Journal of Horticultural Science & Ornamental Plants 11 (2): 97-106, 2019
ISSN 2079-2158

DOI: 10.5829/idosi.jhsop.2019.97.106

Effect of Local and Imported Smart Films on the Quality of Pomegranate Fruits to Enhance the Export

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Abstract: A novel technology such as 'smart' packaging offers the potential of further increase in the shelf life and safety of modified atmosphere packing (MAP) pomegranate whole fruit and arils. This study aimed to evaluate the effect of three different postharvest passive modified atmosphere packaging (PMAP) materials types on maintaining fruit quality to better marketability of "Wonderful" pomegranates and prolong the storage period during two successive seasons (2017 and 2018). The new local smart passive packaging materials including, Local Intelligent bags (P2), Imported Intelligent bags (P3) and Polypropylene blown bags (P4) compared with corrugated carton boxes as control (P1). All treatments and control fruits were stored at 7±1°C and 90-95% RH for 120 days. Fruit quality and related determinations such as physiological weight loss (WL), fruits decay incidence (DI), peel and arils firmness, peel and arils color (Hue angle), juice (JP) percentage, total soluble solids (TSS), total acidity (TA), TSS/TA ratio and total anthocyanin content (TAC) were evaluated periodically after 30 days of cold storage period for 120 days. The obtained results revealed that local produce passive modified atmosphere packaging (MAP) remarkably reduced weight loss, decay incidence and maintained whole fruit quality compared to imported (peak fresh) bag and control (carton box) which in turn increase the foreign marketability of pomegranate fruits.

Key words: Pomegranate "Wonderful" · Passive modified atmosphere packaging · Fruit quality

INTRODUCTION

Pomegranate (*Punica granatum* L.) fruit consumption has increased rapidly throughout the world, mainly because of its medical and nutritive attributes. Thus, considerable commercial and scientific interest exists in prolonging its postharvest life with non-chemical applications as much as possible to meet the year-round demand for this fruit [1]. Pomegranate is an important fruit crop, it is considered one of the promising exportation fruits in Egypt in the last years [2]. Wonderful pomegranate is late cultivar with high yield, large fruit, rich red aril, high juice and good palatability [3]. The limiting factors for prolonged storage of pomegranates are weight loss and shrinkage, higher susceptibility to decay, appearance of skin blemishes (especially scalds). These symptoms may often reach the arils and impair quality and taste [4, 5]. Modified Atmosphere Packaging, known as MAP technology and controlled atmosphere storage (CAS) are novel techniques that are widely applied for preservation of agricultural products especially fruits and vegetables.

Modified atmosphere packaging (MAP) is a passive or active dynamic process of altering gaseous composition within a package [6]. MAP in particular, has proven to be a successful mean of reducing water loss, shrinkage and decay and can also facilitate maintenance of fruit quality for three months or more after harvest [7, 8]. It has been also reported to maintain arils pigments (anthocyanins) better in comparison to samples packed without MAP [9]. In addition, MAP technology has been reported as a simple and also low-cost method to reduce these problems and keep pomegranate quality for up to 12-16 weeks after harvest [10]. In such concern, Caleb *et al.* [11] declared that MAP is a dynamic process of altering gaseous composition inside a package, relying on the interaction between the respiration rate (RR) of the produce and the transfer of gases through the

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packaging material and he added that these two processes are dependent on numerous factors such as storage temperature, film thickness, surface area, produce weight, as well as free headspace within the pack.

Storage temperature is the most important environmental factor affecting on senescence of fruits, because it regulates the rate of physiological and biochemical processes. The effect of storage temperature on keeping the quality of some pomegranate cultivars was studied by [12, 13]. It is known that; the cold storage plays an important role in prolonging shelf life of many fruits and vegetables with keeping their quality during storage. For economically undeveloped countries, it is necessary to discover a cheap and effective storage method to increase its shelf-life by decreasing the natural physiological deterioration and preventing the activity of decay organisms [14].

Therefore, the aim of this study was to investigate the effects of new local smart passive-MAP packages on pomegranate fruits. This was achieved by accomplishing the following specific objectives:

- Investigate the influence of local smart modified atmosphere packaging treatment on fruit quality compared with imported smart packaging during storage periods.
- Prolonged the storage period of pomegranate fruits with retention the highest quality of marketing and consumables with the lowest cost.

MATERIALS AND METHODS

Fruits: Pomegranate fruits (*Punica granatum* L.) cv. 'Wonderful' were harvested from 8-year-old 'trees grown in experimental station of National Research Centre, at Al-Nobaria district, Al-Behera governorate, Egypt during 2017 and 2018 seasons. Pomegranate trees similar in growth and received the common horticultural practices. Fruits were harvested at maturity stage when total soluble solids (TSS) range between 15 and 17°Brix and acidity below 1.85% [15]. Maturity fruits were transported to the laboratory and then selected for uniformity of weight, size and free from any visible blemishes, all fruits washed by tap water and air dried. No postharvest chemicals or fungicides were applied.

Treatments: Fruits were packed in three different postharvest passive modified atmosphere packaging included, Local Intelligent bags (P2), Imported Intelligent bags (P3) and Polypropylene blown bags (P4) while the control fruits (P1) were packed in corrugated carton boxes (Table 1). Each treatment consists of three replicates, 5 kg of fruits for each. All treated fruits and control placed in a cold storage room at (7±1°C and 90 ± 5% RH) for a total storage period of 120 days. Fruit quality assessment were taken at 30-day intervals through storage periods.

Postharvest measurements:

Physical properties:

Weight loss (%): At each date, samples of each treatment were weighed and weight loss (%) was calculated as follows:

$$\text{Fruit weight loss (\%)} = [(A-B)/A)] \times 100.$$

Where:

A= initial fruit weight; B=weight at sampling date

Decay Incidence: was estimated visually using scores, as described by Kader *et al.* [15], on 5 scales, with reference points of 5, severe; 4, moderately severe; 3, moderate; 2, slight; 1, none. The score attribution depends on visible defects and decay percentage on fruits.

Peel and Arils Firmness (Ib/inch^2): were measured using lefra texture analysis (Mehteric Stevens, Model TA/000) with a test speed of 2 mm/sec and 2 mm depth.

Peel and Arils Color: Color was measured with a Minolta colorimeter (Minolta Co. Ltd., Osaka, Japan) on the basis of the CIELAB color system (L*, a*, b*, C* and h?). Peel and arils color as hue angle (h°) value is calculated based on a* and b*values according to the following equation: $h° = \tan^{-1}(b^*/a^*)$ as described by McGuire [16].

Fruit Juice percentage were evaluated.

Total Soluble Solids (TSS, %): was measured to using a digital pocket refractometer (Model PAL 1, ATAGO TM, Tokyo Tech.) in fruit juice [17].

Table 1: Different passive modified atmosphere packaging types.

No.	Packaging types	Characteristics	Thickness	OTR Cc/m^2/d	WVP g/m^2/d
P1	Control Carton box	Lined and coated corrugated paperboard package	-	-	-
P2	Local Intelligent bags	Compost LDPE + LLDPE 3 layers	50 µm	150	39.0
P3	Imported Intelligent bags	Peak fresh Polyethylene 3 layers	50 µm	100	1.8
P4	Polypropylene	Blown film PP	50 µm	190	49.0

Gas Composition: The CO_2 and O_2 concentrations in the headspace gases within sealed bags (3 replicates) were determined with a Food Pack Gas Analyzer (Model 1450 C) once every 4 weeks to measure carbon dioxide production. A sample of 0.5 mL of headspace gas was taken from each bag with a calibrated syringe [18].

Chemical Properties: Total acidity (TA, %): was determined by titrating 5ml juice with 0.1N sodium hydroxide using phenolphthalein as an indicator (expressed as citric acid) described by A.O.A.C. [17]. TSS/Acid ratio was calculated as percent.

Anthocyanin Content (mg/100 ml): was determined calorimetrically at 535 nm in fruit juice as described by Hsia *et al.* [19].

Statistical Analysis: Data of the present study were subjected to the analysis of variance test (ANOVA) as factorial experiment completely randomized design (CRD). Since some recorded data were nil, the data were modified to be statistically analyzed according to the description of "problem data" by Gomez and Gomez [20]. The least significant differences (LSD) was used to compare means at the 5% level of probability.

RESULTS AND DISCUSSION

Fruit Weight Loss (%): Data of the present investigation in Table (2) showed the effect of some types of passive modified atmosphere packaging (PMAP) on weight loss of pomegranate fruits cv. Wonderful during cold storage in 2017 and 2018 seasons. The results indicated that, in both seasons, all enhanced treatment significantly decreased fruit weight loss as compared with the control (P1). Moreover, packaging treatment Local Intelligent bags (P2) was more effective in decreasing weight loss percentage compared with other treatments. The highest weight loss in control carton box (P1) fruits might be due to exposure of fruit surface to the open atmosphere, resulting in higher rate of transpiration and respiration which, in turn, leads to higher weight loss [21]. In the meantime, MAP has proven to be a successful means of reducing water loss during storage, [5]. In addition, MAP of fresh fruit limits water vapor diffusion, thereby generating higher water vapor pressure and relative humidity within the package. Regarding the effect of storage periods on the changes in fruit weight loss was increased with increasing storage period and the differences among all tested storage period were statistical analysis compared with initial date in the two experimental seasons. The main effect of weight loss during storage of pomegranate fruits could be explained as the physiological weight loss of fresh fruit is mainly due to the water loss during the whole period of cold storage and also to the loss of carbon dioxide in respiration processes.

Fruit Decay Percentage: Results in Table (3) showed that, all packaging treatments caused a significant decreased in fruit decay as a compared with the control in two seasons of study. In addition, P2 and P3 treatment was more effective in decreasing fruit decay percentage compared with other treatment. On the other side, fruit decay percentage increased significantly throughout the storage period after 30, 60 and 90 days compared with zero time during 2017 and 2018 seasons respectively. The most observed, decay of pomegranate fruits during storage are mostly the cause of *Penicillium* sp [22]. Moreover, the function of coating is a partial retention of gas exchange through the fruit peel and inhibiting the action of ethylene. Inhibition can give more prevention against postharvest decay and the water loss from the peel so decrease the incidence of decay during storage [23]. The stored apple fruits in polyethylene bags had minor percentage of decay [24].

Table 2: Effect of smart films on fruits weight loss percentage of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons.

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0.00	30.00	60.00	90.00	Mean		0	30	60	90	Mean
P1	0	4.17	6.64	8.75	4.89 ab	P1	0	4.07	6.95	10.41	5.36 a
P2	0	2.70	5.31	9.08	4.27 b	P2	0	3.75	6.04	10.73	5.13 a
P3	0	3.27	6.00	10.24	4.88 ab	P3	0	3.66	8.16	9.22	5.26 a
P4	0	4.04	5.68	9.27	4.75 ab	P4	0	3.97	5.74	10.98	5.17 a
Mean	0 d	3.68 c	6.01 b	9.89 a		Mean	0 d	3.98 c	6.62 b	10.53 a	
LSD at 0.05	T: 0.89 D: 0.80 T×D: 1.77					LSD at 0.05	T: 1.12 D: 1.00 T×D: 2.22				
T: Treatment D: Storage Periods (Days). T×D: Interaction											

Table 3: Effect of smart films on fruits decay percentage of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season42018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	0	11.11	22.22	61.11	**23.61 ab**	P1	0	16.67	38.89	66.67	**30.55 a**
P2	0	5.56	5.56	50	**15.28 b**	P2	0	5.56	33.33	66.67	**26.38 a**
P3	0	16.67	22.22	33.33	**18.06 ab**	P3	0	5.56	11.11	38.89	**13.61 a**
P4	0	5.56	5.56	66.67	**19.44 ab**	P4	0	11.11	22.22	61.11	**23.61 a**
Mean	**0 c**	**12.22 b**	**19.99 b**	**56.66 a**		Mean	0 c	9.73 c	26.34 b	58.34 a	**23.54 a**
LSD at 0.05	T: 13.24	D: 11.84	T×D: 26.16			LSD at 0.05	T: 12.16	D: 10.88	T×D: 24.03		
T: Treatment	D: Storage Periods (Days)	T×D: Interaction									

Table 4: Effect of smart films on fruits peel firmness (Ib/inch^2) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	415.0	336.3	201.7	132.0	**171.3 b**	P1	461.3	368.0	257.0	196.0	**320.6 bc**
P2	415.0	325.7	224.3	172.7	**284.4 b**	P2	461.3	419.3	349.0	252.3	**370.5 a**
P3	415.0	356.0	282.3	231.3	**321.2 a**	P3	461.3	391.0	306.0	251.0	**352.3 ab**
P4	415.0	362.3	284.7	218.0	**320.0 a**	P4	461.3	363.3	309.0	230.0	**340.9 abc**
Mean	**415.00 a**	**346.60 b**	**248.73 c**	**188.07 d**		Mean	**461.33 a**	**386.13 b**	**305.13 c**	**232.67 d**	
LSD at 0.05	T: 25.90	D: 23.17	T×D: 51.18			LSD at 0.05	T: 26.83	D: 23.99	T×D: 53.01		
T: Treatment	D: Storage Periods (Days)	T×D: Interaction									

Table 5: Effect of smart films on fruits arils firmness (Ib\inch^2) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	10.33	9.00	7.33	6.33	**8.25 ab**	P1	11.00	10.00	8.33	7.33	**9.16 ab**
P2	10.33	10.00	9.33	8.00	**9.42 a**	P2	11.00	10.67	10.00	9.67	**10.33 a**
P3	10.33	9.67	8.67	7.67	**9.08 ab**	P3	11.00	10.67	9.33	8.00	**9.75 a**
P4	10.33	9.33	7.67	6.33	**8.42 ab**	P4	11.00	10.00	8.67	7.67	**9.33 ab**
Mean	**10.33 a**	**9.20 b**	**8.00 c**	**6.87 d**		Mean	**11.00 a**	**10.26 a**	**8.60 b**	**7.60 c**	
LSD at 0.05	T: 1.01	D: 0.90	T×D: 1.99			LSD at 0.05	T: 0.99	D: 0.89	T×D: 1.97		
T: Treatment	D: Storage Periods (Days)	T×D: Interaction									

Peel Firmness (Ib/inch^2): Data demonstrated in Table (4) declared that as an average for all used treatments, the initial of peel firmness increased in both seasons compared with control. Moreover, the statistical analysis showed that packaging treatment P2, P3 and P4 were more effective in increasing peel firmness and the differences were big enough to be significant compared with the control (P1). Meanwhile, peel firmness values were decreased with prolonging the storage periods recorded the least values at the end of storage period. Differences among all tested storage periods were statistically significant compared with the initial date in the two seasons of study. Caleb *et al.*, [11] found that lower temperature and high relative humidity has been reported to play a major role in maintaining the physical quality like firmness by reducing its rate of water loss.

Arils Firmness (Ib/inch^2): Data in Table (5) showed that, in both seasons, all packaging materials treatments (P2, P3 and P4) increased arils firmness compared with the control (P1). In addition, statistical analysis declared that P2 treatment in first season, P2 and P3 in second season

Table 6: Effect of smart films on fruits peel Hue angle (h°) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	27.05	24.78	22.51	19.97	**23.58 a**	P1	26.44	23.82	22.1	20.68	**23.26 ab**
P2	27.05	23.66	20.65	20.59	**22.98 a**	P2	26.44	25.79	23.94	21.7	**24.47 a**
P3	27.05	24.64	23.92	20.25	**23.96 a**	P3	26.44	24.57	22.76	20.41	**23.54 ab**
P4	27.05	24.45	23.99	19.94	**23.86 a**	P4	26.44	24.62	21.7	20.62	**23.34 ab**
Mean	**27.05 a**	**23.79 b**	**22.00 c**	**19.80 d**		Mean	**26.44 a**	**24.17 b**	**22.16 c**	**20.50 d**	
LSD at 0.05	T: 0.90 D: 0.80 T×D: 2.21					LSD at 0.05	T: 1.20 D: 1.07 T×D: 2.37				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

Table 7: Effect of smart films on fruits arils Hue angle (h°) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	37.69	27.25	20.8	18.6	**26.09 b**	P1	34.01	28.98	20.74	17.16	**25.22 b**
P2	37.69	30.21	22.93	18.27	**27.27 b**	P2	34.01	28.3	21.59	19.22	**25.78 b**
P3	37.69	33.36	29.53	24.7	**31.31 a**	P3	34.01	31.32	27.11	21.84	**28.59 a**
P4	37.69	30.02	23.88	20.46	**28.01 b**	P4	34.01	30.62	24.42	19.74	**27.19 ab**
Mean	**37.69 a**	**31.09 b**	**25.12 c**	**20.65 d**		Mean	**34.01 a**	**29.69 b**	**23.62 c**	**19.78 d**	
LSD at 0.05	T: 2.16 D: 1.93 T×D: 4.26					LSD at 0.05	T: 1.84 D: 1.64 T×D: 3.63				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

were more effective in increasing arils firmness and the differences were big enough to be significant compared with the control. As for the effect of storage periods on the changes in arils firmness were significantly decreased with increasing storage periods in two seasons of study.

Peel and Arils Color (Hue Angle)

Peel Hue Angle (h°): There were significant differences in fruit peel color (Hue angle) during the storage period using some types of passive modified atmosphere packaging (PMAP) in both seasons compared with untreated (control) fruits in Table (6). Fruits packing with Local Intelligent bags (P2) showed the highest level of Hue angle(h°) at the second season. Meanwhile, there were no significant differences between all used treatments at first season. The peel color Hue angle (h°) was decreased significantly with increasing storage periods in two seasons of study recorded the least values after 90 days of storage compared with zero time.

Arils Hue Angle (h°): Treatment of passive modified atmosphere packaging (PMAP) types showed better color stability and redness during storage period in both seasons compared with control fruits (Table 7). Arils Hue angle (h°) revealed increased by using different packing materials compared with control. Moreover, the statically analysis showed that packaging treatment P3 in the first season, P3 and P4 in the second season were more effective in increasing arils color compared with the control (P1). As for the effect of storage periods on the changes in arils color were decreased with increasing storage periods in two seasons of study and the differences among all tested storage periods were statistically significant compared with the initial date (zero time). Ayhan and Esturk [25] reported that MAP application or storage time had no significant effect on redness, but observed small fluctuations throughout the 18 days of storage at 5°C.

Fruit Juice Percentage: Data of the present investigation in Table (8) showed the effect of some types of passive modified atmosphere packaging (PMAP) on pomegranate fruit quality cv. Wonderful during prolonged cold storage in 2017 and 2018 seasons. All PMA packing treatment (P2, P3 and P4) revealed increase of fruit juice volume compared with control (P1) in both seasons of study. Moreover, Polypropylene blown bags (P4) recorded the highest fruit juice volume compared with other treatments

Table 8: Effect of smart films on fruits juice percentage of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	76.54	76.47	74.67	73.65	**75.33 a**	P1	81.83	79.93	78.43	76.13	**76.08 b**
P2	79.91	76	74.56	73.65	**75.99 a**	P2	79.03	78.47	77.12	75.32	**77.48 b**
P3	78.02	77.05	76.97	74.15	**76.55 a**	P3	79.23	77.85	76.92	75.28	**77.32 b**
P4	79.2	75.33	74.58	74.27	**75.84 a**	P4	79.1	77.5	76.33	74.65	**79.89 a**
Mean	77.45 a	75.49 b	74.43 bc	73.12 c		Mean	78.86 a	77.61 b	76.51 b	74.82 c	
LSD at 0.05	T: 1.72 D: 1.54 T×D: 2.66					LSD at 0.05	T: 1.29 D: 1.15 T×D: 2.23				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

Table 9: Effect of smart films on total soluble solids content of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	17.03	17.2	17.43	18.07	**17.43 bc**	P1	17.6	17.76	17.88	18.3	**17.89 a**
P2	17.03	17.13	17.37	17.8	**17.33 cd**	P2	17.6	17.88	17.9	18.13	**17.88 a**
P3	17.03	17.2	18.07	18.27	**17.64 ab**	P3	17.6	17.92	18.02	18.16	**17.88 a**
P4	17.03	17.93	18.07	18.28	**17.83 a**	P4	17.6	17.77	17.8	18.17	**17.83 a**
Mean	17.03 d	17.32 c	17.62 b	17.94 a		Mean	17.60 b	17.79 ab	17.88 ab	18.14 a	
LSD at 0.05	T: 0.22 D: 0.20 T×D: 0.43					LSD at 0.05	T: 0.35 D: 0.30 T×D: 0.66				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

in 2nd Season 2018. As for the effect of storage periods on the changes in fruit juice volume were decreased with increasing storage periods in two seasons of study and the differences among all tested storage periods were statistically significant compared with the initial date.

Total Soluble Solids (%): Results in Table (9) indicated that all PMA packaging treatment increased fruit total soluble contents compared with the control in both studied seasons. In addition, in first season, statically analysis showed that P3 and P4 treatment were more effective in increasing total soluble solids and the differences were big enough to be significant compared with the control. Meanwhile, there were no significant differences between all treatment in the second season. Regarding the effect of storage periods on the changes in fruit total soluble solids were significantly increased with increasing storage periods and the differences among all tested storage periods were statistically significant compared with the initial date in the two seasons of study. Pomegranate is a non-climacteric fruit of a low respiration rate and recorded a slight decrease in total sugar content during storage at different temperatures. However, the increasing in juice TSS was referred to the loss water of fruit then leading to increase concentration of the soluble solids. The obtained data were agreement with those found by [8, 26].

CO_2 Production and O_2 Consumption: The respiration rate is an indicator of metabolic activity and gives an indication of the potential shelf life of the product. Data in Tables (10 and 11) showed the effect of some types of passive modified atmosphere packaging on carbon dioxide production and oxygen uptake of pomegranates fruit throughout 120 days of storage period at 7±1°C during two successive seasons under study (2017 and 2018). All packages material (Local Intelligent bags P2, Imported Intelligent bags P3 and Polypropylene blown bags P4) showed a significant increase in CO_2 concentration compared with untreated fruits (P1). Local Intelligent bags (P2) treatment gave the highest level of CO_2 production followed by P3, P4 and P1 which recorded the least level during both seasons. By the extension of cold storage period, CO_2 concentration was increased significantly and recorded the highest level after 120 days of storage. On the other hand, O_2 uptake showed the opposite trend. All postharvest packages material showed significant and gradual decrease in O_2 concentration

Table 10: Effect of smart films on gases content (CO_2) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

Storage Period	1st season 2017					Storage Period	2nd season 2018				
	P2	P3	P4	P1	Mean		P2	P3	P4	P1	Mean
	CO_2	CO_2	CO_2	CO_2			CO_2	CO_2	CO_2	CO_2	
0	0.1	0.1	0.1	0.10	**0.1 c**	**0**	0.10	0.10	0.10	0.10	**0.1 c**
30	22.0	18.0	15.0	0.30	**13.83 b**	**30**	22.0	19.0	17.0	0.10	**14.53 b**
60	27.0	20.0	22.0	0.40	**17.35 ab**	**60**	22.0	22.0	22.0	1.00	**16.75 ab**
90	29.0	26.0	21.0	0.50	**19.13 ab**	**90**	25.0	20.0	21.0	1.00	**16.75 ab**
120	35.0	32.0	23.0	0.80	**22.7 a**	**120**	25.0	23.0	23.0	1.00	**18 .00a**
Mean	**22.62 a**	**19.22 b**	**16.22 c**	**0.42 d**		**Mean**	**18.82 a**	**16.82 b**	**16.62 b**	**0.64 c**	
LSD at 0.05	**T: 1.89 D:3.80 T×D: 1.75**					**LSD at 0.05**	**T: 1.72 D: 1..27 T×D: 2.22**				
T: Treatment D: Storage Periods (Days). T×D: Interaction											

Table 11: Effect of smart films on gases content (O_2) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

Storage Period	1st season 2017					Storage Period	2nd season 2018				
	P2	P3	P4	P1	Mean		P2	P3	P4	P1	Mean
	O_2	O_2	O_2	O_2			O_2	O_2	O_2	O_2	
0	21.0	21.0	21.0	21.0	**21.00 a**	**0**	21.0	21.0	21.0	21.0	**21.00 a**
30	10.0	15.0	16.0	20.0	**15.25 b**	**30**	13.0	14.0	16.0	19.0	**15.5 bc**
60	5.0	10.0	14.0	20.0	**12.25 c**	**60**	10.0	15.0	14.0	19.0	**14.5 c**
90	4.0	7.0	15.0	19.0	**11.25 cd**	**90**	13.0	13.0	15.0	20.0	**15.25 bc**
120	2.0	5.0	15.0	19.0	**10.25 d**	**120**	15.0	16.0	15.0	20.0	**16.5 b**
Mean	**8.40 d**	**11.60 c**	**16.20 b**	**19.80 a**		**Mean**	**14.40 c**	**15.80 b**	**16.20 b**	**19.80 a**	
LSD at 0.05	**T: 2.31 D: 1.01 T×D: 2..99**					**LSD at 0.05**	**T: 0.99 D: 1.09 T×D: 1.97**				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

Table 12: Effect of smart films on titratable acidity percentage of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

Treatment	1st Season 2017					Treatment	2nd Season 2018				
	Storage Periods (Days)						Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	1.17	0.88	0.85	0.73	**1.00 a**	**P1**	1.08	1.00	0.97	0.94	**1.00 a**
P2	1.17	0.93	0.92	0.81	**0.96 ab**	**P2**	1.08	0.93	0.9	0.87	**0.94 b**
P3	1.17	0.97	0.96	0.77	**0.97 ab**	**P3**	1.08	0.91	0.89	0.87	**0.94 b**
P4	1.17	1.09	1.06	0.77	**0.91 b**	**P4**	1.08	0.96	0.93	0.91	**0.97 ab**
Mean	**1.17 a**	**0.98 b**	**0.96 b**	**0.77 c**		**Mean**	**1.08 a**	**0.96 b**	**0.93 bc**	**0.90 c**	
LSD at 0.05	**T: 0.06 D: 0.05 T×D: 0.12**					**LSD at 0.05**	**T: 0.04 D: 0.03 T×D:0.07**				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

compared with control (P1) which revealed the lowest O_2 concentration. There was a significant decrease in O_2 concentration by prolonging cold storage duration till 120 days. The gas content changed rapidly during the first 30 days and then the change was slowing during 120 days of storage period. The reduction in O_2 levels reduces respiration rate of fruit and vegetables, due to a decrease in the activity of oxidative enzymes such as glycolic acid oxidase, ascorbic acid oxidase and polyphenol oxidase [27]. Decreasing respiration rate via MA and lowering temperature delays enzymatic degradation of complex substrates and reduces sensitivity to ethylene synthesis [28, 29].

Titratable Acidity (%): Titratable acidity of pomegranate fruits cv. Wonderful were decreased by using all passive modified atmosphere packaging (PMAP) treatment compared with control in Table (12). P2 and P3 packaging treatment were more effective in decreasing fruit titratable acidity compared with other treatments in the second season. On the other side, P4 packaging treatment showed the least percent of titratable acidity in the first season. As for the effect of storage periods data indicated that fruit titratable acidity content significantly decreased in both seasons, with increasing the storage periods reached the lowest percent after 120 days of storage. The observed decrease in acidity with ripening could be

Table 13: Effect of smart films on total soluble solids/acid ratio of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	14.62	16.89	17.04	21.9	**17.61 b**	P1	16.38	17.65	18.3	19.16	**17.87 b**
P2	14.62	19.47	20.43	24.95	**19.87 a**	P2	16.38	19.21	19.83	21.13	**19.13 a**
P3	14.62	18.46	18.95	22.6	**18.66 ab**	P3	16.38	19.66	20.14	20.94	**19.28 a**
P4	14.62	17.79	18.75	23.74	**18.73 ab**	P4	16.38	18.36	19.03	19.48	**18.31 ab**
Mean	**14.62 c**	**17.82 b**	**18.46 b**	**23.47 a**		Mean	**16.38 c**	**18.68 b**	**19.31 b**	**20.14 a**	
LSD at 0.05	T: 1.40 D: 1.25 T×D: 2.77					LSD at 0.05	T: 0.85 D: 0.76 T×D: 1.68				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

Table 14: Effect of smart films on total anthocyanin content (mg/100 ml) of pomegranate cv. Wonderful during cold storage at 7±1°C and 90 ± 5% RH in 2017 and 2018 seasons

1st Season 2017						2nd Season 2018					
Treatment	Storage Periods (Days)					Treatment	Storage Periods (Days)				
	0	30	60	90	Mean		0	30	60	90	Mean
P1	30.0	28.37	26.15	22.05	**26.64 a**	P1	31.0	29.22	28.46	25.9	**28.64 a**
P2	30.0	28.95	26.49	23.62	**27.27 a**	P2	31.0	28.51	27.13	26.05	**28.17 a**
P3	30.0	27.04	26.75	25.12	**27.23 a**	P3	31.0	29.01	28.98	25.89	**28.72 a**
P4	30.0	28.69	26.58	25.56	**27.71 a**	P4	31.0	29	27.9	26.75	**28.66 a**
Mean	**30.00 a**	**28.39 a**	**26.61 a**	**24.36 a**		Mean	**31.00 a**	**28.19 b**	**27.49 b**	**25.72 c**	
LSD at 0.05	T: 4.86 D: 4.35 T×D: 9.61					LSD at 0.05	T: 1.28 D:1.15 T×D: 2.53				
T: Treatment D: Storage Periods (Days) T×D: Interaction											

attributed to an array of factors, such as transformation of acids to other compounds and reduced ability of fruits to synthesize acids with maturity [30, 31]. Organic acids in pomegranate such as citric, malic, acetic, fumaric, tartaric and lactic acids while, the main acid accounting for terrible acidity in pomegranate arils is citric acid. At storage, fruits still respire and this process was consumed the main acid content of fruits (citric acid). For this reason, the acidity decreased during storage [32].

TSS/Acid Ratio (%): Data in Table (13) showed that all PMA packaging treatment increased fruit total soluble solids/acid ratio compared with the control during the two successive seasons under study. In addition, statically analysis cleared that P2 treatment in 1st season 2017, P2 and P3 2nd season were more effective in increasing total soluble solids/acid ratio and the differences were big enough to be significant compared with the control. Regarding the effect of storage periods on the changes in fruit total soluble solids/acid ratio were significantly increased with increasing storage periods and the differences among all tested storage periods were statistically significant compared with the initial date in the two seasons of study. It is known that, during storage there is antagonistic relation between T.S.S and acidity while water loss and TSS increase but acidity decreases that due to the process of respiration in fruits, thus, T.S.S/Acid ratio increases too. The same line of results was showed by [33, 34].

Total Anthocyanin Content (mg/100 ml): Anthocyanins represent a group of widespread natural phenolic compounds in plants and are responsible for their colors [35]. All PMA packaging treatment increased total anthocyanin content in arils compared with the control in both seasons Table (14). As for the effect of storage periods on the changes in anthocyanin contents were decreased with increasing storage periods in two seasons of study and the differences among all tested storage periods were statistically significant compared with the initial date (harvest) in the first season of study. Talarposhti *et al*. [36] reported that one possible reason for increase in anthocyanins such as Pg35dG could be the post-harvest biosynthesis of phenolic compounds, which is, in turn, dependent on the enzyme activity of the biosynthetic pathway, such as PAL in the arils of two commercial pomegranate cultivars (‘Malas-e-Saveh’ and ‘Yousef-Khani’. On the other side, Gil *et al*. [9]. found no significant change in total anthocyanin content of 'Mollar' arils harvested in early October during MAP storage at 1°C for 7 days.

ACKNOWLEDGEMENT

This research was supported by Science and Technology Development Fund in Egypt (STDF) No (10489) for the production and evaluation of the first smart film produced in Egypt with the cooperation of El-Kadysia company to enhance shelf life of fruit and vegetables during exporting.

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