 days at 20 °C.

Statistical analysis

The experiment was conducted and repeated twice during the 2006 and 2007 harvest seasons. The data were analyzed as a factorial experiment in a completely randomized block design by analysis of variance using SAS software. Mean separation was performed using Duncan's multiple range test at a $P < 0.05$ level using the SAS GLM procedure.

Results

Headspace gas compositions

The O_2 concentration in the MAP decreased during the 60-day storage period from 20.8 kPa to 6.3 kPa and 4.8 kPa in 'Black Beauty' and 'Autumn Giant' plums, respectively. The CO_2 concentration in the MAP increased during the first month of storage from 0 kPa to 6.7 kPa and 8.9 kPa in 'Black Beauty' and 'Autumn Giant' plums, respectively, and then continued to increase to 14.8 kPa and 15.8 kPa in 'Black Beauty' and 'Autumn Giant' plums, respectively, after 60 days of storage (Figure 1).

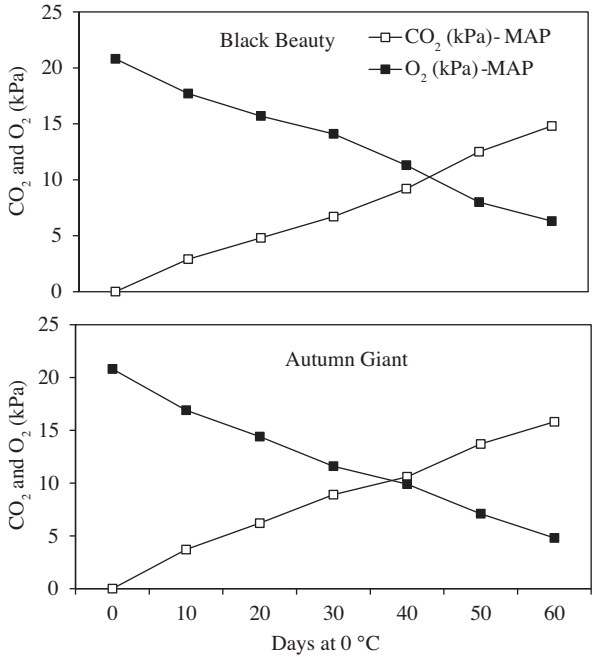

Figure 1. Changes in headspace CO_2 and O_2 concentrations inside MAP for 'Black Beauty' and 'Autumn Giant' plums during storage at 0 °C.

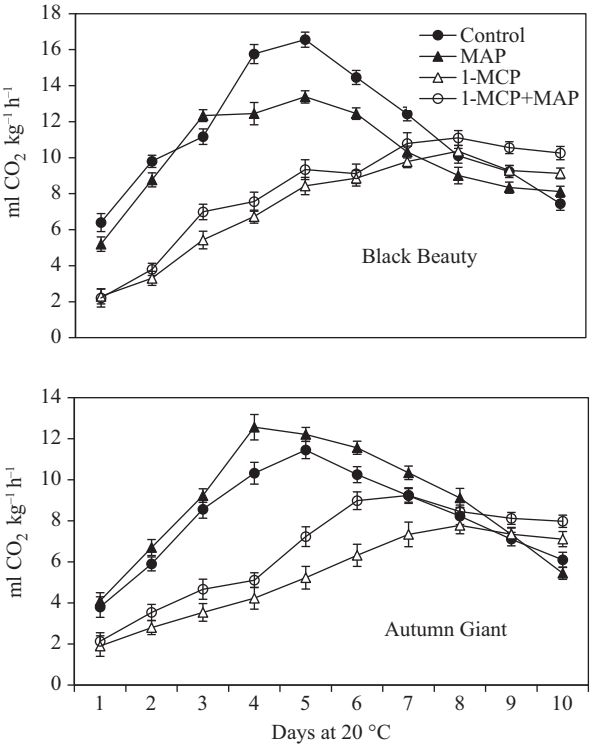

Figure 2. Respiration rate (mL CO_2 kg^{-1} h^{-1}) of 'Black Beauty' and 'Autumn Giant' plums during ripening at room temperature (20 °C). Vertical bars represent standard deviations of means.

Respiration rate

During the study, the respiration rate of the plums was measured at 20 °C. In all treatments, the respiration rate of the plums first increased and then decreased, like other climacteric fruit. However, the respiration rates of the fruit with the 1-MCP treatment and the 1-MCP+MAP treatment were lower than those of the control and MAP-treated plums. 'Autumn Giant' plums stored in MAP reached a climacteric respiration peak of 12.2 mL CO_2 kg^{-1} h^{-1} at 4 days, control plums reached a climacteric peak of 11.4 mL CO_2 kg^{-1} h^{-1} at 5 days, plums treated with 1-MCP+MAP reached a climacteric peak of 9.2 mL CO_2 kg^{-1} h^{-1} at 7 days of storage, and plums treated with 1-MCP reached a climacteric peak of 7.8 mL CO_2 kg^{-1} h^{-1} at 8 days of storage. In 'Black Beauty' plums, while the control and MAP plums reached a climacteric peak of 16.6 and 13.4 mL CO_2 kg^{-1} h^{-1} during the first 5 days, respectively, the plums treated with 1-MCP and 1-MCP+MAP reached climacteric peaks of 10.4 and 11.1 mL CO2 kg^{-1} h^{-1} at 8 days of storage, respectively (Figure 2).

Ethylene production

The fruit treated with 1-MCP exhibited delayed and suppressed ethylene production, as compared to the control (untreated) fruit in both cultivars. In both the control and MAP fruit, ethylene production reached a maximum on day 4 and day 5 in 'Black Beauty' and 'Autumn Giant' plums, respectively, and gradually declined to 0.50 and 0.41 μmol kg^{-1} h^{-1}, respectively, on day 12 in 'Autumn Giant' plums and 0.64 and 0.71 μmol kg^{-1} h^{-1}, respectively, on day 12 in 'Black Beauty' plums, both at 20 °C (Figure 3), while the fruit treated with 1-MCP (including the 1-MCP+MAP combination) showed a slow increase in ethylene production until day 6 in 'Black Beauty' and 'Autumn Giant' plums at 20 °C. Plums treated with 1-MCP and 1-MCP+MAP reached a maximum ethylene production at 8 days of storage in 'Black Beauty' plums, and at 8 and 9 days of storage, respectively, in 'Autumn Giant' plums.

Weight loss

Significant weight loss occurred during the prolonged storage periods at 0 °C and 20 °C. The MAP and the combined 1-MCP+MAP treatment dramatically inhibited weight loss compared to the control and

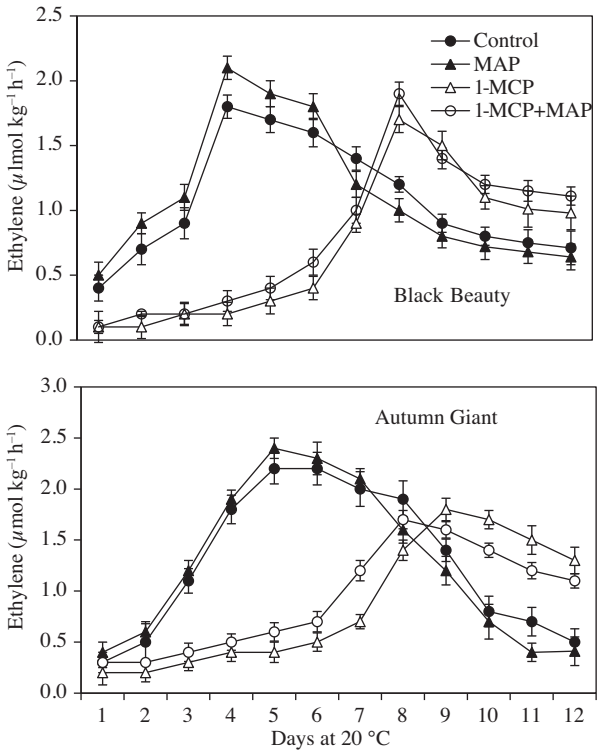

Figure 3. Ethylene production (μmol kg^{-1} h^{-1}) of 'Autumn Giant' and 'Black Beauty' plums during ripening at room temperature (20 °C). Vertical bars represent standard deviations of means.

plums treated with 1-MCP. The increase in weight loss continued in relation to the duration of the shelf-life period. During the storage period, the lowest weight loss was obtained from the 1-MCP+MAP treatment for both cultivars. The control 'Autumn Giant' and 'Black Beauty' plums lost 4.85% and 4.47% of their weight during the 60-day storage period, respectively. During the same storage period, the plums with MAP and 1-MCP+MAP treatments lost only 1.58% and 1.16% of their weight, respectively, in 'Autumn Giant', and 1.78% and 1.89%, respectively, in 'Black Beauty', (Table 1 and Table 3). For the 'Autumn Giant' plums, the control group lost 17.32% of its weight during the storage period (60 days at 0 °C plus 7 days at 20 °C), while those treated with 1-MCP, MAP, and 1-MCP+MAP lost 14.46%, 5.18%, and 4.56% of their initial weight, respectively (Table 2). For the 'Black Beauty' plums, the weight loss during the shelf-life period was 23.21%, 18.45%, 8.34%, and 6.89% in the control, 1-MCP, MAP, and 1-MCP+MAP treatments, respectively (Table 4).

Flesh firmness

Flesh firmness was greatly affected by both 1-MCP and the combination treatment of 1-MCP+MAP. Flesh firmness declined during storage for all 'Black Beauty' and 'Autumn Giant' plums, but firmness was always significantly higher in the plums with the 1-MCP and 1-MCP+MAP combination treatments even after the shelf-life period. When treated with a 500 ppb dose of 1-MCP or treated with a 500 ppb dose of 1-MCP and stored in MAP, 'Autumn Giant' plums had a lower rate of firmness loss in comparison to 'Black Beauty' plums. In 'Autumn Giant' plums stored for 60 days at 0 °C, firmness decreased from an initial 26.7 N firmness at harvest to 16.6 N and 16.3 N in the 1-MCP and 1-MCP+MAP combination treatments, respectively. The flesh firmness of 'Autumn Giant' plums was 11.3 N and 12.4 N in the MAP and control treatments, respectively (Table 1). After holding the plums for 7 days at room temperature following 60 days of cold storage, the 'Autumn Giant' plums treated with 1-MCP and 1-MCP+MAP were firm, while the control and MAP-treated fruit were less acceptable to consumers (Table 2). Similar to the 'Autumn Giant' plums, among the 'Black Beauty' plums that were held at room temperature for 7 days following 60 days of cold storage, the fruit treated with 1-MCP and 1-MCP+MAP were firm, while the control and MAP-treated fruit were very soft and unacceptable to consumers (Table 4).

Total soluble solids

The total soluble solids content of the plums first increased then decreased in all treatments during cold storage at 0 °C or after 7 days at 20 °C following the different storage periods. However, the increase in TSS was delayed by the 1-MCP and 1-MCP+MAP treatments compared to the control and MAP treatment. At harvest, the average TSS content was 15.73% and 16.17% for 'Autumn Giant' and 'Black Beauty' plums, respectively (Table 1 and Table 3). After storage, the TSS content was higher in all treatments compared to the initial TSS levels at harvest; however, the TSS content was higher in the 1-MCP+MAP treatment compared to the control in both cultivars while being held at room temperature after 60 days at 0 °C (Table 2 and Table 4).

Table 1. Quality assessment parameters of 'Autumn Giant' plums during cold storage at 0 °C.

Storage duration (days)	Treatments	Weight loss (%)	Flesh firmness (N)	TSS (%)	TA (%)	Overall quality
0			26.7 a[z]	15.73 c	1.60 a	4.0 a
10	Control	0.61 k	19.5 c	16.47 bc	1.31 d	4.0 a
	MAP	0.25 n	17.2 e	16.27 bc	1.36 cd	4.0 a
	1-MCP	0.36 m	24.8 b	15.98 c	1.47 b	4.0 a
	1-MCP+MAP	0.16 o	24.7 b	16.04 bc	1.44 b	4.0 a
20	Control	1.21 gh	18.1 de	17.40 b	1.10 fg	3.3 bc
	MAP	0.51 l	16.4 f	18.07 ab	1.14 f	3.5 b
	1-MCP	0.85 i	20.0 c	16.12 bc	1.35 cd	3.8 ab
	1-MCP+MAP	0.39 m	20.0 c	16.33 bc	1.39 c	3.8 ab
30	Control	1.83 d	17.3 e	18.78 a	0.64 j	2.8 cd
	MAP	0.64 k	16.1 f	17.87 ab	0.70 i	3.1 bc
	1-MCP	1.11 ij	19.6 c	16.80 b	1.24 e	3.6 b
	1-MCP+MAP	0.63 k	18.7 d	16.67 bc	1.20 ef	3.7 ab
40	Control	2.16 c	16.6 f	18.56 a	0.58 k	2.5 d
	MAP	0.80 j	15.9 f	17.65 ab	0.63 j	2.2 e
	1-MCP	1.44 f	19.3 c	17.06 b	1.16 f	3.1 bc
	1-MCP+MAP	0.79 j	17.3 e	17.30 b	1.18 ef	3.4 b
50	Control	3.11 b	13.2 g	17.97 ab	0.48 l	2.2 e
	MAP	1.29 g	12.9 g	17.13 b	0.50 l	2.0 e
	1-MCP	2.10 c	17.0 f	16.83 b	1.08 fg	2.9 c
	1-MCP+MAP	0.99 i	16.4 f	17.20 b	1.11 fg	3.0 c
60	Control	4.85 a	12.4 h	17.73 ab	0.18 m	1.7 f
	MAP	1.58 e	11.3 i	16.90 b	0.20 m	1.5 f
	1-MCP	2.99 bc	16.6 f	16.80 b	0.99 h	2.5 d
	1-MCP+MAP	1.16 h	16.3 f	17.00 b	1.04 g	2.8 cd

[z]Values within columns within each attribute followed by the same letter are not significantly different at $P < 0.05$.
TSS: Total soluble solids
TA: Titratable acidity

Table 2. Quality assessment parameters of 'Autumn Giant' plums during storage at 20 °C.

Storage duration (days)	Treatments	Weight loss (%)	Flesh firmness (N)	TSS (%)	TA (%)	Overall quality
0			26.7 a[z]	15.73 c	1.60 a	4.0 a
10 + 7	Control	4.58 fg	14.3 de	18.23 ab	1.11 c	3.7 ab
	MAP	0.97 j	15.8 e	17.44 b	1.16 bc	4.0 a
	1-MCP	3.67 g	22.7 b	16.29 bc	1.27 bc	4.0 a
	1-MCP+MAP	0.89 j	23.2 b	16.43 bc	1.34 b	4.0 a
20 + 7	Control	7.86 e	13.7 de	18.78 ab	0.92 cd	2.8 bc
	MAP	1.69 i	14.6 de	19.12 a	0.98 cd	3.3 b
	1-MCP	6.54 ef	18.8 c	17.26 b	1.19 bc	3.5 b
	1-MCP+MAP	1.56 i	18.3 c	16.94 bc	1.24 bc	3.7 b
30 + 7	Control	10.55 d	9.1 f	19.27 a	0.44 ef	2.0 cd
	MAP	2.54 h	8.8 f	18.92 ab	0.51 e	2.8 bc
	1-MCP	7.89 e	16.4 d	18.54 ab	1.03 cd	3.3 b
	1-MCP+MAP	2.33 h	15.8 d	18.82 ab	1.11 ef	3.5 b
40 + 7	Control	12.23 c	5.7 g	18.29 ab	0.21 fg	1.5 d
	MAP	3.17 gh	4.9 g	18.03 b	0.32 f	2.0 cd
	1-MCP	10.29 d	14.3 c	19.24 a	0.82 d	2.8 bc
	1-MCP+MAP	2.98 gh	13.9 de	19.76 a	0.87 d	3.2 b
50 + 7	Control	15.21 b	2.2 g	16.52 bc	0.18 fg	0.0 f
	MAP	4.12 fg	3.1 h	17.26 b	0.26 f	1.0 e
	1-MCP	12.19 c	13.2 e	18.29 ab	0.67 de	2.2 c
	1-MCP+MAP	3.69 g	12.7 e	18.69 ab	0.75 de	2.7 bc
60 + 7	Control	17.32 a	1.9 i	14.28 c	0.10 g	0.0 f
	MAP	5.18 f	2.2 i	15.32 c	0.12 g	0.8 e
	1-MCP	14.46 bc	11.8 ef	16.34 bc	0.57 e	2.0 cd
	1-MCP+MAP	4.56 fg	12.1 ef	17.16 b	0.68 de	2.3 c

[z] Values within columns within each attribute followed by the same letter are not significantly different at $P < 0.05$.
TSS: Total soluble solids
TA: Titratable acidity

Table 3. Quality assessment parameters of 'Black Beauty' plums during cold storage at 0 °C.

Storage duration (days)	Treatments	Weight loss (%)	Flesh firmness (N)	TSS (%)	TA (%)	Overall quality
0			20.0 a[z]	16.17 g	1.34 a	4.0 a
10	Control	0.68 gh	18.8 b	16.80 cd	1.11 b	4.0 a
	MAP	0.23 i	15.8 e	16.63 d	1.15 b	4.0 a
	1-MCP	0.71 gh	19.8 a	16.25 ef	1.30 a	4.0 a
	1-MCP+MAP	0.24 i	20.1 a	16.30 ef	1.30 a	4.0 a
20	Control	1.38 f	17.8 c	17.67 a	0.80 f	3.1 c
	MAP	0.54 h	15.6 e	17.80 a	0.91 e	3.2 c
	1-MCP	1.40 f	18.1 c	16.33 ef	1.02 c	3.6 b
	1-MCP+MAP	0.56 h	17.9 c	16.40 e	1.09 bc	3.8 ab
30	Control	1.83 d	15.8 g	17.47 ab	0.55 h	2.2 de
	MAP	0.71 gh	13.5 h	17.53 ab	0.59 h	2.4 de
	1-MCP	1.88 d	17.0 d	16.93 c	0.89 e	3.0 c
	1-MCP+MAP	0.67 gh	15.2 f	16.80 cd	0.97 d	3.1 c
40	Control	2.58 c	11.6 k	17.17 b	0.41 j	1.4 f
	MAP	0.87 g	10.9 l	17.47 ab	0.46 i	1.5 f
	1-MCP	2.40 cd	13.7 h	17.03 b	0.83 f	2.7 d
	1-MCP+MAP	0.83 g	12.3 j	17.00 bc	0.91 e	2.8 d
50	Control	3.49 b	10.2 m	16.93 c	0.35 k	0.8 g
	MAP	1.34 f	9.9 m	17.03 b	0.34 k	1.0 g
	1-MCP	3.60 b	12.7 i	16.87 c	0.71 g	2.2 de
	1-MCP+MAP	1.26 fg	12.1 k	16.72 cd	0.80 f	2.4 de
60	Control	4.47 a	8.8 ö	16.65 d	0.24 m	0.6 h
	MAP	1.78 ef	9.5 n	16.88 c	0.29 l	0.9 g
	1-MCP	4.28 ab	11.9 k	16.43 e	0.67 gh	2.1 e
	1-MCP+MAP	1.89 d	12.1 j	16.24 ef	0.77 fg	2.2 de

[z] Values within columns within each attribute followed by the same letter are not significantly different at $P < 0.05$.
TSS: Total soluble solids
TA: Titratable acidity

Table 4. Quality assessment parameters of 'Black Beauty' plums during storage at 20 °C.

Storage duration (days)	Treatments	Weight loss (%)	Flesh firmness (N)	TSS (%)	TA (%)	Overall quality
0			20.0 a[z]	16.17 b	1.34 a	4.0 a
10 + 7	Control	4.92 f	13.5 b	18.20 a	1.01 b	3.0 b
	MAP	1.03 h	14.4 b	17.00 ab	1.08 b	3.6 ab
	1-MCP	4.01 fg	15.8 ab	16.90 ab	1.22 ab	3.5 ab
	1-MCP+MAP	0.99 h	16.0 ab	17.10 ab	1.24 ab	3.9 a
20 + 7	Control	8.23 e	10.2 c	18.80 a	0.64 de	2.0 c
	MAP	1.98 g	11.0 c	18.10 a	0.78 d	2.7 bc
	1-MCP	7.04 ef	14.9 b	17.10 ab	0.96 c	3.1 b
	1-MCP+MAP	1.76 g	14.5 ab	17.40 ab	0.97 c	3.3 ab
30 + 7	Control	11.34 d	6.1 e	17.30 ab	0.25 fg	1.0 de
	MAP	2.96 g	7.4 d	17.90 a	0.39 f	2.0 c
	1-MCP	9.54 e	12.2 bc	17.90 a	0.68 de	2.5 bc
	1-MCP+MAP	2.43 g	11.0 c	18.10 a	0.73 d	2.6 bc
40 + 7	Control	15.20 c	4.0 g	16.20 b	0.11 g	0.0 e
	MAP	5.79 f	5.0 f	16.90 ab	0.14 g	1.0 de
	1-MCP	12.87 d	9.1 cd	17.60 ab	0.49 ef	1.8 c
	1-MCP+MAP	4.55 f	8.1 d	17.90 a	0.54 e	2.0 c
50 + 7	Control	19.21 b	2.0 g	14.10 b	0.05 g	0.0 e
	MAP	6.90 ef	2.0 g	15.30 b	0.09 g	0.6 e
	1-MCP	16.46 c	7.2 d	16.20 b	0.28 fg	1.5 cd
	1-MCP+MAP	5.72 f	6.8 de	16.90 ab	0.32 f	1.7 c
60 + 7	Control	23.21 a	0.0 g	12.08 c	0.03 g	0.0 e
	MAP	8.34 e	0.0 g	14.64 bc	0.07 g	0.4 e
	1-MCP	18.45 bc	6.8 de	15.12 b	0.25 fg	1.3 d
	1-MCP+MAP	6.89 ef	6.6 de	15.78 b	0.29 fg	1.5 cd

[z] Values within columns within each attribute followed by the same letter are not significantly different at $P < 0.05$.
TSS: Total soluble solids
TA: Titratable acidity

Titratable acidity

At harvest, the average titratable acid content was 1.60 (as % malic acid) in 'Autumn Giant' and 1.34% in 'Black Beauty' plums. The malic acid content of the plums decreased continuously in both cultivars and all treatments during the cold and room temperature storage periods. However, malic acid in the plums treated with the 1-MCP and the 1-MCP+MAP combination reduced more slowly than that of the control and MAP-treated plums during the entire storage period. After 2 months of storage, the final amount of malic acid in the plums with the 1-MCP+MAP treatment remained around 1.04% and 0.77% in 'Autumn Giant' and 'Black Beauty' plums, respectively. The malic acid content of the control fruit decreased to 0.18% and 0.24% in the 'Autumn Giant' and 'Black Beauty' plums, respectively (Table 1 and Table 3). A similar pattern was observed during the shelf-life conditions and plums treated with 1-MCP and 1-MCP+MAP maintained higher values of malic acid content compared to the control and MAP-treated fruit during the shelf-life period of 7 days at 20 °C following 60 days of cold storage (Table 2 and Table 4).

Flesh browning

Flesh browning was always higher in the control and MAP treatments compared to the 1-MCP and 1-MCP+MAP treatments during storage at 0 °C (Figure 4). After 7 days of storage at 20 °C following 60 days of cold storage, the incidence of flesh browning in 'Autumn Giant' and 'Black Beauty' plums in the control treatments reached 63.67% and 56.26%, respectively. Flesh browning remained at a relatively low level in the fruit with the 1-MCP+MAP treatment, staying at 24.65% and 18.76% in 'Autumn Giant' and 'Black Beauty' plums, respectively (Figure 5).

Decay development

Both cultivars had decay-free fruit during the entire cold and room temperature storage period.

Overall quality

The overall quality (external appearance and sensory evaluation) of the 1-MCP-treated and 1-MCP+MAP-treated 'Autumn Giant' and 'Black Beauty' plums after 50 and 30 days of cold storage, respectively, was judged good and acceptable; however, the overall

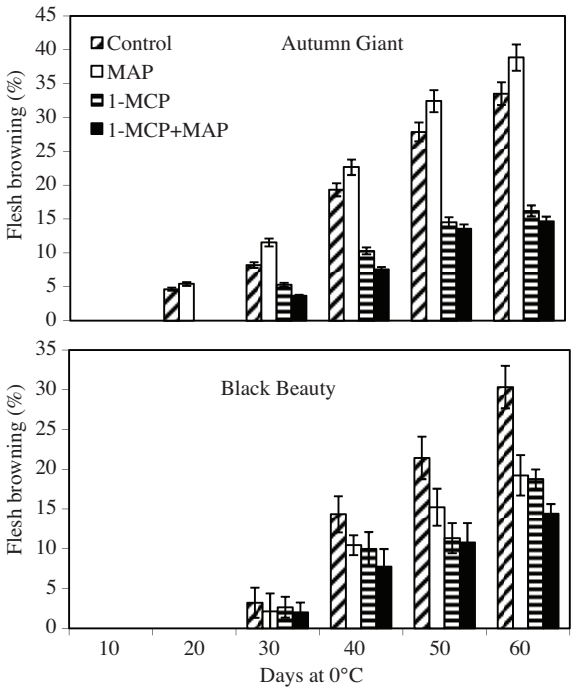

Figure 4. Flesh browning (%) of 'Autumn Giant' and 'Black Beauty' plums during storage at 0 °C. Vertical bars represent standard deviations of means.

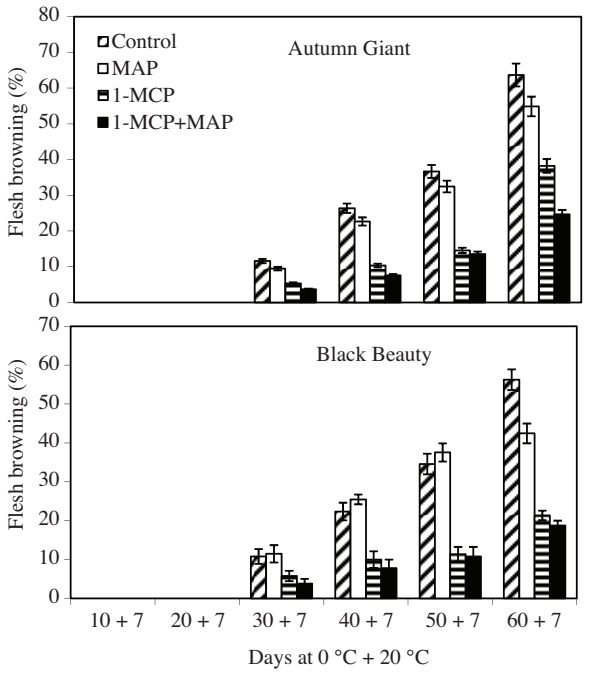

Figure 5. Flesh browning (%) of 'Autumn Giant' and 'Black Beauty' plums during shelf life (20 °C) following cold storage (0 °C). Vertical bars represent standard deviations of means.

quality of the control and MAP-treated fruit was only judged as fair (Table 1 and Table 3).

Discussion

In this study, all fruit samples showed a true climacteric respiration peak at 20 °C during storage, which was also accompanied by increases in ethylene production. However, the 1-MCP and 1-MCP+MAP treatments delayed the timing of the respiration and ethylene peaks compared to the control and the MAP treatment. Similar results on delaying climacteric rise and ethylene peak were also found by different researchers on plum storage (Valero et al. 2004; Khan and Singh 2007).

In our study, a noticeable weight loss was observed in the control and 1-MCP-treated fruit during the entire storage period even under high relative humidity (90%-95%). However, the weight loss of the fruit given the MAP and 1-MCP+MAP treatments was lower than that of the control and 1-MCP-treated fruit. Shriveling due to water loss is a common storage problem in Japanese-type plums, like many fruit and vegetables, due to water loss from the skin. In our study, MAP appears to be the most effective method in reducing weight loss and shriveling. Woods (1990) reported that weight loss from fruit during storage is caused by water exchange between the internal and external atmosphere, and the transpiration rate is accelerated by cellular breakdown.

In our study, the 1-MCP and 1-MCP+MAP combination treatments reduced the incidence of flesh browning and softening during storage at 0 °C. The inhibition of softening was always greater during the entire storage period with the 1-MCP and 1-MCP+MAP treatments. After 60 days of storage, the 'Autumn Giant' and 'Black Beauty' control fruit had softened to 12.4 N and 8.8 N respectively while the 'Autumn Giant' and 'Black Beauty' plums treated with 1-MCP softened to 16.6 N and 11.9 N, respectively. In the same storage period, the flesh firmness of the 'Autumn Giant' and 'Black Beauty' plums treated with 1-MCP+MAP was 16.3 N and 12.1 N, respectively. In our study, even after 60 days of storage, the firmness of the 'Autumn Giant' plums treated with 1-MCP and 1-MCP+MAP was always greater than 15 N. According to Khan and Singh (2007), reduced ethylene production due to using 1-MCP delayed plum fruit softening. Our study confirmed these results. During the first 7 days, the amount of ethylene production in the control and the MAP-treated fruit was always higher than that of the fruit treated with 1-MCP and 1-MCP+MAP. The role of 1-MCP on flesh firmness and softening has been reported by Blankenship and Dole (2003) for numerous fruit and vegetables.

During storage, the quality parameters such as firmness, acidity, flesh browning, and overall quality quickly changed in the control and MAP-treated fruit, while the plums treated with 1-MCP and 1-MCP+MAP showed significantly delayed quality loss as measured by all the parameters except TSS. The TSS content of the control fruit was always higher than that of the treated fruit. Similarly, the 1-MCP and the 1-MCP+MAP combination treatments were equally effective in delaying the loss of firmness, TA, and TSS content at 0 °C. However, at 20 °C, the 1-MCP+MAP combination was found to be the most effective treatment. In our study, there were differences between the 1-MCP-treated and control fruit in terms of TA and TSS. In contrast to our results, Dong et al. (2002) and Menniti et al. (2004a) found that 1-MCP had no effect on soluble solids content or acidity. These results could perhaps be explained by differences in harvest maturity between the studies. Therefore, further studies are required to confirm the exact effect of 1-MCP on plums grown at different locations. Similar to our findings, an absence of decay has been shown in 1-MCP-treated plums, but a 1-MCP application increased the incidence of decay in strawberries (Jiang et al. 2001).

In conclusion, our data have shown that the 1-MCP and 1-MCP+MAP combination treatments have a positive effect on prolonging storage up to 60 days by controlling fruit shrivel and softening and increasing shelf life for the 2 Japanese-type plum cultivars 'Autumn Giant' and 'Black Beauty', and the combined treatment of 1-MCP+MAP maintained the best fruit quality after 0 °C storage plus 20 °C storage.

Acknowledgments

The authors wish to acknowledge the financial support given by the Scientific Research Projects Administration Unit of Akdeniz University.

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