

Application of different coating treatments to enhance storability and fruit quality of pomegranate (*Punica granatum* L., cv. Wonderful) during prolonged storage

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Abstract – This study was carried out on pomegranate fruits cv. “Wonderful” with the aim of maintaining fruit quality and water content, reducing weight loss, chilling injury and browning symptoms during cold storage at 5 °C and 90% RH for 60 d followed by simulated shelf life at 20 °C for 14 d. Coating treatments included gum arabic at 5% and 10%, paraffin at 10% and 20%, chitosan at 1% and 2%, and beeswax at 5% and 10%. All conducted coatings treatments significantly maintained fruit quality as compared to the control (uncoated ones). Chitosan at 2% significantly preserved fruit quality, firmness, visual appearance, husk colour, ascorbic acid and anthocyanin content, furthermore it reduced browning, peroxidase enzyme activity and decay incidence. Paraffin at 10% and beeswax at 10% were effective in maintaining fruit water content, in addition to the significant preservation of husk distention using paraffin at 20%, moreover, application of gum arabic at 5% maintained moderate rates of fruit respiration and total soluble solids content as compared to control.

Index terms: pomegranate, beeswax, gum arabic, chitosan, coating, paraffin, storage, chilling injury.

Aplicação de diferentes tratamentos de revestimento para melhorar a capacidade de armazenamento e a qualidade do fruto da romã (*Punica granatum* L., cv. Wonderful) durante o armazenamento prolongado

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Resumo - Este estudo foi realizado em frutos de romã cv. “Wonderful” com o objetivo de manter a qualidade do fruto e o teor de água, reduzindo a perda de peso, a injúria por frio e os sintomas de escurecimento durante o armazenamento refrigerado a 5 °C e 90% UR, por 60 dias seguido de vida útil simulada a 20 °C por 14 dias. Os tratamentos de revestimento incluíram goma arábica a 5% e 10%, parafina a 10% e 20%, quitosana a 1% e 2% e cera de abelha a 5% e 10%. Todos os tratamentos de cobertura realizados mantiveram significativamente a qualidade dos frutos em relação ao controle (sem cobertura). A quitosana a 2% preservou significativamente a qualidade do fruto, a firmeza, a aparência visual, a cor da casca, o teor de ácido ascórbico e da antocianinas, além de reduzir o escurecimento, a atividade enzimática de peróxidos e a incidência de podridões. A parafina a 10% e a cera de abelha a 10% foram eficazes na manutenção do teor de água dos frutos, além da preservação significativa da distensão da casca, utilizando parafina a 20%; além disso, a aplicação de goma arábica a 5% manteve taxas moderadas de respiração dos frutos e a solubilidade total do teor de sólidos em relação ao controle.

Termos de indexação: romã, cera de abelha, goma arábica, quitosana, revestimento, parafina, armazenamento, injúria por frio.

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Introduction

Pomegranate (*Punica granatum* L.) is an important fruit crop that has emerged as one of Egypt's most promising export fruits in recent years (KHEDR, 2018). "Wonderful" pomegranate is a medium to large fruit cultivar with a high yield, light aril, high juice, and exceptional palatability (HOLLAND et al., 2009). Because it offers the optimum balance of productivity and quality, variety "Wonderful" is currently one of the most competitively planted pomegranate cultivars in Egypt. Despite its classified as a non-climacteric fruit and a lower respiratory commodity, pomegranate fruits are exceedingly perishable (MEIGHANI et al., 2015). Pomegranate quality has been impacted by a variety of issues, including excessive water loss, which has led in shriveling, a rough skin, and browning during storage (FAWOLE; OPARA, 2013). Also, fruits are sensitive to low temperatures during cold storage, resulting in chilling injury symptoms (MIRDEHGHAN et al., 2007). These symptoms include husk pitting, browning of white segments that separate the arils, discolouration of arils, and peel surface scald, which will become more noticeable during the marketing life of the fruit.

Natural waxes on the fruit surface maintain water and gas permeability; nevertheless, these natural waxes can be washed off or destroyed during fruit handling methods (MIRDEHGHAN et al., 2007). Fruit waxing is a defensive technique for reducing post-harvest losses and extending the shelf life of fruits and vegetables (BALDWIN et al., 1999). The main objectives of fruit waxing are to reduce water loss from the fruit surfaces and weight loss, Baldwin et al. (1999) reported that the coating can reduce fruit weight loss by about 50%, in addition to maintaining fruit quality and improving fruit appearance (KHEDR, 2018). Waxing reduces respiration rate significantly, and waxed fruit maintains a better physical look, according to Meighani et al. (2015), while extreme reductions in respiration rate have the opposite impact through anaerobic respiration.

Many edible coatings are employed to preserve fruits such as oranges, apples, and grapefruits; however, in certain situations, the edible coatings were ineffective, and the quality of the fruit deteriorated (VARASTEH et al., 2017). Beeswax is a solid at room temperature, composed primarily of fatty acids, esters, and alcohols (ZHANG; ZHANG 2008). According to some researchers, beeswax benefits as a coating material include keeping fruit colour, brightness, and hardness as compared to untreated fruits (SHAHID; ABBASI, 2011; KHEDR, 2017). Chitosan is a highly recommended edible film and one of the most valuable edible antioxidants (CANDIR et al., 2018). Varasteh et al. (2017) explored postharvest chitosan coating treatment and found that it delayed anthocyanin pigment degradation and hence delayed colour changes

in pomegranate fruits, as well as reducing respiration rate and weight loss. Furthermore, oils compounds are helpful in many circumstances for decreasing decay, improving quality, and extending the life of many fruits after harvest; paraffin is a thin layer used to coat fruits. Paraffin has an essential function in the preservation and marketing of fruits, since it gives them a lustrous appearance and protects them from mechanical damage, as well as physical and chemical changes (MAGASHI; BUKAR, 2007; KHEDR, 2017). Gum arabic is a dehydrated and adhesive exudate extracted from the stems or branches of Acacia species. It is distinguished by its small gelatinous particles and soluble ability, and it is widely used in the industrial sector for emulsification, film development, and encapsulation. Gum arabic demonstrated significant improvements in fruit quality preservation (MAQBOOL et al., 2011).

The main goals of this study were to evaluate how different postharvest treatments, such as beeswax, chitosan, paraffin, and gum arabic, affected the postharvest quality characteristics of "Wonderful" pomegranate during cold storage at 5 °C and 90% RH for 60 d, and marketing life at 20 °C for 2 weeks, representing the average period for shipment and transportation during handling and marketing conditions to global markets or storage for domestic markets.

Materials and methods

Pomegranate fruits cv. "Wonderful" were harvested manually from a private orchard in Beheira Governorate, Egypt, according to quality indices published by Kader (2006) at completely mature stage and homogeneous in size and colour, following prescribed agricultural techniques. Fruits were promptly moved to a postharvest laboratory (Agricultural system development project, Giza) after harvesting, where they were cleaned in a disinfectant solution containing 100 ppm NaOCl.

Beeswax was prepared in two different concentrations: 5% and 10%. The coating emulsion was made by dissolving beeswax in 1000 ml water phase and heating it to 100 °C until all of the wax was completely hydrated (HASSAN et al., 2014). Chitosan was made in two concentrations, 1 and 2% w/v, using 1% v/v glacial acetic acid (aqueous solution). The stock solution was sterilised for 20 minutes at 120 °C. The pH was adjusted to 5.2 using 1 N NaOH, according to Miranda et al. (2004). The process indicated by Khedr (2017) was used to apply paraffin at 10 and 20%.

According to the methodology described by Asgar et al. (2010), gum arabic solutions were prepared in two concentrations; 5 and 10% w/v, by dissolving in distilled water heated to 40 °C and stirring continuously for one

hour on a magnetic stirrer hot plate until the solution became clear, the pH of the solution was adjusted to 5.6 pH using 1 N NaOH.

Selected pomegranate fruits were randomly divided into nine groups, each of which was coated with one of the following coatings; beeswax at 5%, beeswax at 10%, chitosan at 1%, chitosan at 2%, paraffin at 10%, paraffin at 20%, gum arabic at 5%, gum arabic at 10%, and untreated fruits (control). The coating treatments were carried out by dipping pomegranates in the prepared coating materials for 5 min, with the coating solution uniformly covering the entire fruit surface, while the control (uncoated fruits) were dipped in distilled water for the same duration of time, and then all fruits were air dried. Fruits were divided into groups for decay incidence evaluation, weight loss follow-up, and sampling for physical, chemical, and quality analysis. They were then packed in open top carton packages and cold stored for 60 d at 5 °C and 90% RH, followed by 14 d at 20 °C to simulate shelf life conditions. Data was collected before treatments, then at 15-day intervals during cold storage and 7-day intervals during shelf life, with nine fruits from each replicate and three repetitions for each treatment.

The physical, chemical and quality characteristics of the fruit were determined as follows; the percentage of decayed fruits recorded by observing all of the injured fruits, resulting of physiological disorders, chilling injury, rots, fungus or bacteria, the proportion of deteriorated fruits was estimated by counting and calculating the ratio of discarded fruits /total number of fruits at the start of storage $\times 100$.

The difference in weight between the initial weight of the fruits and the weight recorded at the time of sampling was computed as (initial fruit weight - fruit weight at each sampling date) / initial fruit weight $\times 100$.

According to Mitcham et al. (2003), pomegranate peel firmness was measured on the two opposite surfaces of each fruit using a fruit penetrometer with an 8 mm diameter probe, and the results were expressed in lbf units. The thickness of the husk layer in the samples fruits was measured with a digital caliper and represented in mm.

On a scale of one to nine, with 1 indicating unacceptable quality, 3 indicating poor quality, 5 indicating fair quality, 7 indicating good quality, and 9 indicating excellent quality, the general appearance of fruits was observed visually using the procedure described by Khedr (2018). In addition, the instrumental colour of the peel was measured objectively using a chroma metre (Minolta CR-400, Minolta, Osaka, Japan) on three different places of the husk layer surface of the fruit according to the CIE L* a* b* standards (International Commission on Illumination) according to McGuire (1992).

Pomegranate respiration rate was determined using a gas analyzer (Model 1450 - Servomex 1400, Japan) according to Oluwafemi et al. (2012) method; fruit was occluded in airtight glass jars (4 liter) under the same experiment conditions for 24 hours, and respiration rate was measured in mL of CO₂ per kg of fruit per hour. Total soluble solids (TSS) percent were calculated using drops of pomegranate fruit arils juice and a digital hand refractometer (PAL-1, ATAGO, Japan).

According to Zhang and Zhang (2008), twenty-seven fruits of each replicate were evaluated based on the severity scale of browning signs as a ratio between the area of the fruit peel that was affected by brown spots to the total fruit peel area on each sampling date, and fruits were classified into four classes; where 0 indicating no browning, 1 indicating less than 30% browning, 2 indicating 30-70% browning, and 3 indicating more than 70% browning, then percentage was calculated using the following formula; browning index= (sum of (browning category \times fruits number of this category))/(the highest browning category \times total fruits number) $\times 100$.

The activity of the peroxidase (POD) enzyme was measured using the Ghasemnezhad et al. (2015) technique. 1 g of pomegranate arils was ground in 1 mL extraction buffer (50 mM phosphate buffer, pH = 7) with 0.5 mM EDTA and 2% w/v polyvinylpyrrolidone. The homogenate was centrifuged at 15,000g for 15 min, and the supernatant was utilized to assess enzyme activity. At 470 nm, enzyme activity was determined by mixing 250 μ L enzyme extract with 375 μ L guaiacol (10 mM) and 375 μ L H₂O₂ (10 mM). The activity of peroxidase is measured in units per milligram of fresh weight.

According to Nielsen (2010), ascorbic acid was tested using titration methods against a 2,6 dichlorophenol-indophenol solution, and the results were expressed as mg ascorbic acid per 100 g fruit fresh weight (FW). Total anthocyanins in pomegranate arils were extracted from ten gram fresh weight of arils using 100 mL methanolic HCL (0.1%), filtered, and colorimetrically measured at 520 nm (LEE et al., 2008).

All of the results were grouped and analysed as a randomised complete design with three replicates in a factorial arrangement. The influence of coating treatments, storage periods, and their interaction was evaluated using a two-way analysis of variance. The LSD range test was used to examine the variances between means at the 5% level of probability, as reported by Snedecor and Cochran (1989).

Results and discussion

Decay percentage

The impact of the postharvest coating treatments on fruit quality (decay, weight loss, firmness, respiration rate, fruit appearance, and L* value for husk) during storage at 5 °C and shelf life at 20 °C of “Wonderful” pomegranate fruits is shown in Table 1. Under long-term trial conditions, the number of discarded fruits gradually increased. When

compared to untreated fruits, which showed the greatest significant deterioration values during cold storage and simulated market life periods, all of the treatments were helpful in managing fruit deterioration. Chitosan at 1% and 2% considerably reduced fruit deterioration in cold storage, while chitosan applied at a greater concentration (2%) demonstrated the least significant decay under shelf life circumstances.

Table 1. Effect of various prestorage fruit coating treatments on mean performance of pomegranate fruit quality (decay, weight loss, firmness, husk integrity, fruit appearance, and L* value for husk) during storage at 5 °C and shelf life at 20 °C.

Treatment	Decay percentage	Weight Loss percentage	Firmness	Husk Integrity	General Appearance	L value for husk
During 60 d of storage at 5 °C						
Beeswax at 5%	3.16 bcd	4.46 c	37.75 a	5.28 d	8.38 bc	49.14 abc
Beeswax at 10%	2.11 cd	4.24 c	37.97 a	5.32 c	8.47 b	49.32 abc
Chitosan at 1%	1.05 d	5.59 ab	38.11 a	5.34 bc	8.83 a	49.40 ab
Chitosan at 2%	1.05 d	4.14 c	38.03 a	5.37 ab	8.87 a	49.54 a
Paraffin at 10%	4.22 bc	3.29 d	37.65 a	5.39 a	8.16 cd	48.61 de
Paraffin at 20%	5.27 b	3.96 cd	37.58 a	5.40 a	8.03 d	48.25 e
Gum arabic at 5%	2.65 bcd	5.27 b	37.87 a	5.25 de	8.83 a	49.03 bcd
Gum arabic at 10%	1.60 cd	5.34 b	37.93 a	5.22 e	8.74 a	48.93 cd
Control	7.55 a	6.31 a	35.80 b	5.16 f	7.40 e	46.44 f
During 14 d of shelf life at 20 °C						
Beeswax at 5%	8.69 bc	4.96 bc	29.81 a	4.77 d	6.72 b	42.30 c
Beeswax at 10%	7.60 bc	4.09 c	30.15 a	4.96 c	6.72 b	42.45 bc
Chitosan at 1%	4.89 c	5.84 c	30.29 a	5.03 c	7.98 a	42.62 ab
Chitosan at 2%	4.35 c	4.39 c	30.27 a	5.13 b	8.20 a	42.79 a
Paraffin at 10%	9.77 b	4.18 c	28.92 b	5.17 ab	6.06 c	40.62 e
Paraffin at 20%	10.86 b	4.32 c	28.53 b	5.20 a	5.83 c	40.38 e
Gum arabic at 5%	7.06 bc	4.13 c	29.99 a	4.74 d	7.16 b	41.88 d
Gum arabic at 10%	7.06 bc	4.31 c	30.06 a	4.66 e	6.80 b	41.82 d
Control	17.92 a	6.69 a	25.69 c	4.48 f	4.06 d	37.17 f

Means with the different letters are significantly different according to LSD range test ($\alpha < 0.05$).

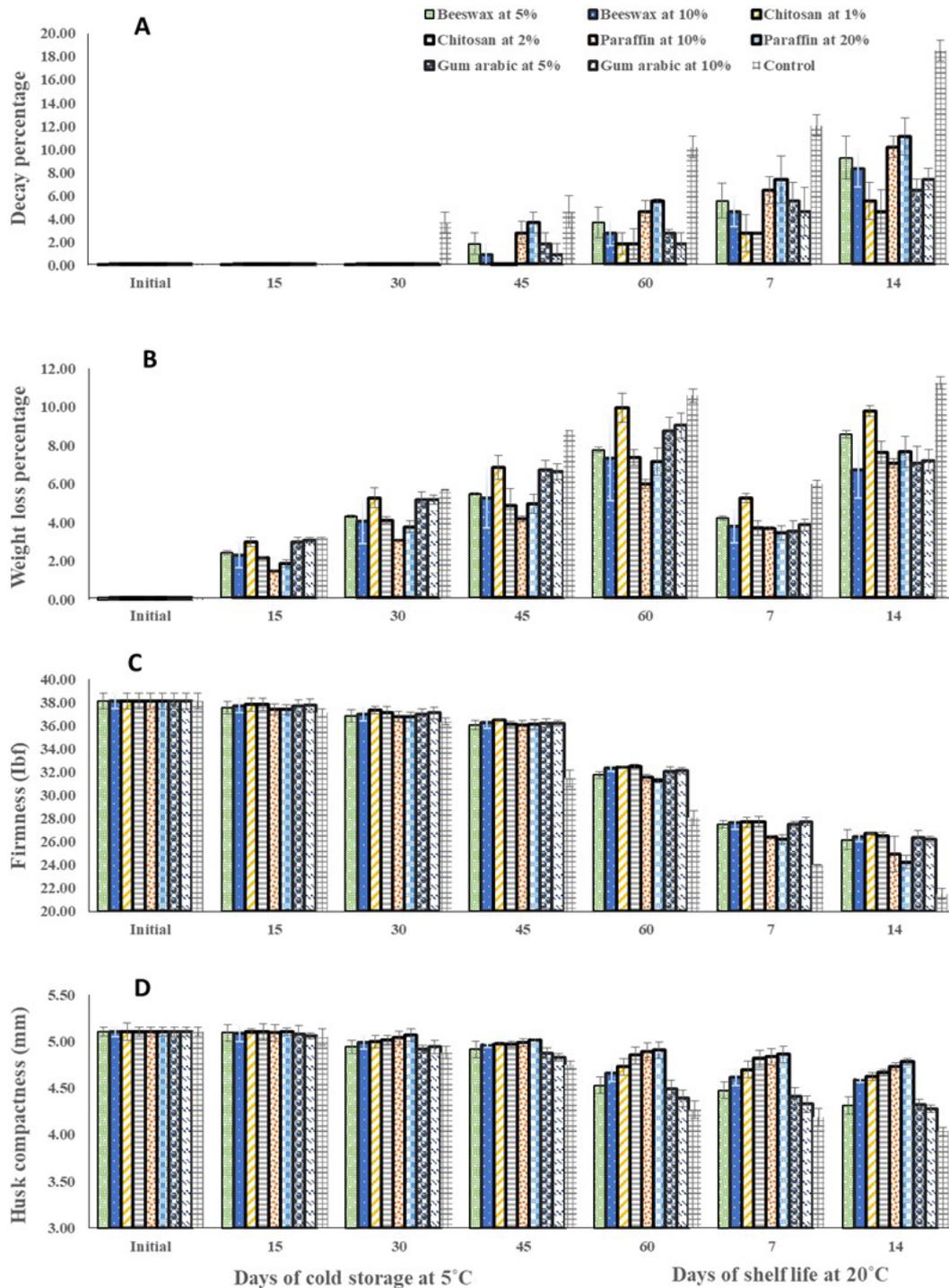


Figure 1. Influence of different postharvest coating treatments on A) Decay percentage (L.S.D^{0.05} = 2.44), B) Weight loss percentage (L.S.D^{0.05} = 1.35), C) Firmness (L.S.D^{0.05} = 1.41), and D) Husk compactness (L.S.D^{0.05} = 0.04) in pomegranate fruit cv. “Wonderful” during cold storage at 5 °C for 60 d, followed by market shelf life at 20°C for 14 d. Error bars represent standard error (SE, n = 3).

Figure 1A. shows the interaction impact of coating treatments and storage periods. Chitosan was the most successful treatment after 60 d of cold storage, as it did not surpass 1.72%. Similarly, by the end of the shelf life period, 2% chitosan had the lowest significant decay value (4.55%), while control had the highest. Under the trial conditions, the percentage of fruits that were discarded increased dramatically after 7 d on the shelf. It is possible that the maximum retention of marketable fruit life under coating is related to reducing gas exchange and respiration rates, which is reflected in the pace of deterioration; it also blocks out tiny defects on the exterior fruit surface, which reduces fruit illnesses and chilling injury (FAWOLE; OPARA, 2013).

The findings show that chitosan is effective in preventing fruit degradation. The findings were consistent with those of Khedr (2018), who found that applying edible coating combined with cold storage (5 °C) on “Valencia” oranges reduced the percentage of discarded fruits when compared to uncoated fruits.

Weight loss percentage

Weight loss percentage increased gradually under all conditions, and all treatments showed lower significant weight loss values during cold storage and shelf life periods compared to untreated fruits (Table 1). Fruits coated with 10% paraffin and 10% beeswax showed the lowest significant weight loss values during cold storage and shelf life, respectively. Figure 1B. shows that by the end of the storage period, control had the greatest significant weight loss (10.22%), whereas paraffin had experienced the least significant weight loss (6.76%). Beeswax at 10%, showed the least substantial weight loss by the end of the shelf life term (7.11%).

These findings are in line with those of Khedr (2017), who reported that paraffin reduced weight loss rate significantly. Post-harvest mass loss from fresh pomegranates is a serious problem, resulting in shrinkage and mass loss (MAGASHI; BUKAR, 2007). To reduce water loss, avoid shriveling of the fruit skin, and fruit weight loss due to respiration, oxidation, and moisture evaporation, surface coatings are commonly used in fruits. The coating procedure leaves a thin layer of coating material on the fruit’s surface, which can act as a semi-permeable barrier to the passage of oxygen, carbon dioxide, and moisture. As a result, water loss rates may be reduced (SHAHID; ABBASI, 2011). The amount of time it takes for water loss or evaporation depends on the temperature, the length of time the fruit has been stored, and the thickness of the fruit skin (FAWOLE;OPARA, 2013).

Firmness (lbf) and husk thickness (mm)

Fruit firmness is an important quality indicator and a factor of post-harvest life. In comparison to untreated pomegranate fruits, all applied coverings aided to preserve fruit firmness (Table 1). The data in Figure 1C. illustrate the influence of various prestorage fruit coating treatments on the firmness of pomegranate fruits, with firmness decreasing as storage time increased. Chitosan at 2% maintained fruit firmness at 33.62 lbf by the end of cold storage at 5 °C, and chitosan at 1% represented higher firmness value (25.14 lbf) by the end of the simulated shelf life period. Khedr (2018) found similar results on postharvest chitosan treatments effects on pomegranate. The findings reveal that there are significant changes in fruit firmness between coatings; these findings are consistent with those reported by Meighani et al. (2015). The coating can be utilized to prevent peel water loss, slow cell wall disintegration, and retain fruit firmness (CANDIR et al., 2018). According to Abu-Goukh and Bashir (2003), fruit softening during storage is linked to changes in the cell wall, and the softening process is thought to be caused by the activities of pectin methyl esterase and polygalacturonase. Furthermore, the improved water retention of these coatings aids in the reduction of water loss and respiration, hence preserving cellular moisture.

Husk compactness reduced steadily with time, and under experimental conditions, fruits treated with 20% paraffin had the greatest significant values when compared to untreated fruits (Table 1). Figure 1D. declare that after 2 weeks of shelf life, the maximum meaningful value for paraffin at 20% treatment was 4.83 mm. Peel thickness indicates to the chemical changes in fruit composition, which is related to the water content and the integrity of the cell wall. The obtained results confirm the role of coating in maintaining cell turgidity; Naeini et al. (2020) discovered similar data related to hardness in the “Malase Yazdi” and “Malase Daneh Siah” cultivars; the cumulative effect could be due to the reduction of the respiratory rate and the greater hardness retained by coating affect the soluble components of the skin.

General appearance score (visual appearance and husk colour)

Figure 2A. illustrate how different prestorage fruit coating treatments affect the overall appearance score of pomegranate fruits. After 30 d of cold storage, the visual quality of the fruit deteriorated progressively, and this deterioration was significant. The treatments used, particularly chitosan at 1 or 2 percent, significantly slowed this deterioration (Table 1). Fruits treated with chitosan at 2% maintained great visual quality during the cold storage period, and it was also effective during shelf life, as its score only reached 7.66 by the end of shelf life, indicating that it maintained a very good appearance at least in comparison to the control.

Figure 2B. presents changes in pomegranate husk colour as a lightness degree (L value). The lightness of the fruit's colour diminished in a linear relationship with storage time. Coated fruits were significantly higher in this value compared to control, and 2 percent chitosan showed superior L values under experiment conditions, recording the highest significant lightness value (46.44) after 60 d of cold storage at 5 °C, as well as the highest significant lightness value (46.44) after 2 weeks of shelf life (40.03). The data shows that the chitosan treatment is still effective after 60 d of cold storage and 14 d of the shelf. The results are congruent with Varasteh et al. (2017), who found that chitosan coatings of 1% and 2% could retain the quality of the pomegranate fruit "RabbabeNeyriz," since chitosan helps to keep the rind colour, decrease browning, and provide a thin layer of glitter to the fruit's surface.

Selcuk and Erkan (2014) stated that the coating could minimize water loss, hence minimizing exterior colour variations, because fruit colour is the first basic quality signal that directly grabs consumers' attention. Previous research has found that the outcomes of long-term storage of sweet pomegranate fruit are similar (BARMAN et al., 2011). The colour shift on the surface of the peel is consistent with the overall appearance of the fruit; chitosan-treated fruits were brighter in colour than the control, which rapidly darkened. Khedr (2018) found comparable results in pomegranates, reporting that chitosan slowed the breakdown of anthocyanins and pomegranate colour degeneration.

Respiration rate (ml CO₂ / kg fruit / hr)

Table 2. declare the effect of different prestorage coating treatments on pomegranate fruit quality (respiration rate, TSS, browning index, peroxidase activity, ascorbic acid, and anthocyanin) during storage at 5 °C and shelf life at 20 °C. Figure 2C. presents the variations in respiration rate of the "Wonderful" pomegranate in response to chitosan, paraffin, beeswax, and gum arabic treatments. The rate of respiration dropped in the early days of cold storage, then increased by degrees as the storage period was extended. In comparison to uncoated fruits, all applied coating materials inhibited fruit respiration of pomegranate fruits, especially gum arabic at 5% and chitosan at 1%, according to the given findings. Gum arabic at 5% demonstrated the lowest significant respiration rates at the end of cold storage and shelf life, 6.31 and 11.35 ml CO₂ / kg fruit / hr, respectively.

These findings are consistent with those of Khedr (2017), who discovered that coating lowered respiration rate. As well, Khedr (2018) discovered comparable outcomes with chitosan-treated "Wonderful" pomegranates. Similarly, the chitosan and gum arabic coatings inhibited respiration rate in terms of O₂ consumption and CO₂ production, forming a thin layer on the fruit's outer surface that acts as a semi-permeable barrier to limit the flow of oxygen, carbon dioxide, moisture, and solutes (SHAHID; ABBASI, 2011).

TSS (%)

The effect of various performed treatments on the TSS content of "Wonderful" pomegranate is shown in Figure 2D. Total soluble solids content increased gradually during cold storage, but went in the reverse direction during shelf life. When compared to untreated ones, gum arabic at 5% had the highest significant fruit concentration of TSS (Table 2). In this regard, towards the completion of the cold storage period, 5% gum arabic recorded 16.32%. In addition, when compared to untreated fruits, gum arabic at 5% had the highest significant fruit level of TSS at 16.81 percent after two weeks under shelf life conditions. The results of this experiment are consistent with those reported by Khedr (2017), and Sanchez-Gonzalez et al. (2011) reported that changes in soluble solids in fruits are usually related to starch hydrolyzing enzymes, with high-level activity of enzymes being the reason for the change from starch to sugars.

Furthermore, because the chemical formula of acid is related to glucose, acid degradation can result in an increase in TSS (BALDWIN et al., 1999). Gum arabic coating inhibited respiration rate in terms of O₂ consumption and CO₂ production significantly. This coat forms a thin film on the fruit's outer surface that works as a semi-permeable barrier to impede the flow of oxygen, carbon dioxide, moisture, and solutes (SHAHID; ABBASI, 2011).

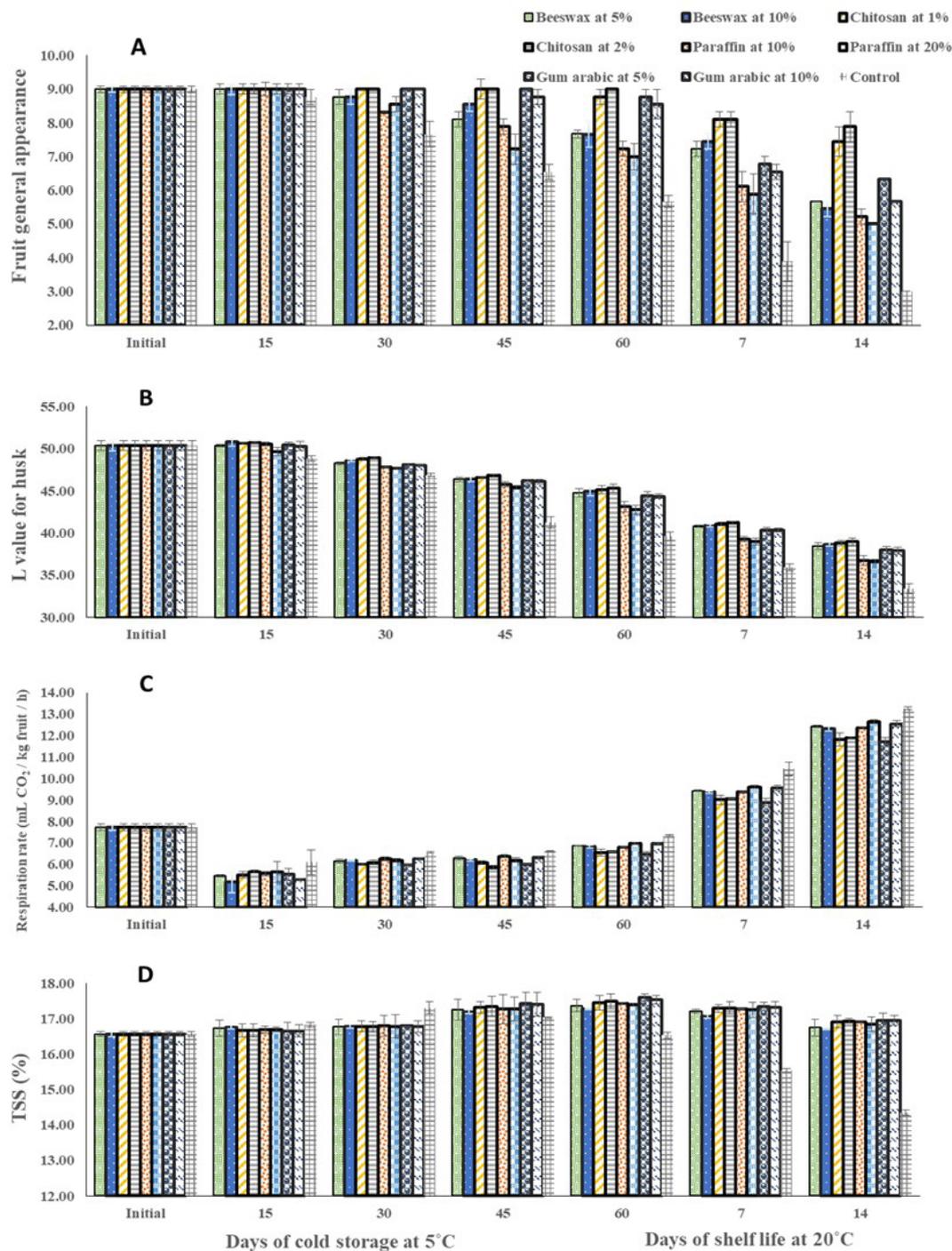


Figure 2. Influence of different postharvest coating treatments on A) General appearance (L.S.D^{0.05} = 0.55), B) L value for husk (L.S.D^{0.05} = 0.91), C) Respiration rate (L.S.D^{0.05} = 0.33), and D) TSS (L.S.D^{0.05} = 0.16) in pomegranate fruit cv. “Wonderful” during cold storage at 5 °C for 60 d, followed by simulated market shelf life at 20°C for 14 d. Error bars represent standard error (SE, n = 3).

Table 2. Impact of various prestorage fruit coating treatments on mean performance of pomegranate fruit quality (respiration rate, TSS, browning index, peroxidase activity, ascorbic acid and anthocyanin) during storage at 5 °C and shelf life at 20 °C.

Treatment	Respiration rate	TSS (%)	Browning index	Peroxidase activity	Ascorbic acid (mg/ 100g FW)	Anthocyanin (mg/ 100g FW)
During 60 d of storage at 5 °C						
Beeswax at 5%	7.30 b	17.09 bc	0.49 c	0.351 c	11.23 cd	13.82 bc
Beeswax at 10%	7.21 b	17.07 c	0.41 c	0.356 c	11.22 de	13.80 cd
Chitosan at 1%	7.15 b	17.11 abc	0.00 d	0.295 e	11.32 ab	13.86 ab
Chitosan at 2%	7.18 b	17.12 abc	0.00 d	0.295 e	11.33 a	13.88 a
Paraffin at 10%	7.34 b	17.10 bc	1.16 b	0.482 b	11.20 de	13.77 de
Paraffin at 20%	7.34 b	17.10 bc	1.24 b	0.505 b	11.19 e	13.74 ef
Gum arabic at 5%	7.12 b	17.16 a	0.08 d	0.326 d	11.26 c	13.84 bc
Gum arabic at 10%	7.31 b	17.14 ab	0.25 cd	0.323 d	11.30 b	13.82 bc
Control	7.72 a	16.99 d	2.90 a	0.780 a	11.14 f	13.72 f
During 14 d of shelf life at 20 °C						
Beeswax at 5%	10.76 bc	17.26 e	5.66 c	0.645 d	10.04 d	11.16 cd
Beeswax at 10%	10.68 c	17.17 f	5.39 c	0.683 c	10.01 de	11.14 de
Chitosan at 1%	10.24 d	17.37 bcd	2.90 e	0.530 e	10.14 ab	11.22 ab
Chitosan at 2%	10.30 d	17.39 abc	2.63 e	0.516 e	10.17 a	11.25 a
Paraffin at 10%	10.69 c	17.35 cd	6.91 b	0.909 b	10.00 e	11.11 ef
Paraffin at 20%	10.94 b	17.31 de	7.06 b	0.915 b	9.99 e	11.09 f
Gum arabic at 5%	10.13 d	17.45 a	3.87 d	0.614 d	10.08 c	11.19 bc
Gum arabic at 10%	10.88 bc	17.43 ab	4.98 c	0.624 d	10.12 b	11.19 b
Control	11.62 a	15.60 g	9.96 a	1.077 a	9.78 f	10.85 g

Means with the different letters are significantly different according to LSD range test ($\alpha < 0.05$).

Browning index and Peroxidase activity

When compared to uncoated fruits, all treatments were beneficial in reducing husk browning incidence, especially chitosan treatments at 1 or 2 percent (Table 2). The pomegranate peel's browning index gradually rose, with the increase being more visible during the shelf life period. The impact of various prestorage fruit coating treatments on the browning index score of "Wonderful" pomegranate is shown in Figure 3A. When compared to the control, the chitosan treatments at 1 and 2 percent prevented browning during cold storage. In comparison to control fruits, which had their visual quality deteriorated sharply by the end of the shelf life period, fruits treated with chitosan at 2% kept their excellent quality during shelf life as their browning score did not exceed 4.25 by the end of the shelf life period. These results are consistent with those obtained by Shengyou et al. (2013). In the enzymatic browning reaction, peroxidase is an important enzyme. In the presence of H_2O_2 , it can rapidly oxidize polyphenols, causing fruits to brown due to the synergistic effect of polyphenol oxidase. Figure 3B. shows the peroxidase activity of pomegranate fruits in response to the treatments used; peroxide activity steadily increases with storage time, but varies substantially during storage. Chitosan at 1 and 2 percent had the lowest significant activities, compared to control, which had the highest significant activities. After 60 d of cold storage, chitosan

at 1% had the lowest significant activity of $0.421 \text{ U mg}^{-1} \text{ FW}$, and chitosan at 1% had the lowest significant activity of $0.726 \text{ U mg}^{-1} \text{ FW}$ after 2 weeks of shelf life conditions.

Browning is one of the limiting factors for long-term preservation of pomegranates, as it not only affects the fruit's visual appearance but also causes undesired flavour alterations and nutrient loss, and there is a substantial association between peroxidase activity and skin browning index (ZHANG; ZHANG, 2008). Vitamin C, according to Tomas-Barberan and Espin (2001), can deoxidize quinone molecules into phenolic compounds, reducing browning. Under low temperature or low humidity, however, this process is hindered, and vitamin C is degraded, resulting in the accumulation of quinone and browning. Shengyou et al., (2013) found that the pomegranate skin tissue has many pores, which causes excessive water loss and browning, and the effect of chitosan may also be related to gas exchange, which is another factor that causes fruit browning, using the right gas composition (low O_2 and high CO_2) can effectively control browning. Physiological metabolic disorders will produce reactive oxygen species and enzymatic browning will rise if the O_2 concentration is too low or the CO_2 concentration is too high, in other words, improper gas composition causes the pomegranate shell to turn brown during storage (TOMAS-BARBERAN; ESPIN, 2001).

Ascorbic acid (mg/ 100g FW)

As shown in Figure 3C, post-harvest interventions had a considerable impact on the concentration of ascorbic acid in pomegranate fruits. Despite ascorbic acid degradation during storage, the conducted treatments were able to preserve a higher level than untreated fruits.

Chitosan at 2% was shown to be the most efficient treatment for preserving ascorbic acid during cold storage and shelf life (Table 2). After 60 d of cold storage at 5 °C and 14 d of shelf life at 20 °C, Chitosan at 2% had the highest significant ascorbic acid concentration of 11.93 and 10.12 mg/ 100g FW, respectively.

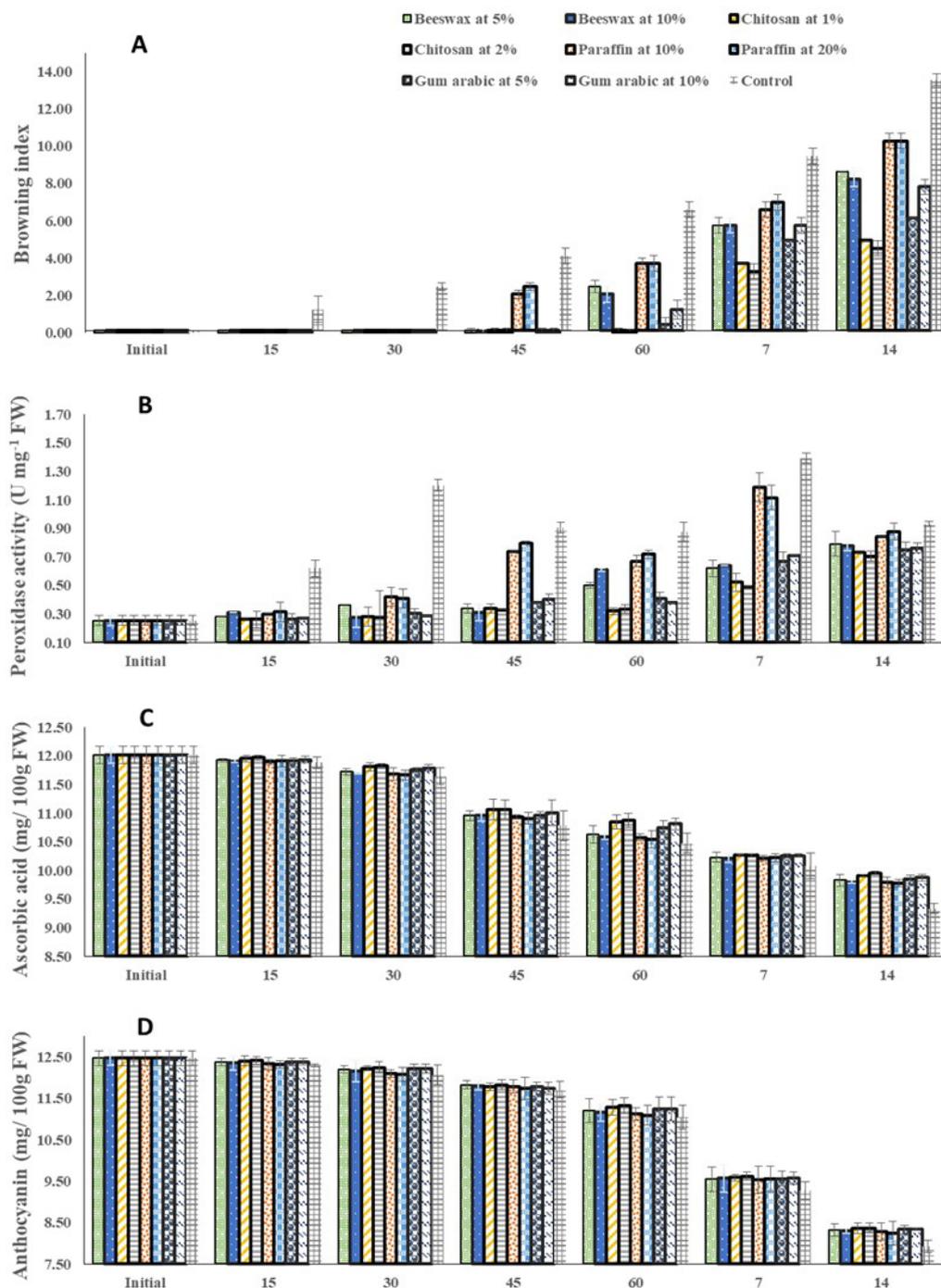


Figure 3. Influence of different postharvest coating treatments on A) Browning index (L.S.D^{0.05} = 0.58), B) Peroxidase activity (L.S.D^{0.05} = 0.02), C) Ascorbic acid (L.S.D^{0.05} = 0.11), and D) Anthocyanin (L.S.D^{0.05} = 0.13) in pomegranate fruit cv. "Wonderful" during cold storage at 5 °C for 60 d, followed by stimulated shelf life at 20 °C for 14 d. Error bars represent standard error (SE, n = 3).

According to the findings, there is a link between ascorbic acid content and peel browning. Ascorbic acid, found in the tissues of fruits and vegetables, is a powerful antioxidant that can effectively prevent browning. When ascorbic acid is exposed to air, it is converted to dehydroascorbate, which loses its antioxidant properties and increases the oxidation of tannins into browning chemicals. The loss of ascorbic acid during storage agrees with a recent work by Khedr (2018), and this degradation could be caused by the indirect dissolution of polyphenol oxidase and peroxidase activity (LEE; KADER, 2000). According to Manzano and Diaz (2001), ascorbic acid is susceptible to oxidative breakdown, which results in the creation of dehydroascorbic acid. Because it decreases ascorbic acid breakdown by hydrolase, the combination treatment and preservation of ascorbic acid from chitosan plays an essential role (ZHANG; ZHANG, 2008).

Anthocyanin (mg/ 100g FW)

Pomegranates, like other red fruits, are high in phenolic components such phenolic acids, flavonoids, and tannins. Anthocyanins are the largest and most important flavonoids found in pomegranate juice (VARASTEH et al., 2017). The effect of several postharvest coating treatments on the anthocyanin pigment concentration of pomegranate fruits is shown in Figure 3D. During cold storage and shelf life periods, anthocyanin pigment concentration declined gradually in all conditions; nevertheless, all treatments had higher significant anthocyanin pigment content than the control, which had the lowest significant anthocyanin content (Table 2). The results are similar with the appearance of the fruit and instrumental colour measurements. Under cold storage and shelf life circumstances, fruits coated with 2% chitosan had the greatest significant anthocyanin content values. The highest value was obtained from chitosan at 2%, which recorded 11.43 mg/ 100g FW at the end of the storage period, and the highest value was obtained from chitosan at 2%, which recorded 8.74 mg/ 100g FW at the end of the shelf life period.

The findings reveal that chitosan is the most efficient in preserving the colour of the “Wonderful” pomegranate. Varasteh et al. (2017) found that “RabbabeNeyriz” pomegranates treated with 1% and 2% chitosan had greater anthocyanin content in pomegranate arils, indicating that di-glucoside anthocyanins are more immutable than mono-glucoside anthocyanins. Additionally, the chitosan coating prevents anthocyanin degradation and pomegranate colour degeneration (KHEDR, 2018).

Conclusion

In conclusion, all treatments considerably improved the quality of the “Wonderful” pomegranate fruit compared to the uncoated ones. Beeswax at 10% and paraffin at 10% reduced weight loss percentages significantly, while gum arabic at 5% maintained moderate rates of fruit respiration and total soluble solids content, and fruit peel thickness was significantly maintained by using 20% paraffin, in addition to chitosan at 1% and 2%, which had a significant effect on peroxidase activity. Many fruit properties improved when chitosan was used at a concentration of 2%, including firmness, fruit appearance, peel colour, ascorbic acid, and anthocyanin content, as well as decay and browning decrease. This suggests that the applied coating treatments, particularly chitosan at 2%, have a valuable effect in maintaining the fruit quality of ripe pomegranate cv. “Wonderful” during cold storage at 5 °C and 90% RH for 2 months and shelf life at 20 °C for 2 weeks, which could be an applied treatment that aids in fruit handling and trading in global and local markets.

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