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Application of edible coatings based on guar gum and essential oil of Shirazi thyme for improving quality of pomegranate arils cv. 'Zagh' during storage life

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ABSTRACT

Pomegranate arils have a short shelf-life due to their high sensitivity to fungal agents. The use of chemical antifungal compounds to increase the postharvest life of fruit has raised many concerns. For this reason, it is necessary to use safe methods to control spoilage and maintain the quality of minimally processed pomegranate cv. Zagh arils during storage. The edible coating made from biodegradable ingredients has been considered as a technology to extend the shelf life of coated products by modifying their internal atmosphere. The aim of this study was to assess the influence of guar gum edible coatings enriched with Shirazi thymus (*Zataria multiflora)* essential oils on extending cold storage life and maintaining fruit quality of minimally processed pomegranate arils during storage at 4 ± 2 °C. This study was conducted in a completely randomized design (CRD) in a factorial experiment using guar gum in four concentrations (0, 0.25, 0.5 and 1%), essential oils of thyme at three levels (0, 500 and 1000 µl/L) in four periods of times (7, 14, 21 and 28 days) with three repetitions. The results showed that by the time, the weight of arils, titratable acidity and anthocyanin significantly decreased; while the amount of soluble solids content, taste index, pH and phenol content increased. On the last day of storage, arils coated with 0.25% guar gum and 500 µl/L of thyme essential oil showed lower weight loss and higher taste index compared to other treatments. The application of guar gum in all three concentrations significantly decreased titratable acidity and anthocyanin content and increased total soluble solids and phenol content of arils. Titratable acidity and pH decreased significantly by increasing the concentration of thyme essential oil. In general, low concentrations of guar gum (0.25 and 0.5%) and 500 µl/L of thyme essential oil can be introduced to improve the quality and increase the cold storage life of 'Zagh' pomegranate arils.

1.Introduction

Consumer interest in consuming fruits is increasing widely, as fruits are considered one of the important pillars of a healthy diet [1]. However, post-harvest losses, which lead to a reduction in the quality and quantity of fruits, are among the important problems we face in the modern era [2]. These losses are likely due to improper handling and storage or inadequate packaging, which causes microbial and fungal contaminations.

Recently, consumer interest in pomegranates has increased due to their antioxidant properties and health benefits [3, 4]. Pomegranates are an important source of anthocyanins, phenolic compounds, vitamins and minerals [3]. The edible portion of the fruit consists of arils, which make up 52% of the total fruit weight and contain 78% (W/W) water and 22% (W/W) seed [5]. Arils are consumed fresh or can be preserved as juice-based processed products. However, the time-consuming nature and difficulty of separating the arils from the peel has limited the consumption of fresh pomegranates [6]. With this in mind, ready-to-eat pomegranates with minimal processing are popular products. The shelf life of commercially produced pomegranate arils is limited. It has been reported that approximately 10 to 20% of the surface of the arils is damaged during the aril separation process. As a result, liquids exude from the damaged arils, leading to microbial contamination [7]. The shelf life of pomegranates can be increased by using edible coatings instead of chemical preservatives or modified atmosphere packaging.

Fresh produce, especially whole fruits and vegetables, have a natural wax coating, and the application of edible coatings only improves their performance. However, with fresh-cut fruits or minimally processed fruits, the surface of the product is exposed to external (microbial)/environmental factors [8 & 9], and handling such products is challenging. Fresh-cut fruits and vegetables, or minimally processed products, are more susceptible to damage due to numerous metabolic reactions such as changes in colour, texture and a faster ripening process [10].

Edible coatings protect the outer layers of produce. They act as an additional layer that covers pores, leading to a reduction in transpiration and, consequently, preventing weight loss, which is the first positive effect of edible coatings [11]. Coatings have also been shown to reduce respiration rate and delay the consumption of organic acids [12]. Maintenance of titratable acidity has been reported in many fruits treated with edible coatings. Edible coatings are able of reducing post-harvest diseases and the microbial load of produce [11]. Common edible coatings include chitosan, nanoparticles, essential oils, and mucilages, sometimes used in various combinations and concentrations. Nevertheless, to date, few studies have been conducted on preserving pomegranate arils using edible coatings.

Guar gum is a galactomannan consisting of a mannose backbone [linked by (1 → 4) beta-D-mannopyranose] with galactose side groups [linked by (1 → 6) alpha-D-galactopyranose]. This gum is obtained from the endosperm of the *Cyamopsis tetragonoloba* plant, which belongs to the Fabaceae family. These organic polymers are commonly used to inhibit the growth of various food-related microbes such as *Escherichia coli, Bacillus subtilis*, and *Staphylococcus aureus* by delaying their growth [13]. Furthermore, due to their high water solubility, easy solubility in organic acids, high molecular weight, and long polymer chains, these materials have been proposed for film and coating formation [14]. Researchers studied the effect of *Aloe vera* gel and pectin on pomegranate arils [15]. The

results indicated a positive and significant effect of both coatings on titratable acidity, vitamin C content, soluble solids, total polyphenols, free radical scavenging activity and antioxidants during refrigerated storage compared to the control. In terms of color characteristics, arils treated with 50% *Aloe vera* gel showed higher values compared to other treatments and the control after 8 days of storage. However, arils treated with pectin (0.375%) had a relatively longer shelf life and showed better organoleptic evaluation than other treatments and the control.

The addition of essential oils with antioxidant and/or antimicrobial properties in edible coatings may preserve product quality [16]. Edible coatings have great potential to act as carriers for various active ingredients, including antimicrobial agents. Recently, a number of materials with antimicrobial properties, such as essential oils from various sources, have been used in coatings and films used for fresh and fresh-cut fruits and vegetables [17, 18].

The application of various edible essential oils in coating formulations can improve the overall quality and safety properties of fresh/freshly cut produce, and researchers are interested in studying the effect of these essential oils. Edible oils and plant essential oils and natural oils significantly inhibit the growth and reduce the density of some serious pathogenic microbes such as *Candida spp., E. coli* and *Salmonella spp*. In addition, these essential oils have a superior position in the public (consumers) opinion compared to synthetic compounds [19]. Essential oils from various plant sources act as natural antimicrobial compounds and are classified as generally recognized as safe (GRAS) [20, 21]. Essential oils are widely used as bactericides, virucides, fungicides, antiparasitics, insecticides, especially in the pharmaceutical, health, cosmetic, agricultural and food industries [22, 23].

In a study to increase the shelf life of pears, edible coatings of chitosan (1%) and guar gum (2%) were used with five concentrations of lemon peel essential oil (1, 1.5, 2, 2.5, and 3%). The findings showed that the combination of edible coatings and lemon peel essential oil significantly reduced weight loss and improved firmness of pears up to 45 days of storage at 2±4°C. In addition, the combination of edible coatings and lemon peel essential oil increased the antioxidant capacity, antibacterial efficacy, and malondialdehyde levels of pears during storage [24].

Based on the studies conducted, it was found that thyme essential oil and guar gum edible coating have been used in separate studies to improve the shelf life of various products, but their combination has not been investigated in any study. The aim of the present study was to investigate the role of these compounds individually and in combination in increasing the shelf life and reducing the rate of microbial growth and losses of arils of pomegranate cultivar ‘Zagh’.

2. Materials and Methods

Pomegranate fruits of the ‘Zagh’ cultivar were harvested at the ripening stage from a commercial orchard located in Taft city, Yazd province. The harvested fruits were immediately transferred to the postharvest physiology laboratory of the Department of Horticultural Sciences, Ardakan University. Pomegranates with defects (sunburn, bursting, and damage) were removed. Fruits with healthy skin and uniform size and appearance were selected, and the arils were separated manually and collected in a container. In the next step, the arils were washed in a solution containing 100 µL of chlorine (NaOCl) for 5 minutes, then washed again under running water, and excess water was removed from the arils with a paper towel [24]. Then, the arils were immersed in the desired solutions for five minutes. Finally, the arils were placed in a strainer to

dry. After coating, approximately 200 g of arils were placed in disposable polyethylene containers and their lids were tightly closed and stored at 4 ± 2 °C with a relative humidity of 85 ± 5% for 30 days. Samples were removed from the storage every seven days and tested. Each treatment consisted of three replications.

This study was carried out as a factorial in a completely randomized design using thyme essential oil at three concentrations (0, 500 and 1000 µl L^{-1}) and guar gum derivatives (each with three concentrations of 0, 0.5 and 1%) separately and in combination with the essential oil and storage times at four levels of 7, 14, 21 and 30 days at 4 ± 2 °C with three replications.

2.1. Guar Gum

To prepare a solution of guar gum (*Cyamopsis tetragonoloba*) at concentrations of 0.25, 0.5 and 1%; 2.5, 5 and 10 grams of ground guar powder were weighed using a digital scale and then made up to one liter with distilled water. To prepare a uniform solution, it was thoroughly stirred on a stirrer for 20 minutes.

2.2. Shirazi thyme essential oil

To prepare the essential oil, Shirazi thyme (*Zataria multiflora*) was obtained from the Jihad Daneshgahi Medicinal Plants Research Institute in Karaj and its flowering branches were used to extract the essential oil. The essential oil of Shirazi thyme was extracted using a Clevenger device (Iranian glass teardrop model) by water distillation. For this purpose, 15 grams of the completely crushed dried plant sample was washed with distilled water and poured into a flask. Then, it was made up to 500 ml with distilled water so that about 70% of the flask volume was water and crushed Shirazi thyme plant material. The essential oil extraction operation was completed within 4 hours. The density of the essential oil is lower than water due to the compounds in it and for this reason it is placed on the surface of the water. Then, the outlet valve of the Clevenger device was opened carefully and the essential oil was collected in a special dark container. Sodium sulfate was used to absorb water and purify the essential oil. The container containing the essential oil was wrapped in foil and stored in a refrigerator at 4°C for next experiments [25].

2.3. Preparation of combined treatment of essential oil and guar gum

To add essential oils to the guar gum solution to coat the arils at concentrations of (0, 0.25, 0.5 and 1%), first the essential oil was dissolved in Tween 80 at a ratio of (2:1 v/w) and added to the guar solution at three levels (0, 500 and 1000 µl L^{-1}) and mixed thoroughly using a stirrer to obtain a uniform solution. After preparing the solutions, the pomegranate seeds were immersed in the desired solutions for 2 minutes. Then the arils were placed in a strainer and dried at room temperature. After coating, 200 g of arils were packed in disposable polyethylene containers (by the capacity of 280 ml), tightly closed, and placed in a cold room at a temperature of 4 ± 2 °C and a relative humidity of 85 ± 5% for 30 days. Samples were taken out of storage every seven days and tested. Three replicates were considered for each treatment.

2.4. Evaluated characteristics

2.4.1. Weight loss

The weight loss of the arils was measured at the beginning of the experiment and at the end of each storage period. The findings were reported as a percentage corresponding to the original weight loss [26].

2.4.2 TSS, pH and TA

The process of evaluating the total amount of total soluble solids (TSS) present in both coated and control arils was executed using a digital refractometer (ATAGO's model N1, originating from Japan). The gathered data was then articulated in terms of °Brix. For the determination of pH and titratable acidity (TA), a desktop pH meter (model 827, fabricated in Switzerland) was utilized. The TA level, articulated in grams of citric acid per 100 g of fresh weight, was deduced by diluting 10 mL of aril juice with 10 mL of

pure distilled H2O, subsequently titrated with 0.1 mol L-1 NaOH until a pH of 8.2 was reached. Equation (1) was applied for the computation of TA, where v signifies the volume of the used 0.1 N NaOH and m denotes the mass of the fruit juice.

$$TA = \frac{= v \times 0.067 \times 0.1 \times 100}{m} \quad (1)$$

2.4.3. Total phenol content

The quantification of the total phenol content in both coated and uncoated arils was carried out by applying the method elaborated by Singleton et al. (1965). Specifically, 300 µL of fruit juice was meticulously mixed with 1500 µL of Folin Ciocalteu reagent and subsequently subjected to an incubation period of 5 min. Following this, 1200 µL of 7% sodium carbonate solution was introduced to the mixture. Thereafter, the mixtures were maintained in a dark environment for 90 min at ambient temperature. The absorbance of each solution was determined using a spectrophotometer at 765 nm. The outcomes were presented as milligrams of gallic acid equivalents for every 100 mL of fruit juice [28].

2.4.4. Total Anthocyanin

Total anthocyanin was measured using the pH difference absorption method between two buffer systems. To determine total anthocyanin in pomegranate arils, the supernatant of pomegranate juice, which had been centrifuged for three minutes at 4500 rpm, was used. Buffer 1, potassium chloride and 0.2 M hydrochloric acid with a pH of 1, and buffer 2, acetic acid and sodium acetate, each at a concentration of 0.2 M with a pH of 4.5, were used. Two wavelengths of 510 and 700 nm were used to read total anthocyanin. For this purpose, the spectrophotometer (Pharmacia/LKB model, made in England) was first calibrated with buffer 1, and 500 µl of the extract was diluted with buffer 1 and read at two wavelengths. After this step, the device was calibrated with buffer 2 and 500 µL of the extract was mixed with buffer 2 and reading was done as in the previous step [29]. The anthocyanin content was calculated according to equation 2.

(2): Amount of monomeric anthocyanin pigment (mg.L-1) = (A×MW×DF×1000)/(ε*1)

In this equation, MW is the molecular weight of the dominant anthocyanin (cyanidin 3-glucoside) in pomegranate extracts, which is 26900. ε is the molar absorption coefficient for the dominant anthocyanin, which is 2.449. DF is the dilution factor of the samples, and A is the difference in absorption of the samples at two pHs, which was calculated by Equation 3.

(3): A = (A520 -A700) pH1.0 - (A520 -A700) pH4.5

2.5. Data analysis

This research was conducted as a three-factor factorial (guar gum, thyme essential oil, and time) in a completely randomized design with three replications. Data analysis was performed using IBM SPSS statistics version 20 software through parametric and nonparametric tests; data that had a normal distribution were examined through analysis of variance and Duncan's post hoc test, and data that did not have a normal distribution and data obtained through scoring were used through the nonparametric Kruskal-Wallis test, and then the difference between the means was performed pairwise through the Mann-Whitney test. EXCEL software was used to draw graphs.

3. Results and Discussion

3.1. Weight Loss

Based on the results of the analysis of variance table (1), the simple effect of time and the interaction effect of thyme by time at the probability level of 1%, as well as the triple effects of time in guar in thyme at the probability level of 5%, were significant on the weight loss of arils. Other simple and interaction effects did not show any significant effect on this parameter.

Table 1 Analysis of variance of the effect of thymus essential oil, guar gum and storage time on some physiological and biochemical characteristics of pomegranate arils cv. 'Zagh'

Sources of variance	Mean Square							
	df	Weight loss	TSS	TA	TSS/TA	pH	Anthocyanin	Phenol
Thymus EO (a)	2	0.008^{ns}	0.067^{ns}	0.036**	2.41**	0.19**	1759.6**	0.109**
Guar gum (b)	3	0.011^{ns}	0.66**	0.006**	0.6**	0.004**	121.46**	1.04**
Storage time (c)	3	0.32**	5.8**	0.016**	5.91**	0.016**	555.62**	0.11**
a × b	6	0.008^{ns}	0.009^{ns}	0.002**	0.22**	0.008**	9.22**	0.006**
a × c	6	0.014**	0.009^{ns}	0.002**	0.062^{ns}	0.007**	29.3**	0.002^{ns}
b × c	9	0.007^{ns}	0.54**	0.001^{ns}	0.13**	0.001^{ns}	4.98*	0.013**
a × b × c	18	0.009*	0.017^{ns}	0^{ns}	0.055*	0.001^{ns}	3.17^{ns}	0.002^{ns}
Error	95	0.004	0.024	0.001	0.030	0.001	2.5	0.002
CV%	-	0.62	0.22	0.025	0.038	0.018	0.086	0.0006

^{ns}, * and **: not significant, significantly at the 5 and 1 % of probability level, respectively.

The results of the triple effects of time on guar in thyme essential oil showed that weight loss increased with storage time (Fig. 1). The lowest weight loss (0.001%) was observed in arils coated with 1000 µl L^{-1} thyme essential oil on the seventh day of storage. The highest weight loss (0.36%) was observed in the combined treatment of 0.5% guar gum and 1000 µl L^{-1} thyme essential oil on the 28th day of storage (Fig. 1). On the last day of storage, the lowest weight loss (0.22%) was observed in arils treated with 500 µl L^{-1} thyme essential oil + 0.25% guar gum (Fig. 1).

Weight loss, which is a natural characteristic of horticultural crops during storage, is mainly due to water loss due to respiration and transpiration processes [30]. The prevention of weight loss by polysaccharide-based coatings could possibly be related to the better formation of hydrogen bonds between the hydroxyl groups of edible coatings and hydrophilic substances such as phenols [31]. The results obtained were also consistent with the findings of Dong and Wang (2018), who reported that the incorporation of ginseng extract into guar gum edible coatings reduced the weight loss of sweet cherries by reducing the respiration rate and reducing water loss during storage at ambient temperature [32]. It was also found that, in accordance with the findings of this study, edible coatings of chickpea starch and guar gum enriched with oleic acid and shellac significantly prevented weight loss of oranges during storage at 5 and 20 °C [33]. In a study, it was found that mango fruits coated with guar gum and *Aloe vera* gel had a lower weight loss rate than the control, which was consistent with the results of this study [34].

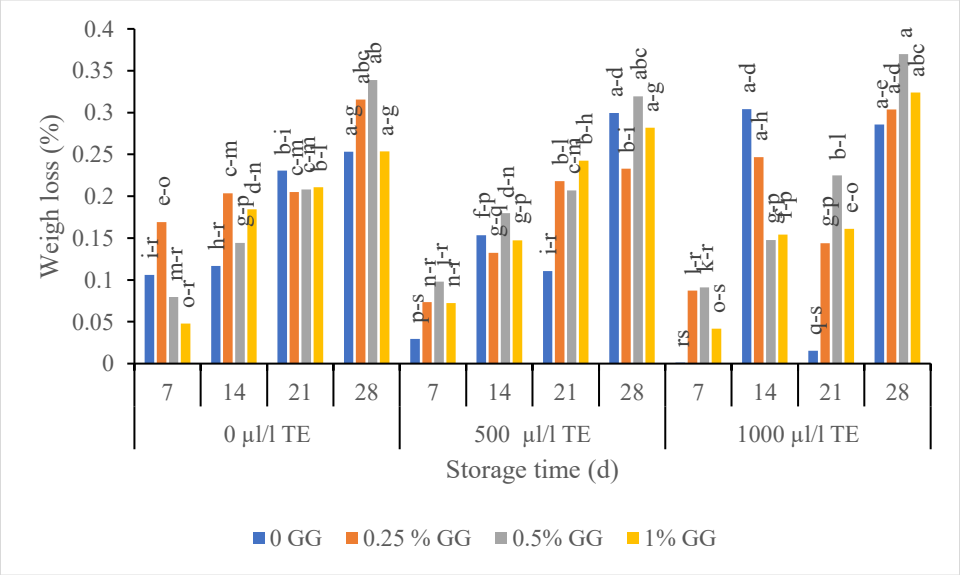

Fig 1 Triple effects of thymus essential oil, guar gum and storage time on weight loss of pomegranate arils cv. 'Zagh'

2.3. Total soluble solids (TSS)

The results showed that the simple effect of time and guar gum and their interaction at the 1% probability level on the total soluble solids of the arils was significant, and the other treatments did not show a significant effect (Table 1). With the passage of storage time, the total soluble solids increased significantly until day 14, but on day 21, the TSS decreased slightly and increased again until day 28 (Fig. 2). The highest TSS was observed in the 0.25, 0.5 and 1% guar treatments on day 14. At the end of the arils storage time, the TSS of the samples treated with 1% guar gum was 78.7% higher than the control (Table 2). Total soluble solids are an important factor related to consumer acceptability of fruits. The gradual increase in total soluble solids during fruit storage could be due to hydrolysis of cell wall polysaccharides or an increase in sugar concentration, which may be caused by water loss or conversion of starch to sugar as a result of increased fruit respiration rate [35]. Edible coatings are believed to prevent drastic changes in fruit TSS by restricting gas exchange, reducing respiration, and inducing metabolic processes in the coated fruits [32]. Naeem et al. (2018) showed that ethanolic and methanolic extracts of *Foeniculum vulgare* in combination with guar gum and ethanolic extract of *Nigella sativa* seed in combination with guar gum significantly increased lemon TSS [36], while other coatings had no significant effect on it. Consistent with the results of this experiment, Yousuf and Srivastava (37) reported that the TSS of arils coated with Flaxseed gum increased with time. They reported that TSS levels decreased in control samples, unlike treated samples. Another study found that TSS levels increased in pomegranates stored under modified atmosphere, which was consistent with the results of this study [38].

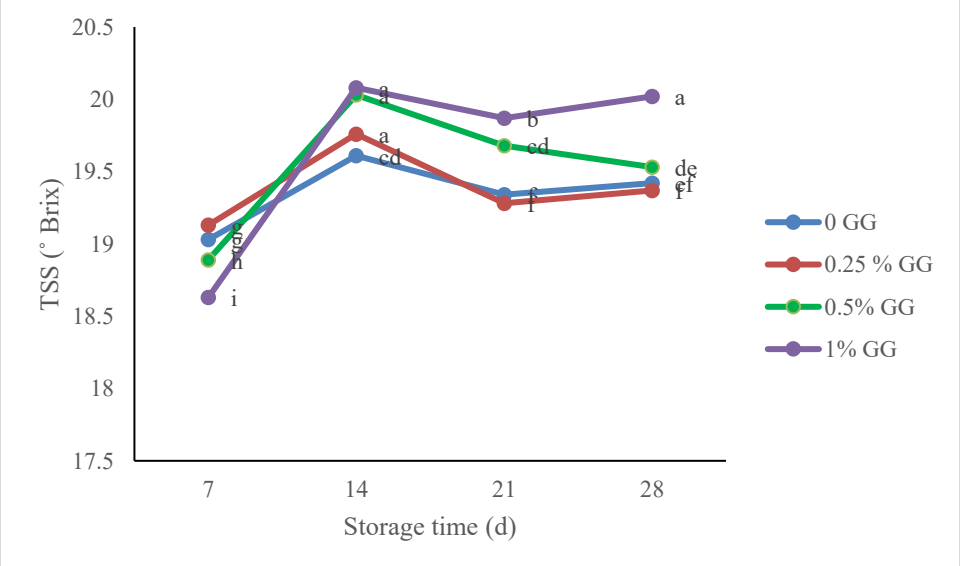

Fig 2 Interaction effects of guar gum and storage time on TSS of pomegranate arils cv. 'Zagh'

3.3. Titratable acidity (TA)

The results of the analysis of variance table (1) showed that the effect of time, thyme essential oil, guar gum and the interaction effects of guar in thyme and time in thyme were significant at the 1% probability level on the TA of arils. The results showed that

over time, the amount of TA in arils treated with thyme essential oil decreased and this decrease was greater in the 1000 µl L^{-1}essential oil treatment than in the 500 µl L^{-1} essential oil treatment and the control (Fig. 3A). The highest amount of TA (1.67%) was obtained in the uncoated arils (control) and the lowest amount (1.56%) was obtained in the combined treatments of 0.25% guar gum with 500 and 1000 µl L^{-1} thyme essential oil (Fig. 3B). Titratable acidity is directly related to the concentration of organic acids in the fruit and, consequently, to the quality of the fruits. Organic acids are the energy source of fruits that are consumed during fruit ripening by increasing metabolism during the oxidation of acids in the TCA cycle [39]. The higher TA value in coated fruits could be due to the low oxygen permeability and low respiration rate, thus preventing the oxidation of organic acids. Previous results obtained on mango have shown that guar gum in combination with essential oils reduces the loss of acidity, which was not consistent with the results of this study [36]. Guar gum coating with ginseng extract on cherry fruit [32] significantly prevented the loss of acidity, while in this study the combination of guar gum and thyme essential oil resulted in a decrease in TA compared to the control. In another study, it was found that arils coated with lemon essential oil had lower acidity than the control at the end of the storage period, which was consistent with the findings of this study [37]. Therefore, the effect of coating on fruit quality depends on the variety, coating formula, and storage conditions.

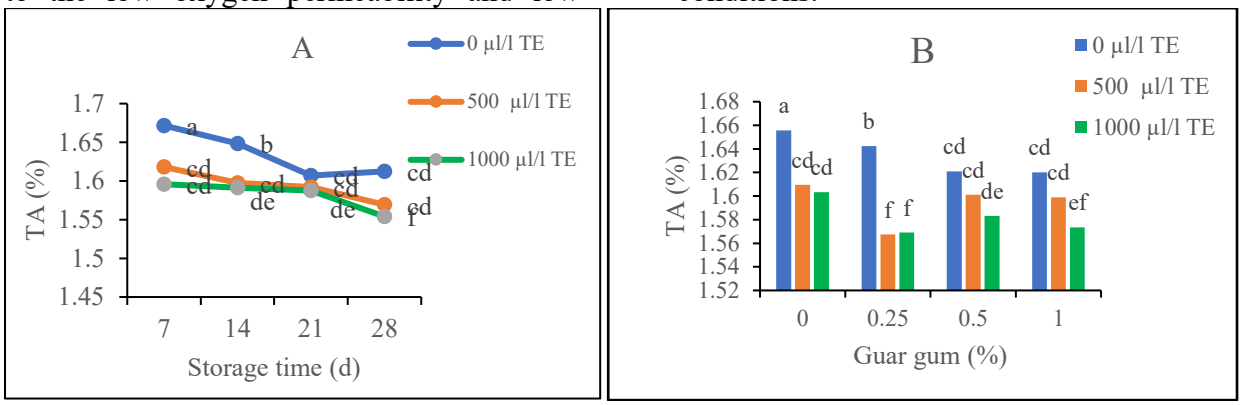

Fig 3 Interaction effects of A: thymus essential oil and storage time B: thymus essential oil and guar gum on TA of pomegranate arils cv. 'Zagh'

4.3. Ripening Index (TSS/TA)

Based on the results of the variance analysis table (1), the effects of time, thyme, guar gum, the interaction effects of guar in time and guar in thyme at the probability level of 1%, as well as the triple effects of time in guar in thyme at the probability level of 5% on the flavor index of arils were significant. With increasing the concentration of essential oil and guar gum, the flavor index also improved. The results of the triple effects of time in guar in thyme essential oil showed that the flavor index increased with the passage of storage time (Table 2). The highest flavor index (13.6) was obtained in the combined treatment of 0.25% guar gum with 500 µl L^{-1} thyme essential oil on day 28 of storage (Table 2). At the end of the storage period, the flavor index was higher in all treatments than in the control (Table 2).

The TSS/TA ratio, often called the ripening (or flavor) index, is an important criterion for evaluating the flavor of pomegranate arils. The results showed that the ripening index increased with storage time, which was consistent with the results of Martinez-Romero et al. (2013) on pomegranate arils. They reported that this index decreased

significantly in arils treated with acid alone or in combination with aloe vera gel [40]. Jahani et al. (2020) investigated the interaction effects of essential oil type and its concentration on pomegranates treated with *Aspergillus niger* and showed that the highest TSS/TA index was obtained in the clove essential oil treatment (800 µl L^{-1}) [41].

Table 2 Triple effects of thymus essential oil, guar gum and storage time on TSS/TA of pomegranate arils cv. 'Zagh'

Treatments	Time (day)			
	7	14	21	28
Control	$^{t.v}$ 11.39	11.80^{o-s}	11.93^{l-r}	11.90^{k-r}
0.25% GG	^{uv} 11.29	11.94^{j-r}	11.86^{m-s}	12.07^{j-r}
0.5% GG	^{v} 11.23	12.15^{h-m}	12.42^{d-h}	12.21^{g-l}
1% GG	^{uv} 11.31	12.07^{i-o}	12.27^{e-k}	12.57^{c-f}
500 µl L^{-1} TEO	$^{r.t}$ 11.63	12.26^{e-l}	12.16^{h-m}	12.14^{h-m}
1000 µl L^{-1} TEO	$^{o.s}$ 11.72	12.15^{h-m}	12.07^{i-r}	12.35^{d-j}
500 µl. L^{-1} TEO × 0.25% GG	$^{o.s}$ 11.77	12.25^{d-h}	12.60^{c-f}	13.20^{a}
500 µl. L^{-1} TEO × 0.5% GG	$11.59^{s.u}$	12.28^{d-j}	12.25^{f-l}	12.56^{c-f}
500 µl. L^{-1} TEO × 1% GG	$11.58^{s.u}$	12.47^{d-h}	12.29^{d-i}	12.56^{c-f}
1000 µl. L^{-1} TEO × 0.25% GG	$11.82^{n.s}$	12.52^{c-g}	12.41^{d-h}	13.02^{ab}
1000 µl. L^{-1} TEO × 0.5% GG	$11.72^{q.s}$	12.44^{d-h}	12.35^{d-i}	12.85^{bc}
1000 µl. L^{-1} TEO × 1% GG	$11.74^{p.s}$	12.57^{c-f}	12.62^{cd}	12.80^{bc}

Similar letters in each column don't have a significant difference statistically in P<0.05 level. GG: Guar gum; TEO: Thyme essential oil

5.3. pH

The results of the analysis of variance table (1) showed that the effects of time, thyme essential oil, guar gum and the interaction effects of guar in thyme and time in thyme were significant at the 1% probability level on the pH of the arils, and the other interaction and triple effects did not show a significant effect on the pH content of the arils (Table 1). The study of the interaction effects of gum and essential oil showed that the use of guar gum had a greater effect on increasing the pH than the essential oil, so that the highest amount was observed in the 1% guar gum treatment (Fig. 4A). During storage time, the pH of the fruits showed a significant increase, and this increase was greater in the control and less in the 1000 µl L^{-1} thyme essential oil treatment (Fig. 4B). Changes in the pH of the fruits during storage are due to changes in titratable acidity and their conversion to sugar during metabolic processes. The pH change could be due to the effect of coatings on the biochemical conditions of the fruit, which may reduce respiration rate and metabolic activity. The pH of strawberries increased during storage in control or *Aloe vera*-coated fruits, but was higher in control fruits compared to coated samples, which was consistent with the findings of this study [42].

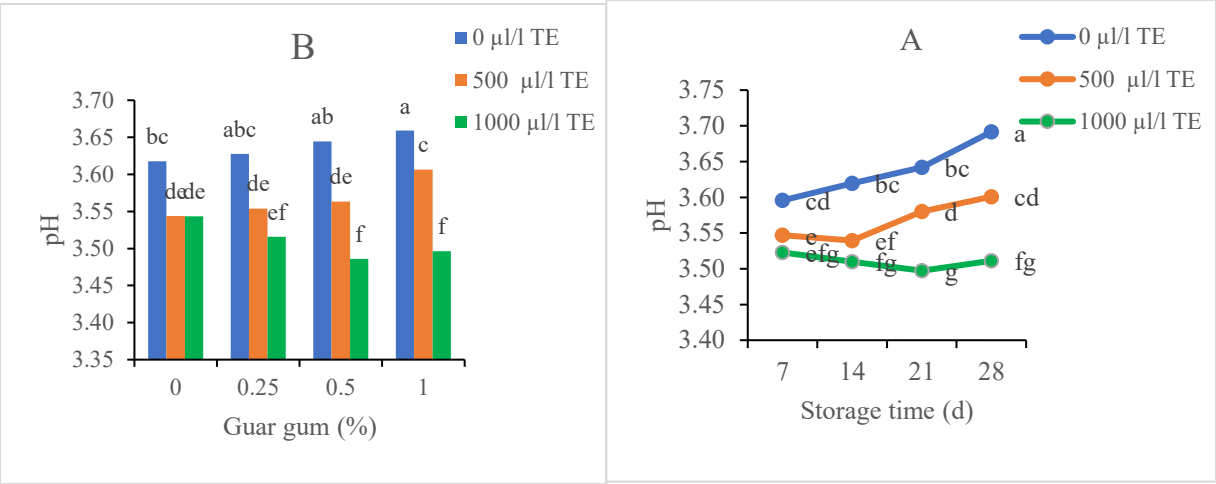

Fig 4 Interaction effects of A: thymus essential oil and storage time B: thymus essential oil and guar gum on pH of pomegranate arils cv. 'Zagh'

6.3. Anthocyanin

The results of the analysis of variance table (1) showed that the effects of time, thyme essential oil, guar gum, and the interaction effects of guar in thyme and time in thyme were significant at the 1% probability level and the interaction effect of guar by time at the 5% probability level on the amount of anthocyanin in arils. The triple effects on this index were not significant.

During storage time, the anthocyanin content decreased significantly in all treatments. The greatest decrease was observed in samples treated with 1000 µl L^{-1} thyme essential oil, so that at all sampling times, the amount of anthocyanin in this treatment was less than the control and 500 µl L^{-1} essential oil (Fig. 5A). By examining the interaction effects of guar gum and thyme essential oil, it was found that the highest anthocyanin content was obtained in the control (83.01 mg L^{-1}) and the lowest in the arils coated with 1% guar gum along with 1000 µl L^{-1} thyme essential oil (67.11 mg L^{-1}), which was 23.69% less than the control (Fig. 5B). The reason for the decrease in anthocyanin content in high concentrations of edible coatings may be due to insufficient oxygen exchange with the surrounding environment, which ultimately led to reduced respiration and browning of the arils. It was also found that a low concentration of guar (0.25%) alone and in combination with 500 µl L^{-1} essential oil was effective in preserving fruit anthocyanin. In a study, black caraway oil at a concentration of 800 µL significantly maintained the anthocyanin content in cherries compared to other treatments [43]. Also, the highest and lowest anthocyanin levels were observed in strawberry fruits treated with 600 µl L^{-1} fennel oil and control fruits, respectively, which was not consistent with the findings of this study [44]. Also, the anthocyanin levels of peach fruits treated with essential oils were significantly different between the essential oils and the control, which was consistent with the findings of this study at high concentrations of essential oils [45]. Jahani et al. (2020) examined the interaction effects of essential oil type and its concentration on pomegranates treated with *Aspergillus niger* and showed that the highest amount of anthocyanin was obtained in the eucalyptus essential oil treatment (800 µl L^{-1}) [41].

In a study that investigated the effect of *Aloe vera* gel as a food coating on the microbial, physicochemical, and sensory properties of fresh strawberries during storage [46], the amount of anthocyanin in the coated fruits decreased during storage, which was consistent with the results of this study. In another study, the effect of chitosan-containing nanoemulsion coating on

increasing the shelf life and quality characteristics of strawberry fruit after harvest was investigated [47]. In this study, the anthocyanin concentration in strawberries coated with chitosan nanoemulsion showed an increasing trend until the twelfth day, but after that and until the end of the storage period, a decrease in the anthocyanin concentration was recorded in the treated sample [47]. The results of this study showed a decreasing trend in the anthocyanin content of the samples. However, the changes in anthocyanin also depend on the fruit variety in question and the composition of the indicator under study. In their study, the researchers stated that the slower rate of anthocyanin reduction in the treated samples compared to the control sample could be due to lower polyphenol oxidase enzyme activity and ascorbic acid retention. The reduction in anthocyanin content is most likely related to anthocyanin degradation, which occurs over a long period of time.

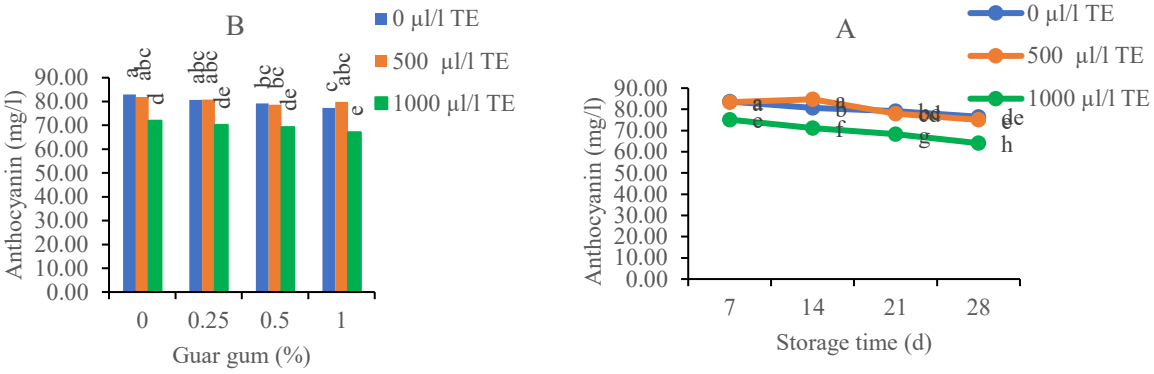

Fig 5 Interaction effects of A: thymus essential oil and storage time B: thymus essential oil and guar gum on anthocyanin content of pomegranate arils cv. 'Zagh'

7.3. Total phenol content

Based on the analysis of variance table (1), the effects of time, thyme essential oil, guar gum, and the interaction effects of guar in thyme and time in guar were significant at the 1% probability level on the phenolic content of arils. Other interaction and triple effects did not show a significant effect on the phenolic content of arils (Table 1). The results of comparing the mean interaction effects of guar gum and time showed that the phenol content increased with time and this increase was significantly higher in arils treated with 0.5 and 1% guar on day 28 of storage (265.36 and 265.41 µg of gallic acid in dry weight, respectively) (Fig. 6A). By examining the interaction between thyme essential oil and guar gum, it was found that the phenol content increased with increasing concentrations of guar gum and thyme essential oil, such that the highest phenol content was obtained in arils coated with 1% guar gum (265.35 µg of gallic acid in dry weight) and the combination of 1% guar gum + 500 µl L^{-1} of thyme essential oil (265.37 µg of gallic acid in dry weight) (Fig. 6B).

Phenolic compounds are present in almost all parts of the plant. Phenolic compounds are one of the most important secondary plant metabolites with good antioxidant potential. They can scavenge reactive oxygen species and regulate the function of certain enzymes [48]. Phenolic compounds, especially flavonoids, can interact with membrane phospholipids through hydrogen bonding to the polar ends of phospholipids, thereby accumulating them inside and outside the membrane and preventing the access of molecules [49]. Phenolic compounds gradually decrease with ripening; therefore, preserving these compounds is important to prevent loss of fruit quality during storage.

Natural coatings play a key role in the metabolism of phenolic compounds by creating a modified atmosphere around the fruit and reducing the rate of respiration and oxidation of phenols by reducing the activity of polyphenol oxidase [50]. Recently, it was observed that the combination of *Aloe vera* gel coating with *Fagonia cretica* extract had a significant effect on the retention of total phenolics and flavonoids of sapodilla fruit during post-harvest storage [51]. Similarly, alginate coating enriched with pomegranate peel extract had a significant effect on the retention of phenolic content of guava during a 20-day storage period [2], which was consistent with the results of this study.

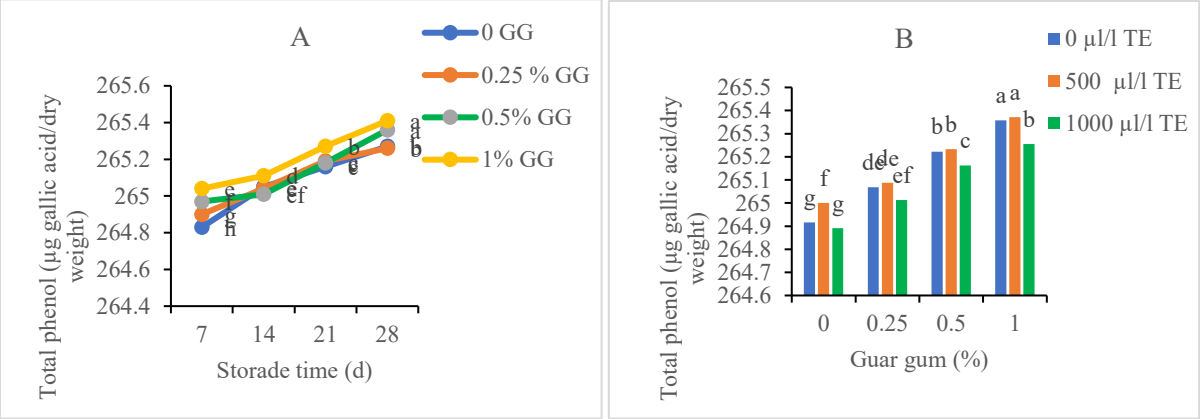

Fig 6 Interaction effects of A: guar gum and storage time B: thymus essential oil and guar gum on total phenol of pomegranate arils cv. 'Zagh'

4. Conclusions

The results of this study showed that the combination of essential oils with guar gum coating can improve the post-harvest quality of pomegranate arils by minimizing weight loss and slowing down the TSS changes of this fruit. Higher soluble solids were observed in fruits coated with guar gum coating. The addition of 500 µl L^{-1} of Shirazi thyme essential oil improved bioactive compounds such as pomegranate aril phenols compared to the control and 1000 µl L^{-1} of essential oil. High concentrations of essential oil (1000 µl L^{-1}) showed a negative effect on the quality of pomegranate arils in most of the parameters studied. Also, the combination treatments with high levels of essential oil and guar gum did not achieve favorable results. Considering the positive effects of Shirazi thyme essential oil in combination with guar gum, since there is a great global concern about human health, this formula can be suggested to improve the storage quality of pomegranate arils. However, further research on other fruits and vegetables is needed to understand the possible mechanisms of the effects of these compounds.

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مقاله علمی_پژوهشی

استفاده از پوشش‌های خوراکی برپایه صمغ گیاه گوار و اسانس آویشن شیرازی جهت بهبود کیفیت آریل‌های انار رقم زاغ در دوره انبارمانی

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چکیده

آریل‌های انار به‌دلیل حساسیت زیاد به عوامل قارچی ماندگاری کمی دارند. استفاده از ترکیبات شیمیایی ضد قارچ برای افزایش عمر پس از برداشت میوه‌ها نگرانی‌های زیادی ایجاد کرده است. به‌همین دلیل استفاده از روش‌های ایمن برای کنترل فساد و حفظ کیفیت آریل‌های انار در زمان نگه‌داری ضروری است. پوشش‌های خوراکی ساخته شده از مواد زیست‌تخریب‌پذیر به‌عنوان یک فناوری برای افزایش ماندگاری محصولات خوراکی از طریق تغییر اتمسفر درونی آنها در نظر گرفته شده است. هدف از این مطالعه بررسی تأثیر پوشش‌های خوراکی صمغ گیاه گوار غنی‌شده با اسانس آویشن شیرازی (***Zataria multiflora***) بر افزایش عمر انبارمانی و حفظ کیفیت آریل‌های میوه انار رقم "زاغ" در طول نگهداری در دمای ۴±۲ درجه سانتی‌گراد بود. این مطالعه در قالب طرح کاملا تصادفی (**CRD**) در یک آزمایش فاکتوریل با استفاده از صمغ گوار در چهار غلظت (۰، ۰/۲۵، ۰/۵ و ۱ درصد) و اسانس آویشن در سه سطح (۰، ۵۰۰ و ۱۰۰۰ میکرولیتر برلیتر) و در چهار زمان (۷، ۱۴، ۲۱ و ۲۸ روز) با سه تکرار انجام شد. نتایج نشان داد که با گذشت زمان وزن آریل‌ها، **TA** و محتوای آنتوسیانین به‌طور قابل‌ملاحظه‌ای کاهش یافت؛ درحالی‌که میزان **TSS**، شاخص طعم، **pH** و محتوای فنل افزایش یافت. در آخرین روز انبارمانی، آریل‌های پوشش‌داده شده با تیمار ترکیبی ۰/۲۵ درصد صمغ‌گوار + ۵۰۰ میکرولیتر بر لیتر اسانس آویشن نسبت به سایر تیمارها کاهش وزن کمتر و شاخص طعم بالاتری نشان دادند. استفاده از صمغ‌گوار در هر سه غلظت به‌طور معنی‌داری موجب کاهش **TA** و محتوای آنتوسیانین و افزایش مواد جامد محلول کل و محتوای فنل آریل‌ها شد. با افزایش غلظت اسانس آویشن **TA** و **pH** به‌طور معنی‌داری کاهش یافت. به‌طور کلی می‌توان غلظت‌های پائین صمغ گوار (۰/۲۵ و ۰/۵ درصد) و نیز غلظت ۵۰۰ میکرولیتر در لیتر اسانس آویشن شیرازی را در بهبود کیفیت و افزایش ماندگاری آریل‌های انار رقم زاغ معرفی نمود.