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POSTHARVEST QUALITY AND CHILLING INJURY OF "SUCCARY" POMEGRANATES AS AFFECTED BY DIFFERENT PACKAGING TYPES

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ABSTRACT

Fully ripe 'Succary' pomegranate fruits were harvested from a private orchard in Ismailia, Egypt in 2015 & 2016 seasons. The fruits were packed in: 1- freely packed fruits (control) 2- sealed fresh bags of high ethylene absorption (HEA) 3- perforated polyethylene (PPE) 4- polyethylene (PE) film (stretchable cling film) 5- commercial PVC (poly vinyl chloride) pages. All packaging treatments were stored at 5 ˚C and 90 – 95% RH for 12 weeks**.** Samples were taken every 2 weeks followed by 4 days at 20˚C. Fruit weight (g) rind thickness (mm), aril /fruit (%), juice content %, juice colour, SSC, acidity%, total sugars%, total phenols% and vitamin C were evaluated at harvest time. Chilling injury of the fruit was reduced by all packaging types. Changes in acidity, and SSC of the packed fruits were lower than that of freely packed fruits (control) during storage period. Cold storage at 5 ˚C with packaging treatments would be the best for preserving the freshness and vitamin C, increasing antioxidant activity, reducing chilling injury and maintaining fruit quality. Consequently, the fruits were more commercially acceptable.

Key words: *Punica granatum L. – fruit quality – packaging – cold storage*

INTRODUCTION

Pomegranate fruits (*Punica granatum* L.) are widely grown in many tropical and subtropical countries, especially in the moderate climate of the Mediterranean region. During the last few years, the activity in research on pomegranate fruit has aimed at the application of new postharvest storage technologies to prolong the storage life of the fruits and to maintain fruit quality.

The physiological status of the fruit play an important role during cold storage and handling processes, aiming to minimize the quality loss. As a non-climacteric fruit, pomegranate does not ripen after harvest, for this reason it has to be harvested when it shows the optimal organoleptic characteristics.

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An essential way to prolong shelf life of pomegranates is optimizing the environmental conditions that will maintain the quality specifications of the fruits within economic margins **(Artés and Tomás-Barberán, 2000)**.

Previous studies have demonstrated that temperature is the most important factor to control the respiratory activity, transpiration and the development of microbial pathogens. This temperature has to be around 5˚C to prevent the production of physiological disorders, during 2-3 months storage. Pomegranates are susceptible to chilling injury when stored for more than 2 months at a temperature below 5˚C **(Kader *et al*., 1984; Artés, 1992)**.

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Chilling injury symptoms of pomegranates appear in the form of brown discoloration of the skin, surface pitting, husk scald, pale colour of arils, brown discoloration of the white segments separating the arils and a high sensitivity to fungal development **(Elyatem and Kader, 1984; Kader *et al.*, 1984; Kader, 1985; Hardenburg *et al.*, 1986; Arte´s, 1992)**.

The use of plastic packaging of intact pomegranates, or even pomegranate arils, in micro perforated polyethylene bags, has also been studied. In these cases, the respiration of pomegranates inside the bags and the selective permeability of the polypropylene films for the different gases in bags that are hermetically sealed (a modified atmosphere, low O_2 and high CO_2) is generated around the fruit. It is important to use films that allow adequate gas level to be produced to achieve the beneficial effects without triggering the fermentative metabolism that leads to off flavour. In this concept, very promising preliminary results have been obtained **(Artés et al., 1995)**. Thus, it is possible to prolong storage life of the fruits with an acceptable quality and to reduce water loss by packaging films.

The aim of this study was to evaluate the effect of different packaging types under cold storage on pomegranate fruits quality, freshness, control of chilling injury and storability.

MATERIALS AND METHODS

This work was conducted during two successive seasons of 2015 & 2016 on 'Succary' pomegranate ((*Punica granatum* L.) fruits. Trees were grown in a private orchard in Ismailia, Egypt. Fruits were harvested and transported to the lab. Sound fruits uniform in size, colour and weight were selected. Initial quality of the fruits at harvest was determined using 20 fruits.

Neither washing nor postharvest chemical treatments were applied. Pomegranate fruits were hand-peeled as shown in images from (1); the arils and rind were weighed separately and expressed as percentages of fruit weight.

Figure 1. Source: http://toriavey.com/how-o/2011/09/how-to-seed-a-pomegranate

Juice was extracted from the arils by using a commercial blender and the juice content was expressed as a percentage. Juice was used for evaluation of juice colour, SSC, titratable acidity, total sugars, total phenols and vitamin C percentages **(AOAC, 1995)**. The data are shown in Table (1).

Table 1. Succary pomegranate fruits quality at harvest in 2015 & 2016 seasons.

Parameters	2015	2016
Fruit weight (g)	434	448
***Rind thickness (mm)**	0.40	0.42
Aril /fruit (%)	65.8	66.5
Juice content %	46.2	45.9
****Juice colour**	0.49	0.47
SSC	16.6	16.2
Acidity%	0.78	0.75
Total Sugars%	13.6	13.4
Total phenols%	43.0	42.8
Vitamin C	85.8	86.4

* Rind thickness measured by using a digital caliper.
** Juice colour measured by a spectrophotometer at 510 nm after making suitable dilution with distilled water (Nanda *et al.*, 2001).

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After fruit conditioning at 30 ± 3 °C and 65% RH for 3 days (Artés and Tomás-Barberán, 2000) the fruits were randomly divided into five groups as following:

1. Freely packed fruits (control; FP).
2. Individual fruit packed in sealed fresh bags of high ethylene absorption (HEA) with permeability of 150-300 cm^3/hour.
3. Fruit packed in lined perforated polyethylene PPE (30µm thickness).
4. Fruits were wrapped with polyethylene (PE) film, 15µm thickness (stretchable cling film; **El Oraby *et al*., 1996)**.
5. Fruits were wrapped in a commercial PVC (poly vinyl chloride) film "X-tend wrapping sheets"; **El Oraby *et al*., (1996)**.

Each of the previous group had 180 fruits divided into two unequal groups 60 labeled fruit, individually weighted and used for weight loss, chilling injury incidence evaluation. Then, 120 fruits were used for quality evaluation, marketability and overall acceptability. After paging, the fruits were placed in one-layer plastic boxes and stored at 5 °C and 90 – 95% RH for 12 weeks **(Fawole and Opara 2013a)**. Fruit samples (20 fruits from each treatment) were removed from the cold storage for quality evaluation at 2, 4, 6, 8, 10 and 12 weeks of storage. Ten fruits were analyzed directly from the cold storage while the rest were kept for 4 days at 20 °C to simulate market condition and to assess fruit quality.

Fruit weight Loss (%): Labeled fruits were weighted individually at each sampling time (15 days). Weight loss was expressed as a percentage of the fruits original fresh weight according to the following equation:

$$\text{FWL\%} = \frac{Wi - Ws}{Wi} x100$$

Where: *Wi* = initial fruit weight,
Ws = fruit weight at sampling date.

External rind colour: Three different measurements at three equidistant points on the equatorial region of each individual fruit was done on 10 fruit of each treatment using a chromameter (Minolta CR 300 color-difference meter, Ramsey, NJ), which provided CIE L, a, and b values. Negative a value indicates green while positive a value indicates red colour. Positive b value indicates yellow rind colour while negative b value indicates blue colour. These values were then used to calculate hue degree, where 0° = red-purple; 90° = yellow; 180° = bluish green; 270° = blue (McGuire, 1992 and El-Shiekh, 2002) and Chroma, which indicates the intensity or colour saturation.

Evaluation of Chilling Injury: After 2, 4, 6, 8, 10 and 12 weeks of cold storage at (5°C ± 0.1 and 90 % RH) fruits were evaluated for chilling injury severity according to the following scale: 0 = sound (no pitting), 1 = slight (a few scattered pits), 2 = moderate (pitting covering up to 30% of the fruit) and 3 = severe (extensive pitting covering more than 30% of the fruit. The chilling injury index was determined for each treatment by multiplying the number of fruit in each category times their score then dividing this sum by the total number of fruit assessed **(Selcuk & Erkan, 2014)**.

Sensory quality for freshness: Aril colour, juiciness and flavour were evaluated by a panel of ten assessors at harvest & after 2, 4, 6, 8, 12 weeks of cold storage at 5°C and during shelf life period.

The evaluation was done on a scale of 1–5, where 5= very good (like harvest freshness; bright pink juicy arils without any off flavour) and 1= very bad (dislike completely, desiccated fruits with brown tough peel, brown colored arils with low juiciness. Scores of 3 (like moderately with retention of arils freshness, colour and juiciness).

Soluble Solids Content (SSC): It was measured in juice by using ATTAGO hand refractometer at 20°C and expressed as percentage.

Titratable Acidity: Was determined in fruit juice by using 0.1 NaOH in the presence of phenolphthalein

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until pH 8.0 and expressed as citric acid percent. As described by **AOAC (1998).**

Vitamin C: Was determined as mg Ascorbic acid / 100 ml fruit juice by titration with 2, 6-dichlorophenolindophenol solution in the presence of oxalic acid **(AOAC, 1998).**

Total phenolic compounds: Were determined using Folin–Ciocalteau reagent and absorbance was read at 760 nm **(Singleton and Rossi, 1965)**. The values were expressed as mg of gallic acid/ 100 g fresh weight **(Spanos and Wrolstad, 1990).**

The antioxidant activity: The samples were analyzed by using DPPH assay according to the procedures of **Gadow *et al*., (1997) and Maisuthisakul *et al*., (2007)**. Diluted sample extract (100 mL, prepared at 5 different concentrations and provided 10–90% inhibition for DPPH radical) was added into 4 mL of freshly prepared DPPH (2,2-diphenyl-1-picryhydrazyl radical) solutions (6 × 10−5 M in MeOH). The mixtures were shaken and kept in the dark at room temperature for 30 min. Absorbance values of the final solutions were estimated at 515 nm using a spectrophotometer (UNICO UV/Visible 2100, USA) versus a control solution (80% MeOH, in place of sample, in DPPH solution). The antioxidant activity of the samples was expressed as percentage inhibition of the DPPH radical, which was calculated by using the following Eq.:

$$I\ \%\ (\text{inhibition percentage}) = \frac{Ac-As}{Ac} \times 100$$

Where, Ac and As are the absorbance values of the control and test samples, respectively. The sample extract concentration providing 50% inhibition (EC_{50}) of the DPPH radical was calculated by plotting the concentration versus inhibition %.

Evaluation of Chilling Injury: After 2, 4, 6, 8, 10 and 12 weeks of cold storage at (5 ˚C ± 0.1 and 90 % RH) chilling injury index was assessed on a 1–5 scale (1 = no injury; 2 = 25%; 3 = 50 %; 4 = 75% of the fruit surface, and 5 = entire fruit Injured). The chilling injury index was determined for each treatment by multiplying the number of fruit in each category times their score then dividing by the total number of fruit assessed **(Selcuk & Erkan, 2014)**.

Statistical Analysis: The experimental design was completely randomized blocks **(Snedecor and Cochran, 1980)**. Groups of four replicates per treatment for the cold storage and shelf-life periods were established. The data analyzed using the Co-Stat program version 3 (Co.Hort. Software) and treatments means were statistically compared using the Duncan's multiple range test ($P \leq 0.05$).

RESULTS AND DISCCUSION

It is clear from (Table 4) that a significant ($P \leq 0.05$) effects of packaging, cold storage and packaging treatments × cold storage interaction on weight loss percentage were noticed at the end of cold storage period in addition 4 days at 20 ˚C.

There were a significant weight loss during storage. The HEA and PPE treatments significantly reduced weight loss compared to the control fruit followed by PE and PVC. The increments in weight loss continued during shelf life. The highest percentage of weight loss was obtained with control fruits whereas the highest was 17.1 % at the end of cold storage.

Pomegranate fruits in PE and PVC pages lost just 4.2% and 4.7% of their weight, respectively (Table 2). With the effect of storage period and shelf life (12 weeks at 5 ˚C plus 4 days at 20 ˚C), the control fruits lost 22.8 % of their weight while fruits of HEA, PPE, PE and PVC pages lost 5.0 %, 5.6 %, 5.2% and 5.9%, respectively (Table 4). The pomegranates are profoundly susceptible to weight loss because of high porosity of the fruits rind, which allows free water vapour development **(Elyatem and Kader, 1984).** The data reported herein showed that all packaging types greatly decreased weight loss during cold storage and shelf life. This could be because of the lower water vapor transmission rate of

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HEA and PPE affecting in dampness loss from the fruits. These findings came in agreements with **Nanda *et al*., (2001), Artés *et al.*, (2000) and Porat *et al*., (2009)**. They noticed that shrink wrapped 'Ganesh' pomegranates at 8 ˚C for 12 weeks or at 15 ◦C for 10 weeks had a low percentage of weight loss in contrast with non-wrapped fruits. While in free packed control 'Mollar de Elche' pomegranates, thermally treated and stored at 2 or 5 ◦C for 12 weeks, weight loss percentage was higher than packed fruits under the same conditions. They illustrated that unpackaged cold stored fruit (control) recorded a higher weight loss percentage, compared with packed ones.

There were a significant ($P \leq 0.05$) effect on lightness values (L) either in cold storage or in shelf life. The L values decreased along the cold storage in all packaging treatments. Whereas fruits in HEA and PPE packaging achieved significantly higher values than the control as for shelf life which had the same trend. The L value decreased from 49.6 at harvest time to 45.8, 45.5, 44.4 and 44.5 for fruits in HEA, PPE, PE and PVC packaging, respectively. But, it was 43.8 for the control fruits (Table 2). The packed fruits in HEA, PPE, PE and PVC seemed fresher and fabulous than control fruits (Table 2).

No noteworthy impact of packaging on Chroma estimations of the fruit ($P \leq 0.05$), showing that the fruit colour stayed steady. It can be noticed that the storage period significantly influenced C values which diminished after harvest. The C value at zero time was 47.4 and diminished to 36.2, 38.4, 38.8, 37.8 and 38.1 for the fruit in HEA, PPE, PE and PVC, respectively (Table 2). During shelf-life period The C esteems somewhat decreased (Table 4)

From the data presented in Tables 2 and 4, cold storage and packaging had a significant effect ($P \leq 0.05$) on h˚ angle. But, at the end of cold storage and 4 days at 20 ˚C there was no significant difference among packaging for the h˚. There was a continuous increment in h˚ values of pomegranates along cold storage. The control fruits recorded the highest significant value compared to packed fruits which was 25.4 at the end of cold storage, whereas the h˚ values at zero time was 18.2.

Based on the data presented here, rind colour values (L, C and h˚) are in concurrence with Artés et al. (1996); Gil et al., (1996); Elyatem and Kader (1984); Gil et al., (1995); Kupper et al., (1995); Palou et al., 2007) who had reported a reduction in rind redness during conventional air storage.

The chilling injury index was significantly ($P \leq 0.05$) affected by storage time and packaging at 5 ˚C. No chilling injury symptoms were appeared on the fruits within the first six weeks of cold storage. At the end of the 12 weeks, chilling injury indexes were 2 in control fruit while HEA and PPE contrasted with 1.65 and 1.6 in PE and PVC, respectively. The chilling injury index was always lower but data failed to show any significant differences between PE and PVC contrasted with the FP (control), HEA and PPE (Tables 2).

In a similar way, **Segal (1981)** reported that 'Wonderful' pomegranate fruits rind punctuates browning with storage temperatures under 14˚C. **Mirdehghan *et al*., (2007)** found that chilling injury developed in all pomegranates fruit from the initial testing date, increased with storage time, and it could be noticed by rind browning, ion leakage and h˚ colour value.

The freshness of pomegranate fruits significantly ($P \leq 0.05$) was affected by storage time and packaging materials. For all types of packaging, the fruits were scored as attractive and satisfactory after 12 weeks of cold storage at 5 ˚C. A significant difference was noticed between control fruits and packed ones after 12 weeks of cold storage at 5 ˚C and after shelf life. Freshness was vigorously influenced by weight loss (Table 2). It was obvious from Tables 2 and 4 that control fruits lost significantly freshness during cold storage and self-life and the fruits became unmarketable. After 4 days at shelf life, no significant

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differences ($P \leq 0.05$) were observed among fruits stored in different types of packaging.

During either cold storage or shelf life periods there was a significant ($P \leq 0.05$) reduction in SSC of pomegranates fruit. However, fruit SSC increased up to the fourth week of cold storage after which fruit SSC decreased for all treatments (Tables 3 and 5). Similar pattern was detected for control fruit. At the end of cold storage and shelf life, no significant differences, in SSC, were noticed between the control and all packed fruits (Table 5).

It can be postulated that, as a result of moisture loss from the most part of fruit rind and arils, SSC content increased. Previous researches on pomegranates by several authors came in agreement with the results of this work **(Navale *et al*., 2010; Koksal, 1989; Ghafir *et al*., 2010; Selcuk & Erkan, 2014). In the contrary, Elyatem and Kader (1984); Nanda *et al*., (2001); D'Aquino *et al*., (2010) Laribi *et al*., (2012); Fawole and Opara (2013b)** noticed a reduction in SSC of pomegranate fruit along the cold storage period and with increasing storage temperature.

There were significant ($P \leq 0.05$) effects of storage time and packaging × storage time interaction for fruit titratable acidity (TA). At zero time, the TA percentage was 0.81% then decreased gradually during cold storage and shelf life. Citric acid at the end of cold storage recorded 0.38 %, 0.4 %, 0.41%, 0.39% and 0.36%, in the control fruit, HEA, PPE, PE and PVC, respectively (Table 3).

A same pattern was detected during shelf life, HEA and PPE packaging treatments where the fruits maintained higher values of citric acid compared to PE, PVC and the control fruits but data failed to show any significant differences (Table 5). Similarly, Artés et al., (2000) decided that there was a relation between metabolic activities and the slow consumption of organic acids in respiration process during cold storage. **Koksal (1989); Gil *et al*., (1996); Waskar *et al*., (1999); Selcuk & Erkan (2014)** noted the same results in different pomegranate cultivars. On the other hand, **Nanda *et al*., (2001)** found a higher maintenance of TA in shrink film wrapped pomegranates in a comparison with the control fruit.

Because pomegranate is a nonclimacteric fruit **(Kader *et al*., 1984; Wonderful cv) and (Artés *et al*., 1998 & 2000; Mollar cv)** fruit lost acidity with the on-going metabolism.

Total polyphenol compounds at harvest were 42.2 mg / 100 g fresh weight. A significant ($P \leq 0.05$) effect of storage time, packaging types, and storage time × packaging interaction was noticed for fruit total phenolic. An increment in total phenolic was detected along cold storage for all types of packaging. Generally, total phenolic increased slightly in the fruits until the end of 5 ◦C storage and shelf life (Tables 3 and 5). Control fruits had higher total phenolic than the packed ones during cold storage. At the end of 5 ◦C storage, total phenolic scored the highest values for the control fruit (46.5 mg / 100 g fresh weight) while the lowest value was achieved by HEA packed ones (37.7 mg /100 g fresh weight; Table 3). The same trend was obtained by the control fruit stored at 5 ◦C plus 4 days at 20 ◦C where phenolic content was the highest (45.5 mg /100 g fresh weight) while the PVC packed fruits had the lowest (37.5 mg /100 g fresh weight; Table 5) content.

The increases in total phenolic were delayed by the use of different packaging. These were in agreement with the findings of **Selcuk & Erkan (2014), Fawole & Opara (2013b), Ayhan & Esturk (2009), D'Aquino *et al*., (2010) and Pe¯na *et al*., (2013)**. When low temperature storage was combined with Modified Atmosphere Packaging (MAP), there was a delay in phenolic accumulation, which might be due to the effect of MAP in delaying postharvest over ripening. This was concluded through the reduction in ethylene production, fruit softening, colour change and acidity loss **(Díaz-Mula *et al*., 2011)**. Also, low O_2 and high CO_2 atmosphere has an effect on delaying each of phenylalanine ammonia lyase (PAL), chalcone

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synthase and/or anthocyanidin synthase, the key enzymes in the biosynthesis of phenolic compounds **(Desjardins, 2008)** or the reduction of polyphenol oxidase (PPO) and/or peroxidase activities **(Pourcel *et al*., 2007)**, the main enzymes responsible of polyphenol degradation.

There were significant ($P \leq 0.05$) effects of storage time, and packaging × storage time interaction on fruits' vitamin C content after 12 weeks of cold storage and shelf life (Tables 3 and 5). At harvest, the average vitamin C content was 86.5% and it decreased continuously in all treatments during the cold storage and shelf life. At the end of cold storage, final amount of vitamin C in pomegranates control fruit, HEA, PPE, PE and PVC scored 60.8 %, 70.6 %, 70.7%, 70.4% and 70.6%, respectively (Table 3). A similar pattern was observed during shelf life and in fruits stored in all bags where the fruits maintained higher values of vitamin C compared to the control. **Koksal (1989)** reported significant loss in vitamin C in pomegranate fruits (Gok Bahce cv.) stored at higher temperatures. **Nanda *et al*., (2001)** also stated that the loss in vitamin C of non-wrapped fruits during storage at different temperatures was significant. The vitamin was better retained in film-wrapped fruits stored at 8 and 15 ˚C for a period of 12 and 9 weeks, respectively, than for other treatments.

Concerning the effect of cold storage duration on EC50 values, there was a significant increment during the first 6 weeks and then fluctuated in all treatments till the end of cold storage (Table 3). These increments were also observed for control and all packed fruits during shelf life until 6 weeks + 4 days, after which changes were detected. The control fruit or fruit packed in HEA had lower antioxidant activity, in a comparison with PE, PVC and PPE packed ones toward the end of shelf life (Table 5). At the early stage of cold storage, EC50 values tended to rise then decreased gradually toward the end of cold storage. EC50 factor is generally utilized by various researchers to decide antioxidant activity **(Vinson *et al*., 1995; Brand- Williams *et al*., 1995)**, the lower the EC50 the higher the antioxidant activity.

There was a direct relation between total phenolic content and antioxidant activity, showing an impact of polyphenol content on antioxidant activity. These outcomes came in agreement with those of **Ayhan & Esturk (2009) and Selcuk & Erkan (2014)** who noticed an increment of antioxidant activity in pomegranate arils during cold storage. But, **Lopez-Rubira *et al*., (2005)** did not find any significant change in antioxidant activity among fruit treated with UV-C radiation doses, storage duration or harvest seasons in pomegranate arils. **D'Aquino *et al*., (2010)** demonstrated that in all cold storage treatments of pomegranates fruit, the antioxidant capacity remained steady.

In conclusion, storage of pomegranates in different packaging significantly reduced weight loss, chilling injury, maintained freshness, increased antioxidant activity and had no significant effect on internal quality of fruit SSC, TA and total phenol. A marked change in external rind, expressed as L, C and h˚ at the end of the cold storage and shelf life was detected. All packaging helped in maintaining nice red color of the fruit at the end of cold storage at 5 ˚C. 'Succary' pomegranates can be stored up to 12 weeks by using packaging without chilling injury or influential loss in weight.

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Table 2. Weight loss %, L, C and h° colour values, chilling injury index and freshness of 'Succary' pomegranates during cold storage at 5 °C (average of two seasons).

Storage period in weeks	[a] Treatments	Weight loss %	Colour values			[b] Chilling injury index	Freshness
			L	C	h°		
0		-	49.6 a	47.4 a	18.2 d	-	5.0 a
4	control; FP	6.8 c	43.7 gh	38.3 de	21.2 bc	1.0 b	4.4 a
	HEA	0.55 h	46.5 b	43.1 b	20.1 c	1.0 b	4.6 a
	PPE	0.64 h	46.4 b	43.2 b	20.3 c	1.0 b	5.0 a
	PE	0.7 h	44.3 e-h	43.0 b	20.2 c	1.0 b	4.8 a
	PVC	0.8 h	44.6 ef	43.0 b	20.2 c	1.0 b	4.8 a
8	control; FP	12.2 b	43.6 h	38.1 de	22.3 b	2.0 a	3.0 b
	HEA	1.9 g	46.3 b	39.6 c	21.3 bc	1.6 ab	4.4 a
	PPE	2.1 fg	46.2 bc	39.2 cd	21.2 bc	1.4 ab	4.5 a
	PE	2.2 fg	44.9 de	39.1 cd	21.2 bc	1.4 ab	4.5 a
	PVC	2.7 f	44.8 de	39.5 c	21.0 bc	1.3 b	4.5 a
12	control; FP	17.1 a	43.8 fgh	36.2 f	25.4 a	2.0 a	2.2 c
	HEA	3.4 e	45.8 bc	38.4 de	22.3 b	2.0 a	3.2 b
	PPE	3.6 e	45.5 cd	38.8 cde	22.4 b	2.0 a	3.2 b
	PE	4.2 d	44.4 e-h	37.8 e	22.3 b	1.65 ab	3.3 b
	PVC	4.7 d	44.5 efg	38.1 de	22.2 b	1.6 ab	3.5 b

- The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Duncan's multiple range test.
[a] FP freely packed fruits (Control), (HEA) high ethylene absorption), PPE polyethylene (30µm thickness), PE polyethylene film, 15µm thickness (stretchable cling film). PVC (poly vinyl chloride) film "X-tend wrapping sheets.
[b] chilling injury index was assessed on a 1–5 scale, describing the severity of chilling injury symptoms (1 = no injury; 2 = 25%; 3 = 50%; 4 = 75% of the fruit surface, and 5 = entire fruit Injured.

Table 3. Soluble solids content SSC, titratable acidity TA, total phenols, Vitamin C and antioxidant activity of 'Succary' pomegranates during cold storage at 5 °C (average of two seasons).

Storage period in weeks	Treatments	SSC (%)	TA (% citric acid)	T. Phenols [b]	Vitamin C [b]	EC50 values [a] (mg mg−1 DPPH)
0		16.6 b	0.81 a	42.2 cd	86.5 a	32.6 h
4	control; FP	17.8 a	0.7 b	43.4 bc	79.4 b	36.7 cde
	HEA	17.4 a	0.72 b	38.0 efg	80.6 b	35.6 ef
	PPE	17.5 a	0.68 b	35.7 gh	81.0 b	34.6 fg
	PE	17.6 a	0.72 b	33.0 i	80.9 b	35.8 de
	PVC	17.4 a	0.7 b	35.0 hi	80.4 b	34.6 fg
8	control; FP	16.2 bc	0.5 de	45.6 ab	68.0 d	39.7 a
	HEA	16.6 b	0.6 c	36.6 fgh	75.0 c	33.6 gh
	PPE	16.2 bc	0.55 cd	40.5 de	74.5 c	34.6 fg
	PE	16.4 b	0.48 e	38.0 efg	75.3 c	36.5 cde
	PVC	16.5 b	0.52 de	39.3 ef	74.6 c	32.6 h
12	control; FP	15.8 cd	0.38 f	46.5 a	60.8 e	40.2 a
	HEA	16.0 cd	0.4 f	37.7 efg	70.6 d	38.6 b
	PPE	15.7 d	0.41 f	39.0 ef	70.7 d	36.4 cde
	PE	15.9 cd	0.39 f	40.0 de	70.4 d	37.2 c
	PVC	15.8 cd	0.36 f	40,5 de	70.6 d	37.3 c

- The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Duncan's multiple range test.
[a] EC50 of Trolox (an antioxidant vitamin E derivative) was determined as 0.12 ± 0.01 mg mg−1 DPPH
[b] (mg /100 g fresh weight)

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Table 4. Weight loss %, L, C and h° colour values and freshness of 'Succary' pomegranates during cold storage at 5 °C plus days at 20 °C (average of two seasons).

Storage period in weeks + 4 days	[a] Treatments	Weight loss %	Colour values			Freshness
			L	C*	h°	
0		-	49.6 a	47.4 a	18.2 e	5.0 a
4 + 4 days	control; FP	9.8 c	43.9 d	38.3 c	21.8 cd	2.8 d
	HEA	1.6 i	46.0 b	40.1 b	20.6 d	4.5 ab
	PPE	1.6 i	45.8 b	40.2 b	20.8 d	4.4 b
	PE	1.7 i	44.1 d	40.0 b	20.7 d	4.6 ab
	PVC	2.0 i	44.2 d	39.6 b	20.8 d	4.4 b
8+ 4 days	control; FP	16.8 b	42.2 d	37.1 d	23.3 b	2.0 e
	HEA	2.9 h	46.0 b	38.6 c	21.8 cd	3.5 c
	PPE	3.1 h	45.8 b	38.4 c	21.9 cd	3.5 c
	PE	3.2 gh	44.5 cd	38.5 c	21.8 cd	3.6 c
	PVC	3.7 g	44.3 d	38.2 c	21.7 cd	3.8 c
12+ 4 days	control; FP	22.8 a	42.1 e	36.0 e	25.8 a	1.2 f
	HEA	5.0 f	45.4 bc	38.5 c	22.9 bc	2.4 de
	PPE	5.6 de	45.7 b	38.6 c	22.8 bc	2.1 e
	PE	5.2 ef	44.2 d	38.3 c	22.9 bc	2.2 e
	PVC	5.9 d	44.1 d	37.8 cd	22.7 bc	2.3 de

- The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Duncan's multiple range test.
[a] FP freely packed fruits (Control), (HEA) high ethylene absorption), PPE polyethylene (30µm thickness), PE polyethylene film, 15µm thickness (stretchable cling film). PVC (poly vinyl chloride) film "X-tend wrapping sheets.

Table 5. Soluble solids content SSC, titratable acidity TA, total phenols, Vitamin C and antioxidant activity of 'Succary' pomegranates during cold storage at 5 °C plus 4 days at 20 °C (average of two seasons).

Storage period in weeks + 4 days	Treatments	SSC (%)	TA (% citric acid)	T. Phenols [b]	Vitamin C [b]	EC50 values [a] (mg mg−1 DPPH)
0		16.6 b	0.81 a	42.2 bc	86.5 a	32.6 h
4 + 4 days	control; FP	17.4 a	0.66 b	40.4 cde	73.4 bc	40.1 bc
	HEA	17.6 a	0.62 b	38.0 de	77.6 b	38.2 d-g
	PPE	17.5 a	0.62 b	37.7 de	77.8 b	38.6 de
	PE	17.4 a	0.64 b	37.0 e	77.5 b	37.6 d-g
	PVC	17.4 a	0.60 b	37.0 e	76.9 b	37.6 d-g
8+ 4 days	control; FP	16.0 cde	0.50 c	43.6 ab	62.0 ef	41.3 b
	HEA	16.2 bcd	0.50 c	39.6 cde	70.0 cd	38.3 def
	PPE	16.2 bcd	0.52 c	40.5 cd	70.5 cd	39.0 cd
	PE	16.4 bc	0.48 c	39.0 cde	70.3 cd	38.2 d-g
	PVC	16.3 bc	0.50 c	39.9 cde	69.9 cd	38.2 d-g
12+ 4 days	control; FP	15.2 f	0.33 d	45.5 a	58.8 f	42.7 a
	HEA	15.7 def	0.39 d	37.7 de	66.6 de	38.8 cd
	PPE	15.6 ef	0.38 d	39.0 cde	66.7 de	36.8 g
	PE	15.6 ef	0.35 d	38.0 de	66.4 de	37.3 efg
	PVC	15.6 ef	0.36	37.5 de	66.6 de	36.9 fg

- The values within a column with different letters are significantly different at $P \leq 0.05$ according to the Duncan's multiple range test.
[a] EC50 of Trolox (an antioxidant vitamin E derivative) was determined as 0.12 ± 0.01 mg mg−1 DPPH
[b] (mg /100 g fresh weight)