Impact of postharvest treatment with salicylic acid and storage period on Salakhani pomegranate fruit

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Abstract

To determined chemical and physical properties for pomegranate fruits (cv. 'Salakhani') over postharvest treatment with three Salicylic acid (SA) concentrations (0, 2 and 4 mM) and four storage periods (25, 50, 75 and 100 days) at 2-3°C with 85-95% relative humidity, fresh pomegranate juice of every treatment was evaluate for TSS, TTA, TSS/TTA, Total sugar, Anthocyanin, Vit. C, pH and Juice percentage. Fruit physical disorder such as weight loss, chilling injury, chilling injury index, decay, scald, aril and peel moisture content were also investigated after each treatment.

The results showed that the TSS, TSS/TTA ratio, Total sugar, Anthocyanin and Vit. C increased significantly ($p<0.05$) throughout the treatment 2mM SA, however, the pH value for complete fruit increased as a result of TTA (1.02 %) decreasing, despite the change within the chemical properties of the juice, the percentage of juice didn't differ significantly after treatment fruits with (2 and 4mM) SA compared to the control, for decreasing weight loss, chilling injury, chilling injury index, decay and scald 4 mM SA was more affective comparing to control.

The results showed that most of chemical and physical disorder properties increased during storage with increasing storage duration exception of peel moisture content.

The interaction between treatments with different concentrations of SA then storage fruits for various periods led to the improvement of these characteristics, especially the concentration 2 mM and storage periods 25 and 50 days. Contrariwise, there have been decreases in (TTA) throughout the storage duration 100 day at 4 mM SA.

Furthermore, aril and peel moisture content significantly change at majority of the storage period 100day and 4 mM SA.

Keywords: Pomegranate; Salakhani; Storage period; Salicylic acid; Quality.

تأثير المعاملة بعد الحصاد بحامض الساليسيليك وفترة التخزين على ثمار الرمان صنف ساليخاني

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الخلاصة

تم تحديد الخواص الكيميائية والفيزيائية لثمار الرمان صنف "Salakhani" بعد المعاملة بحامض الساليسيليك(SA) (0 ، 2 و 4 ملي مول) و (25، 50 ، 75 ، 100 يوم) فترة التخزين في 2 – 3 م° مع 85–95٪ رطوبة نسبية. تم تحضير عصير الرمان الطازج لكل معاملة لتقديرنسبة المواد الصلبة الذائبة الكلية (TSS)، نسبة الحموضة المعايرة (TTA) ، نسبة المواد الصلبة الذائبة الكلية الى نسبة الحموضة المعايرة (TTA/TSS)، نسبة السكريات الكلية، الرقم الهيدروجيني(pH) ، الأنثوسيانين، فيتامين سي و نسبة العصير. كما تم تقدير نسبة الاضرار في الثمار مثل فقدان الوزن، الإصابة بالبرودة ،مؤشر الإصابة بالبرودة، التعفن، نسبة تدهور الثمار و محتوى الرطوبة قي الفصوص والقشرة بعد كل معاملة.

أظهرت النتائج أن TSSونسبة TTA/TSS والسكريات الكلية والأنثوسيانين والفيتامين سي زادت معنويا ($p < 0.05$) خلال المعاملة ب 2 ملي مول منSA ، ومع ذلك ، زادت قيمة الرقم الهيدروجيني (pH) نتيجة لانخفاض TTA (1.02٪) ، على الرغم من التغيير في الخصائص الكيميائية للعصير فإن النسبة المئوية للعصير لم تختلف بشكل كبير بعد المعاملة ب SA (2 و 4 ملي مول) مقارنة بالكونترول ، لتقليل فقدان الوزن ، و اضرار البرودة، مؤشر الاصابة بالبرودة ، التعفن و تدهور الثمار كان المعاملة ب SA (4 ملي مول) أكثر تأثيراً مقارنة بالكونترول.

أظهرت النتائج أن معظم الخواص الكيميائية والاضرار الفيزيائية للثمار زادت زيادة معنوية ($P < 0.05$) مع زيادة فترة التخزين باستثناء المحتوى الرطوبي للقشرة.

التداخل بين المعاملة بتراكيز مختلفة من SA ثم تخزين الثمار لفترات مختلفة أدت إلى تحسين الخصائص المذكورة اعلاه، وخاصة التركيز 2 ملي مول من SA وفترات التخزين 25 و 50 يومًا. على العكس من ذلك ، كان هناك انخفاض معنوي ($P < 0.05$) في نسبة الحموضة المعايرة عند خزن الثمار لمدة 100 يوم مع 4 ملي مول SA. علاوة على ذلك تغيرت محتوى الرطوبة في الفصوص وقشرة الثمار بشكل كبير عند فترة التخزين 100 يوم و 4 ملي مول SA.

الكلمات المفتاحية: رمان ، ساليخاني ، فترة التخزين ، حامض السالسليك، الجودة.

Introduction

Pomegranate (*Punica granatum* L.), also goes by the common name in Kurdistan "Hanar" belongs to the Punicaceae family. Its commercial famous fruit plant in Kurdistan Region/ Iraq, which is one of the world's producers of pomegranates, especially Halabja governorate is extremely famous for its high quality pomegranate cultivars. Pomegranate is native to Persia and widely cultivated in the Mediterranean region, it is a fruit of tropical and subtropical regions, however the pleasant nice pomegranates are located in which cool winters and warm dry summers (Akhtar *et al*., 2013).

Pomegranates should be harvest when they are fully ripe and have the right size and color. Fruits cannot continue the ripening process once detached from the plant. To increase its market value, the fruit is stored at temperatures below 10°C for several months. Several post-harvest disorders can occur during storage (Ghafir *et al*., 2010). The edible part (aril) of the pomegranate is about 55-60% of the total weight of the fruit and consists of about 75-85% juice and 15-25% seeds. Pomegranate is consumed both as a fresh fruit and as a fruit juice. It is also used to make jams, wines, liqueurs, food colorings and flavor enhancers. Various parts of its tree (leaves fruit and bark) are traditionally used for purposes such as medicinal properties and tanning (Rania *et al*., 2007).

There are over 23 cultivars of pomegranate grown in Iraq, Salakhani which known as Hawraman pomegranate (Hanary Hawraman) is one of the well-known pomegranate cultivars in Halabja and Sulaimani governorates. It could be a nearby pomegranate genotype of quality developed naturally and well adapted to the local climate and development in private ranges is an imperative source of income.

A number of significant exterior and internal characteristics are used to evaluate the quality of pomegranate fruit. Fruit size, shape, and skin condition (color, free of cracks, sun scalds, and bruises) are considered external characteristics. Internal characteristics include Total soluble solids, Titratable acidity and TSS/TTA, because of this, the selection of postharvest handling and storage procedures should take into account delivering harvested fruit to consumers in the best condition for acceptable nutritional, and antioxidant properties (Kader, 2008).

Salicylic acid (SA) is a plant hormone that performs critical roles in numerous physiological processes, from seed germination to flowering to fruit maturation, however its maximum studied function is in diverse biotic and abiotic stressors (Koo *et al*., 2020). After harvest treatment with salicylic acid has been reported to increased shelf life of strawberry (Babalar *et al*., 2007), pomegranate (Sayyari *et al*., 2009), postharvest application of SA were effective to reduce water loss, fungal decay, fruit softening rate, delayed rachis browning, and enhanced the increase of total phenolic content of berry skin cv. Thompson Seedless and reduced spoilage (Ranjbaran *et al*., 2011). Post-harvest treatment with salicylic acid has been reported to reduce spoilage and cold damage in a variety of fruits and to improve other quality attributes such as appearance, texture and nutritional associations (Glowacz and Ree, 2015).

SA role in controlling fungal decay may be through activation of antioxidant defense responses (Xu and Tian, 2008) or its direct antifungal effects on fungal development (Amborabe *et al*., 2002). Tiwari *et al*., 2017 and Koo *et al*., 2020 have been shown that Salicylate postharvest treatments to prevent decay and chilling injury in some fruits while also enhancing other qualities like appearance, texture, and nutritional content (Asghari and Aghdam, 2010; Glowacz and Ree, 2015). Accordingly, SA, ASA, or MeSa applied as postharvest treatments resulted in higher quality attributes in kiwifruit (Zhang *et al*., 2003), mango (Ding *et al*., 2007), sweet cherries (Valero *et al*., 2011) and peaches (Tareen *et al*., 2012), with additional effects on delaying the postharvest ripening process, apricots (Wang *et al*., 2015) and increased the content on anthocyanins and other bioactive compounds in blood oranges (Habibi *et al*., 2020).

Annual demand for pomegranate fruit is met by post-harvest storage (Kahramanoğlu and Usammaz, 2016). The limited post-harvest life of pomegranate fruit is a major challenge limiting its consumption. Fruit storage under ambient conditions is limited to a few weeks (Fawole and Opara, 2013).

Cold storage is often used to preserve post-harvest quality and extend fruit shelf life, pomegranates are very susceptible to cold injury when stored at recommended temperatures, mold and burns are also common post-harvest problems during cold storage. Opara *et al*., (2015) showed that, cold storage is often used to preserve post-harvest quality and extend fruit shelf life, pomegranates are highly susceptible to cold injury (CI) when stored at recommended temperatures, and also develop mold and scald as post-harvest problems during cold storage. The loss of pomegranate physical, chemical, and sensory characteristics was shown to be lower under cold storage than at room temperature (Patil *et al*., 2022).

What happens to the fresh produce's nutritional quality criteria while it is being stored is one of the main problems. These are useful in determining how long fresh produce may be kept without losing quality. Thus, the aim of this research is to study the effect of different concentrations of salicylic acid and storage periods, either separately or in combination, on quality and storage life pomegranate fruits cv. 'Salakhani'.

1. Materials and Methods

This research was carried out in the laboratory of Horticulture Department, College of Agricultural Engineering Sciences, Salahaddin University-Erbil. Healthy pomegranate fruits cv. 'Salakhani were obtained from a private orchard in Sian village, Dinarta, Duhok governorate, Kurdistan region. In 23 October 2021, commercially ripe fresh fruits with TSS 16 % were picked by hand with assisting of pruning clipper from trees of 11-years old, then immediately transferred to the laboratory. Healthy fruits free from surface defects with uniform weight (350- 400 g) and appearance were selected then divided randomly into three groups (each group contain 72 fruits) and dipped in three concentrations (0, 2 and 4 mM) of salicylic acid (Extra pure, Scharlab S.L., Spain) for ten mint.

1st group dipped in distilled water

2nd group dipped in 2 mM Salicylic acid.

3rd group dipped in 4 mM Salicylic acid.

After dipping, fruits were air-dried at ambient temperature, and then packed in perforated white polyethylene bags (each bag contain 4 pores 5 mm diameter). The bag includes 6 fruits and represented as experimental unit. At last, they were stored in refrigerator at 2-3°C with about 85-95% RH for 100 days.

The experiment is arranged in factorial in Complete Randomized Design (C.R. D), include three Salicylic Acid concentrations (0, 2 and 4 mM) and four storage periods (25, 50, 75 and 100 days) with three replications. The data was analyzed using the SAS statistical tool (SAS 2003), and when distinction is made, the means were suitably isolated and mean values were examined using Duncan's Multiple Range Test at P≤0.05 significant level (Mead *et al*., 2017).

After harvest and at the end of each storage duration (25, 50, 75 and 100 days) fruits for each replicate were used for quality measurements.

Salakhani is a local cultivar of pomegranate mostly their fruits are medium in size and the diameter is greater than the length., color of peel is red to brassy, arils are dark red in color, high juice with sour sweet taste and ripened at late October (AL-Jabary, 2007). Salakhani cultivar is one of the most important commercial pomegranates in Kurdistan especially in Halabja governorate.

2.1 Chemical Measurements

Juice (%): Pomegranate fruits were cut in to two halves and extracted the juice by using a hand manual press fruit juicer. Juice (%) was calculated by knowing the weight of juice divided by the weight of the fruit for each replication (Karomi, 2001)

Juice (%) = (juice weight in fruit/fruit weight) x 100

Total Soluble Solids (TSS) and Total Sugar (%): Total sugar and Total soluble solids (TSS) were measured in duplicate in the same juice by using a digital hand held "Pocket" refractometer (Atago PAL-3, Tokyo, Japan) (Maria *et al.*, 2020).

Titratable Acidity percentage (TTA) (%):

Titratable acidity was performed by taking 10 ml of juice and adding 2-3 drops of phenolphthalein as indicator and titration with 0.1N NaOH, the acidity was determined as citric acid (g/ 100 ml Juice) according to (Feldsine *et al.*, 2002).

$$TTA\% = \frac{\text{Volume of NaOH (ml)} * \text{Normality of NaOH} * V * \text{Milliequivalent}}{Vi * Vs * 1000} \times 100$$

Vi = Initial Volume of the juice before diluting

Vs = Volume of the juice used in the correction

TSS/ TTA ratio: The ratio of TSS/TTA calculated by dividing Total soluble solid percentage by Titratable acidity percentage.

Total anthocyanin (mg .100g^{-1} F.Wt): Total anthocyanin content in fruit arils was determined by blend 5g of fruit arils with 50 ml of ethanolic HCl (85:15): 95% Ethanol + 1.5 N HCl, and left for 24 hours in a refrigerator at 4°C, then filtered through filter paper (watman 0.1N) and added 75 ml ethanolic HCl. Finally, it estimated by using Spectrophotometer at wave length of 535nm (Al-Kwami *et al.*, 2002) and calculated by the following equation:

Anthocyanin (mg.100g^{-1} fresh weight) = Abs535 x Ve x Tv/ Vu xWts x 100

Where:

Abs 535 = Reading of spectrophotometer at 535nm.

Ve = Volume of extracts which is used for color measurement.

Tv = Total volume. Vu = Volume of extracts.

Wts = Weight of the sample.

Vitamin C (Vit.C) (mg.100 ml^{-1} juice): Taking 20 ml of juice and added to it 25 ml of distilled water and 1 ml of starch as indicator. After filling the burette with iodine solution, the juice was slowly titrated until the appearance of blue color. These steps were repeated three times and the average volume of iodine needed for the titration process was recorded (Suntornsuk *et al*., 2002).
pH: pH values were determined with digital pH meter.

2.2. Physical disorders

Weight loss %: It was measured in relation to storage time, six uniformly sized fruits were randomly selected and weighed after each 25 days (Arendse, 2014). The loss in weight was calculated as:

Weight loss %=[(Wi-W_f) / W_i] x 100

W_i= initial weight (g) of the fruit at the beginning of storage

W_f= final weight (g) of the fruit at the time of sampling during storage

Chilling injury and chilling injury index (CI): Was individually evaluated in each fruit with a 4 point hedonic scale based on the percentage of husk surface affected by CI symptoms (dehydration, browning and pitting): 0 (no symptom), 1 (1-25% of damaged area), 2(26-50% of damaged area) and 3(>51% of the damaged area). Results were calculated using the following formula:

CI=∑ (value of hedonic scale) × (number of fruit with the corresponding scale number) / (4×total number of fruit in the sample) (Sayyari *et al*., 2009).

Scald%: The incidence of decay, fruit browning, cold injury, and skin burn was recorded for each storage time and replicate. The percentage of fruit discarded was calculated based on the total number of fruits using the following formula (Abd-Elghany, 2012):

Scald (%) = (Number of discarded fruits at each sampling date / Total number of fruits) x 100

Aril and peel moisture content (%): 10 g kernel and 25 g husk sample was placed in a glass petri dish, , dried in an oven at 80 °C for 24 h, and then weighed on an electronic balance) (Arendse, 2014).

3. Results and Discussion

3.1. Effect of Salicylic acid concentration, storage period on chemical properties of pomegranate cv. Salakhani fruits:

3.1.1. Effect of Salicylic acid:

Results in Table (1) revealed that the average of Total soluble solid (TSS), TTS/TTA ratio, Total sugars and Vitamin .C (Vit.C) in fruits were affected significantly when fruits treated with Salicylic acid (SA) compared with control, The effect of the 2 mM SA treatment was more apparent in increasing TSS (16.69 %), TSS/TA ratio (16.36) Total sugar (16.59 %) and Vit.C (5.84 mg $.100g^{-1}$ F.Wt) , while the lowest contents were noticed in the control (water) (16.46 %), (12.96), (16.36 %) and (5.60 mg $.100g^{-1}$ F.Wt) respectively. The TSS/TA ratio, based on changes in Total soluble solids and Titratable acidity (TTA) of fruit during storage, determines the characteristic flavor and aroma of fruit (Zarei *et al*., 2011). Titratable Acidity is a critical quality of pomegranate juice (Shwartz *et al*., 2009). Citric acid is the major natural products in pomegranate fruits, TTA of pomegranate fruits was decreased with SA treatments as presented in (Table 1) the lowest value was obtained in 2 mM SA (1.02 %), the heights value in control (1.27 %). Moreover, anthocyanin (10.66 mg $.100g^{-1}$ F. Wt), pH (3.48) also increased in the same treatment, while juice percentage in fruits were not affected significantly.

Table (1). Effect of Salicylic acid concentrations on chemical properties of pomegranate cv. Salakhani fruits*.

Salicylic acid (mM)	Parameters							
	TSS (%)	TTA (%)	TTS/ TTA ratio	Total sugars (%)	Anthocyanin (mg $.100g^{-1}$ F. Wt)	Vit.C (mg.100 ml^{-1} juice)	pH	Juice (%)
0	16.46 ab	1.27 a	12.96 b	16.36 b	9.13 b	5.60 b	3.40 ab	39.25 a
2	16.69 a	1.02 b	16.36 a	16.59 a	10.66 a	5.84 a	3.48 a	40.50 a
4	16.57 ab	1.24 a	13.36 b	16.40 ab	9.90 ab	5.83 a	3.41 ab	39.10 a

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at < 0.05 level of probability

3.1.2. Effect of storage period:

The results of the chemical characteristics of the fruits (Table 2) showed highest values of TSS (16.90 %), TTS/TTA ratio (17.07) and Total sugars (16.70 %) in 100 day storage period and the lowest values were detected (12.26%), (12.31) and (16.11 %) when fruits stored 25 day respectively. The key factors affecting pomegranate flavor are juice TSS and the ratios of TSS to

TTA and have been used to describe taste with regards to the sweetness and acidity (Zarei *et al*., 2011).TSS values were generally increased in the fruits during the cold storage that could be due to the reduction in fruit weight then fruit juice concentration (Khademi and Ershadi, 2013).

However, TTA and Vit.C content in pomegranate fruit decreased initially with the advancement of storage period, the highest values of TTA (1.32 %) and Vit.C content ((7.47 mg.100 ml^{-1} juice) determined in fruits stored 25 day and the lowest in fruits stored 100 day (0.99%) and (4.29 mg .100 ml^{-1} juice) respectively. These results are similar to those of Arendse (2014) who reported a decrease in TTA during storage of Wonderful pomegranate fruits at 5 and 7.5 °C for 5 months. pH value (3.47 %) increased after decreasing TTA, fruits stored for 100 days may have less overall acidity because the acid is converted to sugars and used by the fruit's metabolism (Rathore *et al*., 2007)., anthocyanin in fruits was not affected by different storage periods. Our finding is in agreement with the result of (Lòpez-Rubira *et al*., 2005) that there was no significant change in anthocyanin content of pomegranate fruits after 13 days of storage period. A decrease in anthocyanin content of pomegranate was founded with increasing storage time (Caleb *et al*., 2013). Our results suggest that the depletion of Vitamin C in pomegranate fruits during storage may slow biosynthesis and slow the rapid degradation of vitamin C in MAP stores (Abd-Elghany *et al*., 2012 and Barman *et al*., 2014), result of this decline (Khan and Singh, 2008). Opposite result, a critical amount of Vit. C was founded in 'Assaria' and Mollar de Elche' pomegranates fruit when stored at 5 ^{o}C for 4 months. Due to its oxidation during storage, Vit.C is more susceptible to degrading than other nutrients (Veltman *et al*., 2000). Ascorbic acid is highly vulnerable to oxidation, either directly or via enzymes (Sanmartin *et al*., 2007).

The juice content of the fruits was affected significantly, the effect of the storage 100 day was more apparent as compared to another treatments in decreasing the juice content (30.33 %), the highest content was noticed in fruits stored 25 day (43.96 %).

Table (2). Effect of storage periods on chemical properties of pomegranate cv. Salakhani fruits*.

Storage period (day)	Parameters							
	TSS (%)	TTA (%)	TTS/ TTA ratio	Total sugars (%)	Anthocyanin (mg .100g^{-1} F.Wt)	Vit.C (mg.100 ml^{-1} juice)	pH	Juice (%)
25	16.26 c	1.32 a	12.31 b	16.11 b	10.91 a	7.47 a	3.36 b	43.96 a
50	16.61 ab	1.26 ab	13.18 ab	16.40 ab	10.75 a	6.76 b	3.47 a	42.81 a
75	16.52 b	1.14 bc	14.49 ab	16.34 ab	9.51 ab	4.50 c	3.46 a	41.36 a
100	16.90 a	0.99 c	17.07 a	16.70 a	8.41 ab	4.29 c	3.43 a	30.33 b

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at (P≤ 0.05) level of probability.

3.1.3. Effect of interaction:

The effect of interaction between Salicylic acid concentration and storage period on chemical characteristics of pomegranate cv. Salakhani fruits are presented in Table (3).

All concentrations of SA and storage periods were not effect on TSS %, total sugar and pH values, while a significant decrease in TTA% was obtained by 4 mM SA and 100 day storage period treatment (0.94 %), the maximum value (1.76 %) was record when fruits treated with 2mM SA and 50 day storage period, the low percentage of TTA led to a high TSS/TTA ratio (16.59).

The incidence of Anthocyanin concentration decreased with increasing pomegranate fruit storage, regardless of treatment, it was low after 50, 75 and 100 day of storage, highest in 2 mM SA treated fruits and 25 day of storage period (12.60 mg .100g^{-1} F. Wt) and lowest in 0 mM SA-treated fruits and 100 day of storage period (7.62 mg .100g^{-1} F. Wt) (Table 3).

Vit.C content decreased with long-term storage, but 2 mM SA minimized the decrease of Vit.C content when fruits were stored for 25 day (7.67 mg.100 ml^{-1} juice) and the lower value was recorded by 0 mM SA and 100 day storage period (3.92 mg.100 ml^{-1} juice).

Table (3). Effect of interaction between Salicylic acid concentration and storage period on chemical properties of pomegranate cv. Salakhani fruits*.

Salicylic acid (mM)	Storage periods (day)	Parameters							
		TSS (%)	TTA (%)	TTS/ TTA	Total sugars (%)	Anthocyanin (mg .100g^{-1} F. Wt)	Vit.C (mg.100 ml^{-1} juice)	pH	Juice (%)%
0	25	16.70 a	1.19 ab	14.03 b	16.36 a	12.36 a	7.44 a	3.37 a	32.47 c
	50	16.10 a	1.00 b	16.10 ab	16.83 a	9.83 ab	6.94 ab	3.40 a	43.35 a
	75	16.47 a	1.00 b	16.47 ab	16.29 a	8.72 bc	4.12 c	3.47 a	41.91 ab
	100	16.50 a	1.07 ab	15.42 b	16.41 a	7.62 c	3.92 c	3.37 a	39.27 b
2	25	16.37 a	1.13 b	14.49 b	16.24 a	12.60 a	7.76 a	3.47 a	29.89 cd
	50	16.83 a	1.67 a	10.08 c	16.70 a	7.66 a	6.10 b	3.43 a	44.80 a
	75	16.70 a	1.22 ab	13.69 b	16.46 a	9.22 ab	4.90 c	3.50 a	43.39 a
	100	15.93 ab	0.96 b	16.59 a	15.81 a	10.60 a	4.59 c	3.50 a	43.89 a
4	25	16.77 a	1.45 ab	11.57 bc	16.60 a	12.27 a	7.46 a	3.23 a	28.62 d
	50	16.77 a	1.37 ab	12.24 bc	16.59 a	9.96 ab	7.23 ab	3.57 a	41.92 ab
	75	16.40 a	1.20 ab	13.67 b	16.28 a	10.59 a	4.49 c	3.40 a	43.12 a
	100	17.10 a	0.94 b	18.19 a	16.12 a	9.82 ab	4.36 c	3.43 a	42.68 a

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at < 0.05 level of probability

3.2. Effect of Salicylic acid concentrations, storage periods on Physical disorders of pomegranate cv. Salakhani fruits:

3.2.1. Effect of Salicylic acid:

Fruit physical disorders, such as weight loss, chilling injury, chilling injury index, decay and scald percentage in the 4 mM SA treated fruit was significantly lower (P <0.05) (2.31 %), (15.83%), (2.03) (9.72%) and (10.24%) compered to control ones (2.63%), (17.64%), (4.57), (22.58%) and (14.86%) respectively, no significant effects were observed for Salicylic acid concentration in aril and Peel moisture content(Table 4).

SA improved resistance to cold stress and reduced losses. These results also showed that SA concentrations less than 4 mM were less effective in improving physical damage capacity of pomegranate fruits, while 2 mM SA was very effective in reducing chilling damage and chilling damage index of pomegranate fruits (Sayyari *et al* 2009). Commercially, for extend the shelf life pomegranate fruits are stored at 5 ± 1 °C. Below these conditions, the fruit is exposed to cold damage such as discoloration of the pericarp and arial. Application of antioxidant compounds, such as SA can reduce the activity of cell wall-degrading enzymes, increase the activity of antioxidant enzymes that prolong postharvest fruit longevity, and delay fruit maturation (Vlot. *et al*., 2009). When fruit was treated with Salicylic acid, likewise saw less indications of chilling injury, and the effectiveness increased with increasing concentration. Likely due to its conversion to Salicylic acid, Acetyl salicylic acid also decreased chilling injury in "Mollar de Elche" pomegranate (Sayyari *et al*., 2011b).

Table (4). Effect of Salicylic acid concentration on Physiological disorders of pomegranate cv. Salakhani fruits*.

Salicylic acid (mM)	**Parameters**						
	Weight loss (%)	**Chilling injury (%)**	**Chilling injury index**	**Decay (%)**	**Scald (%)**	**Aril moisture content (%)**	**Peel moisture content (%)**
0	2.63 a	17.64 a	4.57 a	22.58 a	14.86 a	77.58 a	72.89 a
2	2.39 ab	17.36 a	2.98 b	18.82 a	10.28 b	77.66 a	72.86 a
4	2.31 b	15.83 b	2.03 b	9.72 b	10.24 b	77.47 a	72.76 a

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at (P≤ 0.05) level of probability.

3.2.2. Effect of storage period:

The data for weight loss, chilling injury, chilling injury index, decay, scald percentage and aril moisture content pomegranate fruits are presented in (Table 5), In all the treatments, studied in the present investigation, Physical disorders increased with increase in the storage period, The minimum values were founded in 25 day of storage, (1.15 %), (0.00), (0.00), (0.00), (0.00 %) and (76.39 %),while, the maximum values was observed in 100 day of storage, (3.60 %), (28.15), (8.66), (30.94), (31.55 %) and (78.53 %) respectively. This may be due to weight loss and water loss from the fruit, under cooling conditions in the fruit tissues the cell membrane lipids change their physical state from a liquid crystal to a gel state solid, increasing membrane permeability and ion outflow and can be related to damage in cellular membranes, specifically lipid peroxidation, being more intense in peel (Gómez-Galindo *et al*., 2004 and Schele *et al*., 2018). Another major cause of postharvest losses limits the shelf life of pomegranate fruits is decay, when stored at temperatures above those that cause chilling injury (Palou *et al*., 2007). Results in same table revealed that there was no significant difference between storage periods on peel moisture content.

Table (5). Effect of storage period on Physiological disorders of pomegranate cv. Salakhani fruits*.

Storage Period (day)	Parameters						
	Weight loss (%)	Chilling injury (%)	Chilling injury index	Decay (%)	Scald (%)	Aril moisture content (%)	Peel moisture content (%)
25	1.15 c	0.00 b	0.00 c	0.00 c	0.00 c	76.39 b	72.19 a
50	2.16 b	0.00 b	0.00 c	7.41 b	0.93 c	77.63 a	72.58 a
75	2.85 ab	26.30 a	4.12 b	29.83 a	14.70 b	77.74 a	73.02 a
100	3.60 a	28.15 a	8.66 a	30.94 a	31.55 a	78.53 a	73.57 a

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at < 0.05 level of probability

3.2.3. Effect of interaction:

The interaction effects of SA concentration and storage period on weight loss values were significant (Table 6), highest loss was observed in fruits treated with 2 mM SA and 100 day storage (3.91 %), while the weight loss in pomegranates fruits treated with 0 mM SA stored for 25 day gave the lowest (1.03 %).

During 25 and 50 day storage with all SA concentration, no chilling injury, chilling injury index, decay and scald percentage were recorded, a highest significant increase for the mentioned properties was at the treatment 0mM SA and 100 day storage period (36.11 %, 12.36, 39.89 % and 47.22 %) respectively.

The present results in Table (6) showed that aril moisture content was dependent on storage period, in 25 day storage period with all SA concentrations the value was between (72.02 to 76.47 %), while 75 day storage period and all SA concentrations were observed between (78.09 to 78.97 %), where the highest aril moisture content (78.97 %) observed in fruit treated with 2mM SA and 75 day storage, while those treated with 4mM and 25 day storage had the least aril moisture content (72.02 %). Significant increases in peel moisture content was recorded in fruit treated with 4mM SA and100 day storage period (74.44 %), on the other side, the 4mM SA and25 day storage period recorded the minimum value (71.61 %). Many fruit crops have previously been reported to benefit from the positive effects of SA on reducing weight loss, chilling injury, reducing decay, and improving fruit quality during cold storage (Khademi and Erachidi, 2013; Alejandra *et al*., 2017; Ennab *et al*., 2020; Lokesh *et al*., 2020; Haggag *et al*., 2020; Haider *et al*., 2020).

Table (6). Effect of interaction between Salicylic acid concentration and storage period on Physiological disorders of pomegranate cv. Salakhani fruits*.

Salicylic acid (mM)	Storage periods (days)	Parameters						
		Weight loss (%)	Chilling injury (%)	Chilling injury index	Decay (%)	Scald (%)	Aril moisture content (%)	Peel moisture content (%)
0	25	1.03 c	0.00 c	0.00 d	0.00 c	0.00 d	76.47 bc	72.65 ab
	50	2.05 bc	0.00 c	0.00 d	13.89 bc	0.00 d	77.77 ab	72.36 ab
	75	2.65 b	34.45 a	5.93 bc	36.56 a	12.22 bc	78.54 a	72.96 ab
	100	3.51 a	36.11 a	12.36 a	39.89 a	47.22 a	77.55 ab	72.60 ab
2	25	1.18 c	0.00 c	0.00 c	0.00 c	0.00 d	76.67 bc	72.33 ab
	50	2.28 b	0.00 c	0.00 d	0.00 c	0.00 d	77.42 ab	72.85 ab
	75	3.12 a	33.33 ab	3.58 cd	33.48 ab	17.98 bc	78.97 a	72.63 ab
	100	3.91 a	33.11 ab	8.33 b	33.48 ab	22.98 b	77.58 ab	73.67 a
4	25	1.24 c	0.00 c	0.00 d	0.00 c	0.00 d	76.02 bc	71.61 b
	50	2.15 b	0.00 c	0.00 d	0.00 c	2.78 cd	77.69 ab	72.54 ab
	75	2.78 b	11.11 b	2.83 cd	19.45 b	13.89 bc	78.09 a	72.47 ab
	100	3.39 a	12.22 b	5.29 bc	19.45 b	24.45 b	78.07 a	74.44 a

*Values within each column followed by the same letter are not significantly different from each other according to Duncan's Multiple Range Test at < 0.05 level of probability

Conclusion

The improvement of science based administration instruments and postharvest care are required for determination of optimal storage period and postharvest treatments pomegranate product. The Kurdistan/Iraqi pomegranate industry suffers from a significant decline in fruit quality due to lack of knowledge about optimal storage and handling methods. The cultivar Salakhani is widely prevalent in Halabja, however to date there is currently limited scientific knowledge on the postharvest handling and storage requirements. Developing quality standards for export markets requires knowledge of optimal storage duration to understand post-harvest quality attributes and consumer perceptions. Postharvest losses in pomegranates during cold storage are caused by microbial infestation and the emergence of physiological diseases like chilling injury and scald. Additional research is also required in the areas of pomegranate fruit marketability and postharvest loss reduction.

References

- **Abd-Elghany, N. A.; S. I. Nasr and H. M. Korkar (2012).** Effects of polyolefin film wrapping and Calcium Chloride treatments on posthravest quality of "wonderful" pomegranate fruits. J. Hort. Sci. Ornament. Plants, 4 (1), 07-17.

- **Akhtar, S.; J. Ali; B. Javed and F. Ali Khan (2013).** Studies on the preparation and storage stability of pomegranate juice based drink. Middle-East Journal of Scientific Research, 16 (2), 191-195.

- **AL-Jabari, A. M. E. O. (2007).** Effect of gibberellin and some nutrient minerals on fruit cracking of pomegranate cultivar Salakhani (*Punica granatum* L.). M.Sc. thesis, Agric. Coll., Hort. Dept., Sulaimania Uni., Iraq (In Arabic).

- **Al-Kwami, S. M. J.; A. M. Salman and M. A. Salman (2002).** Effect of spraying GA3, N, Zn, and Fe on physical and chemical properties of fig fruits (*Ficus carica* L.) cvs. Aswad and Diala. Iraqi. J. Agri. Sci, 33(4), 71-76. (In Arabic).

- **Amborabe, B. E., P. F. Lessard, J. F. Chollet and G. Roblin (2002).** Antifungal effects of salicylic acid and other benzoic acid derivatives towards Eutypa lata: structure–activity relationship. Plant Physiol. Biochem, (40), 1051–1060.

- **Arendse, E. (2014).** Determining optimum storage conditions for pomegranate fruit (cv. Wonderful). M.Sc. thesis, AgriSciences Faculty, Stellenbosch Uni.

- **Asghari, M., and Aghdam, M. S. (2010).** Impact of salicylic acid on post-harvest physiology of horticultural crops. Trends Food Sci. Technol, (21), 502–509. doi: 10.1016/j.tifs.2010.07.009

- **Babalar, M., M. Asghari, A. Talaei and A. Khosroshahi (2007).** Effect pre– and postharvest salicylic acid treatment on ethylene production fungal decay and overall quality of Selva strawberry fruit. Food Chem, (105), 449–453.

- **Barman K, Asrey R, Pal RK, Kaur C, Jha SK (2014).** Influence of putrescine and carnauba wax on functional and sensory quality of pomegranate (*Punica granatum* L.) fruits during storage. J Food Sci Technol, (51), 111–117. https://doi.org/10.1007/s13197-011-0483-0

- **Caleb OJ, Opara UL, Mahajan PV, Manley M, Mokwena L, Tredoux AG. (2013).** Effect of modified atmosphere packaging and storage temperature on volatile composition and postharvest life of minimally-processed pomegranate arils (cvs. ‘Acco’and ‘Her-skawitz’). Postharvest Biol Technol, (79), 54–61.

- **Ding, Z. S., Tian, S. P., Zheng, X. L., Zhou, Z. W., and Xu, Y. (2007).** Responses of reactive oxygen metabolism and quality in mango fruit to exogenous oxalic acid or salicylic acid under chilling temperature stress. Physiol. Plant, (30), 112–121. doi: 10.1111/j.1399-3054.2007.00893.x

- **Fawole OA, Opara UL. (2013).** Effects of storage temperature and duration on physiological responses of pomegranate fruit. Industrial Crops and Products, (47), 300-309. https://doi.org/10.1016/j.indcrop.2013.03.028

- **FELDSINE, P., ABEYTA, C., and ANDREWS, W. H. (2002).** AOAC International methods committee guidelines for validation of qualitative and quantitative food microbiological official methods of analysis. Journal of AOAC international, 85(5), pp.1187-1200.

- **Ghafir, S.A.M., Ibrahim, I.Z. & Zaied, S.A. (2010).** Response of local variety ‘Shlefy’ pomegranate fruits to packaging and cold storage. Acta Horticulturae, (877), 427-432.

- **Glowacz, M., and Ree, D. (2015).** Using jasmonates and salicylates to reduce losses within the fruit supply chain. Eur. Food Res. Technol, (242), 143–156. doi: 10.1007/s00217-015-2527-6

- **Gómez-Galindo, F., Herppich, W., Gekas, V. & Sjöholm, I. (2004).** Factors affecting quality and postharvest properties of vegetables: Integration of water relations and metabolism. Critical Reviews in Food Science and Nutrition, (44), 139-154.

- **Habibi, F., Ramezanian, A., Guillén, F., Serrano, M., and Valero, D. (2020).** Blood oranges maintain bioactive compounds and nutritional quality by postharvest treatments with γ-aminobutyric acid, methyl jasmonate or methyl salicylate during cold storage. Food Chem, 306:125634. doi: 10.1016/j.foodchem.2019. 125634

- **Kader, A.A. (2008).** Mango quality attributes and grade standards: a review of available information and identification of future research needs. Kader Consulting

Services, Davis, CA, USA.

- **Kahramanoğlu I, Usanmaz S. (2016).** Pomegranate production and marketing. Boca Raton, Florida, CRC Press, 134.

- **Karomi, M. F. (2001).** Effect of some growth regulators on sexual ratio and yield characteristics of two pomegranate cultivars El- Saleemi and Rawa seedlees. M.Sc. Thesis, Hort. Dept., Agric. Coll., Mosul Uni., Iraq. (In Arabic)

- **Khademi, Z. and A. Ershadi. (2013).** Postharvest application of salicylic acid improves storability of peach (*Prunus persica* cv. Elberta) fruits. Intern. J. of Agric. and Crop Sci., 5 (6), 651-655.

- **Koo, Y. M., Heo, A. Y., and Choi, H. W. (2020).** Salicylic acid as a safe plant protector and growth regulator. Plant Pathol, J, (36), 1–10. doi: 10.5423/PPJ.RW.12.2019.0295

- **López-Rubira, V., Conesa, A., Allende, A. & Artés, F. (2005).** Shelf life and overall quality of minimally processed pomegranate arils modified atmosphere packaged and treated with UV-C. Postharvest Biology and Technology, (37), 74-185.

- **Maria, E., G. Pastor, P. J. Zapata, S. Castillo, D.M. Romero, F. Guillen, D. Valero and M. Serrano (2020).** The effect of salicylic acid and its derivatives on increasing pomegranate fruit quality and bioactive compounds at harvest and during storage. Frontiers in Plant Science. (11), Article 668.

- **Mead, R., Curnow, R. N., & Hasted, A. M. (2017).** Statistical methods in agriculture and experimental biology. Chapman and Hall/CRC.

- **Opara, U.L.; Atukuri, J.; Fawole, O.A. (2015).** Application of physical and chemical postharvest treatments to enhance storage and shelf life of pomegranate fruit—A review. Sci. Hortic, (197), 41–49.

- **Palou, L., Crisosto, C.H. & Garner, D. (2007).** Combination of postharvest antifungal chemical treatments and controlled atmosphere storage to control gray mold and improve storability of 'Wonderful' pomegranates. Postharvest Biology and Technology, (43), 133-142.

- **Ranjbaran, E., H. Sarikhani, A. Wakana and D. Bakhshi. (2011)**. Effect of salicylic acid on storage life and postharvest quality of grape (*Vitis vinifera* L. cv. 'Bidaneh Sefid').

J. Fac. Agr., Kyushu Univ, (56), 263–269.

- **Patil SS, SA Ranpise, BB Dhakare and VP Kad. (2022).** Studies on effect of storage conditions on physical parameters of pomegranate (*Punica granatum* L.). The Pharma Innovation Journal, 11(1), 1004-1008.

- **Rania, J.; H. Nejib; M. Messaoud; M. Mohamed and T. Mokhtar. (2007).** Characterization of Tunisian pomegranate (*Punica granatum* L.) cultivars using amplified fragment length polymorphism analysis. Scientiae Horticulturae, 115 (3), 231-237.

- **Rathore, H. A., Masud, T., Sammi, S. and Soomro, A. H. (2007).** Effect of storage on physico-chemical composition and sensory properties of mango (Mangifera indica L.) variety Dosehari. Pakistan J. Nut., 6 (2), 143-148.

- **Sanmartin, M., Pateraki, I., Chatzopoulou, F. and A. K. Kanellis. (2007).** Differential expression of the ascorbate oxidase multigene family during fruit development and in response to stress. Planta, (225) 873-885.

- **Sayyari M., M. Babalar, S. Kalantari, M. Serrano and D. Valero (2009).** Effect of salicylic acid treatment on reducing chilling injury in stored pomegranates. Postharvest Biol. Technol, (53), 152–154.

- **Sayyari, M., Castillo, S., Valero, D., Díaz-Mula, H.M. & Serrano, M. (2011b).** Acetyl salicylic acid alleviates chilling injury and maintains nutritive and bioactive compounds and antioxidant activity during postharvest storage of pomegranates. Postharvest Biology and Technology, (60), 136-142.

- **Shwartz, E.; Glazer, I.; Bar-Ya'akou, I.; Matityalm, I.; Bar-Ilan, I.; Holland, D.; Amir, R. (2009).** Changes in chemical constituents during the maturation and ripening of two commercially important pomegranate accessions. Food Chemistry, (115), 965–973.

- **Tareen, M. J., Abbasi, N. A., and Hafiz, I. A. (2012).** Postharvest application of salicylic acid enhanced antioxidant enzyme activity and maintained quality of peach cv. "Flordaking" fruit during storage, Sci. Hortic, 142, 221–228. doi: 10.1016/j.scienta.2012.04.027

- **Tiwari, S., Lata, C., Chauhan, P. S., Prasad, V., and Prasad, M. (2017).** A functional genomic perspective on drought signalling and its crosstalk with phytohormone-mediated signalling pathways in plants. Curr. Genomics, (18), 469–482. doi: 10.2174/1389202918666170605083319

- **Schele. M, C. Huidobro, L. Monsalve, R. Simpson, L. Fuentes and M. Valdenegro,a. (2018).** Biochemical and functional changes in pomegranate fruit (*Punica granatum*) during cold storage M. Acta. Hortic, 1194. DOI 10.17660/ActaHortic.2018.1194.64

- **Suntornsuk, L., Gritsanapun, W., Nilkamhank, S., & Paochom, A. (2002).** Quantitation of vitamin C content in herbal juice using direct titration. Journal of pharmaceutical and biomedical analysis, 28(5), 849-855.

- **Valero, D., Díaz-Mula, H. M., Zapata, P. J., Castillo, S., Guillén, F., Martínez-Romero, D., et al. (2011).** Postharvest treatments with salicylic acid, acetylsalicylic acid or oxalic acid delayed ripening and enhanced bioactive compounds and antioxidant capacity in sweet cherry. J. Agric. Food Chem, (59), 5483–5489. doi: 10.1021/jf200873j

- **Veltman, R. H., Kho, R. M., Van Schaik, A. C. R., Sanders, M. G. and Oosterhaven, J.(2000).** Ascorbic acid and tissue browning in pears (*Pyrus communis* L.) cvs Rocha and Conference under controlled atmosphere conditions. Postharvest Biol. Tech, (19), 129-137.

- **Vlot, A.C., Dempsey, D.A. and Klessig, D.F (2009).** Salicylic Acid, a Multifaceted Hormone to Combat Disease. Annual Review of Phytopathology, (47), 177-206.

- **Wang, Z., Ma, L., Zhang, X., Xu, L., Cao, J., and Jiang, W. (2015).** The effect of exogenous salicylic acid on antioxidant activity, bioactive compounds and antioxidant system in apricot fruit. Sci. Hortic, (181), 113–120. doi: 10.1016/j. scienta.2014.10.055

- **Xu X. and S. Tian (2008).** Salicylic acid alleviated pathogen– induced oxidative stress in harvested sweet cherry fruit. Postharvest Biol. Technol, (49), 379–385.

- **Zhang, Y., Chen, K., Zhang, S., and Ferguson, I. (2003).** The role of salicylic acid in postharvest ripening of kiwifruit. Postharvest Biol. Technol, (28), 67–74. doi: 10.1016/S0925-5214(02)00172-2

- **Zarei M., Azizi M., Bashir-Sadr Z. (2011).** Evaluation of physicochemical characteristics of pomegranate (*Punica granatum* L.) fruit during ripening. Cambridge Journals, (66), 121–129.