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IMPROVING THE STORAGE QUALITY OF POMEGRANATE FRUIT BY COMBINING MODIFIED ATMOSPHERE PACKAGING AND *ORIGANUM SYRIACUM* VOLATILE ESSENTIAL OIL

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Abstract

In the current study, the combined impact of modified atmosphere packaging (MAP) and *Origanum syriacum* volatile essential oil (VEO) on the ability of pomegranate fruits to be stored was examined. Control, MAP bags, MAP bags with 0.50 mL VEO, and MAP bags with 1.00 mL VEO were the four treatments that were studied. The weight loss in the MAP application was significantly less than in the control group. Fruit quality is improved and storage life is extended by the use of MAP bags. Due to VEO's antibacterial and antioxidant qualities, weight loss in the MAP bags was further decreased by its administration. The treatments did not have a substantial impact on the ascorbic acid content. The outcomes additionally demonstrated that the application of both MAP and VEO treatments might postpone the decrease of soluble solids concentration and titratable acidity, which is essential for preserving the fruit's flavor. The study also showed that the fruits packed in MAP bags, either with or without VEO, had a considerably lower decay incidence than the control fruits. However, the addition of VEO to the MAP bags further reduced the decay incidence of the fruits, which highlights the importance of the combination of VEO with MAP bags.

Key words: Postharvest, Weight loss, Chilling injury, Senescence, Marketability.

Introduction

The pomegranate (*Punica granatum* L.) plant, which is mentioned in Dioscorides, Hippocrates, the Bible, and the Quran, is believed to have been cultivated for the first time around 4.000 BC. Pomegranate fruits have significant potential positive health effects, including heart protective activity, hyperglycemia, blood pressure regulation, an anticancer effect, an anti-inflammatory effect, a prebiotic effect, and an improvement in cognitive function, according to recent scientific literature (Giménez-Bastida *et al*., 2021). This scientific confirmation of its health benefits has significantly increased the consumption of pomegranate fruits throughout the world. Pomegranate fruit, which can be grown in many tropical and subtropical regions of the world, do not ripen off the tree after harvest. Its harvesting normally starts in 3rd and 8th months in the southern and northern hemispheres, respectively. Since these times are typically six months apart, postharvest storage is required to satisfy the year-round demand for pomegranate fruit (Kahramanolu & Usanmaz, 2016). However, pomegranate fruits are quite sensitive to storage, and extended periods of time and inappropriate conditions lead to significant weight and quality losses (Elyatem & Kader, 1984). Furthermore, significant issues with pomegranate fruit preservation include fruit decay, chilling injury, and changes in other quality parameters (i.e. soluble solids concentration, phenolic contents, ascorbic acid and etc.) (Kahramanoğlu *et al*., 2018).

Pesticides are essential for keeping pests, diseases and weeds under control during crop cultivation, as well as for maintaining the storability of fresh horticultural crops. For the quality preservation of fresh fruit during storage, fungicides are crucial. However, misuse or overuse of pesticides can pose serious risks to human and environmental health (Coulibaly, 2011). Controversial public discussions over pesticide residues in fresh produce have been held around the world among consumers, social media and scientists (Koch, 2017). Because of the potential risk to human health, pesticide use in agriculture is becoming less acceptable globally (Sharma *et al*., 2009). As a result, finding alternatives to agrochemicals has been a key focus for scientists worldwide.

Previous research demonstrated the existence of several eco-friendly alternatives in postharvest storage of pomegranate fruits, including hot water treatment (Moradi *et al*., 2022), putrescine application (Fawole *et al*., 2020), ozone treatment (Koyuncu *et al*., 2023), ultraviolet light application (Maghoumi *et al*., 2013), chitosan treatment (Candir *et al*., 2018), use of essential oils (Kahramanoğlu *et al*., 2018), propolis application (Kahramanoğlu *et al*., 2018), nano-enabled applications (Helmy *et al*., 2020) and modified atmosphere packaging (Selcuk & Erkan, 2014; Kahramanoğlu *et al*., 2018). Among these techniques, modified atmosphere packaging (MAP) covers an important share which makes it possible to reduce respiration of the fresh products which results with the reduced weight loss, prevented chilling injury, protected quality and reduced microbial growth (Day, 2001; Kahramanoğlu *et al*., 2018). The use of plant and animal derived biomaterials as edible coatings, edible films or vapor applications for the preservation of fresh produce's storage quality is among the main focuses of current postharvest studies (Wan *et al*., 2021).

Recently, scientific studies and industrial applications are focusing more on the synergism impact of different applications. This also helps to prevent the occurrence of resistance in the diseases. In two recent studies, it was suggested that the combination of *Cistus creticus* L. leaf extracts and hot water dipping has higher impact on the preservation of Valencia oranges (Kahramanoğlu *et al*., 2020), while similar findings were noted for the combination of hot water dipping and *Scolymus maculatus* L. plant extracts (Gao *et al*., 2021). The volatile essential oils of *Origanum onites* L. and *Ziziphora clinopodioides* L. had higher significant effects on the prevention of *Botrytis cinerea* infection and preservation of the strawberry quality, according to a different study by Kahramanolu *et al*., (2022). Therefore, it was suggested that combining volatile essential oils with packing materials would produce superior results to single applications and aid in the development of commercial solutions for the handling of fruits after harvest. In light of this information, the current study set out to evaluate the combined effectiveness of packaging materials for changed atmospheres and Origanum syriacum volatile essential oil.

Material and Methods

Fruit samples: cv. Wonderful fruits of pomegranate were utilized in current work. The fruit samples were hand-harvested on 28th of October 2022 at horticultural maturity (SSC:TA 17.80:1.72) from an 13-year-old plantation found in Yayla town in Northern Cyprus. The fruit samples were quickly transported in a ventilated vehicle to the Horticulture Laboratory of the European University of Lefke. After being categorised in accordance with EU regulations, only fruits in the "extra" category with a size of "7-8" were employed in the current study (Anon., 2019).

***Origanum syriacum* essential oils:** *Origanum syriacum* plants were cultivated in Hatay, Türkiye. Second year old plants were harvested in full flowering (June) period in 2021. Harvested plants were air dried in shade and then dried material were steam distilled to obtain essential oils. The volatile essential oil (VEO) was kept at 4°C until the analysis.

The method of Eliuz and Bahadırlı (2022) was followed for the determination of the essential oil composition of the *Origanum syriacum* essential oils.

Modified atmosphere packaging (MAP) materials: The MAP bags of current study, which were produced from low-density polyethylene film, were purchased from Dekatrend Ltd. Company which was placed in Bursa, Turkey. The brand name of the MAP bags is Trendlife.

Treatments: A total of four treatments were tested in present study, namely i) control (no treatment rather than cleaning), ii) packing in MAP bags, iii) packing in MAP bags + 0.50 mL *O. syriacum* VEO and iv) packing in MAP bags + 1.00 mL *O. syriacum* VEO. The application of the VEO was performed by soaking the given amounts onto a filter paper (20 mm^2) and placing it onto the inner part of the bags. To prevent the loss of volatile compounds, firstly the fruits were put into bags, then the filter papers and finally the opening of the bags were quickly closed with rubber tires. Each of the fruits were subjected to the cleaning operation (as in control) by dipping them in pure water for 30 sec and drying them with a packing line dryer. Each treatment had 25 replications, with an average of 8 fruits per replication. Every fruit from every treatment was put into corrugated cartons (40 30 12 cm) and kept in storage for 150 days at 6.5-1°C and 90-95% relative humidity. Prior to the experiment, each fruit was given a number, and its original weight was measured and noted. During this 150 days of storage, 5 replications were taken out from the storage rooms with 30-days interval and following quality characteristics were measured. 5 fruits from each replication were used for the measurement of weight loss and chilling injury, 2 fruits from each replication for ascorbic acid, soluble solids concentration and titreatable acidity measurements, and 1 fruit from each replication was used for the determination of total phenolic contents. The decay incidence was evaluated for all (8) fruits of each of the 5 replications.

Data collection: A digital scale (sensitive to 0.01 g) was used to calculate each fruit's new weight as soon as it was exposed to ambient conditions. This allowed for the calculation of fruit weight loss using the fruits' initial weights, which were determined prior to storage. The decay incidence (%) of each treatment was then determined by counting and reporting the number of rotting fruits for each replication. The grades for each fruit's chilling injury were then given, ranging from 0 to 3 (Kahramanolu *et al*., 2018). The results were as follows: 0, none; 1, slight (25%); 2, moderate (26-50%); and 3, severe (>51%). Fruits were then sliced in half, and the juice was manually squeezed to obtain additional quality evaluations. Then, each fruit's soluble solids content (SSC) was calculated using a hand refractometer. Then it was calculated how much citric acid was titratable acidity (TA - g/100 g): 100 ml of distilled water were used to dilute the 10 ml samples. After being diluted, the samples were titrated with 0.1 NaOH until the pH reached 8.10. The computations were then performed using the following formula:

$$\mathrm{TA}\ (\mathrm{g}\ /\ 100\ \text{citric acid}) = \left(\frac{(\text{mL of NaOH used})\mathrm{x}\ 0.0064}{\text{mL of sample used}}\right)\mathrm{x}100$$

The total phenolic contents were then determined by following the method of Albayrak *et al*., (2010) according to the Folin-Ciocaltue assay (Slinkard & Singleton, 1977). This procedure involved weighing 0.5 g of the isolation solution from each replication, adding 30 ml of distilled water, and adding 2.5 mL of Folin-Ciocalte. Samples received 10 mL of Na2CO3 and were maintained at room temperature in the dark for two hours. At 765 nm, the absorbance of the samples was measured in comparison to a blank sample devoid of fruit juice. The results were represented as mg/100 g of fresh weight for the gallic acid equivalent (GAE) as determined by the calibration curve.

Statistical analysis

The experiment's data were totaled, and averages and standard deviations were calculated using Microsoft Excel. After that, colorful figures were created using the data summary for a better data presentation. The raw data were then subjected to no analysis of variance (ANOVA), and Tukey's (HSD) multiple range test was used at P0.05 to accomplish the statistical comparison of the treatments and separation of means. The SPSS 22.0 statistics package programme was used to perform all of these statistical calculations.

Results

Chemical Composition of the *Origanum syriacum* volatile essential: The chemical composition of the *Origanum syriacum* volatile essential oil has been analyzed and found to consist of 18 different chemical compounds (Table 1). According to the study, the three most abundant compounds in the essential oil are carvacrol (70.54%), p-cymene (9.26%), and Ɣ-terpinene (9.06%). Carvacrol is a monoterpenoid phenolic compound that is known to have high antimicrobial, antioxidant, and anticancer activities (El Gendy *et al*., 2015). It is present in different essential oils, including *Origanum vulgare* L (oregano), *Thymus vulgaris* L. (thyme), *Citrus aurantium* L. (wild bergamot), and *Lepidium flavum* L. (pepperwort). These plants are widely used in traditional medicine to treat a variety of ailments because of their well-known therapeutic properties. The study found that carvacrol is the most common compound in essential oils, and that its free hydroxyl group, hydrophobicity, and phenol moiety account for its potent antibacterial activity. P-cymene has antibacterial, antifungal, and antioxidant properties, whereas -terpinene has antibacterial, antifungal, and insecticidal properties.

The findings of current work have been found to be consistent with previous analyses of the chemical composition of essential oil from *O. syriacum*. Carvacrol, which accounts for 60.8% of the essential oil of *O. syriacum*, is the most abundant component, according to a study by Al Hanifi *et al*., (2016). The volatile essential oil of *O. syriacum* leaves has a total of 18 different chemical constituents, with carvacrol, p-cymene, and -terpinene being the most common. Carvacrol, which makes up 70.54% of the oil, is widely known for its antibacterial, antioxidant, and anticancer qualities. Carvacrol can be detected in substantial proportions in the volatile essential oil of *O. syriacum*, according to past studies on the chemical composition of the oil. The findings of this study imply that the volatile essential oil of *O. syriacum* may have potential therapeutic uses because of its high carvacrol concentration. To better understand the pharmacological effects of *O. syriacum* volatile essential oil, more research is nonetheless required.

Table 1. List of the chemical components of the *Origanum syriacum* volatile essential oil.

No.	RT	Library ID	CAS	Area (%)
1.	5.900	*α*-Thujene	002867-05-2	0.77
2.	6.084	*α*-Pinene	000080-56-8	0.64
3.	6.505	Camphene	000079-92-5	0.09
4.	7.342	*β*-Pinene	018172-67-3	0.12
5.	7.562	*t*-Butylethylideneamine	007020-80-6	0.19
6.	7.793	*β*-Myrcene	000123-35-3	1.31
7.	8.043	3-Octanol	000589-98-0	0.20
8.	8.233	*α*-Phellandrene	000099-83-2	0.22
9.	8.405	*δ*-3-Carene	013466-78-9	0.09
10.	8.603	*α*-Terpinene	000099-86-5	1.79
11.	8.939	*p*-Cymene	000099-87-6	9.21
12.	10.114	Ɣ-Terpinene	000099-85-4	9.06
13.	10.435	4-Thujanol	015826-82-1	0.90
14.	14.494	4-Terpineol	000562-74-3	0.34
15.	17.331	Thymoquinone	000490-91-5	0.13
16.	18.946	Thymol	000089-83-8	3.77
17.	19.456	Carvacrol	000499-75-2	70.54
18.	22.922	Caryophyllene	000087-44-5	0.57

Impacts on weight loss: Loss of weight is a crucial factor that influences the postharvest quality of pomegranate fruits. By altering the form, browning the skin, and hardening the husk of the fruits, weight loss also lessens the appeal of pomegranate fruits (Caleb *et al*., 2012). In this study, the effect of modified atmosphere packaging (MAP) combined with different concentrations of *O. syriacum* volatile essential oil (VEO) on the weight loss of pomegranate fruits during storage was investigated. The findings revealed that after 150 days of storage, the fruits in the control group had lost the most weight, with a final weight loss of 24.9% (Fig. 1). Al-Mughrabi *et al*., (1995) showed 32% weight loss in pomegranate fruits at 8 weeks when fruits were stored at 22°C in a different study under different study settings. With a total weight loss of just 7.8%, the MAP treatment dramatically lessened the weight loss of the fruits when compared to the control group. The use of MAP bags to preserve fruits after harvest has significant benefits for preserving fruit quality, as shown by numerous studies. One of the key benefits of employing MAP bags is the drop in oxygen levels inside the bag, which slows down fruit respiration and delays ripening and senescence (Han, 2014; Fang & Wakisaka, 2021). According to the findings of our study, this can result in increased fruit quality and a longer shelf life.

Furthermore, MAP bags can aid in maintaining a greater relative humidity inside the bag, which can stop fruit shrinking and water loss. Dehydration can result in texture changes, loss of flavour and nutritional value, and other negative effects in fruits with a high-water content, like pomegranates (Selcuk & Erkan, 2016). Additionally, the usage of MAP bags can lessen the development of bacteria and fungi, which can cause fruit to rot and decompose. This may result in less post-harvest losses and higher fruit quality overall (Fang & Wakisaka, 2021). The use of MAP bags may therefore be a successful post-harvest management method for maintaining the quality of pomegranate fruits throughout storage, according to our findings. Reduced oxygen levels, higher relative humidity, and decreased microbial development are to blame for the decreased weight loss and maintaining of overall quality in fruits stored in MAP bags. These results support earlier research (Kader *et al*., 1994; Selcuk & Erkan, 2016; Kahramanolu *et al*., 2018) that shown the advantages of employing MAP bags for fruit postharvest storage.

The addition of VEO further decreased the weight loss of the fruits in the MAP bags, with the ultimate weight losses for MAP+VEO and MAP+VEO2, respectively, ranging from 7.2% to 7.7%. Due to VEO's antibacterial and antioxidant capabilities, weight loss was significantly reduced in the MAP+VEO and MAP+VEO2 therapies. According to several research (Burt, 2004; Sharma *et al*., 2017), certain bacteria that cause postharvest degradation in fruits and vegetables are resistant to essential oils' antimicrobial activities. In addition, VEO has been reported to have antioxidant properties that can prevent oxidative damage to the cell membranes of fruits (Chaovanalikit & Wrolstad, 2004). In order to maintain the quality of pomegranate fruits during storage, MAP and VEO together may have a synergistic impact. As a result, applying MAP along with *O. syriacum* volatile essential oil may be a useful way to prevent weight loss of pomegranate fruits.

Impacts on ascorbic acid content: The impacts of MAP and the volatile essential oil (VEO) of *O. syriacum* during storage of pomegranate fruits at 6.5-1°C and 90-95 percent relative humidity for 150 days is depicted in (Fig. 2). The amount of ascorbic acid in pomegranate fruits rapidly decreased under all storage conditions. According to Miguel *et al*., (2010), ascorbic acid concentration is thought to decline while fruit is stored. The reduction was less pronounced in the fruits treated with MAP and MAP combined with VEO. The ascorbic acid concentration of the control fruits had declined by 36.7% at the end of the 150-day storage period, whereas the MAP, MAP+VEO, and MAP+VEO2-treated fruits had decreased by 20.8%, 14.2%, and 14.2%, respectively. An essential component of the human diet, ascorbic acid is a significant antioxidant (Fenech *et al*., 2019). The findings of the current study support earlier research on pomegranate and other fruits (Moradi *et al*., 2022; Lotfi *et al*., 2022; Shi *et al*., 2022) by showing that the ascorbic acid concentration of pomegranate fruits declines after storage. Ascorbic acid may degrade for a variety of reasons, including respiration rate, enzymatic processes, and oxidation (Lotfi *et al*., 2022).

Fruits and vegetables have been preserved using the modified atmosphere packaging (MAP) method for a long time (Sandhya, 2010; Belay *et al*., 2016). Ascorbic acid breakdown in pomegranate fruits during storage may be slowed by employing MAP, either alone or in combination with *O. syriacum* volatile essential oil (VEO), according to the results of the current study. This might be because MAP can slow down fruit respiration, which in turn slows down ascorbic acid breakdown (Sandhya, 2010; Li *et al*., 2015; Yang *et al*., 2022). Due to its antioxidant qualities, the usage of VEO may also have helped to preserve ascorbic acid (Huang *et al*., 2020; Perumal *et al*., 2021). Results suggested that the ascorbic acid content of fruits might be effectively preserved during storage by using MAP both alone and in conjunction with *O. syriacum* volatile essential oil (VEO).

Impacts on flavor (SSC & TA): The effect of *O. syriacum* VEO and MAP on the storage quality of pomegranate fruits was investigated. The soluble solids concentration (%), which represents the sugar content and sweetness of the fruits, and the titratable acidity (g 100 g^{-1} malic acid), which represents the acidity of the fruits, were measured during 150 days of storage. The results are presented in Fig. 3a and 3b, respectively. As shown in Fig. 1a, the soluble solids concentration of all treatments decreased during the storage period. However, the treatments containing VEO (MAP+VEO and MAP+VEO2) showed a slower decrease in soluble solids concentration compared to the control and MAP treatments. On Day 150, the soluble solids concentration of the control, MAP, MAP+VEO, and MAP+VEO2 treatments were 15.50%, 16.70%, 16.90%, and 16.75%, respectively. These results suggest that the application of VEO in combination with MAP can delay the decrease in soluble solids concentration. Fig. 3b shows that the titratable acidity of all treatments also decreased during the storage period. Similar to the results for soluble solids concentration, the treatments containing VEO (MAP+VEO and MAP+VEO2) showed a slower decrease in titratable acidity compared to the control and MAP treatments. On Day 150, the titratable acidity of the control, MAP, MAP+VEO, and MAP+VEO2 treatments were 1.10 g 100 g^{-1} malic acid, 1.29 g 100 g^{-1} malic acid, 1.31 g 100 g^{-1} malic acid, and 1.30 g 100 g^{-1} malic acid, respectively. These results indicate that the application of VEO in combination with MAP can delay the decrease in titratable acidity, which is important for maintaining the acidity of pomegranate fruits during storage.

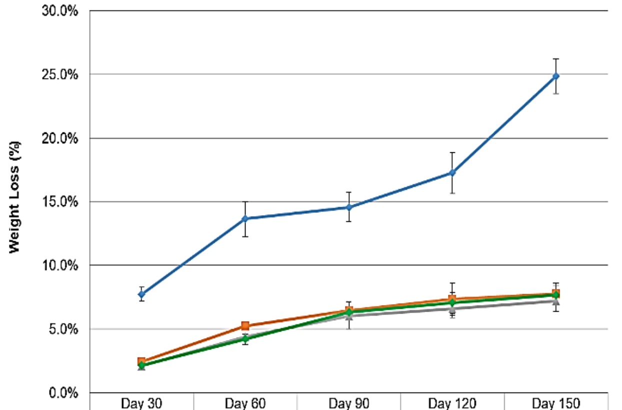
The flavor of pomegranate fruits is mostly influenced by the ratio of soluble solids concentration to titratable acidity. The overall flavor and customer acceptance are influenced by the sweetness and acidity ratio. The findings show that this equilibrium, which is essential for maintaining the quality of pomegranate fruits during long-term storage, may be preserved with the help of the combination of MAP and VEO therapies. Due to the antibacterial and antioxidant qualities of VEO, the drop in soluble solids concentration and titratable acidity in the VEO+MAP treatments were delayed. Several microorganisms, including bacteria and fungi, which can cause fruit spoilage and decay during storage, are known to be resistant to antimicrobial activity by other species of *Origanum*, such as *O. vulgare* VEO (Esmaeili *et al*., 2021). Additionally, the fruits may be shielded by VEO's antioxidant qualities from oxidative damage, a typical reason for quality loss during storage (Coccimiglio *et al*., 2016). Because of this, adding *O. syriacum* volatile essential oil to modified environment packaging can prevent the soluble solids concentration and titratable acidity of pomegranate fruits from declining over time.

These findings imply that the combination treatment can help preserve the flavor and general quality of pomegranate fruits, which is crucial for the product's marketability and acceptability by consumers.

Impacts on decay incidence: According to the study's findings, all treatments experienced an increase in decay incidence as storage duration went up (Fig. 4). According to Maclean *et al*., (2011), *Botrytis cinerea*'s grey mold is the main culprit for the degradation on pomegranate fruits. In the field, this fungus infects the fruit's blossoms and/or crowns. It starts to grow from the crown and then spreads to the rest of the fruit. During storage, it can also spread quickly to surrounding fruits (Caleb *et al*., 2012). However, compared to the control fruits, the decay incidence was considerably lower in the fruits packed in MAP bags, whether with or without VEO (p 0.05). Day 30 saw a 2.5% decay incidence in the control group compared to a 0.0% decay incidence in the MAP and MAP+VEO treatments. On day 150, the degradation incidence in the control group peaked at 30.0%, while it stayed at 7.5% and 5.0%, respectively, in the MAP and MAP+VEO2 therapies. Additionally, there was no discernible improvement in decay incidence between the applications of 0.50 mL and 1.00 mL of VEO.

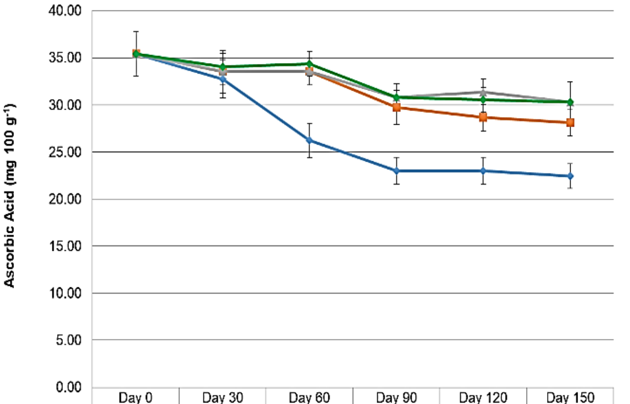
The results of the present study indicated that the use of MAP bags alone was effective in reducing decay incidence during the storage of pomegranate fruits. This finding is consistent with previous studies, which reported that MAP bags can reduce the decay incidence of pomegranate fruits by limiting the respiration rate and inhibiting microbial growth (Kader *et al*., 1994; Selcuk & Erkan, 2016; Kahramanoğlu *et al*., 2018). Similar to this, Artes *et al*., (2000) and Nanda *et al*., (2001) observed that fruits preserved in MAP significantly reduced the formation of grey mold. The findings also demonstrated that adding VEO to the MAP bags substantially decreased fruit deterioration incidence, especially in the later stages of storage. According to other studies (Leyva-López *et al*., 2017; Mohamad *et al*., 2021; Pandey *et al*., 2022; Perumal *et al*., 2022) and findings, VEOs have antibacterial and antioxidant capabilities that can improve fruit quality and lengthen their shelf life. The mechanism of action of VEOs in reducing decay incidence is related to their volatile compounds, which can inhibit the growth of pathogenic microorganisms by damaging their cell walls and membranes, and by disrupting their metabolic processes. In addition, VEOs can scavenge free radicals and prevent lipid oxidation, which are major causes of fruit decay and deterioration (Mohamad *et al*., 2021; Wan *et al*., 2021). Therefore, the combination of MAP bags with *O. syriacum* volatile essential oil can effectively reduce the decay incidence of pomegranate fruits during long-term storage. The use of MAP bags alone is also effective in reducing decay incidence, but the addition of VEOs can further enhance the storage quality of the fruits.

Impacts on chilling injury: The application of *O. syriacum* volatile essential oil (VEO) in conjunction with modified atmosphere packaging (MAP) materials has a substantial impact on the incidence of chilling injury of pomegranate fruits during storage, according to the data obtained (see Fig. 5). After 150 days of storage, the control treatment's incidence of chilling injury peaked at 86.67%. The control had the highest incidence of chilling injury throughout the storage period, but the MAP and MAP+VEO treatments had significantly lower incidences than the control. The incidence of chilling injury for the MAP therapy was 16.0% after 150 days of storage, compared to 10.67% for the MAP+VEO and MAP+VEO2 treatments. After being stored for two months, terrifying injury signs started to surface. This outcome is consistent with the findings of Elyatem & Kader (1984). The observed decline in the incidence of chilling injuries can be attributed to the combined effects of MAP and VEO. In order to preserve the freshness of fruits, MAP lowers the oxygen content inside the packing. This lowers the respiratory rate and delays senescence and deterioration processes (Kader, 2002). The findings of the current investigation, which showed that the control treatment had a considerably higher frequency of chilling injury than the MAP treatment, confirm this impact. Similar to this, MAP lessens the chilling harm to pomegranates, according to Nerya *et al*., (2006).



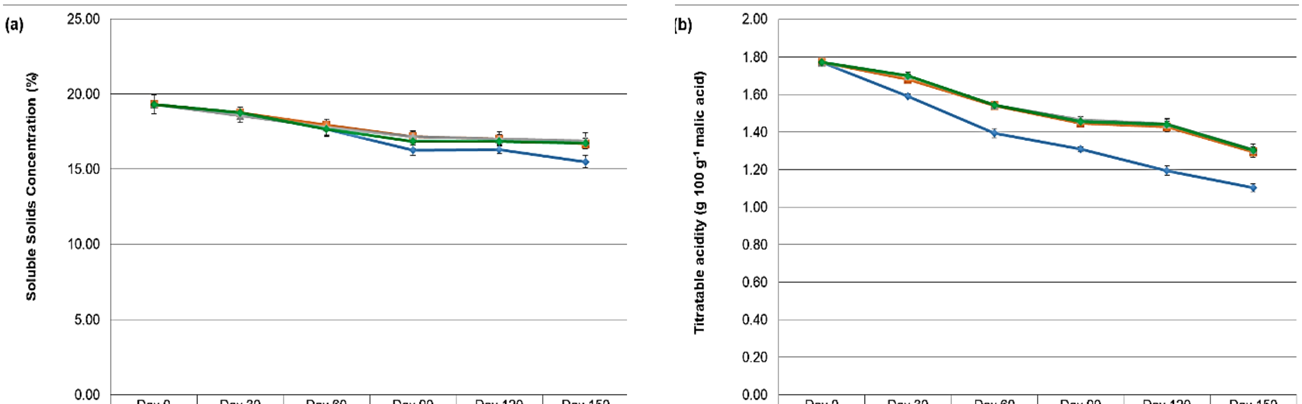
	Day 30	Day 60	Day 90	Day 120	Day 150
Control	7.7% a	13.7% a	14.6% a	17.3% a	24.9% a
MAP	2.4% b	5.2% b	6.5% b	7.4% b	7.8% b
MAP+VEO	2.1% c	4.4% c	6.1% b	6.6% b	7.2% b
MAP+VEO2	2.2% c	4.2% c	6.3% b	7.1% b	7.7% b

Fig. 1. Impacts of MAP and combination of MAP with *O. syriacum* volatile essential oil on the weight loss (%) in pomegranate fruits during 150 days of storage.



	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	35.41 a	32.70 a	26.22 b	22.97 b	22.97 c	22.43 c
MAP	35.41 a	33.51 a	33.51 a	29.73 a	28.65 b	28.11 b
MAP+VEO	35.41 a	33.51 a	33.51 a	30.81 a	31.35 a	30.27 a
MAP+VEO2	35.41 a	34.05 a	34.32 a	30.81 a	30.54 a	30.27 a

Fig. 2. Impacts of MAP and combination of MAP with *O. syriacum* volatile essential oil on the ascorbic acid content in pomegranate fruits during 150 days of storage.



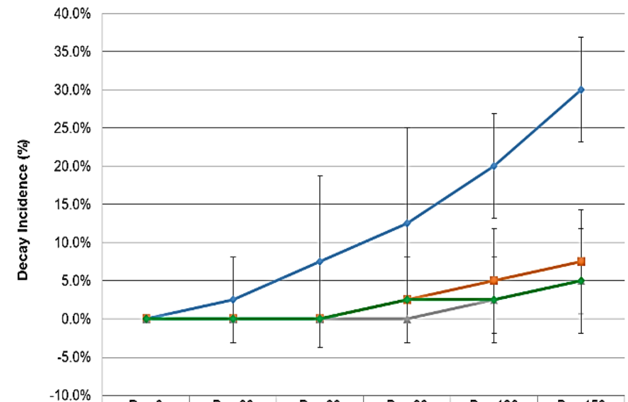
(a)

	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	19.30 a	18.75 a	17.65 a	16.25 b	16.30 b	15.50 b
MAP	19.30 a	18.75 a	17.95 a	17.15 a	17.00 a	16.70 a
MAP+VEO	19.30 a	18.55 a	17.80 a	17.15 a	17.00 a	16.90 a
MAP+VEO2	19.30 a	18.75 a	17.65 a	16.85 a	16.85 a	16.75 a

(b)

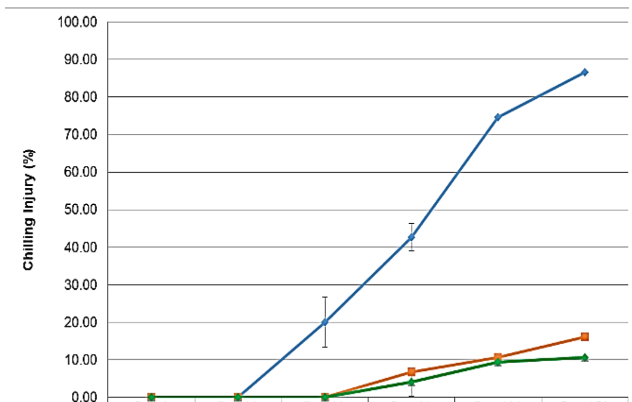
	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	1.77 a	1.59 b	1.39 b	1.31 b	1.19 b	1.10 b
MAP	1.77 a	1.68 a	1.54 a	1.45 a	1.43 a	1.29 a
MAP+VEO	1.77 a	1.70 a	1.54 a	1.47 a	1.44 a	1.31 a
MAP+VEO2	1.77 a	1.70 a	1.54 a	1.46 a	1.44 a	1.30 a

Fig. 3. Effects of MAP and MAP combined with *O. syriacum* volatile essential oil (VEO) on the a) soluble solids content and the b) titratable acidity of pomegranate fruits during the course of 150 days of storage.



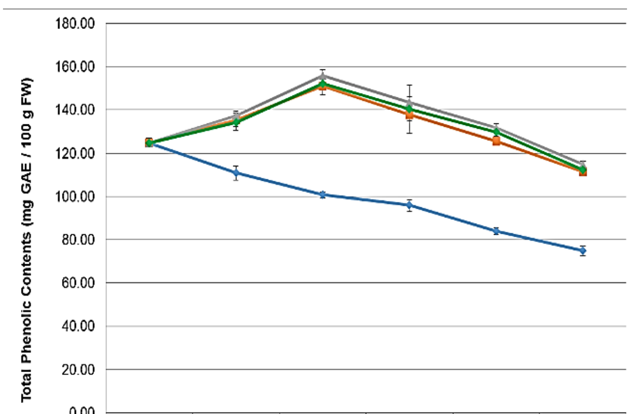
	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	0.0% a	2.5% a	7.5% a	12.5% a	20.0% a	30.0% a
MAP	0.0% a	0.0% a	0.0% a	2.5% a	5.0% b	7.5% b
MAP+VEO	0.0% a	0.0% a	0.0% a	0.0% a	2.5% b	5.0% b
MAP+VEO2	0.0% a	0.0% a	0.0% a	2.5% a	2.5% b	5.0% b

Fig. 4. Impacts of MAP and combination of MAP with *O. syriacum* volatile essential oil on the decay incidence (%) in pomegranate fruits during 150 days of storage.



	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	0.00 a	0.00 a	20.00 a	42.67 a	74.67 a	86.67 a
MAP	0.00 a	0.00 a	0.00 b	6.67 b	10.67 b	16.00 b
MAP+VEO	0.00 a	0.00 a	0.00 b	4.00 b	9.33 b	10.67 b
MAP+VEO2	0.00 a	0.00 a	0.00 b	4.00 b	9.33 b	10.67 b

Fig. 5. Impacts of MAP and combination of MAP with *O. syriacum* volatile essential oil on the chilling injury in pomegranate fruits during 150 days of storage.



	Day 0	Day 30	Day 60	Day 90	Day 120	Day 150
Control	124.77 a	110.85 b	100.71 b	95.94 b	84.02 c	74.93 c
MAP	124.77 a	135.42 a	151.06 a	137.88 a	125.51 b	111.56 b
MAP+VEO	124.77 a	137.27 a	155.78 a	143.37 a	131.73 a	114.77 a
MAP+VEO2	124.77 a	134.32 a	152.15 a	140.31 a	129.61 a	112.25 ab

Fig. 6. Impacts of MAP and combination of MAP with *O. syriacum* volatile essential oil on the phenolic contents in pomegranate fruits during 150 days of storage.

On the other hand, VEO has been shown to have antibacterial, antioxidant, and antifungal properties, making it a potential natural preservative (Leyva-López *et al*., 2017; Mohamad *et al*., 2021; Pandey *et al*., 2022; Perumal *et al*., 2022). Several essential oils, such as black seed oil, cinnamon essential oil, and eugenol, have been proven to have positive effects on a variety of fruits, including pomegranates, guava, and eggplant (Kahramanolu *et al*., 2018; Etemadipoor *et al*., 2020; Huang *et al*., 2019). These findings are supported by the present study's findings, which showed that the application of VEO in addition to MAP materials resulted in a further reduction in the incidence of chilling injury compared to MAP therapy alone. Therefore, the findings of this study indicate that the application of *O. syriacum* volatile essential oil in combination with changed environment packing materials can significantly lower the incidence of chilling injury of pomegranate fruits during storage.

Impacts on phenolic contents: Pomegranate fruit has a significant phenolic content and antioxidant properties, according to Viuda Martos *et al*., (2010). In addition, the current study investigated the effectiveness of MAP and VEO in reducing the total phenolic content (TPC) of pomegranate fruits during a 150-day period at 6.5°C and 90–95% relative humidity (Fig. 6). During the storage period, the TPC of pomegranate fruits significantly differed between treatments (p 0.05). Over the course of storage, the control group's TPC significantly decreased, falling from 124.77 mg GAE/100 g FW (fresh weight) at day 0 to 74.93 mg GAE/100 g FW at day 150. According to earlier studies (Sihag *et al*., 2022) this decline may be related to the natural ageing process. The TPC of pomegranate fruits, on the other hand, dramatically rose throughout the first 60 days of storage when they were treated with MAP, reaching a high value of 151.06 mg GAE/100 g FW at day 60. TPC, however, rapidly decreased from day 90 to day 150 because this rise was not long-lasting.

The TPC of pomegranate fruits, however, was dramatically raised throughout the entire storage time when *O. syriacum* VEO was applied in MAP bags. When compared to the control group, the TPC of fruits in the MAP+VEO1 and MAP+VEO2 treatments significantly increased, reaching maximum values of 155.78 mg GAE/100 g FW and 152.15 mg GAE/100 g FW at day 60, respectively. The antioxidant and antimicrobial properties of VEO compounds, which could prevent enzymatic oxidation and microbial growth during storage (Leyva-López *et al*., 2017; Mohamad *et al*., 2021; Pandey *et al*., 2022; Perumal *et al*., 2022) may be responsible for the improvement of TPC in the VEO-treated groups. Moreover, the synergistic effect of VEO and MAP could enhance the preservation of phenolic compounds.

Conclusions

Results of present study showed that MAP bags leads to extended storage duration and improved pomegranate fruit quality. This is an expected and well-known result. However, it was clearly observed in the current work that the application of *Origanum syriacum* volatile essential oil further reduced weight and quality loss in the MAP bags, possibly due to its antimicrobial and antioxidant properties. It was also found that the combination of MAP and VEO treatments delays the decrease in soluble solids concentration and titratable acidity, lower the decay incidence and reduce chilling injury. Results also suggested that these positive advantages of VEO can be because of the increase in the total phenolic contents of fruits treated with VEO. Since the most abundant of the VEO was carvacrol (70.54%), overall results made it possible to conclude that the nano-products developed by carvacrol could be used for the improvement of the potential benefits of MAP bags. Further research is required for supporting this suggestion and for the development of industrial products for using in postharvest handling of fruits and vegetables, including pomegranates.

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