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# Effects of Size, Storage Duration, and Modified Atmosphere Packaging on Some Pomological Characteristics of Wonderful Pomegranate Cultivar

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<http://dx.doi.org/10.5772/67914>

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## Abstract

Pomegranate fruit is very susceptible to storage conditions, and it losses weight and quality during long storage periods. The aim of the present study was to determine the effects of modified atmosphere packaging (MAP), storage duration, and fruit size on some quality attributes of Wonderful pomegranate cultivar. Results indicated that there is a clear relationship between the fruit weight and number of arils ( $R^2$ , 0.948) as expected. On the other hand, a significant relationship also exists between the number of arils and aril weight ( $R^2$ , 0.973). According to the results, it is also possible to estimate the juice content of pomegranate fruits by its aril weight ( $R^2$ , 0.994) and also from the fruit weight. Results also showed that modified atmosphere packaging has a clear effect on the protection of fruit weight. The loss in the fruit weight after 90 days of storage is found to be between 6.70 and 14.28% without MAP and between 2.64 and 6.24% with MAP. Similar results have been determined for aril weight and juice content. The other important result of the present study is that fruit size significantly affects the weight loss. The bigger fruits showed higher weight loss. No significant effect has been determined on the total soluble solids content of fruits for neither different sizes nor different storage conditions.

**Keywords:** pomegranate, Wonderful, storage duration, modified atmosphere packaging, fruit size

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## 1. Introduction

Pomegranate plant is among the oldest known cultivated crops. According to Ref. [1], domestication of pomegranate tree dates back to 3000–4000 BC in the North of Iran and Turkey. Pomegranate fruits are classified under the group of berries. Diverse number of arils are

found within the pomegranate fruit wrapped to the inside of leathery peel [2]. Pomegranates are reported to be originated from Central Asia [3, 4]. However, pomegranate tree is adaptable to a wide range of climate and soil conditions. The trees can grow in many different geographical places including the Mediterranean Basin, California, and Asia.

Pomegranate fruits are traditionally known to be very beneficial for human health, but its consumption was limited because of the hassle of extracting the arils from the fruit. According to Ref. [5], Hippocrates (400 BCE) used pomegranate extracts for many purposes, such as aid to digestion and eye inflammation. Since the beginning of the twenty-first century, many scientific studies have been done about the health benefits of pomegranate. Besides to fruits, flowers, bark, and leaves of pomegranates may contain beneficial phytochemicals which are antioxidant and antimicrobial, reduce blood pressure, and act against serious diseases such as cancer and diabetes [6].

Confirmation of the health benefits of pomegranates caused an improvement in the public awareness, and this caused an increase in the pomegranate consumption in the world. Therefore, production of this highly beneficial fruit started to increase to meet the increasing demand. Pomegranate plant is produced throughout the world in subtropical and tropical areas. The harvesting period of pomegranate extends from August to November in the northern hemisphere and from March to May in the southern hemisphere. There is a year-round demand for pomegranate fruit throughout the world and its global availability is being met by postharvest storage [2]. However, pomegranate fruit is very susceptible to storage conditions, and it losses weight and quality during long storage periods. The main challenge of pomegranate fruit producers and marketers is maintaining postharvest quality. One of the main postharvest problems of pomegranate fruit is weight loss. Long and inappropriate storage causes huge losses not only on weight but also on fruit quality and income of the farmers. Weight loss also causes hardening of the husk and browning of the rind in which they reduce the attractiveness of fruits [7]. The weight loss of pomegranate fruit is reported to reach up to 32% in 8 weeks if stored at 22°C [8]. Many scientific studies were conducted about the favorable conditions for pomegranate storage in terms of prevention of weight loss, and they suggest 5–7°C and >90% relative humidity for the reduction of weight loss [9–11].

Modified atmosphere packaging (MAP) is a way of extending the shelf life of fresh food products. It helps to protect postharvest quality while reducing the weight loss. In a MAP system, there is a change in the concentration of gases in the packaging headspace due to the dynamic interaction between the metabolic and biochemical processes of the packaged product. When fresh produce respire, O<sub>2</sub> is consumed, and CO<sub>2</sub>, ethylene, and water vapor are generated; and transfer of all of these gases through the packaging is regulated in MAP. The aim of the system is to balance these two processes to provide favorable conditions to preserve the product [7, 12, 13]. MAP is reported to be successful for the prolongation of storage duration of pomegranate fruits up to 3 months while reducing weight loss [8, 14, 15]. However, according to authors' knowledge, no studies were conducted about the combined effects of fruit size and modified atmosphere packaging. In the light of this information, the present study was aimed to determine the combined effects of fruit size, storage duration, and storage conditions on the pomological characteristics of Wonderful pomegranate cultivar.

## 2. Materials and methods

### 2.1. Materials

The main material of the present study was the Wonderful cultivar pomegranate fruits. This cultivar originated in Florida. The fruits are large when compared with most of other varieties/cultivars with a color of deep purple-red fruits. The fruit's inside is a deep crimson in color. The fruit is juicy and has a tart taste. The seeds are not very hard. This cultivar is better for fresh eating and juicing. It is a leading commercial cultivar in California and is the most popular cultivar in the world. It has a ripening Brix of 17–21%. The fruit requires about 160–180 days from flowering to ripening [2]. Fruits of Wonderful cultivar pomegranate were harvested at commercial maturity in October 2016 from 8 years of pomegranate trees grown in Cyprus. After harvest, fruits were classified by professional workers according to EU standards, and “extra” quality fruits were used in the experiments.

The other material of the study was the modified atmosphere packaging (MAP) bags. The MAP materials are purchased from Dekatrend Ltd. with the brand of Trendlife®. The material allows the CO<sub>2</sub> composition inside the package to be 9–15% and O<sub>2</sub> composition 6–10%. Trendlife® bags are reported to be manufactured from a semipermeable film which controls gas exchange. The film is based on the activity of several intelligent molecules placed inside the film. These molecules allow O<sub>2</sub> to enter the package at a rate offset by the consumption O<sub>2</sub> by the commodity. Similarly, the film makes it possible for CO<sub>2</sub> to be vented from the package to offset the production of CO<sub>2</sub> by the commodity. The film, on the other hand, vents the released ethylene gas from the package, thereby eliminating the possibility of acceleration of repining, senescence, deterioration, and decay. It also enriches the modified atmosphere with sufficient relative humidity and completely inhibits the weight loss.

### 2.2. Experimental design, treatments, and measurements

Fruits with five different sizes (4", 6", 8", 10", and 12") were subjected to three different storage durations (*the main plots*: 0, 45, and 90 days) and two different storage conditions (*the subplots*: control and modified atmosphere packaging). The fruit sizes are standard sizes for boxes with dimensions of 30 × 40 × 12 cm. Experiments were carried out with five different sizes of fruits with three replicates for each, and fruits were arranged in split-split plot design in a cold store with 5–7°C and 90–95% relative humidity. At the first day of harvest, fruit weight (g), fruit diameter (mm), number of arils, aril weights (g/100 arils), juice content (ml/100 arils), and total soluble solids (TSS) content (%) were measured and noted for the 0 day main factor. For the other two factors (45 and 90 days), fruit diameters (mm) and fruit weights (g) were measured at the first day of harvest and noted. After 45 and 90 days of storage, either with or without MAP, other measurements (fruit weight, fruit diameter, aril weights, juice content, and TSS) were done.

### 2.3. Statistical analysis

Data from the experiments were subjected to regression analyses to describe the relationship between fruit weight, number of arils, aril weight, and juice content. To determine the effects

of storage condition and storage duration on the quality attributes of pomegranate fruits, the data of the experiments were subjected to an ANOVA, and mean separations were done using Duncan's multiple range test at  $P < 0.05$ .

### 3. Results and discussions

#### 3.1. Relationship between pomological characteristics of pomegranate fruits at harvest

A significant difference has been determined among the fruit sizes for five out of six tested pomological characteristics of pomegranate fruits at harvest (**Table 1**). The results for fruit weight and fruit width are expected due to the nature of the fruit size. As the fruit weight and width increase, the size decreases. Size represents the number of fruits present in the same box. The smallest fruit width and weight are noted for size 12 with  $80.2 \pm 1.00$  mm and  $250 \pm 20.7$  g, respectively. The highest fruit width and weight were determined for size 4 with  $118.1 \pm 3.09$  mm and  $929 \pm 50.3$  g, respectively. Ref. [16] reported that the fruit weight of 12 cultivars ranged from 103.4 to 505.0 g in Iran. In another study, Ref. [17] noted that the average fruit weight of four different varieties ranged from 241.1 to 319.8 g in Turkey. Fruit size is much related with cultivars/varieties, environmental conditions, and growing conditions. Therefore, it is not surprising to have diverse fruit weights.

On the other hand, a clear difference has been determined for the number of arils per fruit among the different sizes. It is an important result for farmers which shows that the fruit size is mainly affected by the number of arils present in the fruits. This proves that the adequate fertilization and pollination during flowering and fruit set are very important for fruits to include an adequate number of cells, which turns into arils during development. According to Ref. [18], some fruits have fewer than 300 arils per fruit and some have up to 985 in the largest fruits. Ref. [4] reported that the production of large fruits requires adequate numbers of both functional ovules and a source of viable pollen on flowers. Ovule differentiation in pomegranates occurs before the opening of flower buds. For this reason, adequate pollination is crucial for fruit size and development.

Sizes	Fruit width (mm)	Fruit weight (g)	Number of arils	Aril weight (g/100 arils)	Juice content (ml/100 arils)	TSS (% Brix)
Size 12	$80.2 \pm 1.00$ (e)	$250 \pm 20.7$ (e)	$331 \pm 31.2$ (e)	$35.7 \pm 3.06$ (d)	$19.3 \pm 2.08$ (d)	$17.8 \pm 0.76$ (a)
Size 10	$86.4 \pm 1.89$ (d)	$354 \pm 24.5$ (d)	$476 \pm 32.7$ (d)	$43.3 \pm 1.53$ (c)	$26.7 \pm 1.53$ (c)	$17.9 \pm 0.85$ (a)
Size 8	$95.6 \pm 3.75$ (c)	$449 \pm 18.4$ (c)	$589 \pm 25.7$ (c)	$47.7 \pm 3.06$ (bc)	$30.5 \pm 2.18$ (b)	$17.5 \pm 0.50$ (a)
Size 6	$112.0 \pm 2.47$ (b)	$680 \pm 68.6$ (b)	$752 \pm 30.0$ (b)	$51.7 \pm 2.31$ (ab)	$33.0 \pm 2.69$ (b)	$17.7 \pm 0.68$ (a)
Size 4	$118.1 \pm 3.09$ (a)	$929 \pm 50.3$ (a)	$860 \pm 18.1$ (a)	$55.0 \pm 2.00$ (a)	$37.1 \pm 0.85$ (a)	$17.5 \pm 0.50$ (a)

Values followed by the same letter or letters are not significantly different at a 5% level (Duncan's multiple range test).

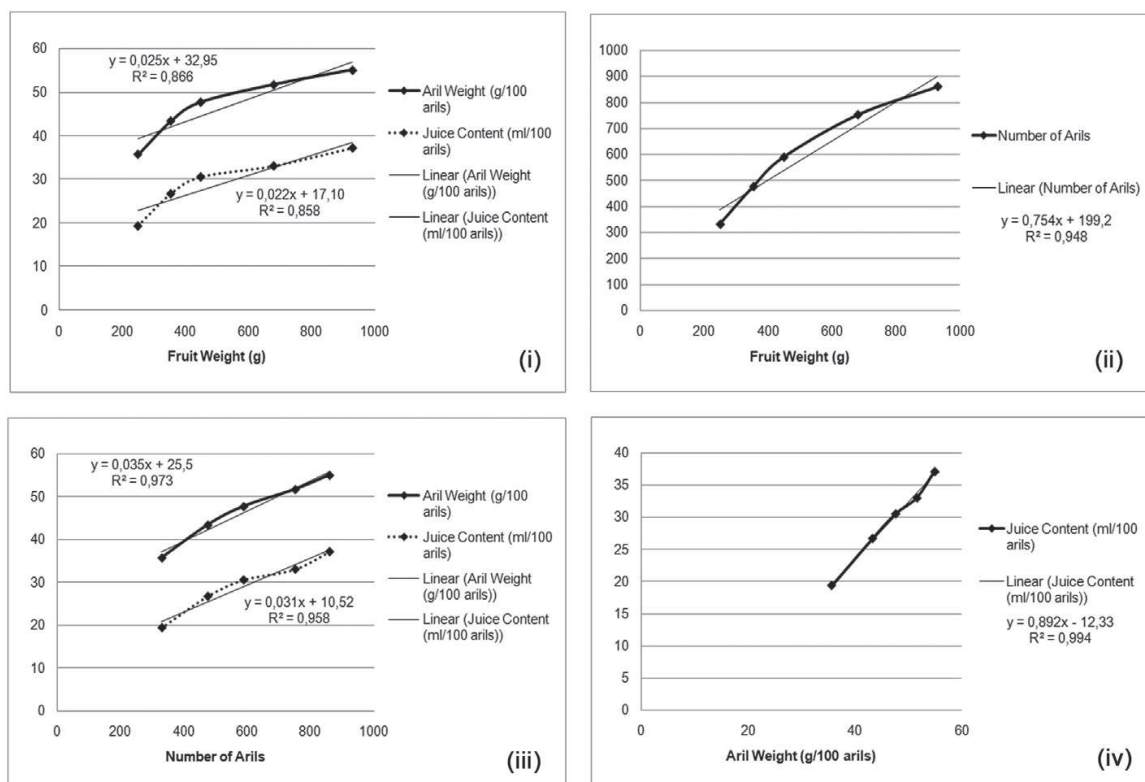
**Table 1.** Summary of some pomological data of pomegranate fruits at harvest.



Moreover, a significant difference has been determined among the aril weights of fruits for different sizes. This, on the other hand, shows that not only the number of arils but also the weight of arils is affecting the fruit size. No significant difference has been determined for the total soluble solids content of the fruits with different sizes.

At the first day of harvest, a clear relationship has been determined between the fruit weight and the aril weight (**Figure 1**). The adjusted  $R^2$  is calculated as 0.866. The results showed that as the fruit weight increases, the aril weight also increases. It is now possible to estimate the aril weight of a Wonderful cultivar pomegranate fruit at harvest by using the equation  $y = 0.025x + 32.95$ . In another study by Ref. [18], the relationship between fruit weight and total aril weight is described with the equation of  $y = 0.525x - 6.725$  ( $R^2 = 0.951$ ). Similar relationship has been determined between the fruit weight and the juice content. The adjusted  $R^2$  is calculated as 0.858 for this relationship.

On the other hand, an important linear relationship has been determined between the fruit weight and the number of arils. One can estimate the number of arils of a Wonderful cultivar pomegranate fruit from its weight by using the equation  $y = 0.754x + 199.2$  ( $R^2 = 0.948$ ). Ref. [18] reported less relationship between the fruit weight and the number of arils with the equation of  $y = 1.258x + 53.715$  ( $R^2 = 0.744$ ). The variance of the fruit weight of the present study is higher than the variance of the study carried out by Ref. [18] which could be the main reason of the difference among the equations. Higher variation for the fruit weight increased



**Figure 1.** Relationship between fruit characteristics in Wonderful cultivar pomegranate: (i) fruit weight vs. aril weight and juice content, (ii) fruit weight vs. number of arils, (ii) number of arils vs. aril weight or juice content, and (iv) aril weight vs. juice content.

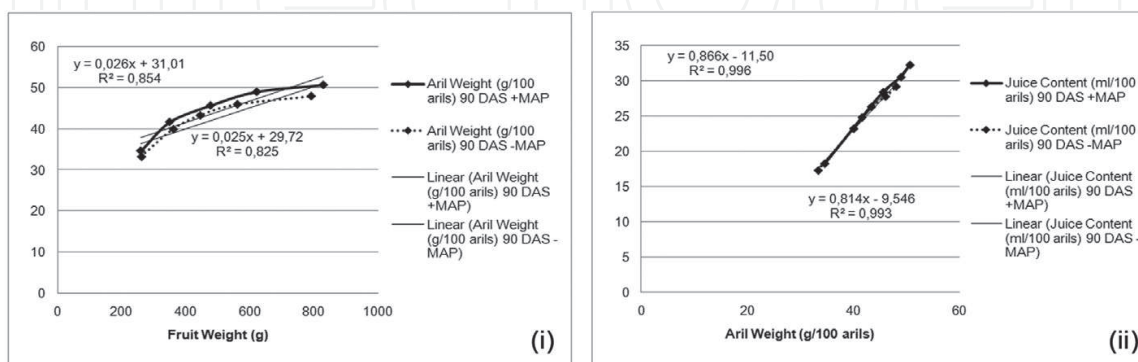
the reliability of the present study by having an improved adjusted  $R^2$ . Since there is a clear relationship between the fruit weight and the number of arils, a significant linear relationship has been determined for the number of arils vs. the aril weight or juice content.

### 3.2. Relationship between pomological characteristics of pomegranate fruits after 90 days of storage

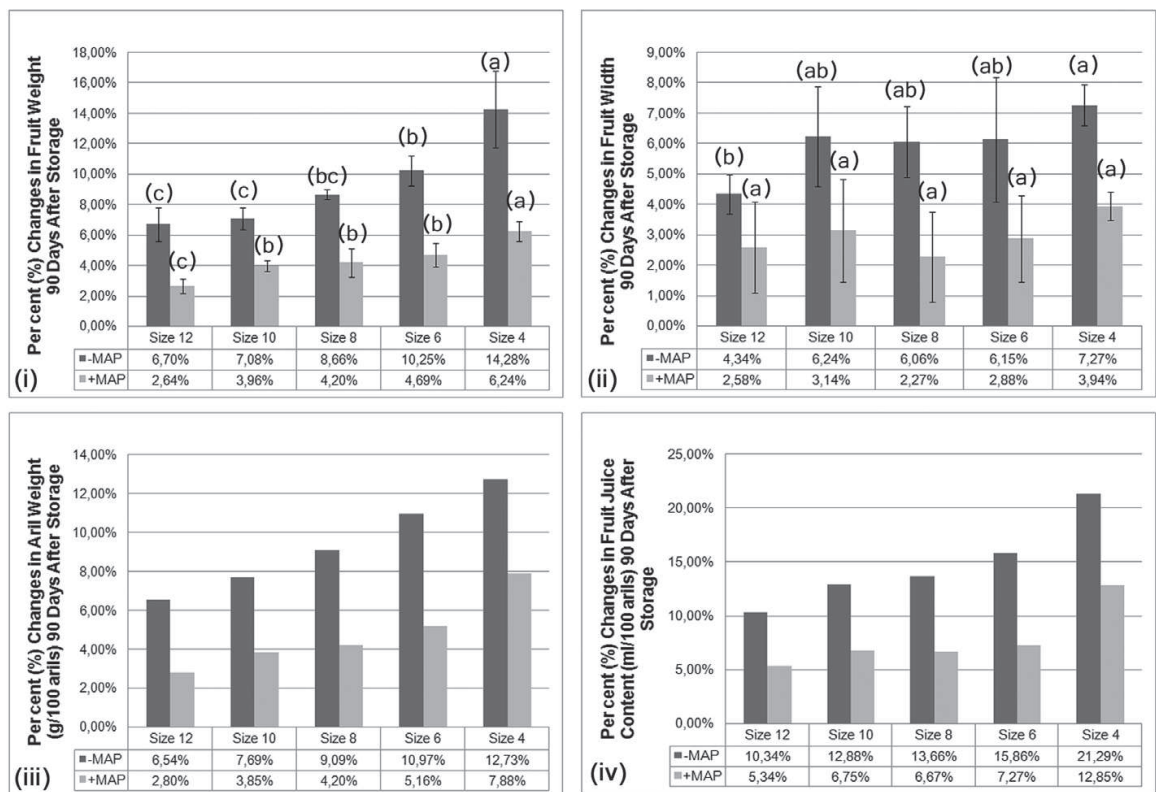
Storage of fruits with or without MAP for 90 days caused a nonsignificant change in the relationship between fruit weight and aril weight (**Figure 2**). At the first day of harvest, the adjusted  $R^2$  for a linear regression was 0.866 which decreased to 0.854 with MAP and to 0.825 without MAP. The relationship is found to be higher at the fruits stored with MAP than the fruits stored without MAP. Similarly, the relationship between the aril weight and the juice content had no significant change in 90 days of storage with or without MAP. These results confirmed that the changes in aril weight and juice content are in accordance with the changes in fruit weight. Although a significant change has been determined in fruit weight, aril weight, and juice content (**Figure 3**), those changes were found to be in accordance with each other.

### 3.3. Effects of storage conditions on some pomological characteristics of pomegranate fruit

Pomegranate fruit is very susceptible to weight loss due to the high porosity on the fruit, and its susceptibility is depending on storage conditions [9]. The present study revealed the effects of modified atmosphere packaging on the prevention of weight loss of pomegranate fruits. After 90 days of storage, a significant difference has been determined on the percent reduction of weight loss between fruits stored without MAP and fruits stored with MAP (**Figure 3**). It is clear from the figure that the modified atmosphere packaging protects the fruit weight. The loss in the fruit weight without MAP is found to be between 6.70 and 14.28%. The results showed that the fruit size is also affecting weight loss. The bigger fruits showed higher losses. The weight loss of the biggest fruits (size 4) is found to be more than twofold of the smallest size (size 12), for both with MAP and without MAP storage. On the other hand, MAP significantly protected the weight of the fruits. The weight loss of fruits with MAP is found to be between only 2.64 and 6.24% in 90 days of storage. Findings of the present study are in agreement with Ref. [19] where they



**Figure 2.** Relationship between fruit characteristics in Wonderful cultivar pomegranate 90 days after storage: (i) fruit weight vs. aril weight and (ii) aril weight vs. juice content.



**Figure 3.** Percent (%) changes in fruit characteristics in Wonderful cultivar pomegranate 90 days after storage: (i) fruit weight, (ii) fruit width, (iii) aril weight, and (iv) juice content.

reported that the physical parameters of pomegranates were better when fruits were wrapped and refrigerated after 20 days of storage. They reported a weight loss for EPE-foam and polyethylene-film wrapped fruits as 0.8 and 0.98% which is about 4.97% for non-wrapped fruits at 20 days of storage at 7.5°C. On the other hand, Refs. [20, 21] also noted that modified atmosphere packaging has a clear influence on the protection of the weight of pomegranate fruits.

No significant difference has been found for the fruit widths of pomegranate fruits after 90 days of storage among different sizes. But, on the other hand, there is a significant influence of modified atmosphere packaging packaging on the fruit width, which protected the fruit width. The percent reduction in the fruit width is found to be between 4.34 and 7.27% for control fruits and between 2.58 and 3.94% for the fruits stored with MAP. The percent reduction in aril weight is found to be between 6.54 and 17.73% for the fruits stored without MAP for 90 days. On the other hand, the fruits with same sizes which stored under MAP conditions had only 2.80–7.88% reduction in the aril weight. These results showed that the MAP has a clear effect on the protection of aril weight as in fruit weight. The other important result of the present work is that the percent reduction in aril weight is increasing as the fruit size decreases (or fruit weight increases). The percent (%) reduction in juice content is found to be between 10.34 and 21.29% for the fruits stored without MAP for 90 days. On the other hand, the fruits with same sizes which stored under MAP conditions had only 5.34–12.85% reduction in the juice content. These results showed that the MAP has a clear effect on the protection of juice content. These results are in accordance with the results for aril weight as expected.



## 4. Conclusions

The results of the present study showed that there is a linear relationship between the fruit weight and the number of arils ( $R^2$ , 0.948), the number of arils and the aril weight ( $R^2$ , 0.973), and the aril weight and the juice content of pomegranate fruits ( $R^2$ , 0.994). The results of the present study made it possible to estimate the number of arils, aril weight, and juice content of Wonderful cultivar pomegranate fruits by its fruit weight at harvest or after 90 days of storage with or without modified atmosphere packaging. The results also showed that the final fruit size of pomegranate fruits is not only related with the number of arils but also related with aril sizes. Understanding this phenomenon has important implications on cultural practices. The number of arils is mainly related with pollination and fertilization which occur during early fruit set and fruit development. Therefore, careful plant management is important during this time of period for obtaining larger fruits. But it must be kept in mind that the final fruit size is not determined at that time and regular fertilization is also crucial to enlarge arils.

The important result of the present study is that the modified atmosphere packaging has a clear effect on the protection of fruit weight, aril weight, and juice content. The loss in the fruit weight after 90 days of storage is found to be between 6.70 and 14.28% without MAP and between 2.64 and 6.24% with MAP. Similar results have been determined for aril weight and juice content. Last but not least, an important finding of the present study indicated that the larger fruits show higher weight loss.

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