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THE EFFECT OF VARIOUS FILM PACKAGING, WAX COATING AND STORAGE CONDITIONS ON THE SHELF LIFE AND QUALITY OF POMEGRANATE FRUITS

Mohammad Reza SAFIZADEH*
Shiraz University, Department of Plant Production,
College of Agriculture and Natural Resources of Darab, 7459117666, Darab, Iran

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ABSTRACT

In this study, 'Rabbab' pomegranates (*Punica granatum* L.) were subjected before storage to single-layered wax coating (SLW), double-layered wax coating (DLW), individual-seal film packaging (ISP), tray wrap film packaging (TWP), and combined treatments of SLW + ISP or SLW + TWP. Treated fruits were then stored at ambient temperature (15–20 °C; 45–50% relative humidity – RH) or in cold conditions (5 °C ± 0.5; 85% RH) for 18 weeks. TWP, ISP, DLW, and SLW extended the shelf life of pomegranates for 18, 18, 12, and 11 weeks at cold (5 °C) condition, and also for 6, 5, 3, and 3 weeks at ambient condition, respectively, whereas the shelf life of control fruits were 10 and 2 weeks at cold and ambient conditions, respectively. After 18 weeks of storage, the weight loss in ISP and TWP fruits was 0.6 and 0.4% at cold condition and 12.4 and 5.4% at ambient condition, respectively. In general, film packaging maintained vitamin C, total titratable acidity, and sensory analysis scores for color, freshness, juiciness, and taste of pomegranates more effectively than wax coating and control. However, the combination of SLW and ISP or TWP did not improve the efficiency of pomegranates packaged as either ISP or TWP.

Keywords: ambient conditions; chemical properties; cold storage; individual-seal packaging; plastic film; tray wrap

INTRODUCTION

Pomegranate fruits are usually earmarked for fresh consumption of arils but in various countries, they are also processed by the food industry into beverages, flavorings and coloring agents (Gil et al. 2000). The edible parts of pomegranate (arils) represent around 60% of total fruit weight and contain about 80% juice and 20% seeds. Arils contain considerable amounts of sugars (mainly fructose and glucose), acids, pectin, ascorbic acid, polyphenolic antioxidant, anthocyanins, amino acids, and minerals (Roy & Waskar 1997).

The health benefits of pomegranate are related to the high antioxidant activity that strongly contributes to the high content of polyphenolic compounds (Smith 2014). Pomegranate fruits are associated with the prevention of the coronary heart disease and some types of cancer (Heber & Bowerman 2009).

Therefore pomegranates have nutritional and commercial importance in terms of its special functional composition and consumption demand. Chilling injury, weight loss, and decay during storage are the most important problems, which limit its marketing and result in a severe postharvest loss (Kader et al. 1984). A proper cold condition during storage is especially important due to fruit susceptibility to chilling injury if stored in air (conventional cold storage) at 5 °C or at lower temperatures (Kader 2006). Fruits are also highly susceptible to weight loss and decay during postharvest storage, especially when stored at a temperature above those that cause chilling injury (Hess-Pierce & Kader 2003). Modified atmosphere packaging (MAP) has been proven to reduce chilling injury and husk scald symptoms (Nanda et al. 2001). Plastic films are widely used in packaging and continue to grow in use as more applications switch to flexible packages

*Corresponding author:
e-mail: safizade@shirazu.ac.ir

such as MAP (Ben-Yehoshua 2005). Individual wrapping of fresh fruit and vegetables in heat-shrinkable film extends the storage life by maintaining firmness and reducing the transpiration rate (Cohen et al. 1990); it also delays the physiological deterioration and increases the storage life of the fruits (Kader & Arpaia 2002). D'Aquino et al. (2001) reported the packaging of fruit in a tray wrapped with plastic film. Wax coating is sometimes used to preserve the quality and surface color and reduce weight loss of pomegranate fruit (Waskar et al. 1999). Thus, the purpose of this study was to investigate the effects of wax coating, individual fruit packaging or tray wrap with heat-shrinkable film and their combination on the shelf life and quality of 'Rabbab' – commercial cultivar of pomegranates – stored at ambient and low temperatures.

MATERIAL AND METHODS

Fruit sampling

The experiment was conducted in 2017 but earlier preliminary tests were carried out for two consecutive years for determining the optimal wax concentration and proper storage temperature of fruits. Pomegranate fruits (*Punica granatum* L.) 'Rabbab', which are commercially grown in the south of Iran (Neyriz-Fars), were harvested at commercial maturity and transported in bins to a local packinghouse. Healthy and uniform fruits, free from cracks, sunburn, bruises, and cuts in the husk, were randomly distributed into different lots. Neither washing nor postharvest chemical treatments were applied.

Treatments

The fruits were divided into seven groups and subjected to the following treatments: (1) control (no film packing or wax coating); (2) single-layered wax coating (SLW); (3) double-layered wax coating (DLW); (4) individual seal packaging (ISP); (5) SLW + ISP; (6) tray wrap packaging (TWP); (7) SLW + TWP.

Surface coating

For the SLW, the fruits were treated with an aqueous wax emulsion, containing 12.5% solids (no off-flavors were noted at this concentration). The composition by the weight of the wax was as follows: carnauba wax 60 parts, bee wax 10 parts, morpholine 15 parts, and oleic acid 15 parts. The fruits were dipped in the wax emulsion for 1 min at 20 °C, and were then drained and dried in a warm flow of air (38–52 °C) with a distance of 50 cm for 3–4 min. In the case of DLW, a commercial wax (Citrashine, Decco, Italy) 1 : 2 was also applied by dipping in the wax emulsion for 1 min at 20 °C after SLW coating. The objective was to control the weight loss with the SLW and increase in gloss with the DLW. When two coatings were applied, the first coating was dried before applying the second one.

Individual seal packaging

Wax-coated (SLW) or uncoated fruits were wrapped individually using heat-shrinkable film, Cryovac MR 15 μm thick (MR) (Grace Italiana, Cryovac Division, Milan). Film characteristics are given in Table 1. Heat-shrinkable film was applied by inserting individual fruits into film envelope sealed with L-bar sealer (Model-M-101, Polytechnic Khavandy Inc., Shiraz). The film was shrunk onto the fruit by being passed through a heat tunnel for 10–15 s at 150–175 °C. The short time exposure of the fruit to the high temperature in the heat tunnel did not adversely affect the quality of pomegranates. Then, six sealed fruits were packed into each plastic tray (20 × 30 × 5 cm).

Tray wrap

Six wax-coated (SLW) or uncoated fruits were packed into each plastic tray and over wrapped with heat-shrinkable film. The film was shrunk onto the tray and the fruits by being passed through a heat tunnel as described for single wrapping.

Table 1. Properties of the used film

Property	Plastic film
	Cryovac MR
Thickness	15 μm
Water transmission rate	23 g·24 h^{-1}·m^{-2} bar at 38 °C and 100% Delta RH
O_2 permeance	9500 cm^3·24 h^{-1}·m^{-2} bar at 38 °C and 100% Delta RH
CO_2 permeance	26500 cm^3·24 h^{-1}·m^{-2} bar at 38 °C and 100% Delta RH

Storage conditions

To study the effect of storage temperature on the fruit quality, 24 fruits (six fruits × four replicates per treatment, randomly selected), each from wax-coated, film-packaged and control (seven treatments), were stored at cold (5 °C ± 0.5; 85–90% relative humidity – RH) or ambient storage (15–20 °C; 45–50% RH), for 6, 12, and up to 18 weeks. In addition, the same number of fruits was considered to be evaluated for shelf life and subjective assessments after 6, 12, and 18 weeks. All fruit traits were measured regardless of their shelf life period by the end of the experiment.

QUALITY ASSESSMENT

Fruit water relations

The samples (six fruits × four replicates per treatment) were weighed at the beginning of the experiment and at the end of each storage period (6, 12, and 18 weeks), and results were expressed as the percentage loss of the initial weight. The fruits were hand peeled; then, 10 disks (10 mm in diameter) of rind tissue of each replicate fruit were cut with cork borer, weighted and then, the water content of the peel was determined by drying peel segments at 80 °C, which was expressed as the percentage of the peel water. Using a juice extractor, fruit juice content was determined by extracting from replicate samples of 100 g of arils per fruit and was expressed as a percentage. Extracted juice was then used to determine the following chemical properties.

Chemical analysis

The juice was filtered through cheesecloth and was then used for measuring total soluble solids (TSS), total titratable acidity (TTA) and vitamin C content. TSS was measured using a refractometer (Abbe Refractometer Model 10450, American Optical, USA). TTA was determined by titration to pH 8.1 with 0.1 N sodium hydroxide solution and expressed as g of citric acid per 100 g of juice. Vitamin C content of the juice was determined by the indophenol titration method (AOAC 2000) and results were expressed in mg·100 ml^{-1} of the juice.

Shelf life and subjective assessments

Ten members of an experienced sensory panel evaluated the visual appearance and flavor after each storage period. Panelists rated the intensity of the attributes including freshness (firm, crisp, bright color, and the absence of visual defects or completely desiccated fruit), aril color (bright pink or brown color), juiciness (juicy or low juicy), and flavor (without any or with off-flavor). Evaluation was scored on a five-point scale (1 – most dislike; 2 – dislike a little; 3 – moderately like; 4 – good; 5 – most like). Scores of 3–5 were considered acceptable for commercial purposes. The shelf life was calculated by counting the days required to attain the border point for freshness and glossy appearance of fruit, flavor, red color, and juiciness of aril. Scores below 3 were considered the border point for quality attributes. Any pomegranate with visible mold growth was considered decayed. Fruit decay incidence was expressed as the percentage of fruit showing decay symptoms. The storage temperature of 5 °C was selected since our preliminary experiments showed that 'Rabbab' could be safely stored at 5 °C for up to 4 months. Therefore, the chilling injury was not considered.

Statistical analyses

The experimental design in this study was completely randomized. Groups of four replicates containing six fruits per treatment were used. Gathered data were subjected to analysis of variance with storage duration, postharvest treatment, and storage conditions as factors using SAS software (SAS Institute, USA).

RESULTS AND DISCUSSION

Weight loss

All pre-storage treatments significantly reduced weight loss comparing to control (Fig. 1). ISP and TWP fruits showed 12.4 and 5.4% weight loss, respectively, at ambient temperature after 18 weeks' storage compared with 47.5% for the control fruits. The weight loss was further reduced when the film-packaged fruits were stored at 5 °C (Table 2, Fig. 1). ISP and TWP fruits lost their weight only 0.6 and 0.4% when stored at 5 °C after 18 weeks, compared with 7% for the control fruits (Table 2). Reduction in weight loss by shrink wrapping was also reported in 'Ganesh' (Nanda et al. 2001) and 'Primosole' pomegranates (D'Aquino et al. 2010). Since transpiration contributes most to the postharvest deterioration of the fruit, more attention has been given to controlling it rather than respiration (Alferez et al. 2005).

High-humidity storage was shown to increase the storage potential of fruits (Henriod 2006), and the major effect of film packaging was to maintain high in-package humidity (Ben Yehoshua et al. 2001). In our experiment, both methods of packaging - ISP and TWP provided conditions for lower water loss. This happened because a saturated humidity atmosphere was formed inside the package; hence, due to the lower permeability of the film package to water vapor, with a decline in water vapor pressure gradient between the fruit and the internal atmosphere of the packaging led to reducing fruit transpiration. The low temperature storage at 5 °C effectively delayed weight loss of the fruits compared with the fruits held at ambient temperature. These findings confirm the results of previous studies (Artés & Tomás-Barberán 2000) which showed that the first and most important factor affecting pomegranate fruit quality is storage temperature.

There was a significant reduction in weight loss for both DLW and SLW fruits compared with the control fruits, although DLW fruits showed significantly lower weight loss (28.6%) than SLW fruits (40%) when they were stored at an ambient condition. Previous research (Hagenmaier & Baker 1993) also revealed that coating with two wax layers kept weight loss low, additionally solving a problems associated with high gloss of fruit surface. However, with regard to the combined treatments of SLW with ISP or TWP, the application of SLW coating did not significantly reduce weight loss when compared with either ISP or TWP. DLW coating provided an attractive sheen to the fruit surface but did not have any superior effect on the reduction of weight loss than those in ISP or TWP. Even though the waxes reduced gaseous exchange, they were not as effective as the plastic film in reducing weight loss.

At ambient temperature, during the storage (Fig. 1) and at the end of the storage period (Table 2), fruits in TWP showed less weight loss than those in ISP. This was also reflected by a lower loss in the rind moisture content of TWP fruits as compared with ISP fruits (Table 2). Kawada (1982) stated that the diffusion surface of gases per respiration mass of an organism in ISP fruits is higher than fruits packed together in a plastic bag. This finding supports our suggestion that ISP fruits have lost more water vapor where the emission surface area was greater than that of TWP fruits. However, no significant differences were found among weight losses of the fruits in TWP and ISP under cold storage condition (5 °C). This result seems to reflect the comparatively low water vapor transmission under cold storage, rather than to disprove our findings.

Table 2. The effects of skin coating with wax and film packaging on the physical parameters and decay incidence (mean ± SD) of pomegranate fruit after 18 week's storage at ambient condition (15–20 °C) and at 5 °C

Treatment	Weight loss (%)		Juice content (%)		Rind moisture (%)		Decay incidence (%)	
	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C
Control	47.5±4.16 e*A	7.0±0.73 cB**	70.1±6.47 cB	76.8±6.16 abA	6.1±0.53 e B	15.5±2.30 cA	25.0±1.91 aA	8.3±0.72 aB
SLW	40.0±5.11 dA	3.5±0.31 bB	76.2±9.15 abA	77.6±7.26 abA	8.7±0.32 d B	18.4±0.92 bA	20.8±3.52 aA	0.0±0.00 aB
DLW	28.6±3.49 cA	2.1±0.18 baB	74.4±6.48 bA	77.4±6.45 abA	11.1±1.08 cB	18.9 ±1.16 abA	25.0 ±2.07 aA	0.0±0.00 aB
ISP	12.4±0.96 bA	0.6±0.53 aB	79.4±6.48 aA	76.5±5.98 abA	13.9±2.14 bB	20.0±2.3 abA	29.2±3.61 aA	0.0±0.00 aB
SLW + ISP	11.2±0.83 bA	0.4±0.06 aB	77.8±7.30 abA	78.9±5.62 abA	13.8±3.07 bB	20.4±1.17 aA	20.8±1.38 aA	8.3±0.66 aB
TWP	5.4±0.37 aA	0.4±0.01aB	78.6±5.02 abA	77.7±5.37 abA	16.6±0.95 aB	19.5±2.44 abA	33.3±2.59 aA	12.5±0.90 aB
SLW + TWP	4.7±0.52 aA	0.3±0.01 aB	77.5±8.39 abA	81.2±8.72 aA	16.9±2.91 aB	20.6±1.76 aA	33.3±3.60 aA	12.5±1.03 aB

*Values within each column followed by the same superscript letter (a, b) are not significantly different according to Duncan's multiple range test at p = 0.05
**Values within each row grouping followed by the same capital letter (A, B) are not significantly different according to t-test (p = 0.05)

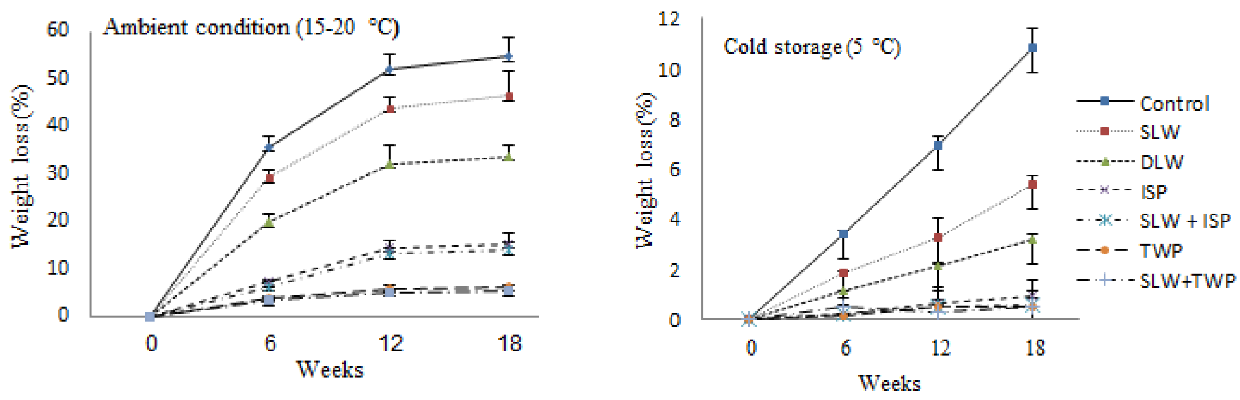

Fig. 1. The effects of skin coating with wax and film packaging on weight loss percentage of pomegranate fruit during storage at ambient condition and at 5 °C. Error bars in means represent standard deviation (SD) of the mean values

Juice content and rind moisture

Except for control fruits stored at ambient condition, treatments had no effects on the juice content but significantly changed the moisture content of rind, which was also reflected in the weight loss of the fruits. The best retention of rind moisture paralleled the lowest weight loss (Table 2). This result indicates that as in citrus fruit (Purvis 1983), the weight loss of rind was proportionally higher than that of the pulp. In just one case, control fruits stored at ambient condition lost significantly more aril moisture than film-covered ones. It is obvious that the water loss in the rind of pomegranate is predominantly caused by the environment. At the same time that the rind undergoes water deficit, this water is then replaced by the arils. Film covering greatly reduced rind moisture loss resulting in the retention of harvest freshness of the fruits in terms of fruit weight, and juice content.

Total soluble solid and total titratable acid

TSS and TTA were not significantly affected by the treatments under storage at 5 °C (Table 3). Although different pomegranate cultivars and conditions have previously been studied, the results of most of the studies comparing storage in the air with different control atmosphere conditions are in agreement with our results showing that changes in TSS or TTA during cold storage are not considerably influenced by gas composition (Hess-Pierce & Kader 2003). In contrast to the cold storage, at the ambient condition, fruits in all treatments had the higher TTA percentage compared with control fruits. Since pomegranate is a non-climacteric fruit, depletion in TTA would tend to happen with ongoing metabolism, as observed in 'Mollar' (Artés et al. 2000) and 'Hicrannar' (Selcuk & Erkan 2014) cultivars. In the film-packaged fruits, slightly elevated carbon dioxide level can lead to senescence delay, especially since CO_2 concentration inside the fruit is greater than the one measured in the package atmosphere (Ben-Yehoshua 1990). The increase in TTA in treated fruits could be related to the changes in the fruit internal atmosphere and consequently in delaying senescence; however, this phenomenon was not pronounced under cold storage condition.

The highest TSS level during storage at ambient condition was found in control fruits, followed by SLW-coated fruits, while SLW + ISP and/or SLW + WTP fruits had the lowest level. We perceived that the moisture loss in the fruit was predominantly from the peel and arils at the end of the storage period; hence, a higher TSS content was associated with concentration. The increases in TSS were delayed by the use of ISP and TWP. Our findings are in agreement with those of Ghafir et al. (2010) and Selcuk and Erkan (2014) who reported increases in TSS content in pomegranate fruits during storage.

Vitamin C

Untreated control fruits and fruits SLW or DLW at either ambient or cold storage conditions had lower vitamin C content compared with the film-packed fruits (Table 3). The current results were in agreement with those of Nanda et al. (2001) who reported that individual seal packaging maintained vitamin C content in pomegranate stored at 8 and 15 °C. The highest content of vitamin C in film-packed fruits could be related to changes in the fruit internal atmosphere and accordingly in delaying senescence. So, film-packing is a proper way of keeping the pomegranate functional properties through the conservation of health-promoting composites.

Storage temperature significantly affected vitamin C content of control, wax-coated (SLW and DLW) and ISP fruits, because fruits stored at 5 °C had higher contents of vitamin C than those stored at ambient condition. Normally, because of its high acid content, vitamin C in fruits is considered more permanent during storage compared with leafy products. However, water loss and high temperature may reduce vitamin C due to an increase in heat oxidation (Nunes et al. 1998).

Shelf life and sensory evaluation

The film wrapping and wax coating extended the shelf life of pomegranates both at ambient and low temperature storage conditions. The maximum shelf life of 18 weeks was obtained by TWP and ISP wrapping as compared with 10 weeks in control fruits kept at 5 °C (Table 3). Nanda et al. (2001) reported a maximum extension of shelf life (12 weeks) at 8 °C. At ambient storage, ISP and TWP, as well as SLW + ISP and SLW + TWP, could extend the shelf life of the fruits to 5 and 6 weeks, respectively, as compared with 2 weeks in control fruits. However, there was no significant difference in the shelf life of pomegranates packaged as TWP or SLW + TWP and as ISP or SLW + ISP at 5 °C. SLW and DLW coating extended the shelf life of fruits only marginally compared with control fruits at both storage temperatures.

The film-packaged fruits were fresh with yellowish red rind color and secured high scores for appearances. At ambient and 5 °C conditions, control fruits were unmarketable beyond 2 and 10 weeks of storage, respectively because they were feeble, desiccated, hard, deformed, and discolored. TWP and ISP equally got better scores for aril color, juiciness, and taste during sensory evaluation compared with control and wax-coated (SLW or DLW) fruits (Table 4, Fig. 2).

Internal decay was only assessed at the last evaluation date, after 18 weeks of storage. During storage, molds caused by *Botrytis cinerea* were developed to a small extent with no significant differences among film-packaged, wax-coated, and control fruits (Table 2). The incidence of internal decay was consistently higher in the pomegranates kept at ambient condition than those kept at 5 °C. Our findings are in line with Fawole and Opara (2013) who observed that decay percentage of pomegranate fruit increased with storage temperature. The result reveals that ambient temperature undoubtedly favored gray mold development in comparison to lower temperature.

Table 3. The effects of skin coating with wax and film packaging on the shelf life and chemical changes (mean ± SD) of pomegranate fruit after 18 week's storage at ambient condition (15–20 °C) and at 5 °C

Treatment	Vitamin C (mg/100 ml)		TTA (% citric acid)		TSS (%)		Shelf life	
	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C
Control	12.3±1.85 c*A	11.0±2.03 cA **	0.55±0.060 cB	0.62±0.083 aA	21.0±1.61aA	18.0±0.87 bcB	2 weeks	10 weeks
SLW	9.3±0.85 cB	12.2±0.72 bA	0.62±0.091 bA	0.63±0.015 aA	19.3±0.98 bA	17.8±0.93 bcB	3 weeks	11 weeks
DLW	9.7±1.26 cB	11.9±0.89 bcA	0.63±0.082 bA	0.63±0.012 aA	18.8±0.75 bcA	17.9±0.66 bcA	3 weeks	12 weeks
ISP	16.5±0.73 bB	17.9±1.40 aA	0.73±0.090 aA	0.63±0.00 aB	18.0±0.69 cdA	18.2±0.91 bcA	5 weeks	18 weeks
SLW + ISP	16.5±0.67 bB	18.9±2.13 aA	0.74±0.096 aA	0.62±0.032 aB	17.7±0.72 dA	18.4±0.88 abA	5 weeks	18 weeks
TWP	17.9±2.41 aA	18.1±1.39 aA	0.73±0.082 aA	0.63±0.021 aB	18.0±1.61 cdA	18.7±1.31 aA	6 weeks	18 weeks
SLW + TWP	18.4±1.53 aA	18.1±1.77 aA	0.75±0.065 aA	0.63±0.043 aB	17.7±0.95 dA	18.2±1.50 bcA	6 weeks	18 weeks

Note: see Table 2

Table 4. Sensory evaluation (mean ± SD) of pomegranate fruit at the end of 18 weeks of storage as affected by skin coating with wax, film packaging, and storage condition (organoleptic score: 0 – very bad; 3 – acceptable; 5 – very good)

Treatment	Freshness		Aril color		Taste		Juiciness	
	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C	15-20 °C	5 °C
Control	1.8±0.032 b*B	2.6±0.018 cA**	2.0±0.015 bB	3.0 ±0.026 bA	2.0±0.056 cB	3.0±0.019 cA	1.6±0.073 bB	3.2±0.060 bA
SLW	2.5±0.015 bB	3.2±0.015 bA	2.0±0.034 bB	3.0 ±0.019 bA	2.2±0.071cB	3.0±0.024 cA	2.2±0.043 bB	3.2±0.059 bA
DLW	2.6±0.032 bB	3.2±0.021 bA	2.2±0.071 bB	3.3±0.023 bA	2.2±0.083 cB	3.2±0.042 cA	2.2±0.031 bB	3.4±0.048 bA
ISP	3.0±0.060 aB	3.3±0.035 bA	3.0±0.063 aB	4.0±0.012 abA	2.8±0.011 bB	3.5±0.029 cbA	2.4±0.053 abB	3.3±0.057 bA
SLW + ISP	3.0±0.090 aB	4.1±0.028 abA	3.2±0.074 aB	4.0±0.015 abA	2.7±0.01 bB	3.8±0.021bA	2.6±0.042 aB	3.4±0.052 bA
TWP	3.2±0.081 aB	4.1±0.039 abA	3.2±0.059 aB	4.3±0.021 aA	3.0±0.090 baB	3.9±0.026 baA	2.6±0.051 aB	3.4±0.038 bA
SLW + TWP	3.2±0.064 aB	4.4±0.0.034 aA	3.3±0.020 aA	3.3 ±0.025 aA	3.2±0.032 aB	4.3±0.029 aA	2.8±0.076 aB	4.3±0.031 aA

Note: see Table 2

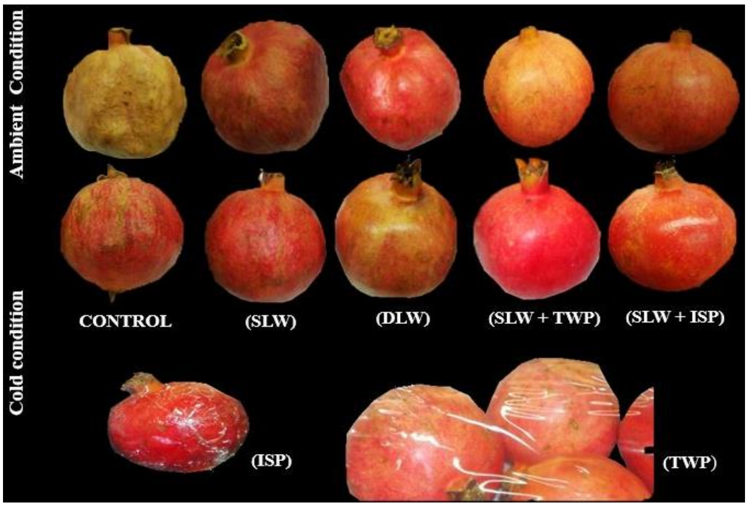

Fig. 2 'Rabbab' pomegranates treated with various film packaging and wax coating after 18 weeks of storage at ambient (15–20 °C; 45–50% RH) and cold conditions (5 °C ± 0.5; 85% RH)

CONCLUSION

Both kind of treatments of pomegranates – tray wrap film and individual-seal film packing – maintained freshness equally and extended the storage life both at ambient and low temperature conditions with the least losses in weight. Pomegranate fruits packed in tray wrap film and individual-seal film could be stored for a period of 18 weeks at 5 °C without much deterioration in quality characters. Apparently, none of the waxes layer, single or double, used in this experiment was as effective as the plastic film in reducing weight loss. With regard to the combined treatments of single wax layer with either individual seal packing or tray wrapping, the application of single wax layer did not significantly reduce weight loss compared with either individual or tray wraps.

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