



Journal of Environmental Science and Technology

ISSN 1994-7887

science
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Research Article

Utilization of Sunscreen Particles Film with Shading to Control Sunburn and Fruit Cracking of Wonderful Pomegranate

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Abstract

Background and Objective: Sunburn and fruits cracking are the serious economic problem in practically all pomegranates growing of the world. Fruits are losses due to sunburn and cracking incidence from 10-50%. Main objective of this study was the utilization of sunscreen particles to control fruit cracking. **Materials and Methods:** The present investigation was conducted during two successive seasons 2016 and 2017 on wonderful pomegranate trees to evaluate the effectiveness of Raynox Plus® and Surround WP® with or without shading by 35% shade net (SN) to control sunburn and fruit cracking. As well as maintaining fruits quality at harvest, after 40 days of cold storage ($5^{\circ}\text{C} \pm 1$ and 90-95% RH) and during marketing for 7 days (20°C and 65-70% RH) to be available for longer period in the season. **Results:** The results at harvest revealed that, application of Raynox Plus® at 2% with shading (35% SN) recorded the highest values of fruit number, weight, yield, juice volume and total phenol. Moreover, Raynox Plus® at 2% alone recorded the highest weight of red and total arils, higher anthocyanin and Vitamin C comparing with all treatments. On the other hand shading by 35% shade net (SN) produced less hue angle color of fruit skin and arils (blush red color). The sprinkle of Surround WP® 3% with shading (35% SN) gave lower significant percent of fruit cracking, sunburn and revealed better percent of marketable fruits. Furthermore, Surround WP® 3% alone produced the higher percent of TSS and total sugar. By the end of cold storage and marketing, Raynox Plus® at 2% with shading (35% SN) showed lowest percent of weight loss, content of pectinase and delaying CI while, produced higher juice volume, total phenol, increment antioxidant activity and gave higher net return to growers as compare to all treatments applied. The sprinkle of Surround WP® 3% with shading (35% SN) presented lowest decay (%), respiration rate and anthocyanin content. Raynox Plus® at 2% alone maintained anthocyanin content and vitamin C. Since, Surround WP® at 3% alone presented higher TSS, sugar content and lower acidity. **Conclusion:** From above mentioned results, it could be concluded that treating pomegranate fruits with surround WP® at 3% with shading (35% SN) had a positive effect to reduce percent of sunburn, respiration rate which led to delay ripening and prolonging fruit storage with good properties along the storage periods comparing with the untreated fruits.

Key words: Wonderful pomegranate fruits, organic films, Raynox Plus®, Surround WP®, shade netting (SN), cold storage and marketing

Citation: M.E. Tarabih, 2020. Utilization of sunscreen particles film with shading to control sunburn and fruit cracking of wonderful pomegranate. J. Environ. Sci. Technol., 13: 69-85.

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Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Pomegranate (*Punica granatum* L.), is one of the oldest tropical and subtropical edible fruits. The total cultivated area for 2015 reached about 50,000 feddans while, the fruiting area was about 14379 feddans which produced about 132031 t with an average productivity ranging about 9.182 t per feddan¹. Wonderful pomegranate is the most commercial variety in Egypt. It was self-pollinated, produces large deep purple-red fruit with deep crimson juicy flesh, which is very high in antioxidants. Plants suffer from many physiological disorder problems when the intensity of sun light is beyond the optimum. Cracking and sunburn fruits are prominent problems to the marketable pomegranate crop. Fruit cracking is a serious problem in pomegranate which hinders its cultivation to a large extent. The loss caused by pomegranate cracking was estimated at 50% of the marketing value of the crop². Various factors are responsible for fruit cracking which include fluctuation of soil moisture and relative humidity, dry wind, rain or heavy irrigation following a dry spell.

Sunburn injury is one of the common physiological disorders on fruits due to high solar radiation levels and air temperatures, low relative humidity and high elevations.

Moreover, pomegranates are especially sensitive to sunburn because they are terminal bearing plants, with generally thin branches that bend with the increase in fruit weight as the season progress. Ultraviolet (UV) radiation is the greatest contributor to damage. Sunlight is the primary source of energy used in photosynthesis by plants to convert carbon dioxide and water into carbohydrates, which the plant uses to make stems, leaves, roots and fruits. Besides, sunlight up to certain level is very much helpful to improve quality and production and reduces incidence of pest and diseases³.

Excess absorbed energy is the greatest contributor to cell death and sunburn. The incidence and severity of sunburn depends upon climatic factor, cultivars, hormonal, nutritional and soil moisture⁴. Sunburn occurs mainly where air temperature and the number of sunny hours are high during the ripening period. Sunburn also occurs when cool or mild weather is abruptly followed by hot, sunny weather. Severe sunburn alters the cuticle even more and damages both the epidermal and sub-epidermal tissues. Cell walls get thicker. Intercellular phenols increase and the structures of plastids and thylakoids change. Sunburn necrosis is caused by heat, when the fruit surface temperature reaches 52°C for 10 min. Sunburn browning is the most common type of sunburn and results in a yellow, brown or dark tan patch on the sun-exposed side of the fruits. Grower must follow best management practices to minimize sunburn and grow

tolerant cultivars, efficient irrigation and shade netting (SN). Among Good Agricultural Practices (GAPs), particle film technology (PFT) is promising for organic fruit production. Now, many particle films (PFs) such as Surround WP® and Raynox Plus®, have been recommended across the globe. Products such as Surround WP and Raynox Plus reduce sunburn browning by reducing the FST and the amount of damaging UV-B radiation reaching the epidermal cells.

Surround WP® has become the most widely used and recommended PF for achieving several benefits in different fruit world over⁵. Sunburn browning occurs when the fruit surface temperature (FST) reaches 115-120°F (46-49°C)⁶. Surround WP (kaolin clay) reduce fruit surface temperature by reflecting ultraviolet and infrared radiation. Raynox Plus is a combination of carnauba wax and bentonite clay that both absorbs and reflects ultraviolet radiation³. Moreover, kaolin can reduce fruit surface temperatures by up to 5-10°C, thereby reducing sunburn and improving red fruit color⁷.

Raynox Plus® (U.S. Patent No. 6,857,224) is a combination of carnauba wax and bentonite clay that both absorbs and reflects ultraviolet radiation³. Raynox® plus considered a sunscreen sunburn suppressant which contains organic-chemical absorbing agents in addition to physical inorganic⁸. Raynox Plus protects fruit from sun damage by forming a thin, clear, natural wax layer that blocks damaging UV rays from harming fruits. Carnauba wax, produced on the leaves of a tropical palm tree, it is a liquid emulsion sprayed onto fruit trees to form a clear film that filters out a significant proportion of the damaging ultraviolet radiation and a small amount of the visible and infrared radiation. It has been shown to significantly reduce sunburn of apples³.

In addition, several reports support the claim that netting directly reduces sunburn. The mechanism for this effect was the capacity of netting to reduce the intensity of direct solar radiation on the fruit surface by interception and scattering of the sunlight. Furthermore, the open sides of the netting structure allowed good airflow through the netted area so that heat from the fruit surface could be easily transferred to the air and from the netted area to outside. The use of Shade netting (SN) in orchards originated from involves the attenuation of solar irradiance by shading, thereby reducing temperature and wind velocity and increasing humidity. Moreover, the dual use of hail nets for protection from hailstorms and sunburn and reduces the adverse effects of climatic extremes⁹.

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good airflow through the netted area so that heat from the fruit surface could be easily transferred to the air and from the netted area to outside¹⁰.

Shade netting is usually designed to reduce mid-day sunlight by about 20-25%. In some situations, wind speeds can be reduced by 50%. It is likely that shade netting will reduce photosynthesis of fruit trees. However, during most of the growing season and most of the day there is an excess of sunlight for photosynthesis and 20% reduction of sunlight due to shade netting is unlikely to reduce the yield potential and fruit quality of a well-managed orchard.

This study was conducted to evaluate application of Surround WP® and Raynox® plus with shading (35%SN) to reduce cracking, sunburn incidence and enhance quality of wonderful pomegranate fruits which net return to the grower at harvest, after cold storage and during marketing.

MATERIALS AND METHODS

Study area: The present investigation was conducted during the two successive seasons 2016 and 2017 on Wonderful pomegranate trees to evaluate the effectiveness of Raynox plus and kaolin with or without shading (35% SN) to control sunburn (physiological disorder) and fruit cracking and maintaining fruits during cold storage and shelf life. Forty-two adult trees were selected at 9 years old healthy and as uniform as possible in vigor and shape which, grown in sandy soil (4×3 m) apart at private orchard located at Cairo-Alexandria desert road, Egypt. The trees subjected to the recommended cultural practices in completely randomized design and divided into seven groups, three replicates for each and two trees for one replicate.

In the present study, selected trees for shading were first covered with covering material providing by 35% shading on July 30th. Then, Surround WP® and Raynox Plus® applications were applied within weekly at four applications:

- First application 30 July: 7 weeks after full bloom (WAFB)
- Second application 6 August: 7-10 days later
- Third application 13 August: 3 weeks later (11-12 WAFB)
- Fourth application 20 August: 4 weeks later (15-16 WAFB)

Treatments:

- Spraying fruits with surround WP® 3%
- Spraying fruits with surround WP® 3+35% shade with pale netting
- Spraying fruits with Raynox Plus 2%

- Spraying fruits with Raynox Plus 2+35% shade with a pale netting
- Shading (35% SN) with a pale netting
- Control (untreated and uncovered)

Tween-20 (0.1%) as a wetting agent was added at the rate of 40 cm/100 L water to the foliar solution in order to obtain best penetration results. Wonderful pomegranate fruits were harvested at maturity stage (fruits become fully colored) at the end of October when full opening of the calyx, TSS range between 15 and 17° Brix, red juice in color (equal to or darker) and acidity below 1.85% according to Mphahlele *et al.*¹¹. Fruits were chosen to be similar as possible in color, size and free of any noticeable pathological or mechanical injuries. Fruits were picked at random in the early morning and packed in plastic boxes and instantly transferred to the fruits handling laboratory.

For storage study, treated fruits were stored in perforated carton boxes in one layer 5 kg (3 boxes for each replicate). All boxes were stored at 5 °C ± 1 and 90-95% relative humidity (RH) for 40 days. After every period of cold storage fruit stored 7 days at 20 °C and 65-70% RH as shelf life. Fruits were examined at initial time and after 20 and 40 days during cold storage. Then, the data were recorded after 7 days at marketing conditions during both seasons. Fruit quality assessment was recorded as described below for different chemical and physical properties:

Number of fruits, weight (kg) and yield (kg): Number and weight of fruits (kg) per every replicate were determined at harvest date to estimated total yield (kg).

Cracking fruits (%):

$$\text{Cracking fruits (\%)} = \frac{\text{Number of cracked fruits}}{\text{Total number of fruit}} \times 100$$

Sunburn fruits (%):

$$\text{Sunburn fruits (\%)} = \frac{\text{Number of sunburn fruits}}{\text{Total number of fruit}} \times 100$$

Marketable fruits (%):

$$\text{Marketable fruits (\%)} = \frac{\text{Total number of fruits} - (\text{number of cracked} + \text{sunburn fruits})}{\text{Total number of fruit}} \times 100$$

Arils characters: Arils were extracted from fruit and the number and weight of red, white and total arils were weighted.

Quality assessments of fruits

Determination of physical and chemical properties at harvest, after cold storage and at the end of marketing

Weight loss (%):

$$\text{Loss in fruit weight (\%)} = \frac{\text{Initial weight} - \text{Weight at sampling date}}{\text{Initial fruit weight}} \times 100$$

Fruit decay (%):

$$\text{Decay (\%)} = \frac{\text{Weight of decayed fruits}}{\text{Initial total fruit weight}} \times 100$$

Respiration rate (mL CO₂ kg⁻¹ h⁻¹): Respiration rate was measured by gas analyzer (Model 1450-Servomex 1400) according to McCollum *et al.*¹² airtight glass jars (4 L) were used to fruit incubation under the same storage circumstances for 24 h, respiration rate was measured as ml of CO₂ kg⁻¹ fruits h⁻¹.

Fruits skin hue color (h°) and arils hue color (h°): Fruit peel and arils color along the equatorial axis of each fruit at two opposite spots were recorded in CIE coordinates (L*, a*, b*) "L* indicates lightness, a* is the red/green coordinate and b* is the yellow/blue coordinate" using a Minolta Chroma Meter CR-400 (Minolta Corp, Osaka, Japan) after calibration with a white tile background from (a*, b*) using the methods described by McGuire¹³ as the following equation:

$$h^{\circ} = \tan^{-1} \left(\frac{b}{a} \right)$$

where, a is the interval of colors between green (-) and red (+), b is the interval of colors between blue (+) and yellow (-), h° is the skin hue color, L* is the lightness, a* is the red/green coordinate and b* is the yellow/blue coordinate.

Juice volume of 100 g arils: Pomegranate fruits were hand peeled then three samples of 100 g of each treatment arils were taken (one sample from each 3 fruits). Each sample was squeezed to obtain the pomegranate juice. The volumes of the above obtained juice were recorded.

Total soluble solids (TSS %): Total soluble solids were measured using drops of pomegranate fruit arils juice using a Carl-Zeiss hand refractometer according to AOAC¹⁴.

Titrateable acidity (TA %): It was determined in fruit juice by titration with 0.1 N sodium hydroxide (NaOH), using phenolphthalein as an indicator and calculated as citric acid according to the method described in AOAC¹⁴.

Total sugars (100 µg mL⁻¹ of glucose): Total sugars were determined on crude fruit dried from each treatment by using phenol 18% and sulphuric acid 96% and the absorbance was recorded with spectrophotometer at 490 nm, according to the method described by Sadasiyam and Manickam¹⁵.

A standard curve was prepared by plotting the known concentrations of glucose solution (100 µg mL⁻¹ of glucose) against respective Optical Density (OD) value of each. From the standard curve, the amount of total sugars actually present in the sample is determined.

Vitamin C (mg/100 mL juice): vitamin C was measured by the oxidation of ascorbic acid with using 2, 6-dichlorophenolindophenol solution and 2% oxalic acid as a substrate then the results were indicated as mg ascorbic acid per 100 mL arils juice according to AOAC¹⁴.

Anthocyanin (mg/100 mL juice): One milliliter from aril juice was blended with 95% ethyl alcohol and 1% HCl and then it measured on spectrophotometer at wavelength 535 nm. The content of total anthocyanin was calculated using the following equations:

$$\text{Total anthocyanin (mg / 100 mL juice)} = \frac{\text{Total absorbance per 100 mL juice}}{98.2 (E)}$$

The (E) value for 1% solution at 535 nm is equal to 98.2. Therefore, the absorbance of a solution containing 1 mL is equal to 98.2 according to Ranganna¹⁶.

Total phenols content (mg/100 g fresh weight): The total phenolics were determined by the Folin-Ciocalteu method as described by Singleton *et al.*¹⁷ with minor modifications, based on colorimetric oxidation/reduction reaction of phenols. Polyphenols extraction was carried out by adding 10 mL methanol (85%) to 1 g fine grind of peach tissue. About 250 µL of sterile distilled water was added to 250 µL of extract and then 2.5 mL of diluted Folin-Ciocalteu reagent (10%) and 2 mL of 7.5% sodium carbonate were added. The samples were shaken for 1.5-2 h. The absorbance of samples was measured at 765 nm by a PG Instruments Ltd-T80+UV/VIS spectrophotometer. Gallic acid was used for calibration curve. Results were expressed as mg gallic acid 100 g⁻¹ FW.

Pectinase activity: Sample of 0.5 mL of supernatant enzyme extraction was used and mixed in acetate buffer then incubated at 45°C for 10 min for pectinase. The reaction was stopped with 3 mL of 3, 5-dinitrosalicylic acid reagent, the color was obtained after heating for 10 min and measured at wavelength of 570 nm and expressed as one unit of pectinase activity liberates 1 M mol D-galacturonic acid in milliliter per min as described by Miller¹⁸.

Antioxidant activity by DPPH assay: The antioxidant activity of the pomegranate arils juice was achieved by using the free radical DPPH method¹⁹. Briefly, 100 µL of juice diluted at 1:100 with methanol: water (6:4), 2 mL of 0.1 mM DPPH in methanol were mixed. After 30 min of reaction, the absorbance was determined at 517 nm. For the background correction, the mixture prepared without DPPH. The antioxidant activity was determined according to the equation:

$$\text{Antioxidant activity (\%)} = 1 - \frac{\text{Abs sample 517 nm}}{\text{Abs control 517 nm}} \times 100$$

Statistical analysis: Data of both seasons of the study were analyzed using analysis of variance (ANOVA). Differences among treatment means were statistically compared using Duncan's multiple tests at a level 0.05, using the CoStat V6.4 program.

RESULTS

The effect of the reflective particle film (Surround WP®) and the sunscreen product (Raynox Plus®) either alone or with netting by shade net (SN) on horticultural and fruit quality traits of wonderful pomegranate as follows during the two successive seasons 2016 and 2017.

At harvest assessments

Fruit number, fruit weight (kg/tree) and yield (kg/tree): Data in Table 1 showed that, yield as number of fruits per tree and weight (kg/tree) of wonderful pomegranate fruits at harvest

was significantly increased by all applied treatments comparing with control during the two seasons. In this respect, Raynox Plus® at 2% with shading (35% SN) recorded the highest fruit number (95 and 99 fruits/tree) in both seasons, respectively. Data of both seasons also showed significant increase in fruit weight by all treatments applied compared to the control (Table 1). The heaviest fruit weight (447 and 459 g) was obtained by Raynox Plus® at 2% with shading (35% SN) in both seasons. On the other hand, the control trees showed the lowest values which recorded 403 and 413 g during both seasons, respectively. Total yield as kg/tree of 'Wonderful' pomegranate tree was significantly increased gradually with the all treatments applied as compared to the control during both seasons (Table 1). In this respect, trees treated by Raynox Plus® at 2% with shading (35% SN) recorded the highest values of yield (42.46 and 45.44 kg/tree) during both seasons, respectively. On the other hand, the control trees recorded the least values of yield (33.45 and 36.43 kg/tree) during both seasons, respectively.

Cracking fruits (%), sunburn fruits (%) and marketable fruits (%):

Data from Table 2 revealed that all applied treatments reduced the percent of fruit cracking and sunburn compared with untreated treatments in both seasons, respectively. In this respect, Surround WP® 3% with shading (35% SN) gave the lowest significant percentage of fruits cracking (0.30 and 0.27%) and lower significant sunburn fruits percentage (2.30 and 2.24%) as compared to the control or the other treatments in both seasons, respectively. While, the highest significant fruits cracking (%) (9.20 and 8.70%) and sunburn fruits% (21.70 and 20.55%) were recorded in untreated fruits in both seasons, respectively.

Data in Table 2 demonstrate that, all treatments caused a highly significant increase in marketable fruits (%) compared with the control during both seasons. In this respect, sprinkle of Surround WP® 3% with shading (35% SN) gave the highest marketable percentage (97.40 and 97.49%) compared with the lowest marketable fruits percentage obtained from the untreated ones during both seasons, respectively. Marketable

Table 1: Number of fruits per tree, fruit weight (g) and yield per tree (kg) of wonderful pomegranate fruits at harvest in 2016 and 2017 seasons

Treatments	Number of fruits/tree		Fruit weight (g)		Yield/tree (kg)	
	2016	2017	2016	2017	2016	2017
Control	83.00 ^f	88.00 ^e	403.00 ^f	413.00 ^e	33.45 ^f	36.43 ^f
Surround WP® 3%	88.00 ^d	90.00 ^{de}	435.00 ^c	445.00 ^b	38.28 ^c	40.05 ^c
Surround WP® 3% with shading (35% SN)	90.00 ^c	92.00 ^c	415.00 ^e	430.00 ^d	37.35 ^d	39.56 ^d
Raynox Plus® 2%	93.00 ^b	94.00 ^b	439.00 ^b	435.00 ^c	40.28 ^b	40.89 ^b
Raynox Plus® 2% with shading (35% SN)	95.00 ^a	99.00 ^a	447.00 ^a	459.00 ^a	42.46 ^a	45.44 ^a
Shading (35% SN)	85.00 ^e	91.00 ^{cd}	420.00 ^d	429.00 ^d	35.700 ^e	39.03 ^e

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 2: Cracking (%), sunburn (%) and marketable (%) of wonderful pomegranate fruits at harvest in 2016 and 2017 seasons

Treatments	Cracking fruits (%)		Sunburn fruits (%)		Marketable fruits (%)	
	2016	2017	2016	2017	2016	2017
Control	9.20 ^a	8.70 ^a	21.70 ^a	20.55 ^a	69.90 ^e	70.75 ^f
Surround WP® 3%	1.30 ^c	1.24 ^b	3.20 ^c	3.00 ^c	95.50 ^c	95.76 ^d
Surround WP® 3% with shading (35% SN)	0.30 ^f	0.27 ^c	2.30 ^e	2.24 ^f	97.40 ^a	97.49 ^a
Raynox Plus® 2%	1.40 ^b	1.32 ^b	3.65 ^b	3.40 ^b	94.95 ^d	95.28 ^e
Raynox Plus® 2% with shading (35% SN)	0.40 ^e	0.38 ^c	2.48 ^d	2.35 ^e	97.12 ^b	97.27 ^b
Shading (35% SN)	0.50 ^d	0.44 ^c	2.60 ^d	2.46 ^d	96.90 ^b	97.10 ^c

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 3: Red arils weight (g), white arils weight (g) and total arils weight (g) of wonderful pomegranate at harvest in 2016 and 2017 seasons

Treatments	Red arils weight (g)		White arils weight (g)		Total arils weight (g)	
	2016	2017	2016	2017	2016	2017
Control	307.00 ^e	311.00 ^f	8.10 ^a	8.00 ^a	315.10 ^f	319.00 ^f
Surround WP® 3%	335.00 ^b	348.00 ^b	5.60 ^d	5.50 ^d	340.60 ^c	353.50 ^b
Surround WP® 3% with shading (35% SN)	329.00 ^c	340.00 ^c	5.30 ^e	5.10 ^e	334.30 ^d	345.10 ^c
Raynox Plus® 2%	340.00 ^a	360.00 ^a	4.70 ^f	4.50 ^f	344.70 ^a	364.50 ^a
Raynox Plus® 2% with shading (35% SN)	335.00 ^b	338.00 ^d	6.50 ^c	6.40 ^c	341.50 ^b	344.40 ^d
Shading (35% SN)	320.00 ^d	327.00 ^e	7.20 ^b	7.00 ^b	327.20 ^e	334.00 ^e

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 4: Fruits skin hue color (h°), arils hue color (h°) and juice volume (mL/100 g arils) of wonderful pomegranate at harvest in 2016 and 2017 seasons

Treatments	Skin hue color (h°)		Arils hue color (h°)		Juice volume (mL/100 g arils)	
	2016	2017	2016	2017	2016	2017
Control	24.10 ^b	25.40 ^b	22.00 ^b	21.80 ^b	173 ^e	168 ^f
Surround WP® 3%	22.80 ^e	23.40 ^e	19.50 ^d	19.90 ^d	176 ^d	175 ^d
Surround WP® 3% with shading (35% SN)	23.90 ^c	24.20 ^c	20.40 ^c	20.50 ^c	180 ^c	178 ^c
Raynox Plus® 2%	21.00 ^f	22.50 ^f	18.90 ^e	19.40 ^e	183 ^b	180 ^b
Raynox Plus® 2% with shading (35% SN)	23.60 ^d	23.60 ^d	19.70 ^f	20.00 ^d	187 ^a	184 ^a
Shading (35% SN)	24.30 ^a	25.60 ^a	22.80 ^a	22.00 ^a	175 ^d	170 ^e

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

fruits percentage increased as a result of decreasing fruit disorders (cracking and sunburn) percentages which were affected by all treatments compared with control.

Red arils weight (g), white arils weight (g) and total arils weight (g):

Data in Table 3 clearly show that the weight of red arils and total arils were significantly increased with all treatments used as compare to the control in both seasons. 'Wonderful' pomegranate trees treated with Raynox Plus® at 2% recorded the highest weight of red arils (340.0 and 360.0 g) and total arils (344.70 and 364.50 g) during both seasons, respectively. The untreated treatment recorded the least weight of red arils (307.0 and 311.0 g) and total arils (315.10 and 319.00 g) during both seasons, respectively.

On the other hand, the weight of white arils was significantly decreased with all treatments applied as compare to the control in both seasons. The highest values of white arils

weight were appeared in control treatment (8.10 and 8.0 g) with significant differences with the other treatments. Whereas, Raynox Plus® at 2% treatment decreased white arils weight (4.70 and 4.50 g) than all applied treatment in both seasons, respectively.

Fruit skin hue angle (h°), aril hue angle (h°) and juice volume (mL/100 g arils)

Fruit color: Fruits quality traits such as skin color (h°) and arils color (h°) were analyzed at harvest as shown in Table 4. Higher hue angle indicates less blush or greener color. In this respect, the skin color (h°) and arils color (h°) were significantly increased (low hue values) with all treatments used as compare to the control in both seasons. Since, Raynox Plus® at 2% showed a decrease in the skin hue values (21.00 and 22.50 h°) and aril hue values (18.90 and 19.40 h°) in contrast to all treatments used or the control at harvest in the two seasons, respectively.

Table 5: Total soluble solid (TSS %), titratable acidity (%) and total sugar (%) of wonderful pomegranate arils at harvest in 2016 and 2017 seasons

Treatments	TSS (%)		Titratable acidity (TA %)		Total sugar (%)	
	2016	2017	2016	2017	2016	2017
Control	15.60 ^d	15.30 ^e	1.80 ^a	1.76 ^a	12.70 ^e	12.40 ^d
Surround WP® 3%	17.20 ^a	17.70 ^a	1.20 ^e	1.23 ^e	14.60 ^a	13.80 ^a
Surround WP® 3% with shading (35% SN)	16.90 ^b	17.40 ^b	1.30 ^d	1.39 ^d	13.50 ^c	13.20 ^c
Raynox Plus® 2%	17.10 ^a	17.00 ^d	1.57 ^c	1.60 ^b	14.00 ^b	13.60 ^b
Raynox Plus® 2% with shading (35% SN)	16.80 ^{bc}	17.20 ^c	1.65 ^b	1.50 ^c	14.10 ^b	13.10 ^c
Shading (35% SN)	16.70 ^c	16.90 ^d	1.56 ^c	1.50 ^c	13.20 ^d	12.40 ^d

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 6: Vitamin C (mg/100 mL juice), anthocyanin content (mg/100 mL juice) and total phenols (mg eq. gallic acid 100 g⁻¹), of wonderful pomegranate arils at harvest 2016 and 2017 seasons

Treatments	Vitamin C (mg/100 mL juice)		Anthocyanin (mg/100 mL juice)		Total phenols (mg eq. gallic acid 100 g ⁻¹)	
	2016	2017	2016	2017	2016	2017
Control	22.80 ^f	23.00 ^f	13.00 ^e	13.20 ^e	87.30 ^f	88.90 ^e
Surround WP® 3%	24.70 ^b	25.00 ^b	13.80 ^b	14.20 ^b	88.00 ^d	89.50 ^d
Surround WP® 3% with shading (35% SN)	24.30 ^d	24.40 ^d	13.30 ^d	13.70 ^d	88.30 ^c	90.10 ^c
Raynox Plus® 2%	25.00 ^a	25.30 ^a	14.10 ^a	14.50 ^a	88.70 ^b	91.00 ^b
Raynox Plus® 2% with shading (35% SN)	24.60 ^c	24.70 ^c	13.50 ^c	13.90 ^c	89.90 ^a	92.10 ^a
Shading (35% SN)	23.90 ^e	24.10 ^e	13.40 ^{cd}	13.60 ^d	87.70 ^e	89.40 ^d

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Moreover, the treatment of shading (35% SN), produced less red (high hue values) pomegranate fruits either at skin or arils as compare to all applied treatments or the control which ranged 24.30 and 25.60 h° while, aril hue angle valued 22.80 and 22.00 h° in the two seasons, respectively. As for juice volume, results presented in Table 4 showed in general that there was somewhat increment in juice volume value among all treatments at harvest comparing with control fruits. On the other hand, Raynox Plus® at 2% with shading (35% SN) treatment achieved the highest value of juice volume (187 and 184 mL/100 g arils) than the other treatments including the control during both seasons under the study. The untreated fruits gave the lowest value of juice volume (173 and 168 mL/100 g arils) in both seasons, respectively.

Total soluble solid (TSS %), titratable acidity (%) and total sugar (%): From Table 5 data presented the effect of different pre-harvest treatments on TSS percentage of Wonderful pomegranate fruits in 2016 and 2017 seasons. In addition, Surround WP® at 3% showed the highest significant TSS value (17.20 and 17.70%) while the untreated fruits showed the lowest significant TSS (15.60 and 15.30%) at harvest in both seasons, respectively.

It also showed in Table 5 that titratable acidity (TA %) of Wonderful pomegranate fruits was significantly declines in all treatments applied as compare to control throughout this study at harvest during both seasons. On the other hand, control treatment led to significant increment in TA (%)

(1.81 and 1.76%) compared with all treated fruits at harvest in the two seasons, respectively. On the other hand, the plants spraying with Surround WP® at 3% gave lower significant acidity at harvest (1.20 and 1.23%) in the two seasons, respectively.

Considering to the effect on total sugar, data in Table 5 revealed that, spraying fruits with Surround WP® at 3% produced a higher value of total sugar at harvest averaged about 14.60 and 13.80% while, untreated ones presented lower values of this trend (12.70 and 12.4%) under the two seasons, respectively.

Vitamin C (mg/100 mL juice), anthocyanin content (mg/100 mL juice) and total phenols (mg eq. gallic acid 100 mL⁻¹): Vitamin C of Wonderful pomegranate fruits decreased gradually as it shown in Table 6 during 2016 and 2017 seasons. At harvest, Raynox Plus® at 2% treatment showed the highest ascorbic acid values (25.0 and 25.30 mg/100 mL juice) while control showed the lowest significant ascorbic acid values (22.80 and 23.0 mg/100 mL juice) in both seasons, respectively.

The influence of different treatments on anthocyanin pigment of Wonderful pomegranate fruits was presented in Table 6. In this respect, Raynox Plus® at 2% treatment showed the highest significant anthocyanin pigment content (14.10 and 14.50 mg/100 mL juice) of Wonderful pomegranate fruits at harvest, while control fruits showed the lowest significant anthocyanin content (13.00 and 13.20 mg/100 mL juice) at harvest in both seasons, respectively.

Table 7: Weight loss (%) and decay (%) of wonderful pomegranate fruits after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Weight loss (%)				Decay (%)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	0.00 ^h	3.63 ^e	6.40 ^a	8.40 ^a	0.00 ^h	3.20 ^b	5.50 ^a	13.40 ^a
Surround WP® 3%	0.00 ^h	2.95 ^a	5.47 ^b	7.35 ^b	0.00 ^h	0.00 ^h	2.40 ^d	5.40 ^c
Surround WP® 3% with shading (35% SN)	0.00 ^h	2.99 ^a	5.25 ^c	6.90 ^{cd}	0.00 ^h	0.00 ^h	2.20 ^f	5.20 ^d
Raynox Plus 2%	0.00 ^h	3.04 ^a	5.41 ^b	7.00 ^c	0.00 ^h	0.00 ^h	2.30 ^e	5.50 ^c
Raynox Plus 2% with shading (35% SN)	0.00 ^h	2.98 ^a	5.00 ^d	6.80 ^d	0.00 ^h	0.00 ^h	2.25 ^{ef}	5.40 ^c
Shading (35% SN)	0.00 ^h	3.14 ^f	5.50 ^b	7.50 ^b	0.00 ^h	0.00 ^h	3.00 ^c	5.90 ^b
Season 2017								
Control	0.00 ⁱ	3.00 ^e	5.80 ^a	7.90 ^a	0.00 ^g	4.20 ^b	6.20 ^a	14.00 ^a
Surround WP® 3%	0.00 ⁱ	2.50 ^f	5.40 ^b	6.70 ^c	0.00 ^g	0.00 ^g	3.20 ^d	6.20 ^d
Surround WP® 3% with shading (35% SN)	0.00 ⁱ	2.20 ^g	5.10 ^c	6.45 ^d	0.00 ^g	0.00 ^g	3.00 ^f	6.00 ^f
Raynox Plus 2%	0.00 ⁱ	2.40 ^f	5.20 ^c	6.50 ^d	0.00 ^g	0.00 ^g	3.20 ^d	6.30 ^c
Raynox Plus 2% with shading (35% SN)	0.00 ⁱ	2.05 ^h	4.90 ^d	6.40 ^d	0.00 ^g	0.00 ^g	3.10 ^e	6.10 ^e
Shading (35% SN)	0.00 ⁱ	2.50 ^f	5.50 ^b	6.90 ^b	0.00 ^g	0.00 ^g	4.00 ^c	6.70 ^b

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Data from Table 6 demonstrate that control fruits at harvest gave a lower value of total phenols (87.30 and 88.90 mg/100 g FW) than all treatments used during the two seasons under the study. Moreover, Raynox Plus® at 2% with shading (35% SN) gave a higher value of total phenols which ranged 89.90 and 92.10 mg/100 g FW during the two seasons under the study.

Storability assessments

Weight loss percentage: Data in Table 7 presented the effect of the different conducted treatments on weight loss percentage of Wonderful pomegranate fruits in 2016 and 2017 seasons. Weight loss percentage increased gradually after 40 days of cold storage and 7 days at the end of cold storage as marketing. Moreover, all treatments showed lower significant weight loss values compared with control which showed the highest significant weight loss values (6.50 and 5.80%) after 40 days of cold storage and 7 days of marketing (8.40 and 7.90%) in both seasons, respectively. On the other hand, Raynox Plus® at 2% with shading (35% SN) treatment showed the lowest significant weight loss values (5.00 and 4.90%) during cold storage and after 7 days of marketing (6.80 and 6.40%) in the both seasons, respectively.

Decay (%): From Table 7 data presented the influence of the different applied treatments on decay percentage of Wonderful pomegranate fruits in both seasons. Decay percentage increased gradually with the prolongation of cold storage period and during marketing. In this respect,

Surround WP® 3% with shading (35% SN) showed the lowest significant decay percentage (2.20 and 3.0%) after 40 days of cold storage while, ranged 5.20 and 6.0% by the end of marketing compared with all treatments or the untreated ones in the both seasons, respectively. Moreover, control showed the highest significant decay percentages (5.50 and 6.20%) after 40 days of cold storage period and after 7 days of marketing (13.40 and 14.0%) in both seasons, respectively.

Respiration rate (mL CO₂ kg⁻¹ fruit h⁻¹): The changes of respiration rate of Wonderful pomegranate fruits in response for the conducted treatments in 2016 and 2017 seasons are presented in Table 8. Respiration rate decreased in the beginning of cold storage then it increased gradually with the prolongation of storage period.

In this respect, control treatment showed the highest significant respiration rates (5.70 and 5.90 mL CO₂ kg⁻¹ fruit h⁻¹) after 40 days of cold storage, while Surround WP® 3% with shading (35% SN) showed the lowest significant respiration rates (5.12 and 5.22 mL CO₂ kg⁻¹ fruit h⁻¹) after 40 days of cold storage during both seasons, respectively. During marketing, control showed the highest significant respiration rates 11.78 and 12.0 CO₂ kg⁻¹ fruit h⁻¹ in both seasons respectively, while Surround WP® 3% with shading (35% SN) recorded 11.0 and 11.20 mL CO₂ kg⁻¹ fruit h⁻¹ by the end of marketing in both seasons, respectively.

Chilling injury (CI %): Chilling injury percentage increased gradually with the prolongation of cold storage period and during marketing. Moreover, all treatments showed lower

Table 8: Respiration rate (mg CO₂ kg⁻¹ h⁻¹) and chilling injury (%) of wonderful pomegranate fruits after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Respiration rate (mg CO ₂ kg ⁻¹ h ⁻¹)				Chilling injury (%)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	6.20 ^a	4.90 ^a	5.70 ^b	11.78 ^a	0.00 ^h	5.50 ^b	11.55 ^a	21.35 ^a
Surround WP® 3%	6.20 ^a	4.55 ^k	5.22 ^e	11.14 ^c	0.00 ^h	0.00 ^h	3.26 ^d	7.10 ^b
Surround WP® 3% with shading (35% SN)	6.20 ^a	4.66 ^j	5.12 ^f	11.00 ^d	0.00 ^h	0.00 ^h	2.44 ^f	6.80 ^c
Raynox Plus 2%	6.20 ^a	4.70 ⁱ	5.15 ^f	11.10 ^{cd}	0.00 ^h	0.00 ^h	2.75 ^e	6.55 ^d
Raynox Plus 2% with shading (35% SN)	6.20 ^a	4.72 ⁱ	5.25 ^d	11.20 ^{bc}	0.00 ^h	0.00 ^h	2.12 ^g	5.85 ^e
Shading (35% SN)	6.20 ^a	4.77 ^h	5.29 ^c	11.30 ^b	0.00 ^h	0.00 ^h	4.50 ^c	7.00 ^b
Season 2017								
Control	6.50 ^a	5.10 ^e	5.90 ^b	12.00 ^a	0.00 ^h	4.90 ^b	10.90 ^a	19.95 ^a
Surround WP® 3%	6.50 ^a	4.65 ^h	5.26 ^{cd}	11.35 ^{cd}	0.00 ^h	0.00 ^h	3.00 ^d	6.20 ^c
Surround WP® 3% with shading (35% SN)	6.50 ^a	4.70 ^{gh}	5.22 ^d	11.20 ^e	0.00 ^h	0.00 ^h	2.20 ^f	6.50 ^b
Raynox Plus 2%	6.50 ^a	4.74 ^{gh}	5.29 ^{cd}	11.40 ^c	0.00 ^h	0.00 ^h	2.30 ^e	6.40 ^b
Raynox Plus 2% with shading (35% SN)	6.50 ^a	4.78 ^{fg}	5.24 ^d	11.30 ^d	0.00 ^h	0.00 ^h	2.00 ^g	5.50 ^d
Shading (35% SN)	6.50 ^a	4.85 ^f	5.35 ^c	11.60 ^b	0.00 ^h	0.00 ^h	4.50 ^c	6.40 ^b

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 9: Fruit skin hue color (h°) and juice volume (mL/100 g arils) of wonderful pomegranate fruits after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Fruit skin hue color (h°)				Juice volume (mL/100 g arils)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	24.10 ^{ab}	23.90 ^b	22.90 ^e	21.30 ^b	173 ^f	140 ⁿ	121 ^q	83 ^f
Surround WP® 3%	22.80 ^e	20.60 ^h	19.80 ⁱ	18.70 ^d	177 ^d	154 ^j	135 ^o	107 ^d
Surround WP® 3% with shading (35% SN)	24.00 ^b	23.00 ^e	20.90 ^g	19.60 ^c	180 ^c	158 ⁱ	143 ^m	112 ^c
Raynox Plus 2%	21.00 ^g	20.00 ⁱ	19.00 ^j	18.30 ^d	183 ^b	163 ^h	149 ^k	116 ^b
Raynox Plus 2% with shading (35% SN)	23.60 ^c	22.10 ^f	20.40 ^h	19.20 ^c	188 ^a	169 ^g	153 ^j	125 ^a
Shading (35% SN)	24.30 ^a	24.00 ^b	23.30 ^d	22.00 ^a	175 ^e	147 ^l	130 ^p	98 ^e
Season 2017								
Control	24.50 ^b	23.60 ^e	23.00 ^g	21.70 ^b	168 ^f	136 ^m	117 ^p	80 ^f
Surround WP® 3%	23.40 ^f	21.60 ^j	20.40 ^m	19.00 ^e	175 ^d	150 ^j	130 ⁿ	100 ^d
Surround WP® 3% with shading (35% SN)	24.20 ^c	22.50 ^h	21.20 ^k	19.90 ^c	178 ^c	154 ⁱ	140 ^j	110 ^c
Raynox Plus 2%	22.50 ^h	21.20 ^k	19.60 ⁿ	18.80 ^f	180 ^b	160 ^h	141 ⁱ	112 ^b
Raynox Plus 2% with shading (35% SN)	23.60 ^e	22.20 ^j	20.80 ^j	19.70 ^d	184 ^a	165 ^g	150 ^j	120 ^a
Shading (35% SN)	25.60 ^a	23.80 ^d	23.30 ^f	22.30 ^a	171 ^e	144 ^k	127 ^o	95 ^e

significant percent of CI compared with control either during cold storage or at the end of marketing during both seasons. In this respect, treatment with Raynox Plus® at 2% with shading (35% SN) was effective for delaying the increase in CI symptoms, since the CI (%) was less about 72% compared with the control fruits after 7 days of marketing (Table 8). The chilling injury in fruits treated with Raynox Plus® at 2% with shading (35% SN) ranged 2.12 and 2.0% after 40 days of cold storage and were 5.85 and 5.50% after 7 days of marketing during the two seasons, respectively. Since, the untreated fruits showed higher symptoms of CI percentage after 7 days at marketing ranged 21.35 and 19.95 during both seasons, respectively.

Fruit skin hue color (h°): The hue color of Wonderful pomegranate fruits surfaces is given in Table 9 during 2016 and 2017 seasons. A higher hue angle value indicates less blush or greener color. In general, hue angle values increased gradually during cold storage but decreased during marketing in both seasons. In addition, shading (35% SN) showed the highest significant h° (23.30 and 23.60) during cold storage, while Raynox Plus® at 2% showed the lowest significant h° (19.0 and 19.60) by the end of cold storage in both seasons, respectively. Also, by the end of marketing shading (35% SN) treatment showed the highest h° (22.0 and 22.30) since, Raynox Plus® at 2% produced the lowest significant h° value (18.30 and 18.80) in both seasons, respectively.

Table 10: Total soluble solid (TSS %) and titratable acidity (%) of wonderful pomegranate arils after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Total soluble solid (%)				Titratable acidity (%)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	15.60 ^m	15.80 ^l	16.10 ^k	16.50 ^c	1.81 ^a	1.55 ^c	1.32 ^d	1.00 ^a
Surround WP® 3%	17.20 ^{ef}	17.50 ^{bc}	17.70 ^a	17.90 ^a	1.20 ^e	1.00 ^{hi}	0.84 ^l	0.68 ^e
Surround WP® 3% with shading (35% SN)	17.00 ^{gh}	17.20 ^{ef}	17.40 ^{cd}	17.60 ^{ab}	1.30 ^d	1.16 ^f	0.93 ^j	0.78 ^c
Raynox Plus 2%	17.10 ^{fg}	17.50 ^{bc}	17.60 ^{ab}	17.80 ^{ab}	1.57 ^c	1.12 ^g	0.89 ^k	0.73 ^d
Raynox Plus 2% with shading (35% SN)	16.80 ^{ji}	17.00 ^{gh}	17.40 ^{cd}	17.50 ^{ab}	1.65 ^b	1.23 ^e	0.98 ⁱ	0.81 ^c
Shading (35% SN)	16.70 ^j	16.90 ^{hi}	17.30 ^{de}	17.40 ^b	1.55 ^c	1.30 ^d	1.03 ^h	0.85 ^b
Season 2017								
Control	15.30 ^g	15.90 ^f	16.00 ^f	16.20 ^c	1.76 ^a	1.50 ^c	1.30 ^e	0.98 ^a
Surround WP® 3%	17.70 ^{ab}	17.70 ^{ab}	17.80 ^a	18.00 ^a	1.23 ^{efg}	1.05 ^{ji}	0.87 ^l	0.64 ^e
Surround WP® 3% with shading (35% SN)	17.40 ^c	17.60 ^b	17.40 ^c	17.80 ^{ab}	1.39 ^d	1.20 ^{fg}	0.97 ^{jk}	0.75 ^c
Raynox Plus 2%	17.00 ^e	17.40 ^c	17.60 ^b	17.90 ^{ab}	1.60 ^b	1.15 ^{gh}	0.93 ^{kl}	0.70 ^d
Raynox Plus 2% with shading (35% SN)	17.20 ^d	17.40 ^c	17.40 ^c	17.70 ^{ab}	1.50 ^c	1.23 ^{efg}	1.00 ^{ijk}	0.79 ^b
Shading (35% SN)	16.90 ^e	17.20 ^d	17.30 ^{cd}	17.60 ^b	1.50 ^c	1.28 ^{ef}	1.07 ^{hi}	0.80 ^b

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Juice volume (mL/100 g arils): As for juice volume, results presented in Table 9 showed in general that juice volume decreased gradually with the prolongation of cold storage period and during marketing in both seasons. On the other hand, Raynox Plus® at 2% with shading (35% SN) treatment achieved the highest value of juice volume among all treatments after 40 days of cold storage (153 and 150 mL/100 g arils) and after 7 days of marketing (125 and 120 mL/100 g arils) during both seasons under the study. While, the untreated fruits gave the lowest value of juice volume after 40 days of cold storage (121 and 117 mL/100 g arils) and after 7 days of marketing (83 and 80 mL/100 g arils) in both seasons, respectively.

Total soluble solid (TSS %): From Table 10 data presented that TSS percentage of Wonderful pomegranate fruits was significantly increased in all treatments applied with the progress of cold storage and marketing in both seasons. Moreover, all applied treatments showed increment in TSS percentage as compare to control either cold storage or marketing in both seasons, respectively. In addition, Surround WP® at 3% showed the highest significant TSS value after 40 days of cold storage (17.70 and 17.80%) and 7 days of marketing (17.90 and 18.00%) while the untreated fruits showed the lowest significant TSS value after 40 days of cold storage (16.10 and 16.0%) and 7 days of marketing (16.50 and 16.20%) in both seasons, respectively.

Titratable acidity (%): Results in Table 10 showed that TA (%) of Wonderful pomegranate fruits was significantly reduced in all treatments applied as compare to control throughout this study after 40 days of cold storage and 7 days of marketing in both seasons.

On the other hand, control treatment led to significant increment in TA percentage (1.32 and 1.30%) after 40 days of cold storage and (1.0 and 0.98%) after 7 days of marketing compared with all treated fruits in the two seasons, respectively.

While, sprinkle Surround WP® at 3% gave lower significant acidity (0.84 and 0.87%) after 40 days of cold storage and (0.68 and 0.64%) after 7 days of marketing in the two seasons, respectively.

Anthocyanins (mg/100 mL juice): In the study, statistical analyses showed that total anthocyanin content of Wonderful pomegranate fruits were significantly ($p < 0.05$) reduced during 40 days of cold storage Table 11. All treatments applied maintain the content of anthocyanin in fruits skin than the control except shading (35% SN) treatment alone under cold storage and during marketing. The results showed that, the treatment of Raynox Plus® at 2% treatment maintained anthocyanin in fruit skin (9.0 and 9.50 mg/100 mL juice) after 40 days under cold storage and 7 days at marketing (8.0 and 8.60 mg/100 mL juice) comparison with other treatments used during both seasons. However, with shading (35% SN) treatment presented lower values of anthocyanin in fruit skin

Table 11: Anthocyanin (mg/100 mL juice) and total sugar (%) of wonderful pomegranate arils after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Anthocyanin (mg/100 mL juice)				Total sugar (%)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	13.00 ^d	9.90 ^j	8.30 ^j	7.10 ^e	12.70 ^o	13.00 ⁿ	13.50 ^l	14.60 ^a
Surround WP® 3%	13.80 ^b	10.50 ^f	8.90 ^j	7.80 ^b	14.10 ⁱ	15.90 ^c	16.10 ^a	17.00 ^a
Surround WP® 3% with shading (35% SN)	13.30 ^c	10.20 ^{gh}	8.60 ^k	7.40 ^d	13.50 ^j	15.40 ^f	15.80 ^d	16.30 ^b
Raynox Plus 2%	14.10 ^a	10.90 ^e	9.00 ^j	8.00 ^a	14.00 ^k	15.70 ^e	16.00 ^b	16.50 ^b
Raynox Plus 2% with shading (35% SN)	13.50 ^c	10.30 ^{fg}	8.70 ^k	7.60 ^c	14.60 ^j	15.00 ^h	15.90 ^c	16.40 ^b
Shading (35% SN)	13.40 ^c	10.00 ^{hi}	8.20 ^j	7.00 ^e	13.20 ^m	15.00	15.30 ^g	16.00 ^c
Season 2017								
Control	13.20 ^e	10.20 ^j	8.50 ^o	7.50 ^d	12.40 ^h	12.90 ^g	13.20 ^f	14.30 ^e
Surround WP® 3%	14.20 ^b	10.90 ^g	9.20 ^j	8.00 ^b	13.80 ^e	15.10 ^{bc}	15.90 ^a	16.30 ^a
Surround WP® 3% with shading (35% SN)	13.70 ^d	10.60 ^h	8.80 ⁿ	7.70 ^c	13.20 ^f	14.90 ^{cd}	15.10 ^{bc}	16.00 ^b
Raynox Plus 2%	14.50 ^a	11.50 ^f	9.50 ^k	8.60 ^a	13.60 ^e	15.30 ^b	15.70 ^a	16.10 ^b
Raynox Plus 2% with shading (35% SN)	13.90 ^c	10.70 ^h	9.00 ^m	7.90 ^b	13.10 ^{fg}	14.80 ^d	15.00	15.80 ^c
Shading (35% SN)	13.60 ^d	10.00 ^j	8.40 ^o	7.40 ^d	12.40 ^h	14.80 ^d	15.00 ^{cd}	15.50 ^d

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

Table 12: Vitamin C (mg AA/100 mL juice) and total phenols (mg eq. gallic acid 100 g⁻¹) of wonderful pomegranate arils after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Vitamin C (mg AA/100 mL juice)				Total phenols (mg eq. gallic acid 100 g ⁻¹)			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	22.80 ^g	21.80 ^h	16.80 ⁿ	13.40 ^e	87.30 ⁿ	94.10 ^j	97.00 ^h	101.40 ^f
Surround WP® 3%	24.70 ^b	23.50 ^f	18.30 ^j	16.00 ^b	88.00 ^{lm}	98.50 ^g	103.60 ^c	108.00 ^d
Surround WP® 3% with shading (35% SN)	24.30 ^c	23.60 ^{ef}	17.70 ^j	15.70 ^c	88.30 ^{kl}	99.10 ^f	105.90 ^b	111.40 ^c
Raynox Plus 2%	25.00 ^a	24.10 ^{cd}	18.60 ^j	16.30 ^a	88.70 ^k	99.70 ^e	106.00 ^b	112.90 ^b
Raynox Plus 2% with shading (35% SN)	24.60 ^b	23.60	18.00 ^k	15.90 ^b	89.90 ^j	101.20 ^d	107.60 ^a	114.80 ^a
Shading (35% SN)	23.90 ^{de}	23.00 ^g	17.40 ^m	15.10 ^d	87.70 ^{mn}	96.50 ^h	101.00 ^d	105.00 ^e
Season 2017								
Control	23.00 ^h	22.00 ^j	17.10 ^o	13.90 ^e	88.90 ^p	95.10 ^k	99.00 ^j	105.20 ^f
Surround WP® 3%	25.00 ^b	24.00 ^e	18.70 ^k	16.30 ^b	89.50 ^a	100.40 ^b	105.40 ^d	111.00 ^d
Surround WP® 3% with shading (35% SN)	24.40	23.70 ^f	18.00 ^m	16.00 ^c	90.10 ⁿ	102.10 ^g	107.50 ^c	113.20 ^c
Raynox Plus 2%	25.30 ^a	24.40 ^d	19.00 ^j	16.60 ^a	91.00 ^m	103.50	109.00 ^b	115.10 ^b
Raynox Plus 2% with shading (35% SN)	24.70 ^c	23.80 ^f	18.30 ^j	16.10 ^c	92.10 ^j	104.00 ^e	110.20 ^a	116.70 ^a
Shading (35% SN)	24.10 ^e	23.30 ^g	17.80 ⁿ	15.60 ^d	89.30 ^a	98.50 ^j	104.00 ^e	108.00 ^e

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

(8.20 and 8.40 mg/100 mL juice) after 40 days of cold storage and 7 days at marketing (7.0 and 7.40 mg/100 mL juice) through the both seasons under the study.

Total sugars (%): Considering to the effect of total sugar, data in Table 11 revealed that, total sugars were increased gradually according to the progress of cold storage and the end of marketing during both seasons. Since, fruits of control samples had significantly the lowest level of total sugars values after 40 days of cold storage (13.50 and 13.20%) and 7 days of marketing (14.60 and 14.30%) in the first and second

seasons, respectively. Conversely, spraying fruits by Surround WP® at 3% produced a higher value of total sugar after 40 days of cold storage (16.10 and 15.90%) and after 7 days at marketing (17.0 and 16.30%) under the two seasons, respectively.

Vitamin C (mg/100 g FW): All treatments used significantly delayed the decrease of vitamin C than the control as showed in Table 12 either after 40 days of cold storage or 7 days through marketing. The amount of ascorbic acid decreased continuously with storage time. The contents of vitamin C in

Table 13: Pectinase (U g^{-1}) pulp and antioxidant activity ($\mu\text{g mL}^{-1}$) juice of wonderful pomegranate arils, as affected by Surround WP®, Raynox Plus® and shading by 35% shade net (SN) treatments after 40 days of cold storage and 7 days at the end of cold storage as marketing in 2016 and 2017 seasons

Treatments	Pectinase (U g^{-1}) pulp				Antioxidant activity ($\mu\text{g mL}^{-1}$) juice			
	Days in cold storage			Days at marketing	Days in cold storage			Days at marketing
	Initial	20	40	7	Initial	20	40	7
Season 2016								
Control	1.55 ^m	6.00 ^b	9.20 ^a	11.50 ^a	19.00 ^j	23.50 ^j	32.00 ^g	41.00 ^f
Surround WP® 3%	1.55 ^m	2.90 ⁱ	4.30 ^d	8.40 ^c	19.00 ^j	31.80 ^g	38.50 ^e	52.00 ^d
Surround WP® 3% with shading (35% SN)	1.55 ^m	2.60 ^k	4.10 ^e	7.90 ^d	19.00 ^j	32.00 ^g	39.80 ^c	53.90 ^c
Raynox Plus 2%	1.55 ^m	2.70 ^j	4.00 ^f	7.00 ^e	19.00 ^j	32.20 ^g	40.60 ^b	55.00 ^b
Raynox Plus 2% with shading (35% SN)	1.55 ^m	2.40 ^l	3.80 ^g	6.70 ^f	19.00 ^j	33.00 ^f	41.00 ^a	56.00 ^a
Shading (35% SN)	1.55 ^m	3.10 ^h	4.90 ^c	9.50 ^b	19.00 ^j	26.00 ^h	39.10 ^d	44.00 ^e
Season 2017								
Control	1.65 ^m	6.80 ^b	9.50 ^a	12.00 ^a	20.00 ^j	24.80 ^h	33.00 ^f	43.00 ^e
Surround WP® 3%	1.65 ^m	3.00 ^j	4.40 ^d	8.70 ^c	20.00 ^j	32.90 ^f	39.50 ^d	54.00 ^c
Surround WP® 3% with shading (35% SN)	1.65 ^m	2.90 ^k	4.30 ^e	8.00 ^d	20.00 ^j	33.00 ^f	40.00 ^c	55.90 ^b
Raynox Plus 2%	1.65 ^m	3.10 ^j	4.20 ^f	7.50 ^e	20.00 ^j	33.20 ^f	41.80 ^b	56.00 ^b
Raynox Plus 2% with shading (35% SN)	1.65 ^m	2.60 ^l	3.90 ^g	6.90 ^f	20.00 ^j	34.50 ^e	42.20 ^a	57.40 ^a
Shading (35% SN)	1.65 ^m	3.40 ^h	5.10 ^c	9.60 ^b	20.00 ^j	27.10 ^g	39.70 ^{cd}	45.10 ^d

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels

control treatments declined to 16.80 and 17.10 (mg/100 mL juice) after 40 days at cold storage at 5°C and ranged 13.40 and 13.90 (mg/100 mL juice) after 7 days through marketing at 20°C during both seasons, respectively. The higher amounts of vitamin C contents were obtained in Raynox Plus® at 2% treated fruits during the entire storage period. The contents of vitamin C in this treatment were 18.60 and 19.00 (mg/100 mL juice) after cold storage at 2°C and were 16.30 and 16.60 (mg/100 mL juice) after 7 days through marketing at 20°C during both seasons, respectively.

Total phenols (mg eq. gallic acid 100 g⁻¹): Results presented in Table 12 showed that total phenols increased as storage proceeded. All investigated treatments increased total phenols after 40 days of cold storage and 7 days at marketing during both seasons.

A significantly higher in total phenols content was detected in fruits treated with Raynox Plus® at 2% with shading (35% SN) compared with all treatments used after 40 days of cold storage (107.60 and 110.20 (mg eq. gallic acid 100 g⁻¹) and after 7 days at marketing (114.80 and 116.70 (mg eq. gallic acid 100 g⁻¹) in both seasons, respectively. Furthermore, control treatment attained the minimum values in total phenol content of pomegranate fruits compared with all treatments used after 40 days of cold storage (97.00 and 99.00 mg eq. gallic acid 100 g⁻¹) and after 7 days at marketing (101.40 and 105.20 (mg eq. gallic acid 100 g⁻¹) in both seasons, respectively.

Total Pectinase Content (U g^{-1} pulp): From Table 13 data showed that all examined pre-harvest treatments succeeded in decreasing the pectinase content of Wonderful pomegranate fruits in both seasons.

The data also indicate that, the pectinase content of Wonderful pomegranate fruits was progressively increased as the cold storage period increased from zero storage periods to 40 days. In this respect, the lowest values of pectinase content were recorded by Raynox Plus® at 2% with shading (35% SN) treatment after 40 days of cold storage (3.80 and 3.90 U g^{-1} pulp) and after 7 days at marketing (6.70 and 6.90 U g^{-1} pulp) during both seasons of study, respectively. On the contrary, the highest values of this parameter were recorded by the by untreated fruits after 40 days of cold storage (9.20 and 9.50 U g^{-1} pulp) and after 7 days at marketing (11.50 and 12.0 U g^{-1} pulp) during both seasons of study, respectively.

Antioxidant activity: Results presented in Table 13 showed that total antioxidant activity increased as storage progressed. All investigated treatments increment antioxidant activity compared to the control after 40 days of cold storage and 7 days at marketing during both seasons. It also showed that Raynox Plus® at 2% with shading (35% SN) resulted significant increment in antioxidant activity compared with all treatments used or the control after 40 days of cold storage (41.0 and 42.20 $\mu\text{g mL}^{-1}$ juice) and after 7 days at marketing (56.0 and 57.40 $\mu\text{g mL}^{-1}$ juice) in both seasons, respectively. Moreover, control treatment attained the minimum significant

Table 14: Economic values of using surround WP®, Raynox Plus® and shading by 35% (SN) of wonderful pomegranate under experimental condition

Treatments	Whole sale (EGP/acre)	Total grower charges (EGP/acre)	Total sunburn management cost (EGP/acre)	Net return to grower (EGP/acre)
Control	16500	6000	0.00	10500
Surround WP® 3%	20500	6400	415	13685
Surround WP® 3% with shading (35% SN)	22600	6400	2115	14085
Raynox plus 2%	21800	6500	440	14060
Raynox plus 2% with shading (35% SN)	22800	6500	2140	14160
Shading (35% SN)	21000	6000	1700	13300

Means followed by the same letters are not significantly different by Duncan multiple range test at 0.05 levels, wholesale price (EGP/acre): This column represents the wholesale value per acre with equalized yield for all treatments (13 t/acre), total grower charges: Values obtained at equalized yield for all treatments (13 t/acre). these charges include storage, agriculture treatment, packing and sales agency fees, total sunburn management cost (EGP/acre): This cost includes: structural cost, labor and machinery charges, Net return to grower (EGP/acre): Values obtained at equalized yield for all treatments (13 t/acre)

values of antioxidant activity in pomegranate fruits compared with all treatments used after 40 days of cold storage (32.0 and 33.0 $\mu\text{g mL}^{-1}$ juice) and after 7 days at marketing (41.0 and 43.0 $\mu\text{g mL}^{-1}$ juice) in both seasons, respectively.

Economic value of using surround WP®, raynox plus® and shading by 35% (SN) of wonderful pomegranate under experimental condition:

Commercial value of the crop depends on both fruit weight and color. However, in this study we included losses due to sunburn and in the determination of the commercial value of the crop. Therefore, we calculated the net return to the grower after sunburn management cost per acre, considering the revenue flows and costs of producing, storing and marketing. To start, we calculated the wholesale value per acre by estimating the sales prices of the various packs' grades. Considering packing and storage costs per acre and sunburn management costs as showed in Table 14, it was calculated the net return to the grower for each treatment, expressed in Egyptian pound/acre. Costs of pest management, fertilizer, irrigation and chemicals were not considered, as they were assumed to be consistent across the different treatments. Fruits harvested at the first and the second pick were weighed then color evaluated individually in the laboratory. Fruit weight was expressed in grams and red color was expressed as percentage of the fruit surface. Fruits from this study were divided into three categories grades as follows:

- First degree: The fruit weight ranges between 400-500 g or higher, price starting from 5000 Egyptian pounds per ton, red color ratio more than 85% of the fruit surface and sunburn = 0% of the fruit surface and carton 10 kg
- Second degree: The weight of fruits ranges between 300-400 g, price starting from 3000 Egyptian pounds per ton, red color ratio more than 70% of the fruit surface and sunburn was >5% of the fruit surface and Carton 10 kg

- Third degree: The weight of fruits ranges between 200-300 g (or less), price starting from 2000 Egyptian pounds per ton, red color ratio less than 60% of the fruit surface and sunburn was >10% of the fruit surface and Carton 10 kg

Fruits that do not belong to these grades are considered not suitable for marketing.

DISCUSSION

Total yield of 'Wonderful' pomegranate tree was significantly increased gradually with all applied treatments during both seasons. Since, the results at harvest revealed that sprinkle of Raynox Plus® at 2% with shading (35% SN) recorded the highest values of fruit number, heaviest weight and higher Yield. Fruit production losses due to sunburn may be 6-30% depending on seasons and the type of fruit. When air temperatures rise above 30-35°C during the daytime, photosynthesis is likely to slow which will reduce potential fruit yield. It was found that untreated trees gave the highest percent of sunburn fruits, while generally kaolin sprays after fruit setting and before the first anticipated reduced the percentages of fruit sunburn²⁰. All applied treatments reduced the percent of fruit cracking and sunburn compared with the untreated treatments in both seasons, respectively. So, the use of a reflective particle film is effective in mitigating environmental stress and has significant economic benefits in agricultural crops. Kaolin reduces heat stress on leaves and increases carbon assimilation, which results in higher fruit yield, weight and better coloration²¹. Since, Abdel Ghani *et al.*²² concluded that, kaolin foliar spray significantly increased yield as number of olive fruits per tree or weight (kg) compared to foliar spray with tap water. Also, shading caused by particle films decreased net leaves photosynthesis due to reduced total efficiency of stomata conductance and reduced day

respiration by 60-70% compared to the control. Moreover, foliar application with kaolin can significantly prevent injury during abiotic and biotic stress conditions and reduce sun damage in pomegranate fruits. It reduces the surface temperature of leaves and fruits by reflecting ultraviolet and infrared light without interfering with stomatal functioning or photosynthetic properties since, it improves the internal water balance within the fruit²³. Kaolin, which is used in Surround WP® is purified and structurally altered by heat treatment to reflect more solar radiation than minimally processed kaolin²⁴. Physiological trials showed that kaolin-based particle film applications, besides reducing fruit surface temperature²⁵, decrease canopy temperature. Radiation reflection studies indicated that Surround WP® application increased UV-B and UV-A reflection from treated fruit surface as compared to control. Rosati *et al.*²⁶ reported 20% reduction in absorption of Photosynthetically active radiation (PAR) by fruits covered with kaolin clay. Another sunburn suppressant (Raynox Plus®) is a sunscreen by definition⁹, as it contains organic-chemical absorbing agents in addition to physical inorganic constituents. In contrast to particle film technology, this formulation provides a clean, rain-fast film on apples that is not washed off by rain or overhead irrigation and does not require specific washing/brushing technology on the packing line to remove residue. Carnuba wax, the principal component of this sunscreen Raynox Plus® contains cinnamates that absorb high-intensity UV rays with excitation to a higher energy state³, but this excess energy is dissipated by emission of longer wavelength light or relaxation by photochemical processes such as isomerization a heat release. Raynox Plus® also contains inorganic components that block, reflect and scatter solar radiation.

Applications of Raynox Plus® caused no phytotoxicity on either leaves or fruit; its application did not decrease the maximum quantum efficiency of Photosystem³ or whole-tree gas exchange indicating no effect on photosynthesis or transpiration of apple trees.

Furthermore, pale netting (35% shade net) enhanced fruit protection from exposure to direct sun light which reduce sunburn percentage. Do Amarante *et al.*²⁷ compared with the effect of shade nets with 15 and 55% light reduction; nets reducing solar radiation by 15% were not effective for sunburn control, but the use of nets with 55% light reduction eliminated sunburn injury. The use of high-density polyethylene (HDPE) shade nets over the tree canopy for shading purposes reduces incident sunlight on the fruit surface and FST via a reduction of the transmission of direct solar radiation through the net; this decreases sunburn injury²⁸.

Since, kaolin spraying significantly reduced sunburn damage of pomegranate fruit from 21.9% in the untreated fruits to 9.4% for treated ones²³. On the other hand, decreasing fruit cracking by pale netting (35% shade net) may be due to their effect on reduce heat stress of fruit and water content of peel which decrease the transpiration from fruit surface. The rapid absorption of water when irrigation is resumed to severely stressed fruit leads to cracking of the skin as water is diverted to the aril and greater stress is placed on the water-deficient skin. It has also been suggested that asymmetrical stretching of the skin occurs as the aril fills with water. This leads to cracking on the same side of the swelling aril. Undulations in fruit surface temperatures combined with increased water evaporation from the surface are known factors that induce pomegranate fruit cracking²⁹. Kaolin application helped reduce pomegranate surface temperatures and fruit cracking by reflecting light away from the fruit thereby preventing sun-scorching of the pomegranate skin. Since, Raynox Plus® at 2% recorded the highest weight of red arils (and total during both seasons, respectively). Also, it was noted a positive increment in the pomegranate fruit weights, aril weights, juice percentages after foliar application of kaolin³⁰. Pomegranate aril refers to the edible, translucent, fleshy membrane that surrounds the kernel³¹. The pomegranate aril contains 76-85% juice, which accounts for approximately 30% of the fruit weight. The aril sac, ranging from deep red to virtually colorless, microscopically comprises epidermal cells³². Also, pomegranate aril contains up to 70.5% hydrolysable tannins, 25% anthocyanins and approximately 5% ellagic acid derivatives.

Sweetness is an important quality attribute of pomegranate fruits. In addition, Surround WP® at 3% showed the highest significant TSS value and gave lower significant acidity after 40 days of cold storage and 7 days during marketing. The change in soluble solids in fruits is generally associated with the hydrolytic enzymes for starch while, the advanced activity of enzymes is responsible for the changes of starch to sugars. Generally, spraying kaolin on 'Okitsu' mandarin enhanced slightly fruit quality in terms of TSS, acidity and attended to significantly increased vitamin C comparing with the control in both seasons³³.

Schrader *et al.*⁶ confirmed that TA generally decreased and TSS increased with sunburn necrosis (SN). Although there is a reduction in ultraviolet and/or infrared light by Surround WP® but due to increased scattering of light and the redistribution of photosynthetically active radiation (PAR), there is an improvement in the red color of 'Delicious'⁶.

Peel color of pomegranate is the most essential quality index, directly attracting consumer attention. Also, color changes in peel surface were in line with fruit general appearance³⁴. Moreover, the treatment of shading (35% SN), produced less red (high hue values) pomegranate fruits either at skin or arils. Because of considerable reduction in the levels of solar radiation under shade nets, physiological processes of the fruit/tree are also altered and affect fruit quality. Also, reduction in anthocyanin accumulation and red color development under shade nets is a commonly reported problem in red and bi-colored cultivars³⁵.

Weight loss is largely due to water loss through natural porosity of the skin. Fresh pomegranate fruits transpiration leads to significant weight loss and finally causing to the softening of flesh, the decrease of juiciness and peel shriveling. Shriveling symptoms on fruit are noticeable only when weight loss exceeds 5% or more of the initial weight³⁶. Postharvest weight losses in pomegranate fruits primarily associated with weight loss in the fruit peel compared with arils. In this study, Raynox Plus® at 2% with shading (35% SN) treatment showed the lowest significant weight loss values. The main key to reduce chilling injury via its effect on antioxidant activity and changes in enzymes activity such as ascorbic acid oxidase, polyphenol oxidase, peroxidase, catalase, which may be related to membrane integrity and electrolyte leakage³⁷.

Surround WP® not only influenced fruit texture but also suppressed respiration and ethylene evolution rates which contribute significantly to higher shelf life of sprayed fruits. In addition, by forming a protective layer over the fruit, Surround WP® acts as physical barrier and thereby it reduced the rates of transpiration and/or evaporation and the rates of respiration and ethylene as well³⁸. The degradation in ascorbic acid during storage might be due to indirect dissolution through polyphenol oxidase and peroxidase activity. Furthermore, ascorbic acid is sensitive to oxidative degradation lead to the formation of dehydroascorbic acid³⁹. Surround WP®-treated apples maintained higher concentrations of total phenolic content. Since, it helps in the synthesis of phenolic compounds in apples by increasing the PAL activity whereas LOX activity was suppressed. In this respect, particle films of Surround WP® might have increased PAR (photosynthetically active radiation) in the plants²⁷ which increased the PAL activity and thereby the total phenolics in treated fruit. The total antioxidant activity also decreased with fruit maturation. The total antioxidant activity is attributed to the levels of phenolic acids, ascorbic acid as well as

anthocyanin and therefore the seasonal changes in total antioxidant activity are different to those seen for the total phenolic content. The level of antioxidant activity is important quality consideration in terms of bioactivity and taste. The polyphenol content includes esters of gallic acid which determines the astringency in the fruit. The loss of astringency is one of the principle changes that occur during ripening of many fruits and this change makes the fruit more palatable when ripe. Also, the level of total phenolic content was reducing through fruit growth and maturation in the arils and the peel⁴⁰.

CONCLUSION

In this experiment, all applied particle films with shading keeping quality and storability of Wonderful pomegranate fruits. Since, sprinkle surround WP® 3% with shading (35% SN) was the best method for preventing sunburn, cracking and extending fruits shelf life. Moreover, Raynox Plus® at 2% with shading (35% SN) gave higher net return to growers as compare to all treatments applied. Thus, it can be concluded that these material with shading net technology have great future as it can become an integral part of organic fruit production.

SIGNIFICANCE STATEMENT

This study discovered the possible effect of sprinkle Surround WP® and Raynox® plus with shading (35% SN) that can be beneficial for maintaining quality during commercial range or the export market of wonderful pomegranate fruits. This study will help the researchers to uncover the critical areas of maintaining quality and decreasing fruit sunburn accompanied by changes in various metabolic and physiological processes during marketing that many researchers were not able to explore. Thus new theories of sunscreen particles film with shading are promising examples that are beginning to be adopted on a commercial scale which may be arrived at retain quality of pomegranate fruits at harvest, after 40 days of cold storage and held for 7 days at ambient conditions as marketing”.

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