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Effect of potassium permanganate, 1-methylcyclopropene and modified atmosphere packaging on postharvest losses and quality of fresh apricot fruit cv. 'Shahroudi'

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ABSTRACT

Purpose: The main objective of this work was to assess the effectiveness of potassium permanganate ($KMnO_4$), 1-methylcyclopropene (1-MCP) and different packaging on reducing the occurrence of decay and extending apricot fruit shelf life during cold storage. **Research Method:** Fruits were harvested manually from a commercial apricot orchard based on peel color (light-green) and total soluble solids approximately 10.5 °Brix. Fruits were then dipped in $KMnO_4$ (20 or 50 ppm) solution for 3 minutes or exposed to 1-MCP (0 or 1 µL L^{-1}) for 20 h at 20 °C. Thereafter, fruits were placed into polyethylene trays and covered with cellophane films or polyethylene lid (packed with its lid) to create a passive modified atmosphere packaging, whilst the control group remained unpacked and then stored at 0.5 ± 0.5 °C with 80% RH. **Findings:** The results showed that weight loss significantly reduced when apricot fruit covered with cellophane (10.02%) or when packed in PE containers (0.86%) compared to the unpacked control (37.61%), consequently, the firmness value was higher in unwrapped than wrapped fruit due to the high dehydration of unpacked fruit. Application of $KMnO_4$ or 1-MCP had no significant effect on TSS. Interestingly, the shelf life extended 3-fold greater in treated fruit with $KMnO_4$ at 20 ppm or 1-MCP (1 µL L^{-1}) when packed in PE container compared to control unwrapped fruit. **Research limitations:** No significant limitation to report. **Originality/Value:** In general, $KMnO_4$ or 1-MCP treatments had a positive effect on fruit color and taste in packed samples on cellophane or PE container.

INTRODUCTION

Apricot is an important fruit in human nutrition, and can be used as fresh, dried or processed fruit. Apricot fruit has a very short storage life due in part to a high respiration rate and a rapid ripening process. Apricots are usually marketed soon after harvest (Hardenburg et al., 1986) but can be stored for 1-2 weeks at 0 °C and 90-95% RH. Apricot fruit is climacteric (Biale, 1960) and the ripening process is regulated by ethylene, therefore, inhibiting ethylene biosynthesis or action should slow the ripening process (Fan et al., 2000). Volatiles are responsible for the characteristic aroma of fruits. Although ethylene does not have a strong aroma, the major volatile formed in climacteric fruits is ethylene (Knee, 2002), and it is well known that ethylene treated fruit have better taste and color. Hence, it is important to control ethylene action with different postharvest technologies in order to delay ripening and also to have fruit with maximum aroma and taste in retailers.

The effects of ethylene (C_2H_4) in plants have been studied for decades (Abeles et al., 1992) and beneficial and detrimental effects of this chemical in fruits, vegetables, and ornamental plants have been reported previously (Saltveit, 1999). It has been indicated that the fruit quality is high when the ethylene, carbon dioxide and oxygen levels, temperature and humidity in the atmosphere around the produce are carefully maintained at optimum conditions during storage (Saltveit, 1999). There are different ways to control the action of ethylene in plants. The first method to control the action of ethylene in fruit is to prevent the plant from being exposed to biologically active levels of ethylene. Potassium permanganate ($KMnO_4$) is used practically in storage or as sachets in packages to decrease detrimental effects of ethylene and to extend postharvest life of horticultural commodities. In addition, it has been reported that application of $KMnO_4$ solution improved quality and extend the shelf life of apricot fruit (Ibrahim, 2005). The second way is preventing the plant tissue from perceiving the ethylene that is in its surrounding atmosphere or that is being produced by the tissue. Several studies have been shown the usefulness of 1-methylcyclopropene (1-MCP) to protect produce from active and detrimental levels of ethylene by temporarily blocking ethylene receptors (Blankenship & Dole, 2003). 1-MCP is not only an extensively studied ethylene-action inhibitor that has been shown to delay ripening and improve postharvest quality of a wide variety of fruits and vegetables, including pome fruits (Watkins et al., 2000), citrus and tropical fruits (Feng et al., 2000; Kleiber et al., 2018; Porat et al., 1999; Moradinezhad et al., 2008), strawberry (Jiang et al., 2001) and stone fruits (Fan et al., 2002; Liu et al., 2015) including apricots (Dong et al., 2002; De Martino et al., 2006; Fan et al., 2000; Mencarelli et al., 2006; Nguyen et al., 2016; Shi et al., 2013), but also its commercial application in some horticultural products has been done since past decade. The third way is to prevent the plant from responding to the perceived ethylene by controlling exposure to C_2H_4. Hence, controlled or modified atmospheres are used as supplementary to fruit cold storage to limit water loss, delay ripening and suppress diseases. A modified atmosphere (MA) is created when the fruit is sealed in polyethylene (PE) bags with a relatively low permeability to gases. Consequently, as the fruit respires, the O_2 level decreases, and the CO_2 level increases in the bags (Kader, 1994). The atmosphere generated by modified atmosphere packaging (MAP) delays ripening of fruits and extend the shelf life of vegetables, including mango (Kader, 1994), apricot (Pretel et al., 2000) and (Hosseini & Moradinezhad, 2018) mushroom.

Although there are some reports on the positive effects of postharvest treatments and MAP technology on improvement of postharvest quality and shelf life extension of apricot (Botondi et al., 2003; De Martino et al., 2006; Ibrahim, 2005; Koyuncu & Can, 2000;

Mencarelli et al., 2006; Pala et al., 1994; Pretel et al., 2000; Souty et al., 1995; Tzoutzoukou & Bouranis, 1997), however, the review of literature shows the efficacy of 1-MCP on ripening process of fruits is cultivar dependent (Blankenship & Dole, 2003) and also the respiratory behavior of different varieties of apricot (Pretel, 2000) varies in MAP to some extent. In addition, there is no report on combination effects of $KMnO_4$ or 1-MCP application with different kinds of packaging on apricot fruit cv. 'Shahroudi' to prevent detrimental effects of ethylene during postharvest storage. Indeed, our research goal was to combine different treatments in order to develop a strategy to control the action of ethylene that will be effective and reliable in reducing postharvest decay and increasing postharvest life of apricots. The main objectives of this investigation, therefore, were to assess the effectiveness of: (1) MAP in apricot fruit cv. 'Shahroudi' held in cold storage, (2) individual and combined application of $KMnO_4$ or 1-MCP with MAP in quality maintenance and extending fruit shelf life in cold storage.

MATERIALS AND METHODS

Plant material and preparation

About 400 mature fruit (40-50 g) 'Shahroudi' apricots were harvested from a commercial apricot orchard in Birjand, South Khorasan, Iran, early in the morning and immediately transferred to the postharvest laboratory of Department of Horticultural Science late in May. Harvest was according to peel color of apricots (light-green background with slightly yellow color) and the total soluble solid approximately 10.5 °Brix. Fruits with defects were discarded, and uniform fruit were selected and used for the following treatments in triplicate (12 fruit per replicate). Fruits were dipped in $KMnO_4$ (20 or 50 ppm) solution for 3 minutes or exposed to 1-MCP (0 or 1 $\mu L\ L^{-1}$) for 20 h at 20 °C. A stock 1-MCP atmosphere (300 $\mu L\ L^{-1}$) was created from SmartFresh (0.14% 1-MCP; AgroFresh, Inc.) according to Moradinezhad et al. (2008). The concentration of 1-MCP used was based on the empty container volume calculations. Control fruit just washed with distilled water at 20 °C. Following treatments, fruits were allowed to completely air-dried at room temperature 20 ± 1 °C and separated into three groups. Thereafter, four fruits from each treatment were placed into polyethylene trays of 120mm × 90mm × 50mm (80 µm thickness and 500 ml volume) and covered with cellophane films (15 µm thickness) or polyethylene lid (80 µm thickness) to create a passive modified atmosphere packaging, whilst the last group remained unpacked. Fruits were then stored in a cool room at 0.5 ± 0.5 °C and 80% RH. Temperature and relative humidity of storage were recorded using datalogger (Extech Instruments, Model RHT 20, Humidity and Temperature Datalogger, USA) during the experiment. After 4 weeks of storage, fruits were assessed for physicochemical parameters and sensory assessments, while shelf life was evaluatedweekly

Fruit weight loss and firmness measurement

To calculate weight loss, fruit weight was measured just after harvest and at the end of experiment and data was expressed as a percentage, relative to initial value. Fruit firmness was measured using a digital penetrometer (Extech Co., Fruit Hardness Tester, Model FHT 200, USA), fitted with a 3 mm diameter tip and data showed as Newton.

Total soluble solids (TSS) and titratable acidity (TA)

Total soluble solid in the extracted juice of fruits was measured by a hand-held refractometer (Extech Co., RF 10, Brix, 0–32 %, USA) and the results were expressed as °Brix. To measure titratable acidity, 2 ml of extracted fruit juice titrated with 0.1 N sodium hydroxide. Titratable acidity was calculated as a percentage of malic acid by the following formula (1) (Nielsen, 2010):

$$TA\% \text{ (wt/vol)} = N \times V1 \times Eq\ wt / V2 \times 10 \quad (1)$$

Where: N = normality of titrant, usually NaOH (mEq/ml), V1 = volume of titrant (ml),
Eq. wt. = Equivalent weight of predominant acid (mg/mEq), V2 = volume of sample (ml)

Shelf life

Shelf life was based on the physical appearance of the fruit as judged by the retention of freshness, color, and glossy appearance of fruit without any desiccation, pathogenic decay, and chilling injury.

Organoleptic evaluation

Sensorial quality for fruit color and the taste was evaluated by a panel of five assessors at the end of the experiment. The evaluation was done on a scale of 1–5, where score 5 indicated as very good (evident harvest freshness and absence of off-flavor) and score 1 considered as a very bad degree (dislike completely, desiccated fruits with brown tough peel, with low juiciness and becoming dry). Scores of 3 (like moderately with retention of freshness, color, and taste of flesh) and above were considered acceptable for commercial purposes.

Statistical analysis

The experiments were conducted using a completely randomized design, with three replicates. Data from the analytical determinations were subjected to analysis of variance (ANOVA). Mean comparisons were performed using LSD test ($P<0.05$). All analyses were performed with Genstat program (Discovery Edition, Version 7.2, 2008, VSN International, Ltd., UK).

RESULTS AND DISCUSSION

Fruit weight loss and firmness

After 4 weeks of storage, $KMnO_4$ dipping at concentration of 50 ppm and 1-MCP treatment significantly reduced fruit weight loss compared with the control only in unpacked fruit (Table 1). However, weight loss decreased slightly when fruit treated with $KMnO_4$ at 20 ppm. Regardless of the chemical treatments, fruit weight loss significantly affected by different packaging materials. In control fruit, weight loss significantly reduced in apricot fruit packed with cellophane (10.02%) and importantly when packed in PE containers (0.86%) compared to the unpacked fruit (37.61%). Similarly, Muftuoğlu et al. (2012) reported that unpackaged 'Kabaaşı' apricots lost 57% of their initial fresh mass after 42 days of storage at 4 ºC. Similar trends in weight loss were observed in treated fruit with either $KMnO_4$ or 1-MCP (Table 1) as reported by Dong et al. (2002) in 1-MCP-treated 'Canino' apricots.

As expected compare to fruit at harvest, firmness of apricot fruits significantly decreased after 4 weeks of storage at 0.5 °C (data not shown). Regardless of the treatments, firmness was higher in unwrapped fruit after 4 weeks of cold storage. Generally, treated fruit either with $KMnO_4$ or 1-MCP had lower firmness, particularly in packed fruit with cellophane or PE. The lowest firmness (18.8 N) obtained in 1-MCP treated apricot that packed in PE container (Table 1). The higher firmness in unwrapped compared to wrapped fruits was due to dehydration of unwrapped fruits occurs during storage, which is a normal process during storage and previously reported in different fruits (Campañone et al., 2001; Yaman & Bayoundırlı, 2002; Khan & Singh 2008). The effect of 1-MCP on controlling tissue deformation in apricots has been previously observed in whole apricot fruit (Botondi et al., 2003).

Total soluble solids (TSS) and titratable acidity (TA)

Regardless of the treatments, TSS of apricot fruits significantly increased in unwrapped fruit compared to fruit at harvest. Application of $KMnO_4$ or 1-MCP had no significant effect on TSS of juice (Table 1) as reported by Menniti et al. (2004) in 1-MCP-treated plum fruit, while the TSS almost maintained in 1-MCP treated Japanese apricot during 18 days of storage, compared to the control (Shi et al., 2013). However, treated fruit with $KMnO_4$ or 1-MCP that were packed in cellophane or PE container had lower TSS than unwrapped fruit. The control group had significantly higher TSS than the other packaged applications during storage time probably due to water loss from the surface of the unpackaged apricots (Toivonen & Brummell, 2008; Muftuoğlu et al., 2012). There were no clear changes in TA of treated fruit with chemicals. However, higher TA was obtained in $KMnO_4$ treated fruit.

Organoleptic evaluation

The color and taste scores of the control were below the acceptability limit (below 3) at the end of storage time. However, the results showed that the color and taste was higher in control and treated fruits when fruit samples were packed in cellophane or PE container, but not in unwrapped fruit prior to storage at 0.5 °C for 4 weeks (Table 2), which was in agreement with findings of Muftuoğlu et al. (2012). $KMnO_4$ or 1-MCP treatments had a significant and acceptable effect on fruit color and taste. It was in agreement with the findings of Ibrahim (2005) and Dong et al. (2002). However, the fruit color in 1-MCP treated fruit that packed in cellophane was not desirable as judged by panelists.

Table 1. Effects of $KMnO_4$ dipping, 1-MCP application and different packaging on weight loss, firmness and chemical changes of apricot fruit cv. Shahroudi after 4 weeks of cold storage at 0.5 °C

Pre-storage treatments	Packaging	Weight loss (%)	Firmness (N)	TSS (%)	TA (%)
Control	Unwrapped	37.61a*	55.2a	14.73a	3.86c
	Cellophane	10.02c	46.3a	10.27b	4.01c
	PE container	0.86d	37.5b	9.33b	2.82e
$KMnO_4$ 20 ppm	Unwrapped	34.47a	52.8a	13.47a	3.69d
	Cellophane	11.32c	30.3b	10.13b	3.98c
	PE container	0.90d	29.2b	10.15b	6.19a
$KMnO_4$ 50 ppm	Unwrapped	32.69b	54.3a	13.44a	4.39b
	Cellophane	9.68c	41.7a	11.40b	4.57b
	PE container	0.89d	29.2b	10.66b	4.53b
1-MCP 1 $\mu l\, l^{-1}$	Unwrapped	32.78b	42.7a	14.73a	2.28f
	Cellophane	11.48c	29.3b	11.60b	3.36d
	PE container	0.96d	18.8c	10.97b	2.48e

* In each column, different letters represent significant differences at the P <0.05 level according to LSD test (n =12).

Shelf life

Fresh and fresh-cut fruits continue all metabolic processes and are susceptible to quality deterioration and microbial infestation due to increase in enzymatic activities, transpiration and respiration (Caleb et al. 2012). Therefore, it is necessary to find out new strategies to minimize postharvest losses, improve the overall quality attributes and also extend the postharvest life of fresh fruits, especially perishable fruits like apricot to have a great response to demand for fresh fruits in the market. The fruit shelf life significantly increased in treated fruit with $KMnO_4$ or 1-MCP compared to the control after 4 weeks of cold storage (Table 2). Packaging fruit in cellophane or PE container also increased shelf life in both control and treated fruits. The interaction of chemical treatments and packaging was significant. Shelf life was 3-fold greater in treated fruit with $KMnO_4$ at 20 ppm (28 days) or 1-MCP (28.3 days) when packed in PE container, compared to control unwrapped fruit (9 days). In this study, in agreement with findings regarding 1-MCP (Dong, 2002; 2006; Liu et al., 2015) and $KMnO_4$ (Ibrahim, 2005) application in apricot fruit, these chemicals inhibited the ripening process manifested as greatly delayed softening and color change, highly likely due to delaying the onset of climacteric and blocking ethylene production, without any unfavorable effect on fruit quality, although we did not measure ethylene production. In addition, it has been previously reported that a combination of postharvest treatments and modified atmosphere packaging (MAP) increased the shelf life greater in apricot (Muftuoğlu et al. 2012; Moradinezhad & Jahani, 2016) in comparison with the individual application. Similarly, MAP limited the microbial growth and enhanced the quality of strawberries (Garcia et al. 1998), mangoes and pineapples (Martinez-Ferrer et al. 2002) and pomegranates (Caleb et al., 2012; Moradinezhad et al., 2013). Reduced concentrations of O_2 combined with appropriate plastic package extended the shelf life of fresh-cut pears for almost 3 weeks under refrigerated storage (Soliva-Fortuny & Martin-Belloso 2003).

Table 2. Effects of $KMnO_4$ dipping, 1-MCP application and different packaging on sensory assessments and shelf life of apricot fruit cv. Shahroudi after 4 weeks of cold storage at 0.5 °C

Pre-storage Treatments	Packaging	Organoleptic score*		Shelf life (day)
		Color	Taste	
Control	Unwrapped	0.46e	1.60f	9.00f
	Cellophane	2.00d	2.56d	12.3e
	PE container	2.63c	2.86c	17.3d
$KMnO_4$ 20 ppm	Unwrapped	2.0d	2.10e	10.0f
	Cellophane	3.36b	3.16b	19.0d
	PE container	3.66b	3.36a	28.0a
$KMnO_4$ 50 ppm	Unwrapped	2.03d	1.96e	9.6f
	Cellophane	3.35b	3.13b	18.0d
	PE container	3.83a	3.56a	23.0b
1-MCP 1 μ l l^{-1}	Unwrapped	1.86d	1.90e	12.3e
	Cellophane	2.63c	3.10b	21.0c
	PE container	4.03a	3.03b	28.3a

* Score: 1, very bad; 3, acceptable; 5 very good

In each column, different letters represent significant differences at the $P < 0.05$ level according to LSD test (n =12).

CONCLUSION

Changes in physical and chemical parameters indicated that ripening continued in control and chemical treated fruits during storage at 0.5 °C, however, modified atmosphere packaging slowed down this process. The findings of the present study have shown that MAP quite effectively reduced losses of whole apricots while unpackaged fruit lost approximately 38% of their initial fresh weight within 4 weeks of cold storage. Modified atmosphere packaging using cellophane film or polyethylene lid preserved the physico-chemical characteristics and sensory quality of apricots for up to 28 days of cold storage. However, the shelf life of unpackaged apricots was less than 10 days due to a significant change in physical and sensory properties. Therefore, in order to maintain the quality, reduce postharvest losses, and to extend the shelf life of apricot fruits (cv. Shahroudi) during cold storage, using passive MAP condition in combination with chemicals would be useful.

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CONFLICT OF INTEREST

The authors have no conflict of interest to report.

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تاثیر پرمنگنات پتاسیم، ا- متیل سیکلوپروپان و بسته بندی با اتمسفر تغییر یافته بر ضایعات پس از برداشت و کیفیت میوه زردآلو تازه رقم شاهرودی

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چکیده:

هدف اصلی از انجام این کار ارزیابی تاثیر پرمنگنات پتاسیم، ۱- متیل سیکلوپروپان و بسته بندی مختلف در کاهش بروز فساد و افزایش ماندگاری زردآلو در طی دوره انبار سرد بود. میوه‌ها به صورت دستی از یک باغ تجاری زردآلو بر اساس رنگ پوست (سبز روشن) و مواد جامد محلول تقریبا ۱۰/۵ درجه بریکس برداشت شدند. سپس میوه‌ها در محلول پرمنگنات پتاسیم (۲۰ یا ۵۰ پی‌پی‌ام) به مدت ۳ دقیقه یا در معرض ۱- متیل سیکلوپروپان (صفر یا ۱ میکرولیتر در لیتر) برای مدت ۲۰ ساعت در دمای ۲۰ درجه سانتی گراد تیمار شدند. پس از آن، میوه‌ها درون سینی‌های پلی اتیلنی قرار داده شدند و با پوشش سولفان پوشانده شدند یا با درب پلی اتیلنی بسته بندی شدند تا شرایط بسته بندی تغییر یافته منفعل ایجاد شود، در حالی که گروه شاهد بدون بسته بندی بود و سپس در دمای ۰/۵ ± ۰/۵ درجه سانتی‌گراد با ۸۰ درصد رطوبت نسبی نگهداری شدند. نتایج نشان داد افت وزن به طور معنی‌داری کاهش یافت هنگامی که میوه زردآلو با سولفان پوشش‌دار شد (۱۰/۰۲ درصد) یا وقتی بسته بندی در ظرف درب‌دار پلی اتیلنی شد (۰/۸۶ درصد) در مقایسه با شاهد بدون بسته بندی (۳۷/۶۱ درصد)، در نتیجه مقدار استحکام در میوه بسته‌بندی نشده بیشتر از بسته‌بندی شده بود. کاربرد پرمنگنات پتاسیم یا ۱- متیل سیکلوپروپان اثر معنی‌داری در مواد جامد محلول نداشت. جالب اینکه، ماندگاری میوه به میزان سه برابر بیشتر در میوه‌های تیمار شده با پرمنگنات پتاسیم ۲۰ پی‌پی‌ام یا ۱- متیل سیکلوپروپان (۱ میکرولیتر در لیتر) هنگامی که در ظرف پلی اتیلنی درب دار بسته‌بندی شدند نسبت به بدون بسته‌بندی بود. به‌طور کلی، تیمارهای پرمنگنات پتاسیم یا ۱- متیل سیکلوپروپان تاثیر مثبتی در رنگ و طعم نمونه‌هایی که در سولفان یا پلی‌اتیلن درب‌دار بسته‌بندی شده بودند داشت.

کلمات کلیدی: پرمنگنات پتاسیم، ۱- متیل سیکلوپروپان، بسته‌بندی با اتمسفر بهبود یافته، حسی چشایی، زردآلو