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A New Approach for Extending Shelf-Life of Pomegranate Arils with Combined Application of Salicylic Acid and Methyl Jasmonate

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Abstract: The consumption of fresh-cut pomegranate fruits (arils) has risen recently due to their bioactive compounds and benefits for consumers. However, pomegranate arils have a limited shelf-life and vastly lose their valuable compounds. Therefore, in this study, we investigated the effects of exogenous postharvest treatment with salicylic acid (SA), methyl Jasmonate (MeJA), and their combination on the shelf-life and chemical composition of pomegranate arils under refrigerated storage (5 °C and 90 ± 2% relative humidity) for 15 days. The results indicated that individual or combined application of SA at 2 mM + MeJA at 0.5 mM decreased weight loss, respiration rate, hue angle (h°), and soluble solids content (SSC) compared to the control. All treatments maintained vitamin C, titratable acidity (TA), anthocyanin content, flavonoids, phenolic compounds, and antioxidant capacity under cold conditions compared to the control. The combined application was more effective than the individual application. In conclusion, SA + MeJA application could be applied during the preparation of fresh-cut pomegranate for maintaining quality and bioactive compounds.

Keywords: cold storage; minimal processing; fresh-cut; *Punica granatum*; bioactive compounds; quality

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1. Introduction

Pomegranate (*Punica granatum* L.) is a fruit with significant commercial value, growing in tropical and subtropical climates [1]. It has been cultivated extensively in Spain, Egypt, Russia, India, France, China, Japan, South Africa, the United States, and Iran. Arils represent 52% of the weight and contain approximately 80% juice or 20% seed. Pomegranate arils contain water (85%), sugars, carbohydrates (10%), organic acids, anthocyanins (3–35 mg/100 g fw), vitamins, polysaccharides, polyphenols (0.2–1%), antioxidative phytochemicals, antimicrobial compounds, and vital minerals [2,3]. Thus, consuming pomegranate arils is ideal for reducing tumorigenesis, weight loss, heart disease, and cancer chemoprevention [4].

Minimal-processed (fresh-cut or ready-to-eat) pomegranate arils are now widely used and used as a healthy alternative to snacks. Fresh-cut pomegranate (arils used) is minimally processed by washing and sanitizing with chemicals to lower the initial microbial load, peeling, arils extract, pretreatments (adding antibrowning agents or others), dewatering, packaging, and refrigerated storage [5,6].

Pomegranate arils are highly perishable fruits, and significant loss of quality happens in arils and peels during postharvest storage, including firmness or aril color loss and reduction in acidity and vitamin C. On the other hand, they are sensitive to low temperatures and severely injured by chilling (between −3 °C and 5 °C for one month). In order to reduce chilling damage and protect the nutritional value of this fruit during cold

storage, it is necessary to develop appropriate and effective approaches [7]. The shelf life and quality of pomegranate whole fruit or arils have been enhanced by the application of several treatments. Many previous applications were applied to extend the shelf-life of pomegranate arils, such as edible chitosan coatings with ascorbic acid [8], carboxymethyl cellulose [9], and *Aloe vera* gel [10], application with methyl Jasmonate [11], malic and oxalic acid treatments [12], arginine application [13], hypobaric treatment [14], methyl Jasmonate treatment [15], and melatonin application [7].

Salicylic acid (SA) is recognized as a plant growth regulator that consists of a phenolic compound. The process of SA controlling ethylene production in plants is well-known. Previous studies have investigated the impact of postharvest SA and its derivatives' application on storage ability and pomegranate fruit quality [16,17].

Plant hormones such as methyl Jasmonate (MeJA) play a significant role in plant development by inducing defense systems against microbes and different abiotic stresses. They are also thought to regulate fruit ripening and growth [18]. According to the FDA-EPA, MeJA is a substance that is generally recognized as safe (GRAS). Postharvest treatment with MeJA improved pomegranate quality characteristics during storage [11]. There is rare literature about postharvest MeJA treatment's effects on minimally processed pomegranate.

There are previous works that mentioned that either SA or MeJA has a role in extending the shelf-life of pomegranate arils. However, as far as we know, there is no available literature regarding the combination of postharvest SA and MeJA treatment on fresh-cut pomegranate (arils), and based on previous literature, we hypothesized that SA + MeJA treatment could conserve the bioactive compounds of arils better than the individual application of either SA and MeJA. Thus, this study evaluated the effects of postharvest treatments with SA, MeJA, and their combination on aril quality, shelf-life, and bioactive compounds during cold storage.

2. Materials and Methods

2.1. Plant Material and Arils Preparation

The pomegranate fruits were harvested from a private orchard at the ripening stage according to commercial practice (normally after 150 d from bloom), and the fruits were transferred to postharvest processing laboratory (Food Science Department) on the same day within 4 h. The fruits that had bruising, sunscald, and physical damage, such as cuts and cracking, were discarded. The remaining fruits were sanitized by soaking for 3 min in solution of 0.1% sodium hypochlorite followed by drying at ambient temperature. The dried fruit was cut precisely with sterile, sharp knives at the equatorial zone. In order to prevent contamination, the arils were manually removed for two hours within a laminar airflow hood that had undergone sterilization. The arils were gathered and separated into four groups in sterilized plastic crates.

2.2. Treatments and Storage Conditions

Four treatments were used in this study as follows: salicylic acid (SA) at a rate of 2 mM, methyl Jasmonate (MeJA) at a rate of 0.5 mM, salicylic acid (2 mM) + methyl Jasmonate (0.5 mM), and distilled water (served as a control) according to previous work [11,17]. Every aril batch (about 500 g) was dipped in 2 L of previous solutions containing 1 mL L^{-1} Tween-20 for 5 min, and they were allowed to fully dry at room temperature under laminar flow to avoid contamination. Arils, lots of about 200 g, were weighed into polyethylene trays (clamshells) and stored in a refrigerated room at 5 °C and 90 ± 2% relative humidity (RH) for 15 days according to Figure 1 [16]. Three replicates were utilized for every previous treatment, and the following parameters were evaluated at 0, 5, 10, and 15 days.

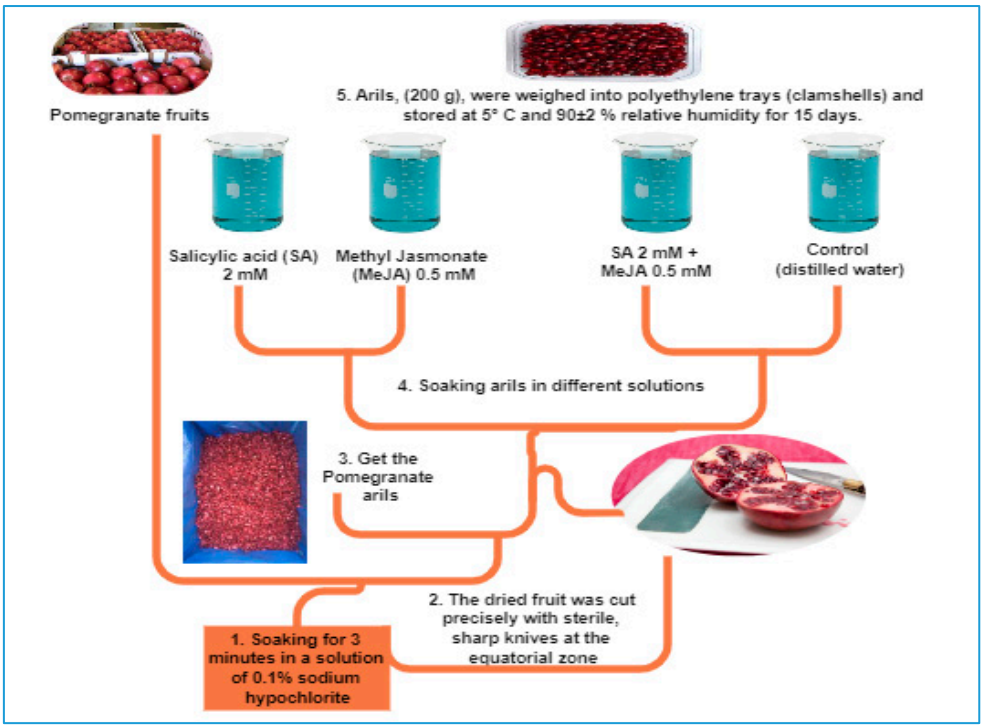

Figure 1. Preparation, treatments, and storage conditions of pomegranate arils.

2.3. Weight Loss and Soluble Solids Content

The weight loss (WL) of arils was measured according to previous investigation by Abdelgawad et al. [19]. Each sample was weighed immediately after treatment, before refrigerated storage, and during each measurement point using a sensitive digital balance. The results are presented based on the percentage of weight loss. About 60 g of arils were squeezed from every sample to measure total soluble content (SSC) and titratable acidity (TA). The SSC was measured twice in juice using a digital refractometer (Model PR101, Atago Co., Ltd., Tokyo, Japan).

2.4. Titratable Acidity and Vitamin C

Titratable acidity was determined in the juice of every sample by diluting 1 mL of juice to 25 mL using distilled water and titrating with sodium hydroxide (0.1 N) up to pH 8.1 using a pH meter (EuTech, Instruments, pH 510, Singapore). Results are expressed as mg 100 g^{-1} fresh weight [20]. Vitamin C was determined according to the 2, 6-dichlorophenol indophenol titration method [21]. The results are expressed as a mg malic acid equivalent to 100 g^{-1} fresh weight.

2.5. Respiration Rate

The respiration rate of fresh arils was detected according to method of Singh et al. [10] with slight modification. Briefly, 50 g of fresh arils were weighed and incubated for one hour in a gas-tight jar (200 mL) to measure the released CO_2. After that, 1 mL was absorbed by O_2/CO_2 gas analyzer (902D, MA, USA) from the headspace. The results of respiration rate are shown as mmol CO_2 kg^{-1} FW h^{-1}.

2.6. Arils Surface Color

The surface hue angle (h°) of arils was measured with colorimeter (Model CR-400, Konica Minolta, INC, Tokyo, Japan) as described before [22]. The colorimeter was calibrated before using a white stander plate. The mean of ten measurements for each replicate was calculated.

2.7. Total Anthocyanins and Total Phenolics

Lorente-Mento et al. [20] method was followed with simple modifications to determine the total anthocyanins. In brief, about 10 g of arils were homogenized with 30 mL of the methanol/formic acid/water solution (25:1:24, *v*/*v*/*v*), a homogenizer (Heidolph DGH Rundfunk- Fernsehen, Typ-DR 22054, Germany). Then, the extract was centrifuged at 10,000× *g* for 15 min (under cooling at 4 °C). Absorbance of the supernatant was read at 520 nm to measure total anthocyanins using spectrophotometer (model UV-2401 PC, Shimadzu, Milano, Italia). Total anthocyanins were calculated as cyanidin 3-glucoside equivalent in a fresh weight basis (molar absorption coefficient of 26,900 L cm^{-1} mol^{-1} and molecular weight of 449.2 g moL^{-1}). Results are expressed as mg 100 g^{-1}.

To measure the total phenolics, Folin–Ciocalteu spectrophotometric method was followed (with gallic acid as standard) as described previously by Zarbakhsh et al. [23] with minor modification. A total of 5 mL of diluted Folin–Ciocalteau reagent (1:10) was added to 1 mL of clear juice, then 4 mL of sodium carbonate (7.5% *w*/*v*) was added. The previous solution was completed up to 100 mL with distilled water. Previous mixtures were kept at room temperature for 2 h in dark. Then, the absorbance at 765 nm was measured by a spectrophotometer, and total phenolics are expressed as mg Gallic acid (GAE) per 100 g^{-1} FW.

2.8. Antioxidant Capacity and Total Flavonoids

Methanolic extract was prepared with homogenized 1 g of the samples in 10 mL of methanol (80%), then centrifuged at 4 °C for 15 min [24]. The extract was used to determine antioxidant capacity according to method of Molla et al. [7]. In brief, 0.025 g of 2,2-diphenyl-1-picrylhydrazyl (DPPH) was dissolved in 100 mL of 100% methanol to make the DPPH solution. Then, 950 µL of DPPH solution was mixed with 50 µL of the sample methanolic extract and kept in the dark for 30 min. Absorbance was measured using a spectrophotometer at 517 nm. Results are expressed as the DPPH scavenging activity (%) as follows:

$$((\text{Absorbance of control} - \text{absorbance of sample})/\text{absorbance of control}) \times 100 \quad (1)$$

Total flavonoids were measured according to method of Shams Ardekani et al. [25] with minor modifications. Utilizing catechin (CE) as standard and quantifing as mg catechin/g FW, total flavonoid content of arils extract was determined. In brief, 0.25 mL of preceding extracts was added to 0.75 mL of methanol followed by 50 µL of 10% $AlCl_3$ and 50 µL of CH_3CO_2K. After being diluted to 1.4 mL with distilled water, the liquid was left in dark for 30 min. At 430 nm, absorbance was measured.

2.9. Statistical Analysis

SPSS software (V.14) was used for statistical analysis, and three replicates of each treatment (n = 3) were used. The values were reported as mean ± SE treatment means and were compared at 0.05 using Duncan's multiple range test. To investigate correlation between all tested parameters, Pearson's correlation was performed utilizing SPSS software, and principal component analysis (PCA) was performed with Statistica 7 software.

3. Results and Discussions

3.1. Effect of Treatments on Weight Loss and Respiration Rate

As expected, the weight loss of all treatments increased continuously at the beginning of storage up to 15 days (Figure 2A). However, the applications of SA, MeJA, and their combination (SA + MeJA) significantly ($p < 0.05$) conserved moisture content in the arils compared to the control treatment by 35.22%, 31.87%, and 42.31%, respectively, at 15 d of cold storage. Additionally, the SA + MeJA treatment is the most effective in minimizing weight loss, especially at the end of the storage period. The most critical factor affecting the quality and shelf life of horticulture crops is weight loss. Therefore, the shelf-life of fresh products could be extended by reducing water loss. According to the previous

report, water loss results in unfavorable metabolic changes in plant cells that activate the enzymes that speed up senescence and reduce nutritional value [26]. Evaporation and transpiration of moisture from the pomegranate aril surface and respiration could be the main reasons for increasing weight loss during storage [27]. The application of SA as exogenous postharvest treatment has been utilized to reduce water loss in other crops, such as papaya fruits [28], strawberries [22], or peaches [29]. The inhibition of ethylene production by SA application [30], which reduces respiration rate [31], may explain the reduced weight loss.

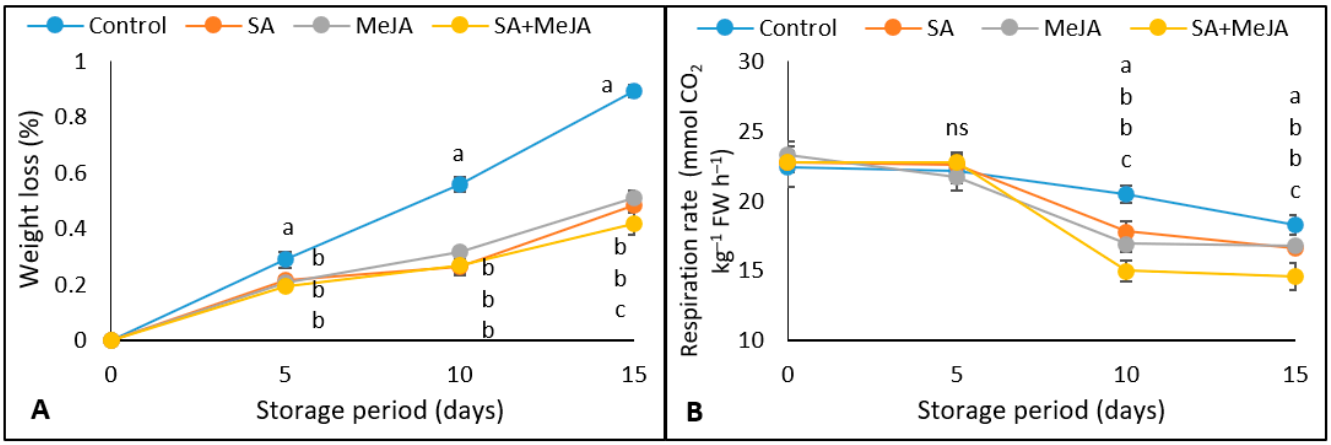

Figure 2. Effects of salicylic acid (SA), methyl jasmonate (MeJA), and their combination postharvest treatments on (**A**) weight loss and (**B**) respiration rate of pomegranate arils stored at 5 °C for 15 days. The presented data are the mean of three replicates ± standard error. Different letters present significant differences between treatments at the same storage point according to Duncan test at $p < 0.05$.

Furthermore, SA may prevent weight loss by pushing stoma closure [32]. The role of MeJA in maintaining the quality of fresh fruits after harvest was also reported in some previous works. For example, dipping strawberry fruits in 0.25 mM MeJA reduced weight loss compared to the control [22]. Table 1 shows a strong correlation between weight loss and color (h° angle), while a high negative correlation was found between weight loss against SSC, TA, vitamin C, and anthocyanin.

Our results in Figure 2B show that the respiration rate decreased after 5 days of storage until the end. The differences between the treatments after 5 days of storage were not significant. However, the control treatment (after 10 and 15 days) showed the highest respiration rate, while the individual treatment with SA and MeJA showed a lower respiration rate (without a significant difference). Additionally, the combined treatment with SA + MeJA showed the lowest respiratory rate after 10 and 15 days of storage compared with all treatments and the control. The role of SA in reducing respiration rate might be due to its role in reducing ethylene production [30]. Additionally, it has been reported that 5 µM MeJA application (dipping fruits) reduced the respiration rate of eggplant fruits during cold storage [33]. Moreover, MeJA application (dipping or vapor applications) reduced weight loss and shriveling as well as maintained the quality of radish roots during storage for 7 days [34].

Table 1. Pearson's correlation analysis between tested parameters of pomegranate arils.

	WL	**Respiration**	**h°**	**SSC**	**TA**	**Vitamin C**	**Anthocyanin**	**Phenolics**	**Flavonoids**	**Antioxidant**
WL		−0.557 **	0.789 **	0.485 **	−0.727 **	−0.826 **	−0.618 **	0.012	−0.341 **	−0.323 *
Respiration	−0.557 **		−0.253 *	−0.073	0.249 *	0.509 **	0.112	−0.352 **	−0.044	−0.092
h°	0.789 **	−0.253 *		0.629 **	−0.760 **	−0.708 **	−0.635 **	−0.330 *	−0.469 **	−0.558 **
SSC	0.485 **	−0.073	0.629 **		−0.611 **	−0.533 **	−0.464 **	−0.339 **	−0.467 **	−0.624 **
TA	−0.727 **	0.249 *	−0.760 **	−0.611 **		0.602 **	0.534 **	0.111	0.410 **	0.523 **
Vitamin C	−0.826 **	0.509 **	−0.708 **	−0.533 **	0.602 **		0.655 **	0.171	0.392 **	0.435 **
Anthocyanin	−0.618 **	0.112	−0.635 **	−0.464 **	0.534 **	0.655 **		0.338 **	0.390 **	0.560 **
Phenolics	0.012	−0.352 **	−0.330 *	−0.339 **	0.111	0.171	0.338 **		0.454 **	0.587 **
Flavonoids	−0.341 **	−0.044	−0.469 **	−0.467 **	0.410 **	0.392 **	0.390 **	0.454 **		0.608 **
Antioxidant	−0.323 *	−0.092	−0.558 **	−0.624 **	0.523 **	0.435 **	0.560 **	0.587 **	0.608 **	

* and **. Correlation is significant at 0.05 and 0.01 levels (2-tailed).

3.2. Effect of Treatments on Hue Angle (h°) Soluble Solids Content (SSC)

The color of pomegranate arils is important because it influences consumer choice when purchasing minimally processed pomegranate arils. A higher h° represents less red of pomegranate arils. Figure 3A revealed that h° values increased by increasing storage time in all treatments. However, the control treatment showed higher h° values than all treatments. At the end of storage time, SA + MeJA treatment showed the lowest h° values. This result could be because SA and MeJA conserved the bioactive compounds, including anthocyanin; as a result, the arils retain more red color than the control. Our results in Table 1 support our hypothesis that a strong negative correlation exists between h° on one side and TA, Vitamin C, and anthocyanin on the other side. A previous study showed that preharvest MeJA application enhanced pomegranate arils' red color (lower h°) during cold storage compared to untreated trees [1]. Additionally, García-Pastor et al. [35] found that h° in pomegranate arils was lower in all treated fruits compared to control fruits, which showed the deep red color of arils.

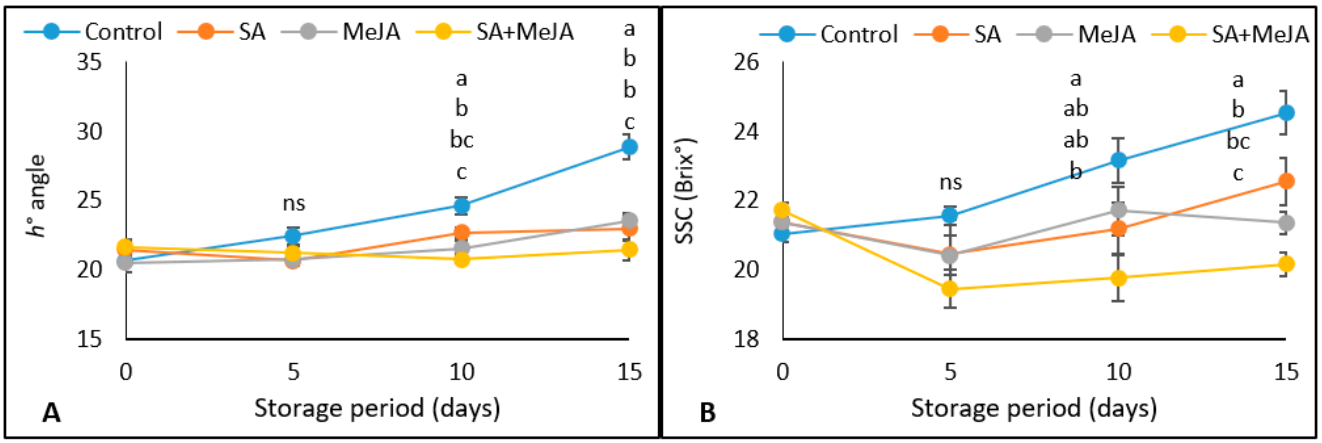

Figure 3. Effects of salicylic acid (SA), methyl jasmonate (MeJA), or their combination postharvest treatments on (**A**) h° angle and (**B**) solid soluble content (SSC) of pomegranate arils stored at 5 °C for 15 days. The presented data are the mean of three replicates ± standard error. Different letters present significant differences between treatments at the same storage point according to the Duncan test at $p < 0.05$.

Our results in Figure 3B show that SSC in pomegranate arils increased during the storage periods for all treatments. However, all treatments recorded lowered SSC content than the control. The lower SSC values were obtained from SA + MeJA treatment followed by the individual application of every compound. The increase in SSC may be due to increased water loss from the pomegranate arils, which leads to an increase in the concentration of SSC. In disagreeing with our results, it has been found that MeJA did not affect SSC in cherry tomato fruits [36]. The difference between them in crop type, storage conditions, and MeJA concentration could be the main causes.

3.3. Effect of Treatments on Titratable Acidity (TA) and Vitamin C

There was a slight decrease in TA during the storage period (Figure 4A). However, all treatments remained higher TA (without a significant difference) than the control treatment. The reduction in TA observed during cold storage might have been caused by the metabolic activity of the arils during refrigerated storage [27]. In accordance with our results, Shaarawi et al. [37] found that TA in the pomegranate arils decreased with increasing storage periods during the cold storage, and SA treatment conserved the TA compared to the control. In accordance with our results, it has been found that TA was higher in blueberry fruits treated with MeJA compared to the control during cold storage [36]. However,

our results are not matching with the results of Liu et al. [38] who found that MeJA did not affect TA in cherry tomatoes, which might be due to the differences with our study in plant type, storage conditions, and treatment concentration.

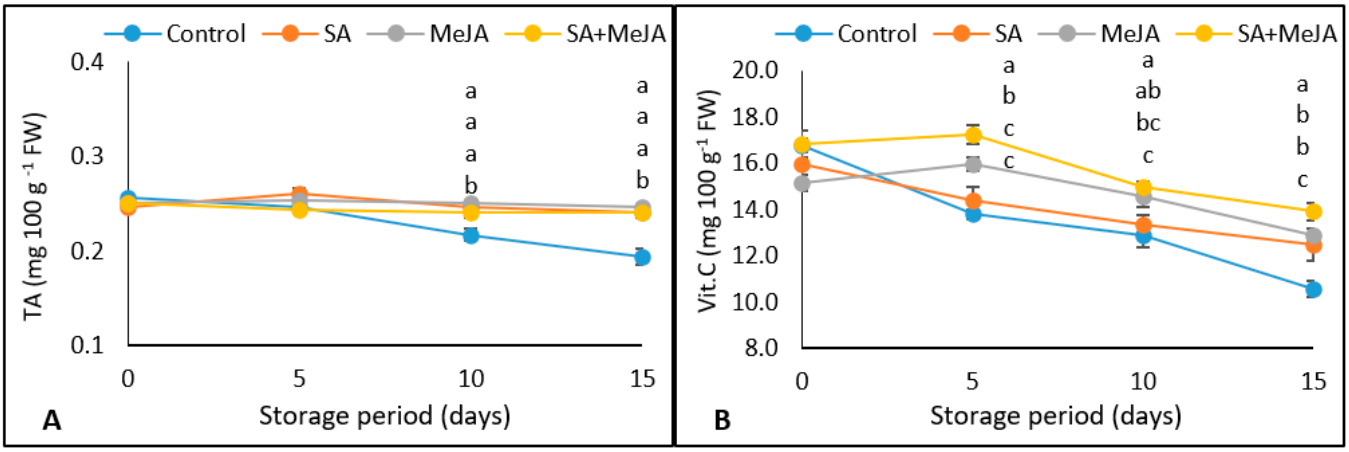

Figure 4. Effects of salicylic acid (SA), methyl jasmonate (MeJA), or their combination postharvest treatments on (**A**) titratable acidity (TA) and (**B**) vitamin C of pomegranate arils stored at 5 °C for 15 days. The presented data are the mean of three replicates ± standard error. Different letters present significant differences between treatments at the same storage point according to the Duncan test at $p < 0.05$.

The results in Figure 4B show that vitamin C in arils decreased continuously during cold storage. However, all treatments conserved vitamin C from loss during the whole storage period. Moreover, SA + MeJA treatment showed higher vitamin C content than other treatments followed by the individual application of either SA or MeJA without significant difference. Vitamin C is considered the most important natural antioxidant in fruit and vegetables. However, it was rapidly degraded after processing harvested fruits and vegetables due to several factors, including enzymatic oxidation and exposure to high temperature, light, and oxygen [39]. The decline of vitamin C in pomegranate arils during cold storage was reported previously [37,39]. Some studies reported the role of postharvest SA treatment in maintaining vitamin C and extending the shelf-life of pomegranate arils [37,40].

Additionally, Sayyari et al. [41] found that exogenous application of SA (2 mM) reduced the loss in vitamin C of pomegranate arils. The effect of SA on reducing the decline of vitamin C might be related to its effects on reducing ethylene production [30]. In agreement with our results, exogenous MeJA treatment showed a high ability to reduce the loss of vitamin C during cold storage of strawberries [22] or cherry tomatoes [38]. Higher vitamin C content in pomegranate arils treated with MeJA might be due to the lower respiration rate of arils treated with MeJA, as presented in Figure 1B [36]. The same results were noticed by Huang et al. [37] and Jin et al. [42] who found that MeJA treatment conserved vitamin C in blueberries and peach fruits from loss during cold storage, respectively.

3.4. Effect of Treatments on Anthocyanin Content and Phenolic Content

In the control and SA treatments, the anthocyanin content of pomegranate arils decreased continuously during cold storage (Figure 5A). However, the treatments with MeJA and SA + MeJA conserved anthocyanin content higher than the control treatment during the storage period. Previous work also found a decline in the anthocyanin content in pomegranate arils during cold storage for all tested treatments [27,37]. Additionally, Dokhanieh et al. [40] and Shaarawi et al. [37] reported that SA treatment conserved anthocyanin content in pomegranate arils during cold storage compared to the control.

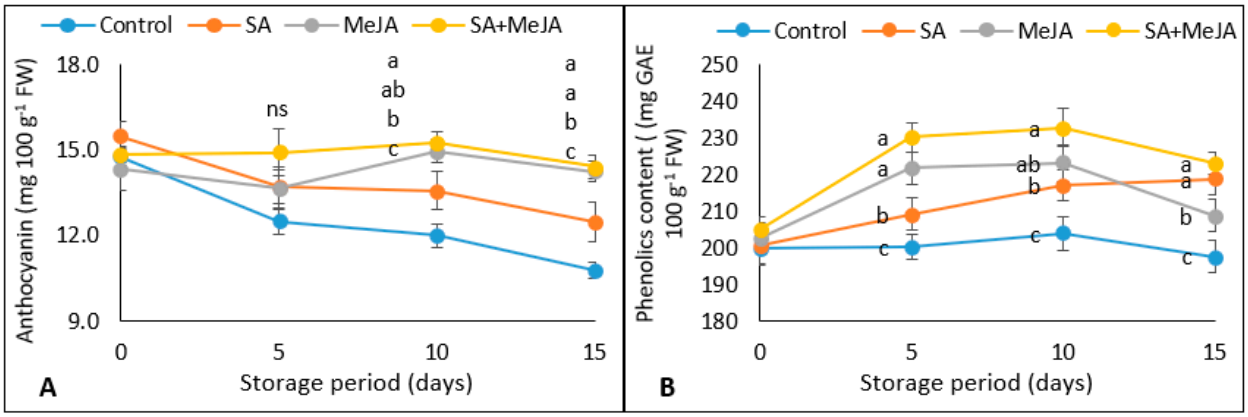

Figure 5. Effects of salicylic acid (SA), methyl jasmonate (MeJA), or their combination postharvest treatments on (**A**) anthocyanin content and (**B**) phenolic content of pomegranate arils stored at 5 °C for 15 days. The presented data are the mean of three replicates ± standard error. Different letters present significant differences between treatments at the same storage point according to the Duncan test at $p < 0.05$.

The results of this study indicated that phenolic content was increased until 10 days of storage and then decreased in all treatments except SA treatment, which remained increased (Figure 5B). The decrease in phenolic contents at the end of cold storage of pomegranate arils may be due to the degradation of the phenolic compound due to the enzyme activities [43]. At the end of the storage time, SA, MeJA, and SA + MeJA treatments showed higher phenolic compounds by 9.63%, 5.29%, and 11.37%, respectively, than the control. The previous study showed the role of SA in retarding the loss of phenolic content in arils during cold storage. The same results were noticed by Dokhanieh et al. [40]; the results are in agreement with our results. They found that SA treatment conserved phenolic compounds in pomegranate arils during cold storage.

3.5. Effect of Treatments on Flavonoids and Antioxidant Capacity

Flavonoid content in pomegranate arils increased after 5 days from the start and then slightly decreased during storage for 15 days (Figure 6A). The control treatment shows lower flavonoid content in stored arils than all other treatments. There were no significant differences between SA, MeJA, and SA + MeJA treatments during all storage periods.

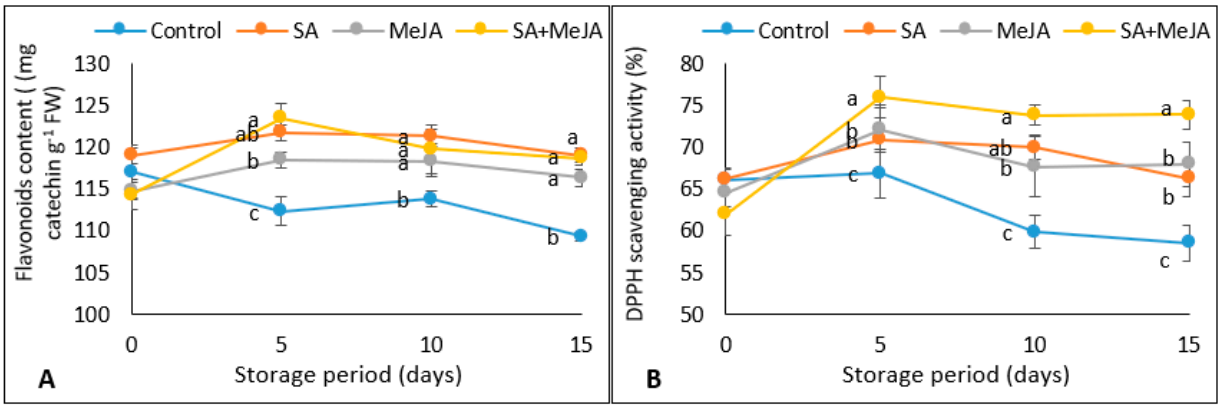

Figure 6. Effects of salicylic acid (SA), methyl jasmonate (MeJA), or their combination postharvest treatments on (**A**) flavonoids content and (**B**) antioxidant capacity (DPPH) of pomegranate arils stored at 5 °C for 15 days. The presented data are the mean of three replicates ± standard error. Different letters present significant differences between treatments at same storage point according to the Duncan test at $p < 0.05$.

Pomegranates display good antioxidant activity due to their high levels of phenolic, flavonoids, and anthocyanin [5]. As shown in Figure 6B, antioxidant capacity increased after 5 days from the start and then slightly decreased (in SA and control treatments) or remained (in MeJA and SA + MeJA treatments) during the storage for 15 days (Figure 6B). Additionally, the SA + MeJA treatment was the most effective in conserving the antioxidant capacity during all storage periods followed by the individual application of SA and MeJA. In accordance with our results, Dokhanieh et al. [40] found that antioxidant capacity decreased with an increasing storage period. Moreover, they mentioned that SA treatment conserved antioxidant capacity compared to the control.

Pomegranates have a high concentration of bioactive substances with antioxidant effects, including AA, flavonoids, and phenolic compounds. In this regard, phenylalanine ammonia-lyase (PAL), involved in the biosynthesis of phenolics, increased during storage in SA-treated sweet cherries [44]. This enzyme may cause the higher phenolic concentration found in SA-treated pomegranates, as has been reported for grapes [45]. On the other hand, SA applied to sour pomegranates, oranges, or broccoli [39,46,47] slowed the rate of reduction in ascorbic acid losses observed in the control fruit. Ascorbic acid and total phenolics are the principal substances contributing to the antioxidant activities of pomegranate arils. Additionally, as previously documented, the preservation of phenolic compounds might be responsible for the increase in antioxidant activity exposed to MeJA [33].

3.6. Correlation Study

The principal component analysis (PCA) biplots based on the physical, biochemical, and enzymatic properties of the pomegranate arils during cold storage presented that PC1 and PC2 together were 71% of the variance (Figure 7). Biplots allow us to visualize how parameters relate to each other. PCA also presents which parameters are similar and which are different. PC1 and PC2 accounted for 51.27% and 19.75 of total variability, respectively, showing that respiration rate, SSC, and vitamin C are located in the same group. TA, anthocyanin, phenolics, and flavonoids are in the same group. Moreover, weight loss is in the private group and h° in the other group.

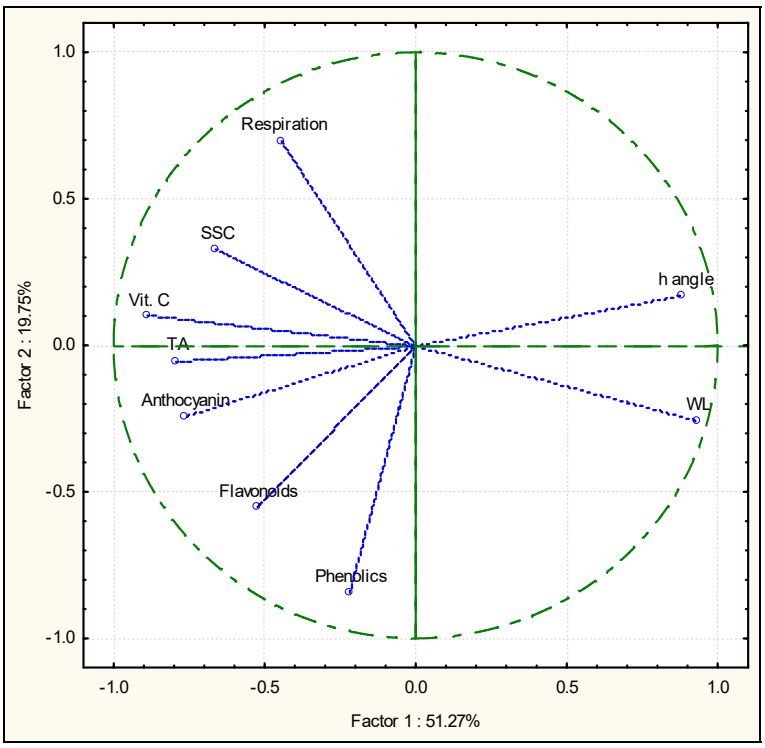

Figure 7. Principal component analysis (PCA) of tested parameters of pomegranate arils.

4. Conclusions

Both 2 mM SA and 0.5 mM MeJA were found to be effective applications of maintaining the quality of pomegranate arils during 15 days of cold storage at 5 °C by reducing weight loss by 52% and respiration rate by 20.23% compared to the control. Additionally, the combined treatment maintains SSC, TA, vitamin C, flavonoids, anthocyanins, and phenolic compounds. As a result, it can be concluded that dipping pomegranate arils in SA + MeJA can be used safely by the minimal processing pomegranate industry (Figure 8) after extracting arils to increase shelf life up to 15 days with high quality under cold storage conditions at 5 °C.

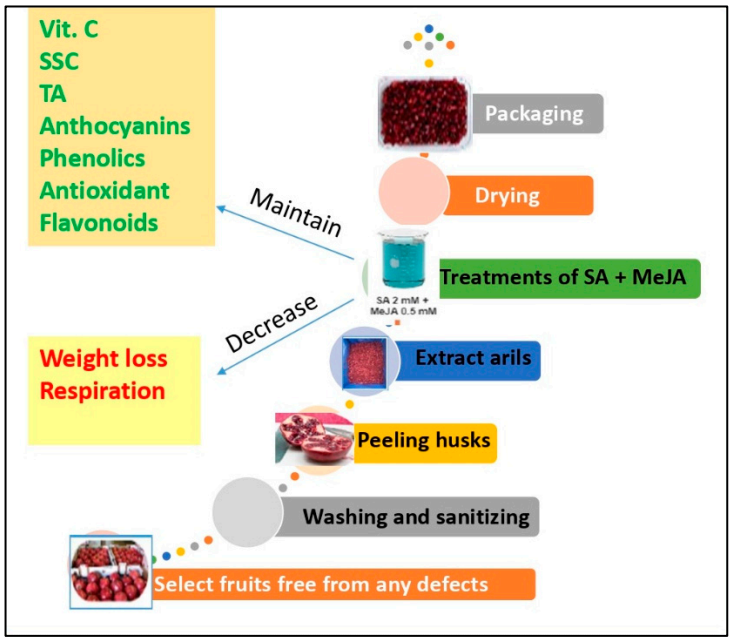

Figure 8. Flowchart of pomegranates processing and effective of SA + MeJA.

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References

1. García-Pastor, M.E.; Serrano, M.; Guillén, F.; Giménez, M.J.; Martínez-Romero, D.; Valero, D.; Zapata, P.J. Preharvest application of methyl jasmonate increases crop yield, fruit quality and bioactive compounds in pomegranate 'Mollar de Elche' at harvest and during postharvest storage. *J. Sci. Food Agric.* **2020**, *100*, 145–153. [CrossRef]
2. Al-Maiman, S.A.; Ahmad, D. Changes in physical and chemical properties during pomegranate (*Punica granatum* L.) fruit maturation. *Food Chem.* **2002**, *76*, 437–441. [CrossRef]
3. Yang, X.; Niu, Z.; Wang, X.; Lu, X.; Sun, J.; Carpena, M.; Prieto, M.A.; Simal-Gandara, J.; Xiao, J.; Liu, C.; et al. The Nutritional and Bioactive Components, Potential Health Function and Comprehensive Utilization of Pomegranate: A Review. *Food Rev. Int.* **2022**, 1–27. [CrossRef]
4. Karimi, M.; Sadeghi, R.; Kokini, J. Pomegranate as a promising opportunity in medicine and nanotechnology. *Trends Food Sci. Technol.* **2017**, *69*, 59–73. [CrossRef]
5. Ayhan, Z.; Eştürk, O. Overall Quality and Shelf Life of Minimally Processed and Modified Atmosphere Packaged "Ready-to-Eat" Pomegranate Arils. *J. Food Sci.* **2009**, *74*, C399–C405. [CrossRef] [PubMed]
6. Bhatia, K.; Asrey, R. Minimal processing of pomegranates (*Punica granatum* L.)—A review on processing, quality, and shelf life. *J. Food Process. Preserv.* **2019**, *43*, e14281. [CrossRef]
7. Molla, S.M.H.; Rastegar, S.; Omran, V.G.; Khademi, O. Ameliorative effect of melatonin against storage chilling injury in pomegranate husk and arils through promoting the antioxidant system. *Sci. Hortic.* **2022**, *295*, 110889. [CrossRef]
8. Özdemir, K.S.; Gökmen, V. Extending the shelf-life of pomegranate arils with chitosan-ascorbic acid coating. *LWT—Food Sci. Technol.* **2017**, *76*, 172–180. [CrossRef]
9. Nazoori, F.; Mollai, S.; Sobhani, F.; Mirdehghan, S.H.; Sahhafi, S.R. Carboxymethyl cellulose and carnauba wax treatments kept the pomegranate fruit (*Punica granatum* L.) quality during cold storage via improving enzymatic defense system and bioactive compounds. *Sci. Hortic.* **2023**, *309*, 111645. [CrossRef]
10. Singh, J.; Pareek, S.; Maurya, V.K.; Sagar, N.A.; Kumar, Y.; Badgujar, P.C.; Fawole, O.A. Application of Aloe vera Gel Coating Enriched with Cinnamon and Rosehip Oils to Maintain Quality and Extend Shelf Life of Pomegranate Arils. *Foods* **2022**, *11*, 2497. [CrossRef]
11. Sayyari, M.; Salehi, F.; Valero, D. New Approaches to Modeling Methyl Jasmonate Effects on Pomegranate Quality during Postharvest Storage. *Int. J. Fruit Sci.* **2017**, *17*, 374–390. [CrossRef]
12. Ehteshami, S.; Abdollahi, F.; Ramezanian, A.; Dastjerdi, A.M.; Rahimzadeh, M. Enhanced chilling tolerance of pomegranate fruit by edible coatings combined with malic and oxalic acid treatments. *Sci. Hortic.* **2019**, *250*, 388–398. [CrossRef]
13. Babalar, M.; Pirzad, F.; Sarcheshmeh, M.A.A.; Talaei, A.; Lessani, H. Arginine treatment attenuates chilling injury of pomegranate fruit during cold storage by enhancing antioxidant system activity. *Postharvest Biol. Technol.* **2018**, *137*, 31–37. [CrossRef]
14. Zhang, X.; Sun, S.; Yang, J.; Zou, M.; Xin, L. Improving pomegranate fruit quality by short-term hypobaric treatment combined with modified atmosphere packaging storage. In Proceedings of the IV International Conference on Fresh-Cut Produce: Maintaining Quality and Safety, Shandong, China, 12–17 September 2021; pp. 217–222.
15. García-Pastor, M.E.; Serrano, M.; Guillén, F.; Zapata, P.J.; Valero, D. Preharvest or a combination of preharvest and postharvest treatments with methyl jasmonate reduced chilling injury, by maintaining higher unsaturated fatty acids, and increased aril colour and phenolics content in pomegranate. *Postharvest Biol. Technol.* **2020**, *167*, 111226. [CrossRef]
16. Sayyari, M.; Castillo, S.; Valero, D.; Díaz-Mula, H.M.; Serrano, M. Acetyl salicylic acid alleviates chilling injury and maintains nutritive and bioactive compounds and antioxidant activity during postharvest storage of pomegranates. *Postharvest Biol. Technol.* **2011**, *60*, 136–142. [CrossRef]
17. Moradi, S.; Zamani, Z.; Fatahi Moghadam, M.-R.; Koushesh Saba, M. Combination effects of preharvest tree net-shading and postharvest fruit treatments with salicylic acid or hot water on attributes of pomegranate fruit. *Sci. Hortic.* **2022**, *304*, 111257. [CrossRef]
18. Wasternack, C.; Strnad, M. Jasmonate signaling in plant stress responses and development—Active and inactive compounds. *New biotechnology* **2016**, *33*, 604–613. [CrossRef]
19. Abdelgawad, K.F.; Awad, A.H.R.; Ali, M.R.; Ludlow, R.A.; Chen, T.; El-Mogy, M.M. Increasing the Storability of Fresh-Cut Green Beans by Using Chitosan as a Carrier for Tea Tree and Peppermint Essential Oils and Ascorbic Acid. *Plants* **2022**, *11*, 783. [CrossRef]
20. Lorente-Mento, J.M.; Guillén, F.; Martínez-Romero, D.; Carrión-Antoli, A.; Valero, D.; Serrano, M. γ-Aminobutyric acid treatments of pomegranate trees increase crop yield and fruit quality at harvest. *Sci. Hortic.* **2023**, *309*, 111633. [CrossRef]
21. El-Mogy, M.M.; Salama, A.M.; Mohamed, H.F.Y.; Abdelgawad, K.F.; Abdeldaym, E.A. Responding of Long Green Pepper Plants to Different Sources of Foliar Potassium Fertiliser. *Agriculture* **2019**, *65*, 59–76. [CrossRef]
22. El-Mogy, M.M.; Ali, M.R.; Darwish, O.S.; Rogers, H.J. Impact of salicylic acid, abscisic acid, and methyl jasmonate on postharvest quality and bioactive compounds of cultivated strawberry fruit. *J. Berry Res.* **2019**, *9*, 333–348. [CrossRef]
23. Zarbakhsh, S.; Kazemzadeh-Beneh, H.; Rastegar, S. Quality preservation of minimally processed pomegranate cv. Jahrom arils based on chitosan and organic acid edible coatings. *J. Food Saf.* **2020**, *40*, e12752. [CrossRef]
24. Singleton, V.L.; Orthofer, R.; Lamuela-Raventós, R.M. [14] Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. In *Methods in Enzymology*; Academic Press: Cambridge, MA, USA, 1999; Volume 299, pp. 152–178.

25. Shams Ardekani, M.R.; Hajimahmoodi, M.; Oveisi, M.R.; Sadeghi, N.; Jannat, B.; Ranjbar, A.M.; Gholam, N.; Moridi, T. Comparative Antioxidant Activity and Total Flavonoid Content of Persian Pomegranate (*Punica granatum* L.) Cultivars. *Iran. J. Pharm. Res. IJPR* **2011**, *10*, 519–524. [PubMed]
26. Breda, C.A.; Morgado, D.L.; de Assis, O.B.G.; Duarte, M.C.T. Effect of chitosan coating enriched with pequi (*Caryocar brasiliense* Camb.) peel extract on quality and safety of tomatoes (*Lycopersicon esculentum* Mill.) during storage. *J. Food Process. Preserv.* **2017**, *41*, e13268. [CrossRef]
27. Caleb, O.J.; Opara, U.L.; Mahajan, P.V.; Manley, M.; Mokwena, L.; Tredoux, A.G.J. Effect of modified atmosphere packaging and storage temperature on volatile composition and postharvest life of minimally-processed pomegranate arils (cvs. 'Acco' and 'Herskawitz'). *Postharvest Biol. Technol.* **2013**, *79*, 54–61. [CrossRef]
28. Hanif, A.; Ahmad, S.; Shahzad, S.; Liaquat, M.; Anwar, R. Postharvest application of salicylic acid reduced decay and enhanced storage life of papaya fruit during cold storage. *J. Food Meas. Charact.* **2020**, *14*, 3078–3088. [CrossRef]
29. Tareen, M.J.; Abbasi, N.A.; Hafiz, I.A. Postharvest application of salicylic acid enhanced antioxidant enzyme activity and maintained quality of peach cv. 'Flordaking' fruit during storage. *Sci. Hortic.* **2012**, *142*, 221–228. [CrossRef]
30. Zhang, Y.; Chen, K.; Zhang, S.; Ferguson, I. The role of salicylic acid in postharvest ripening of kiwifruit. *Postharvest Biol. Technol.* **2003**, *28*, 67–74. [CrossRef]
31. Soleimani Aghdam, M.; Asghari, M.; Babalar, M.; Askari Sarcheshmeh, M.A. 8—Impact of salicylic acid on postharvest physiology of fruits and vegetables. In *Eco-Friendly Technology for Postharvest Produce Quality*; Siddiqui, M.W., Ed.; Academic Press: Cambridge, MA, USA, 2016; pp. 243–268.
32. Zheng, Y.; Zhang, Q. Effects of Polyamines and Salicylic Acid on Postharvest Storage of 'Ponkan' Mandarin. *Acta Hortic.* **2004**, *632*, 317–320.
33. Fan, L.; Shi, J.; Zuo, J.; Gao, L.; Lv, J.; Wang, Q. Methyl jasmonate delays postharvest ripening and senescence in the non-climacteric eggplant (*Solanum melongena* L.) fruit. *Postharvest Biol. Technol.* **2016**, *120*, 76–83. [CrossRef]
34. Wang, C.Y. Methyl jasmonate inhibits postharvest sprouting and improves storage quality of radishes. *Postharvest Biol. Technol.* **1998**, *14*, 179–183. [CrossRef]
35. García-Pastor, M.E.; Zapata, P.J.; Castillo, S.; Martínez-Romero, D.; Guillén, F.; Valero, D.; Serrano, M. The Effects of Salicylic Acid and Its Derivatives on Increasing Pomegranate Fruit Quality and Bioactive Compounds at Harvest and During Storage. *Front. Plant Sci.* **2020**, *11*, 668. [CrossRef] [PubMed]
36. Huang, X.; Li, J.; Shang, H.; Meng, X. Effect of methyl jasmonate on the anthocyanin content and antioxidant activity of blueberries during cold storage. *J. Sci. Food Agric.* **2015**, *95*, 337–343. [CrossRef] [PubMed]
37. Shaarawi, S.A.M.A.; Salem, A.S.E.; Elmaghraby, I.M.K.; Abd El-Moniem, E.A.A. Effect of Salicylic Acid, Calcium Chloride and Calcium Lactate Applications on Quality Attributes of Minimally-Processed 'Wonderful' Pomegranate Arils. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2016**, *44*, 508–517. [CrossRef]
38. Liu, H.; Meng, F.; Miao, H.; Chen, S.; Yin, T.; Hu, S.; Shao, Z.; Liu, Y.; Gao, L.; Zhu, C.; et al. Effects of postharvest methyl jasmonate treatment on main health-promoting components and volatile organic compounds in cherry tomato fruits. *Food Chem.* **2018**, *263*, 194–200. [CrossRef] [PubMed]
39. O'Grady, L.; Sigge, G.; Caleb, O.J.; Opara, U.L. Effects of storage temperature and duration on chemical properties, proximate composition and selected bioactive components of pomegranate (*Punica granatum* L.) arils. *LWT—Food Sci. Technol.* **2014**, *57*, 508–515. [CrossRef]
40. Dokhanieh, A.Y.; Aghdam, M.S.; Sarcheshmeh, M.A.A. Impact of postharvest hot salicylic acid treatment on aril browning and nutritional quality in fresh-cut pomegranate. *Hortic. Environ. Biotechnol.* **2016**, *57*, 378–384. [CrossRef]
41. Sayyari, M.; Babalar, M.; Kalantari, S.; Serrano, M.; Valero, D. Effect of salicylic acid treatment on reducing chilling injury in stored pomegranates. *Postharvest Biol. Technol.* **2009**, *53*, 152–154. [CrossRef]
42. Jin, P.; Zheng, Y.; Tang, S.; Rui, H.; Wang, C.Y. A combination of hot air and methyl jasmonate vapor treatment alleviates chilling injury of peach fruit. *Postharvest Biol. Technol.* **2009**, *52*, 24–29. [CrossRef]
43. BaltacioĞLu, C.E.M.; VelioĞLu, S.; Karacabey, E. Changes in total phenolic and flavonoid contents of rowanberry fruit during postharvest storage. *J. Food Qual.* **2011**, *34*, 278–283. [CrossRef]
44. Qin, G.Z.; Tian, S.P.; Xu, Y.; Wan, Y.K. Enhancement of biocontrol efficacy of antagonistic yeasts by salicylic acid in sweet cherry fruit. *Physiol. Mol. Plant Pathol.* **2003**, *62*, 147–154. [CrossRef]
45. Wen, P.-F.; Chen, J.-Y.; Wan, S.-B.; Kong, W.-F.; Zhang, P.; Wang, W.; Zhan, J.-C.; Pan, Q.-H.; Huang, W.-D. Salicylic acid activates phenylalanine ammonia-lyase in grape berry in response to high temperature stress. *Plant Growth Regulation* **2008**, *55*, 1–10. [CrossRef]
46. Huang, R.-H.; Liu, J.-H.; Lu, Y.-M.; Xia, R.-X. Effect of salicylic acid on the antioxidant system in the pulp of 'Cara cara' navel orange (Citrus sinensis L. Osbeck) at different storage temperatures. *Postharvest Biol. Technol.* **2008**, *47*, 168–175. [CrossRef]
47. El-Beltagi, H.S.; Ali, M.R.; Ramadan, K.M.A.; Anwar, R.; Shalaby, T.A.; Rezk, A.A.; El-Ganainy, S.M.; Mahmoud, S.F.; Alkafafy, M.; El-Mogy, M.M. Exogenous postharvest application of calcium chloride and salicylic acid to maintain the quality of broccoli florets. *Plants* **2022**, *11*, 1513. [CrossRef] [PubMed]