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Comparative effects of salicylic acid and methyl salicylate edible coatings at different concentrations on postharvest quality of Daisy mandarin (*Citrus reticulata*)

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Abstract

Preserving post-harvest quality and extending the shelf life of fruits is vital for reducing food waste and ensuring food security, especially for perishable commodities such as Daisy mandarins. This study evaluated the impact of bioactive agents incorporated into edible coating-based packaging systems on the lifespan and characteristics of Daisy mandarin fruits. The experiment at Lovely Professional University's Department of Fruit Science involved sorting, grading, and washing the fruits with a chlorine solution (100 mg L⁻¹). Fruits were then coated with different concentrations of salicylic acid (1 mM, 1.5 mM, and 2 mM) and methyl salicylate to slow aging, with a control group treated with water. Tween 20 (0.05%) was used as a surfactant. The coated fruits were stored at 18 ± 4 °C in a randomized design with three replications. Various physicochemical attributes were observed at 10, 20, 30, and 40 days. Results showed that 2 mM salicylic acid was the most effective, minimizing physiological weight loss while maintaining juice content and overall fruit quality over 40 days. This treatment also preserved the fruits' sensory attributes. The study highlights 2 mM salicylic acid as a promising edible coating-based active packaging treatment for maintaining postharvest quality of Daisy mandarin under ambient storage conditions.

Keywords: Active packaging, Edible coating, Shelf-life extension, Citrus fruit, Salicylic acid, Methyl salicylate

1. Introduction

Citrus is a significant part of India's fruit economy, with mandarins, especially the 'Daisy' variety, being favored for their sweetness, juiciness, and ease of peeling. The Daisy mandarin (*Citrus reticulata* Blanco) originated from a breeding program that crossed the 'Fremont' and 'Fortune' mandarins. This introduction was particularly important given the dominance of the 'Kinnow' mandarin, which accounts for over 50% of the fruit-growing area in Punjab (Dhillon et al. 2016). Daisy's superiority over Kinnow lies in its precocity, taste, rind color, and juice content (Brar et al. 2020). Daisy mandarin fruits typically mature by mid-November, producing medium- to large-sized fruits with appealing dark orange skin (Chahal and Singh 2017).

Food packaging is essential for preserving freshness and quality by managing moisture, gas exchange, and microbial growth. Recently, edible coatings have gained attention as eco-friendly packaging alternatives for fruits and vegetables. When bioactive substances are added to these coatings, they help maintain the shelf life of produce by reducing respiration and water loss. This approach has been explored in various studies, including that of Fekry et al. (2021). Extending the storage duration of 'Daisy' mandarin increases export opportunities and alleviates oversupply in domestic markets, thereby mitigating post-harvest losses.

Several chemical regulators, including 1-MCP, AVG, salicylic acid, methyl salicylate, polyamines, and brassinosteroids, are used as anti-senescence compounds to slow down senescence, helping keep the fruit marketable for longer periods. This extended storage allows farmers to sell their produce at more opportune times, reducing waste and increasing profitability (Jarman et al. 2021). Salicylic acid (SA) is a naturally occurring plant hormone crucial for regulating plant development, growth, and responses to both biotic and abiotic stresses (Khademi et al. 2019). This phenolic hormone is involved in several plant functions, such as stomatal movement, seed germination, sex determination, photosynthesis, transpiration, and ion uptake and transport (Ali et al. 2020). Additionally, SA contributes to maintaining the taste, aroma, color, and firmness of fruits (Ramezani et al. 2018). Research has shown that SA is beneficial in preserving various fruits, including bananas, peaches, and strawberries (Srivastava and Dwivedi 2000; Babalar et al. 2007).

Methyl salicylate (MeSA), a benzoate ester derived from salicylic acid, has shown the potential to enhance fruit quality and extend the postharvest shelf life of various agricultural

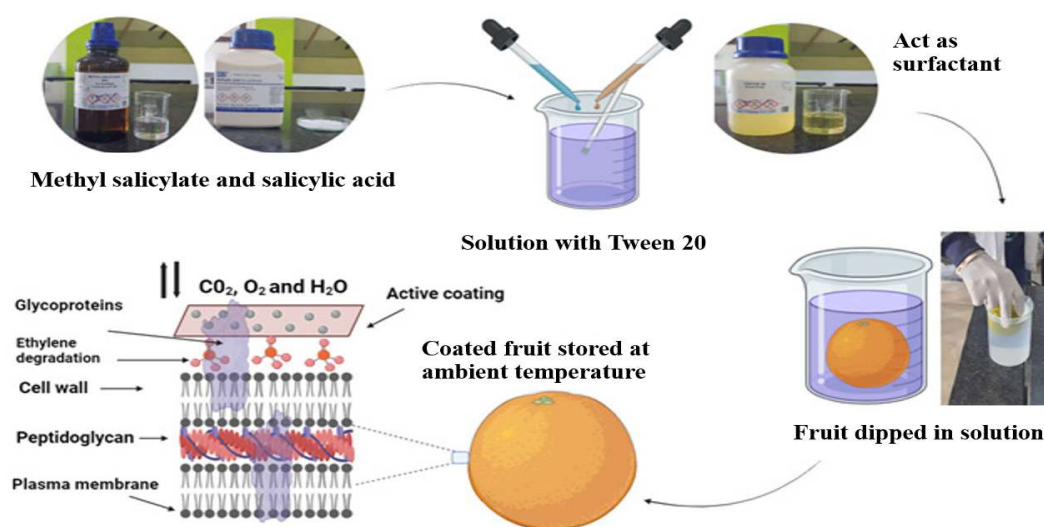
products (Chotikakham et al. 2020). This compound acts as a flavouring agent, metabolite, and insect attractant. MeSA is characterized by its sweet aroma, colorless appearance, molecular weight of 152.149 g/mol, and a boiling point of 223°C (Gondor et al. 2022). Research indicates that MeSA can delay changes in peel color and firmness while mitigating physiological disorders in kiwi (Li et al. 2017). Furthermore, MeSA treatment enhances enzyme activity, reduces oxidative damage, and slows ripening in pomegranates and sweet cherries (Sayyari et al. 2011). Studies have also explored optimizing crops for pest and disease biocontrol to improve overall plant health (Razo-Belman and Ozuna 2023).

Investigating salicylic acid (SA) and methyl salicylate (MeSA) as potential anti-senescence agents for postharvest use has introduced new opportunities in postharvest research. Salicylic acid functions as a signalling molecule in plant defence and stress responses, though its precise role in postharvest physiology remains unclear (Yang et al. 2023). Similarly, MeSA, known for its role in plant communication and defence against pests, requires further investigation to determine its exact impact on senescence processes in harvested fruits (Midzi et al. 2022). Although previous studies have shown that salicylic acid concentrations ranging from 0.1 to 2 mM can extend fruit shelf life (García-Pastor et al. 2020; Baswal et al. 2021), comparative evaluation of SA and MeSA-based edible coatings as active packaging under ambient storage conditions remains limited for Daisy mandarin. Furthermore, understanding the ecological and environmental implications of SA and MeSA applications in postharvest management is crucial for developing sustainable and environmentally friendly preservation methods (Correia et al. 2017). This study aimed to evaluate salicylic acid- and methyl salicylate-based edible coatings as active packaging to extend the shelf life and maintain the quality of Daisy mandarin during ambient storage. This research seeks to address gaps in current understanding of postharvest physiology and to offer practical solutions to minimize postharvest losses, enhance fruit quality, and improve the economic sustainability of citrus production.

2. Materials and methods

The study utilized Daisy mandarin fruits harvested at peak maturity in November. These fruits were obtained from healthy, well-maintained plants, following recommended cultivation practices, at the Punjab Agricultural University fruit orchard in Ludhiana (30.9041°N, 75.8066°E).

86 Uniform-sized fruits, free from disease and bruises, were collected using clippers while leaving a
 87 small stem attached. The harvested fruits were carefully packed in cushioned crates and
 88 transported to the postharvest laboratory of the Department of Horticulture (Fruit Science) at
 89 Lovely Professional University in Phagwara. Upon arrival, the fruits were sorted, graded, and
 90 cleaned with a chlorine solution (100 mg L^{-1}) to ensure proper hygiene. Following these steps, the
 91 fruits were then divided into appropriate groups for further processing. Selected fruits were dipped
 92 inside an emulsion including Tween 20 (0.05%) with three distinct levels (2 mM, 1.5 mM, and 1
 93 mM) of two anti-senescence packaging compounds (salicylic acid and methyl salicylate) for 5–6
 94 min at room temperature (Table 1), followed by the complete drying of the fruits (Fig. 1). Although
 95 applied by dipping, the formulations formed a thin edible coating layer on the fruit surface after
 96 drying and therefore functioned as coating-based packaging systems. After thorough drying, the
 97 fruits were placed on shelves according to the specific treatments and stored at $18 \pm 4^\circ\text{C}$ with 65–
 98 80% relative humidity for up to 40 days. Ripe fruits were evaluated on the initial day for baseline
 99 data. Fruit samples were removed from storage at 10, 20, 30, and 40 days and analyzed for various
 100 physicochemical properties. In the experimental design, the focus was solely on the coating
 101 materials and the duration of storage intervals.



102
 103 **Fig. 1.** Application of methyl salicylate and salicylic acid as a fruit coating of Daisy mandarin

104 **Table 1.** Salicylic acid and Methyl salicylate treatment details for fruit coating

Treatments	Compounds	Concentrations	Emulsifier
SA	Salicylic acid	1 mM	Tween 20 (0.05%)
	Salicylic acid	1.5 mM	Tween 20 (0.05%)
	Salicylic acid	2 mM	Tween 20 (0.05%)
MeSA	Methyl salicylate	1 mM	Tween 20 (0.05%)
	Methyl salicylate	1.5 mM	Tween 20 (0.05%)
	Methyl salicylate	2 mM	Tween 20 (0.05%)
Control	Water	100 %	None

2.1. Fruit weight (g) and Physiological loss in weight (%)

Fruit weight was recorded at each 10-day storage interval and expressed both in grams and as percentage physiological loss in weight (PLW). The physiological weight loss was computed by comparing the final and initial fruit weights using the formula below (Kader 2005).

$$PLW (\%) = \frac{\text{Initial fruit weight (g)} - \text{Final fruit weight (g)}}{\text{Initial fruit weight (g)}} \times 100$$

2.2. Fruit peel weight (g)

The fruit peel weights were recorded using a weighing balance (Wensar Precision Balance Model PGB 1000) after 10-day intervals up to 40 days. The mean values were calculated for five randomly selected fruits from three replications.

2.3. Total soluble solids (°B)

The degree of total soluble solids (TSS) in the fruits (°Brix) was determined using a Milwaukee MA871 Digital Refractometer. The obtained values were adjusted to a standard temperature of 20°C and reported as percentages (AOAC 2005).

2.4. Total sugar (%)

In a conical flask, combine 10 mL of juice with 100 mL of distilled water and 2 mL of 45% lead acetate, then allow the mixture to sit for 2 days. After this period, add 1.9 mL of 22%

potassium oxalate and 250 mL of distilled water to reach a total volume of 250 mL. The following day, introduce 5 mL of concentrated hydrochloric acid into 50 mL of this solution and let it sit for 24 hours. Afterward, neutralize the mixture with 40% NaOH until a pale pink color is achieved, then dilute to 100 mL. In a separate conical flask, mix 2.5 mL each of Fehling's solutions A and B with 50 mL of distilled water and heat the mixture on a hot plate at room temperature. Methylene blue indicator is introduced to the boiling Fehling's solution, and the juice sample is gradually titrated from a burette. The results were expressed as percentages (AOAC 2005).

2.5. Ascorbic acid (mg 100 g⁻¹)

The ascorbic acid level in the fruit was measured using the visual titration method with 2,6-dichlorophenolindophenol (DCPIP) dye (Ranganna 1994).

Dye factor standardization: Take 50 mg of ascorbic acid and dissolve it in a specific volume of either 3% metaphosphoric acid or 4% oxalic acid to achieve the desired concentration. Then, take 4 mL of the prepared solution and dilute to a final volume of 100 mL with either a 3% HPO₃ solution or a 4% oxalic acid solution. The dye factor can be calculated using the following formula (Razo-Belman and Ozuna 2023):

$$\text{Dye factor} = \frac{0.5}{\text{Titer value}}$$

Estimation: A sample weighing 10-20 mg was ground and then combined with either a 3% HPO₃ solution or a 4% oxalic acid solution to reach a final volume of 100 mL. This mixture was filtered through paper. From the prepared sample, 10 mL was taken and titrated against a 0.04% DCPIP dye solution until a persistent pink endpoint was achieved, lasting for at least 15 seconds. The outcomes are presented as mg 100 g⁻¹ of the sample (AOAC 2005).

$$\text{Ascorbic acid } \left(\frac{\text{mg}}{100\text{g}} \right) = \frac{\text{Titer} \times \text{Volume made} \times \text{Dye factor}}{\text{Weight of sample} \times \text{Aliquot made}} \times 100$$

2.6. Total antioxidant activity (%)

To determine the antioxidant capacity of fruit juice, its ability to scavenge DPPH radicals was evaluated using a method adapted from Brand-Williams et al. (1995). The DPPH solution was first

kept in the dark for two hours to stabilize its absorbance. Next, a reaction mixture containing 1 mL DPPH, 800 µL Tris-HCl, and 4.5 mL ethanol was assembled, and the absorbance was read at 517 nm. The control consisted of 1.2 mL ethanol and 800 µL Tris-HCl. For sample preparation, 10 grams of fruit were homogenized with 20 mL of 80% ethanol using a mortar and pestle. After homogenization, the mixture was centrifuged at 10,000 rpm for 20 minutes, and the resulting supernatant was reserved for analysis. For the assay, 200 µL of this extract was mixed with 4.5 mL ethanol, 800 µL Tris-HCl, and 1 mL DPPH in a test tube. The mixture was then incubated in the dark for 30 minutes, after which absorbance was measured at 517 nm. The control sample, containing 1.2 mL ethanol and 800 µL Tris-HCl, was also measured. Antioxidant activity was calculated as a percentage using the equation described by Valko et al. (2007).

$$\text{Inhibition ratio (\%)} = \frac{A_c - A_s}{A_c} \times 100$$

Where A_c - represents the absorbance (OD) of the control (DPPH solution without the sample), and A_s - represents the absorbance (OD) of the sample (DPPH solution with the sample).

2.7. Reducing sugar (%)

The determination of reducing sugars involved titrating a sample aliquot with 5 mL each of Fehling's solutions A and B, both preheated. Methylene blue served as the indicator throughout the process. The titration was stopped once a brick-red endpoint was observed, and the sugar content was calculated as a percentage, following AOAC (2005) guidelines.

2.8. Juice percentage (%)

Fruit juice was extracted using a screw-type extractor, strained through a mesh, and weighed. The juice percentage was calculated based on fresh weight. Mean values were derived from five randomly selected fruits across three replications.

2.9. Peel thickness (mm)

Peel thickness was measured in millimeters using a Mitutoyo 500-196-30 Advanced Onsite Sensor Absolute Scale Digital Caliper. The mean values were calculated for five randomly selected fruits of three replications.

2.10. Spoilage (%)

The percentage of fruit rot was determined by counting the number of spoiled fruits at each storage interval. The spoilage percentage was calculated using the formula provided by Gajanana et al. (2019):

$$\text{Spoilage (\%)} = \frac{\text{Number of spoiled fruits}}{\text{Total number of fruits}} \times 100$$

2.11. Organoleptic sensory attributes (Hedonic scale 1-9)

A semi-trained panel of ten judges evaluated the fruits for flavor, texture, appearance, and taste using a 9-point hedonic scale. Samples were coded and presented in random order under controlled laboratory conditions (Lim 2011). Ethical approval was not required for this study as the sensory evaluation involved voluntary participation of trained panelists and did not involve any clinical or invasive procedures. Informed consent was obtained from all participants prior to the evaluation. The panelists were familiarized with evaluation procedures prior to assessment. Samples were randomized and coded to avoid bias. Evaluations were conducted under controlled conditions (ambient temperature 22–25°C, neutral lighting), and water was provided to cleanse the palate between samples.

2.12. Statistical analysis

A completely randomized design (CRD) was implemented, consisting of three biological replicates per treatment and five fruits per replicate, resulting in 15 fruits per treatment. Statistical analyses were conducted using SPSS. Data were evaluated by one-way ANOVA, and results are presented as mean $\pm$ standard error (SE) based on the three biological replicates. Duncan's Multiple Range Test (DMRT) was applied to separate means at $p \leq 0.01$.

3. Results

3.1. Fruit weight and PLW

The treatments and storage duration significantly influenced ($p \leq 0.01$) the fruit weight and physiological weight loss of Daisy mandarin fruits (Figures 2 a & b). Fruit weight decreased progressively during storage in all treatments. The highest fruit weight at the end of storage (40

days) was observed in fruits treated with 2 mM salicylic acid (106.5 g), followed by 2 mM methyl salicylate (103.8 g), whereas the control fruits recorded the lowest fruit weight (82.4 g). Similarly, PLW increased with storage duration across all treatments. The lowest PLW at 40 days was recorded in fruits treated with 2 mM salicylic acid (22%), followed by 2 mM methyl salicylate (26.5%), while the highest PLW was recorded in control fruits (46%).

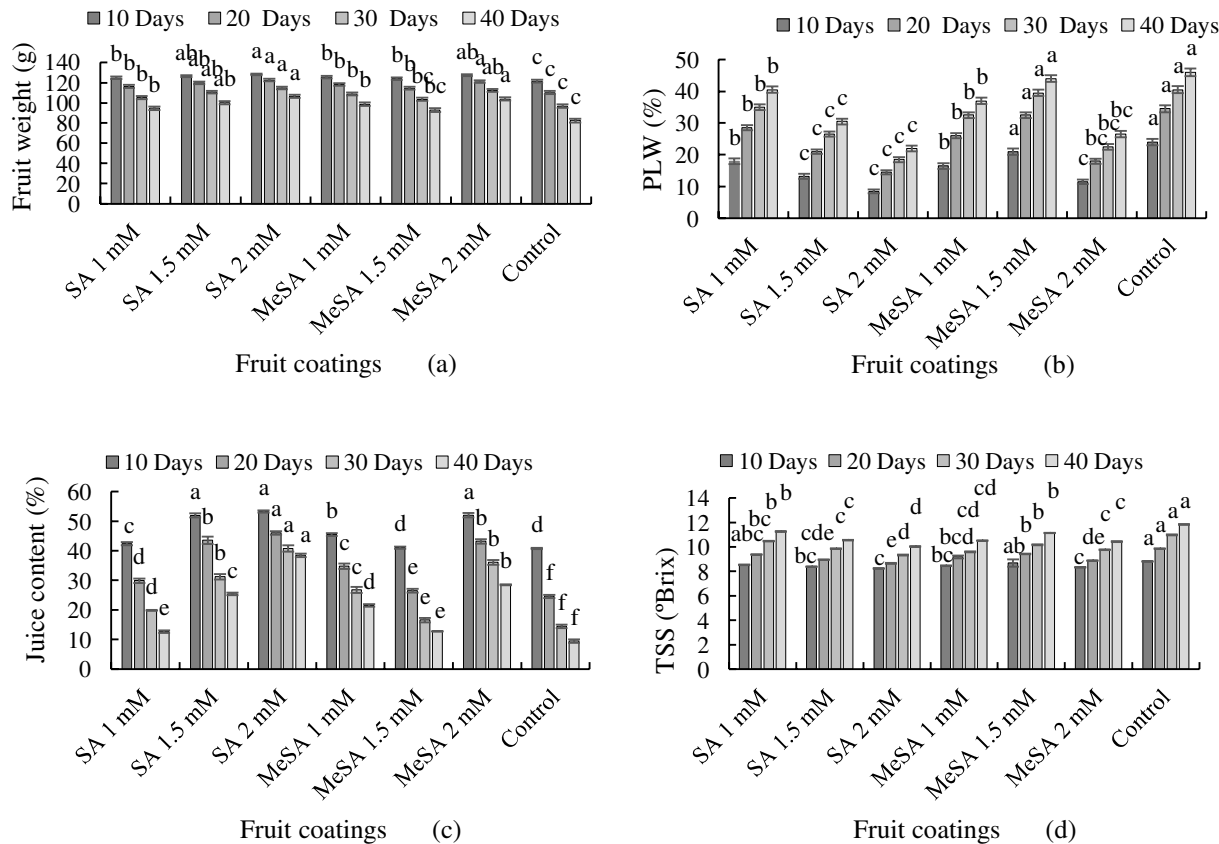


Fig. 2. Effect of salicylic acid (SA) and methyl salicylate (MeSA) based active packaging on Daisy mandarin fruits stored at ambient conditions up to 40 days: (a) fruit weight (g), (b) physiological loss in weight, (c) juice content (%), and (d) TSS (°Brix). The values are presented in mean ($n=3$) and standard error. The letters indicate a significant level at $p \leq 0.01$.

3.2. Juice percentage and TSS

Figure 2 (c) illustrates the impact of salicylic acid and methyl salicylate on juice content, showing a notable but gradual decrease in average cumulative juice content compared to the control. The data showed that juice content decreased during storage across all treatments;

however, fruits treated with 2 mM SA (38.40%) and 2 mM MeSA (28.50%) retained higher juice content at the end of storage (40 days), whereas control fruits recorded the lowest juice content (9.45%). Among the treatments, 2 mM salicylic acid was the most effective. Additionally, Figure 2(d) shows that TSS increased during storage in all treatments; however, control fruits showed a greater increase than treated fruits. After 40 days of storage at room temperature (18 ± 4 °C), control fruits recorded the highest TSS (11.83 °Brix), while fruits treated with 2 mM salicylic acid (10.03 °Brix) and 2 mM methyl salicylate (10.43 °Brix) showed lower values, indicating a slower rate of increase in TSS in treated fruits.

3.3. Peel weight and peel thickness

Throughout storage, treatments with salicylic acid and methyl salicylate reduced peel weight. The weight of the fruit peel is crucial for determining the fruit's overall quality and value. As depicted in Fig. 3 (a), the peel weight was highest at 6.36 g and 5.82 g for fruits treated with 2 mM salicylic acid and 2 mM methyl salicylate, respectively, after 40 days of storage at room temperature (18 ± 4 °C). Peel weight for fruits treated with SA 2 mM and MeSA 2 mM ranged from 12.13 to 6.36 g and 11.6 to 5.82 g, respectively, over the 10 to 40-day storage period. Similarly, Fig. 3 (b) shows a decrease in peel thickness during storage. The thickest peels (0.66 mm and 0.65 mm) were observed in fruits treated with 2 mM salicylic acid and 2 mM methyl salicylate after 40 days at room temperature. Among the treatments, 2 mM salicylic acid was notably superior, with a peel thickness of 0.66 mm after 40 days, while the control group had the thinnest peel thickness at 0.41 mm.

3.4. Total sugar and reducing sugar

Figure 3 (c) shows that total sugar levels in Daisy mandarin fruit increased gradually across all treatments compared with the control during storage at ambient conditions. The highest total sugar content was observed in the control group (9.44%) and in fruits treated with 1.5 mM methyl salicylate (9.12%). The lowest total sugar levels were found in fruits treated with 2 mM salicylic acid (7.00%) and 2 mM methyl salicylate (7.46%), both stored for 40 days at room temperature (18 ± 4 °C). The smallest increase in total sugar was noted in fruits treated with 2 mM salicylic acid. Figure 3(d) depicts a similar pattern for reducing sugars, which were significantly influenced by the treatments and storage time ($p \leq 0.01$). The highest reducing sugar content was recorded in

the control (7.68%) and in fruits treated with methyl salicylate at 1.5 mM (6.86%). The lowest reducing sugar levels were seen in fruits treated with 2 mM salicylic acid (5.53%) and 2 mM methyl salicylate (5.63%) after 40 days of storage at $18 \pm 4^\circ\text{C}$. Among the treatments, fruits treated with 2 mM salicylic acid had the lowest reducing sugar content after 40 days.

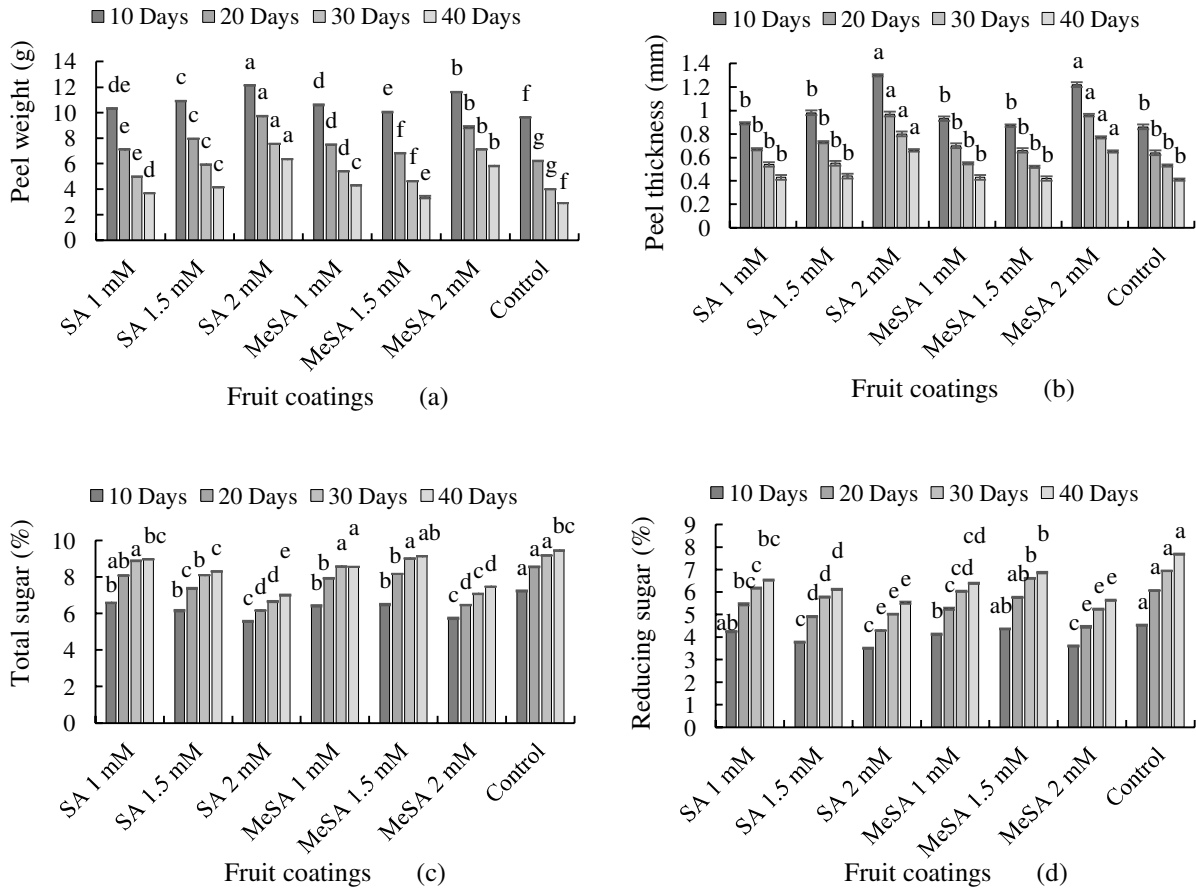


Fig. 3. Effect of salicylic acid (SA) and methyl salicylate (MeSA) based active packaging on Daisy mandarin fruits stored at ambient conditions: (a) peel weight (g), (b) peel thickness (mm), (c) total sugar (%), and (d) reducing sugar (%). The values are presented in mean ($n=3$) and standard error. The letters indicate a significant level at $p \leq 0.01$.

3.5. Ascorbic acid and total antioxidant activity

The influence of salicylic acid and methyl salicylate on ascorbic acid and total antioxidant activity in Daisy mandarin fruit was examined. As depicted in Fig. 4(a), ascorbic acid content decreased gradually during storage across all treatments; however, fruits treated with 2 mM

salicylic acid retained significantly higher levels than the control ($p \leq 0.01$). The highest concentrations of ascorbic acid were observed in fruits treated with 2 mM salicylic acid (24.74 mg 100 g⁻¹) and 2 mM methyl salicylate (21.82 mg 100 g⁻¹). In contrast, the lowest concentrations were found in the control (16.75 mg 100 g⁻¹) and fruits treated with 1 mM methyl salicylate (18.21 mg 100 g⁻¹) after 40 days at 18 ± 4°C. Ascorbic acid decreased during storage in all treatments; however, treated fruits retained higher levels than the control. Similarly, Fig. 4 (b) shows that total antioxidant activity (TAA) increased with treatment.

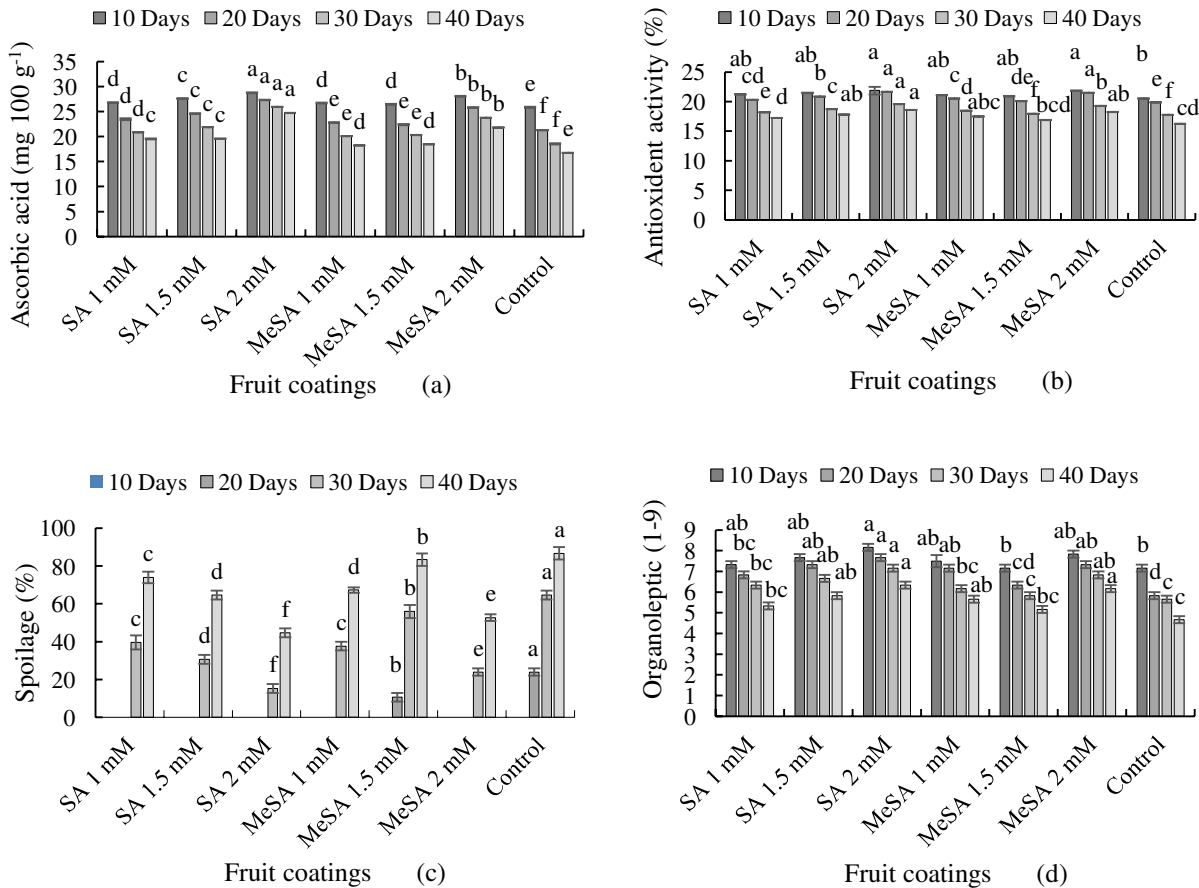


Fig. 4. Effect of salicylic acid (SA) and methyl salicylate (MeSA) based active packaging on Daisy mandarin fruits stored at ambient conditions: (a) ascorbic acid (%), (b) antioxidant activity (%), (c) spoilage (%), and (d) organoleptic sensory attributes (1-9). The values are presented in mean ($n=3$) and standard error. The letters indicate a significant level at $p \leq 0.01$.

The highest TAA values were recorded in fruits treated with 2 mM salicylic acid (18.58%) and 2 mM methyl salicylate (18.24%), while the lowest values were found in the control (16.25%)

and fruits treated with 1 mM methyl salicylate (16.87%) after 40 days of storage at room temperature ($18 \pm 4^{\circ}\text{C}$). Fruits coated with 2 mM salicylic acid exhibited the highest antioxidant activity during ambient storage.

3.6. Spoilage and sensory characteristics of fruits

Over the storage period, spoilage percentages were significantly lower ($p \leq 0.01$) across all treatments than in the control. As shown in Fig. 4 (c), fruits treated with 2 mM salicylic acid exhibited the lowest average spoilage rate of 44.66% after 40 days. In contrast, the control group experienced the highest spoilage at 86.66%, with fruits treated with 1.5 mM methyl salicylate following closely at 83.33%. Other spoilage percentages included 52.66% at 2 mM methyl salicylate, 64.66% at 1.5 mM salicylic acid, 67.33% at 1 mM methyl salicylate, 74% at 1 mM salicylic acid (Fig. 5). The control group had the highest spoilage rate at 86.66% after 40 days. Additionally, Fig. 4 (d) shows the sensory attributes of the fruits after 40 days of storage. Fruits coated with 2 mM salicylic acid received the highest average sensory rating of 6.33, followed by fruits coated with 2 mM methyl salicylate, which had a rating of 6.16. Uncoated fruits had the lowest average sensory score of 4.66. Coated fruits showed a slower decline in sensory attributes compared to those that were uncoated.

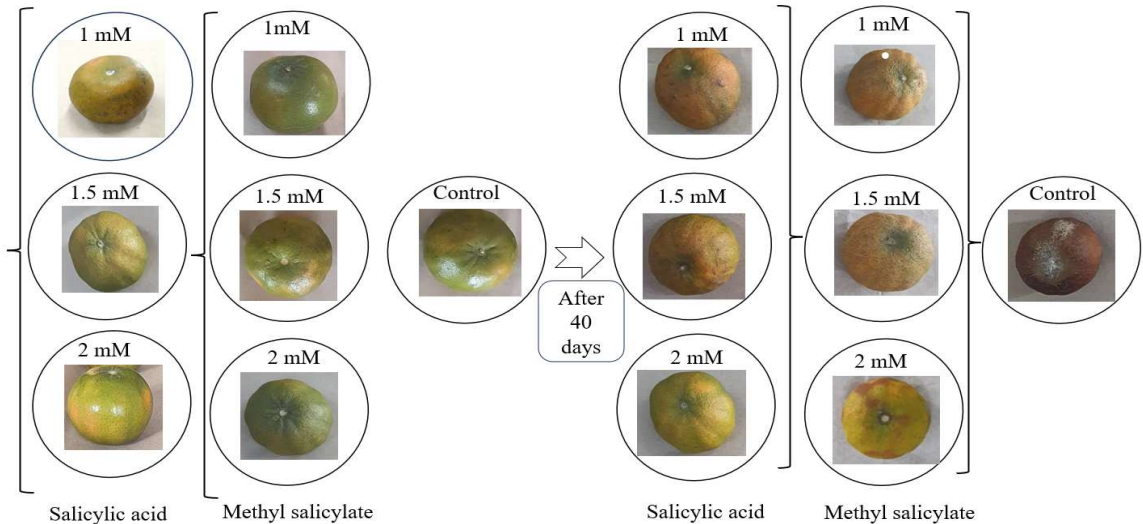


Fig. 5. Fruit physical changes after treatment with salicylic acid and methyl salicylate-based active packaging for a 40-day storage period.

4. Discussion

The present study shows that salicylic acid (SA) at 2 mM was most effective ($p \leq 0.01$) in maintaining higher fruit weight during storage at 18 ± 4 °C, followed by methyl salicylate (MeSA) at 2 mM, compared to the control. Fruits treated with SA (2 mM) recorded the highest fruit weight (106.5 g) and the lowest physiological loss in weight (22%) after 40 days of storage. The higher retention of fruit weight in treated fruits may be attributed to the ability of SA and MeSA to regulate respiration and transpiration, thereby reducing moisture loss and metabolic degradation. These treatments likely slow down the breakdown of stored carbohydrates and limit water loss, which are the primary contributors to postharvest weight reduction (Lufu et al. 2019; Ennab et al. 2020). In contrast, the lower fruit weight and higher PLW observed in control fruits may be due to increased transpiration and faster metabolic activity under ambient storage conditions. Similar results have been reported in mango (Reddy et al. 2016) and citrus fruits (Baswal et al. 2021), where salicylic acid treatments effectively reduced weight loss during storage. Comparable findings have also been reported in grapes (Hazarika and Marak 2022) and mandarins (Orabi and El-Motty 2018).

The present study indicates that 2 mM SA and 2 mM MeSA maintain better retention of juice content during storage. This may be associated with better maintenance of cellular integrity during storage. Microorganisms can feed on the sugars and other nutrients present in the fruit, leading to the breakdown of the cellular structure and a reduction in juice content (Cywińska-Antonik et al. 2023). Similar results have been observed in Mandarin when stored for 45 days at 7.2 °C (Orabi and El-motty, 2018). A similar trend was observed in grapes treated with 2 mM SA during ambient storage conditions (Hazarika and Marak 2022). Although TSS increased during storage, treated fruits showed a slower increase compared to the control, indicating delayed ripening. These treatments delay the ripening process, affecting the conversion of starches into sugars, leading to an increase in TSS (Dwivany et al. 2020). The rise in TSS may be attributed to the production of mono- and disaccharides through the hydrolysis of starch and pectin (Kaur and Dhillon 2015). Similar results were observed in phalsa, which retained lower TSS when treated with 2 mM SA (Vyas et al. 2016).

The weight of the fruit peel is a key factor in determining the fruit's overall quality and value. Peel weight decreased gradually during storage across all treatments, with better retention observed in SA and MeSA-treated fruits. Sabir and Sabir (2017) found a similar trend in grapes when treated with SA 2 mM at 1 °C, and relative humidity was 90% up to 60 days. A similar trend was observed in guava fruit, which retained its quality for up to 14 days at 5 °C (Midzi et al. 2022). Fruit peel thickness significantly influences fruit quality and shelf life (Gupta et al. 2020; Kumar et al. 2021). Treatments of 2 mM SA, followed by 2 mM MeSA, maintained the greatest thickness after 40 days at 18 ± 4 °C compared to the control. Microbial growth may also contribute to a decrease in fruit peel thickness. Bacteria and fungi may colonize the surface of the fruit and break down the cells in the peel. As cells break down, the peel becomes thinner and more susceptible to damage (Gupta et al. 2020). Similar observations have been made with peach fruits, where quality parameters were maintained, extending the shelf life by up to 10 days (Taher et al. 2022). Additionally, consistent results were observed in apricot fruits, which retained their quality during 21 days of cold storage (Ezzat et al. 2017).

The rise in total sugar content during storage plays an important role in determining fruit sweetness and flavor. In the present study, total sugar increased gradually across all treatments, with a slower rate of increase observed in fruits treated with SA (2 mM), followed by MeSA (2 mM), compared to the control. A similar trend was observed for reducing sugars, including glucose and fructose, which increased during storage but at a slower rate in treated fruits. This gradual increase in sugars may be attributed to the breakdown of complex carbohydrates into simpler sugars during ripening (Ghnimi et al. 2018; Lufu et al. 2019). Enzymatic hydrolysis of starch into soluble sugars is a key process contributing to this increase (Kebede and Admassu 2019). Similar findings have been reported in custard apple, where SA (2 mM) treatments influenced sugar accumulation during storage (Vyas et al. 2015), and in guava, where SA application improved shelf life and reduced decay (Madhav et al. 2016).

Ascorbic acid, a potent antioxidant, effectively donates electrons to neutralize free radicals (Gulcin 2020). SA 2 mM and MeSA 2 mM slowed the decline of ascorbic acid compared to the control. During storage, fruits are exposed to air and oxygen, leading to the oxidation and breakdown of ascorbic acid into inactive forms, a process accelerated by temperature and light (Varatharajan and Pushparani 2018). Fruits continue to respire post-harvest, consuming oxygen

and releasing carbon dioxide, which generates reactive oxygen species that degrade ascorbic acid (Alam et al. 2021). Comparable results were reported by Orabi and El-motty (2018) for 'Clementine' mandarins and by Shanbehpour et al. (2020) for Indian jujube. SA may reduce ethylene production and delay senescence, while MeSA acts as a signaling molecule enhancing stress tolerance (Zhang et al. 2020; Wang et al. 2022).

After 40 days of storage at 18 ± 4 °C, coating with SA 2 mM reduces fruit spoilage compared to the control and to MeSA 2 mM. Microorganisms such as bacteria, fungi (like *Penicillium digitatum*), and yeasts are significant contributors to fruit spoilage (Zhao et al. 2022). Rasouli et al. (2019) observed a similar trend of spoilage in SA 2 mM. This is consistent with a previous study on phalsa fruit, which showed that SA at 2 mM with sodium benzoate resulted in a lower spoilage percentage (Vyas et al. 2016). The same is true in the case of the sensory attributes of fruits. After 40 days of storage, fruits treated with 2 mM SA and 2 mM MeSA had the highest sensory ratings compared to the control group. The coated fruits showed a slower decline in sensory attributes than the uncoated fruits. Storage conditions can induce physicochemical changes in food products, resulting in sensory deterioration. Oxidation, moisture loss, enzymatic activity, and loss of volatile compounds are key factors that can alter the sensory attributes of stored food items (Barrett et al. 2010). The application of SA 2 mM has demonstrated the highest acceptability scores for pomegranate fruit stored at 5 ± 2 °C and 85-90% relative humidity for 90 days (Sayyari et al. 2011; Opara et al. 2015).

Edible coatings containing salicylic acid and methyl salicylate functioned as active packaging by forming a semipermeable barrier that regulated moisture loss, gas exchange, and oxidative reactions. In the present study, salicylic acid and methyl salicylate coatings effectively reduced physiological weight loss, delayed sugar accumulation, preserved antioxidant capacity, and minimized spoilage, demonstrating their role beyond chemical treatments. This highlights their relevance as sustainable alternatives to conventional packaging materials in citrus supply chains.

5. Conclusion

Salicylic acid and methyl salicylate-based edible coatings effectively extended the shelf life of Daisy mandarin while maintaining physicochemical and sensory quality. These compounds likely help in reducing enzymatic and metabolic degradation and microbial activity, mitigate pigment degradation, and regulate the synthesis of secondary metabolites. As a result, they maintain the firmness, color, texture, nutritional content, and flavor profiles of fruits, enhancing their visual appeal, textural integrity, taste, aroma, and overall sensory quality, thereby ensuring the shelf life of produce. The findings demonstrate that salicylic acid-based edible coatings, particularly at 2 mM, function effectively as active packaging by regulating physiological and biochemical deterioration in Daisy mandarin. These coatings offer a low-cost, eco-friendly packaging strategy for extending shelf life under ambient conditions and thereby demonstrating their potential application in citrus postharvest handling and sustainable food packaging systems

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Declarations

Human Ethics and Consent to Participate: This study involved sensory evaluation by a semi-trained panel. Ethical approval was not required as the study did not involve clinical or invasive procedures. Informed consent was obtained from all participants prior to evaluation.

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Data Availability: The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

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Consent to Publish: Not applicable

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Reference

AOAC (2005) Official methods of analysis, 18th edn. Association of Official Analytical Chemists, Washington, DC, p 1213.

Alam AU, Rath P, Beshai H, Sarabha GK, Jamal Deen M (2021) Fruit quality monitoring with smart packaging. *Sensors* 21:1–30. <https://doi.org/10.3390/s21041509>

Ali Q, Shahid S, Nazar N, Hussain AI, Ali S, Chatha SAS, Hussain SM (2020) Use of phytohormones in conferring tolerance to environmental stress. In: Hasanuzzaman M (ed) *Plant ecophysiology and adaptation under climate change: mechanisms and perspectives II*. Springer, Singapore, pp 245–355. https://doi.org/10.1007/978-981-15-2172-0_11

Babalar M, Asghari M, Talaei A, Khosroshahi A (2007) Effect of pre- and postharvest salicylic acid treatment on ethylene production, fungal decay and overall quality of ‘Selva’ strawberry fruit. *Food Chemistry* 105:449–453. <https://doi.org/10.1016/j.foodchem.2007.03.021>

Barrett DM, Beaulieu JC, Shewfelt R (2010) Color, flavor, texture, and nutritional quality of fresh-cut fruits and vegetables: desirable levels, instrumental and sensory measurement, and the effects of processing. *Critical Reviews in Food Science and Nutrition* 50:369–389. <https://doi.org/10.1080/10408391003626322>

Baswal AK, Dhaliwal HS, Singh Z, Mahajan BVC (2021) Postharvest application of methyl jasmonate, 1-methylcyclopropene and salicylic acid elevates health-promoting compounds in cold-stored ‘Kinnow’ mandarin (*Citrus nobilis* Lour × *C. deliciosa* Tenora). *International Journal of Fruit Science* 21:147–157. <https://doi.org/10.1080/15538362.2020.1860865>

Brand-Williams W, Cuvelier ME, Berset C (1995) Use of a free radical method to evaluate antioxidant activity. *LWT – Food Science and Technology* 28(1):25–30. [https://doi.org/10.1016/S0023-6438\(95\)80008-5](https://doi.org/10.1016/S0023-6438(95)80008-5)

431 Brar HS, Thakur A, Singh H, Kaur N (2020) Photosensitive coverings influence plant growth, root
 432 development, and buddability of citrus plants in protected nursery. *Acta Physiologiae*
 433 *Plantarum* 42:1–15. <https://doi.org/10.1007/s11738-019-2998-3>

434 Chahal T, Singh N (2017) Studies on fruit growth and development in Daisy tangerine. *Indian*
 435 *Journal of Horticulture* 74:27–32. <https://doi.org/10.5958/0974-0112.2017.00009.3>

436 Chotikakham S, Faiyue B, Uthaibutra J, Saengnil K (2020) Exogenous methyl salicylate alleviates
 437 senescent spotting by enhancing the activity of antioxidative ascorbate–glutathione cycle in
 438 harvested ‘Sucrier’ bananas. *Scientia Horticulturae* 267:109324.
 439 <https://doi.org/10.1016/j.scienta.2020.109324>

440 Correia S, Schouten R, Silva AP, Gonçalves B (2017) Factors affecting quality and health-
 441 promoting compounds during growth and postharvest life of sweet cherry (*Prunus avium*
 442 L.). *Frontiers in Plant Science* 8:2166. <https://doi.org/10.3389/fpls.2017.02166>

443 Cywińska-Antonik M, Chen Z, Groele B, Marszałek K (2023) Application of emerging techniques
 444 in reduction of the sugar content of fruit juice: current challenges and future perspectives.
 445 *Foods* 12:1181. <https://doi.org/10.3390/foods12061181>

446 Dhillon WS, Mahajan BVC, Chahal TS, Kumar M, Sidhu MK, Singh SP (2016) Effect of different
 447 packaging films on shelf-life and quality of Daisy mandarin under ambient conditions.
 448 *Indian Journal of Horticulture* 73:262–266. [https://doi.org/10.5958/0974-](https://doi.org/10.5958/0974-0112.2016.00058.X)
 449 [0112.2016.00058.X](https://doi.org/10.5958/0974-0112.2016.00058.X)

450 Dwivany FM, Aprilyandi AN, Suendo V (2020) Carrageenan edible coating application prolongs
 451 Cavendish banana shelf life. *International Journal of Food Science* 2020:1–11.
 452 <https://doi.org/10.1155/2020/8861610>

453 Ennab HA, El-Shemy MA, Alam-Eldein SM (2020) Salicylic acid and putrescine to reduce
 454 postharvest storage problems and maintain quality of Murcott mandarin fruit. *Agronomy*
 455 10:115. <https://doi.org/10.3390/agronomy10010115>

456 Ezzat A, Ammar A, Szabó Z, Nyéki J, Holb IJ (2017) Postharvest treatments with methyl
 457 jasmonate and salicylic acid for maintaining physicochemical characteristics and sensory

458 quality properties of apricot fruit during cold storage and shelf life. Polish Journal of Food
459 and Nutrition Sciences 67:159–166. <https://doi.org/10.1515/pjfn-2016-0013>

460 Fekry WM, Rashad YM, Alaraidh IA, Mehany T (2021) Exogenous application of melatonin and
461 methyl jasmonate as a preharvest treatment enhances growth of Barhi date palm trees,
462 prolongs storability, and maintains quality of their fruits under storage conditions. Plants
463 11:96. <https://doi.org/10.3390/plants11010096>

464 Gajanana TM, Murthy DS, Sudha M, Saxena AK, Rao DS, Dakshinamoorthy V (2019) Postharvest
465 loss and marketing of fruits: economic analysis of pink flesh guava in local and distant
466 markets in India. Journal of Horticultural Sciences 14:1–6.
467 <https://doi.org/10.24154/jhs.v14i1.714>

468 García-Pastor M, Zapata P, Castillo S, Martínez-Romero D, Valero D, Serrano M, Guillén F (2020)
469 Preharvest salicylate treatments enhance antioxidant compounds, color and crop yield in
470 low-pigmented table grape cultivars and preserve quality traits during storage. Antioxidants
471 9:832. <https://doi.org/10.3390/antiox9090832>

472 Ghnimi S, Al-Shibli M, Al-Yammahi H, Al-Dhaheri R, Al-Jaberi A, Jobe F, Kamal-Eldin A (2018)
473 Reducing sugars, organic acids, size, color, and texture of 21 Emirati date fruit varieties
474 (Phoenix dactylifera L.). Journal of Food and Nutrition Research 6:525–532.
475 <https://doi.org/10.1016/j.nfs.2018.04.002>

476 Gondor OK, Pál M, Janda T, Szalai G (2022) The role of methyl salicylate in plant growth under
477 stress conditions. Journal of Plant Physiology 277:153809.
478 <https://doi.org/10.1016/j.jplph.2022.153809>

479 Gulcin İ (2020) Antioxidants and antioxidant methods: an updated overview. Archives of
480 Toxicology 94:651–715. <https://doi.org/10.1007/s00204-020-02689-3>

481 Gupta A, Sahni P, Sharma S, Singh B (2020) New insight in active packaging of fruits. In:
482 Emerging technologies for shelf-life enhancement of fruits. Apple Academic Press, pp 129–
483 160. <https://doi.org/10.1201/9780429264481-6>

484 Hazarika TK, Marak T (2022) Salicylic acid and oxalic acid in enhancing the quality and extending
 485 the shelf life of grape cv. Thompson Seedless. *Food Science and Technology International*
 486 28:463–475. <https://doi.org/10.1177/10820132211020612>

487 Jarman A, Thompson J, McGuire E, Reid M, Rubsam S, Becker K, Mitcham E (2023) Postharvest
 488 technologies for small-scale farmers in low- and middle-income countries: a call to action.
 489 *Postharvest Biology and Technology* 206:112491.
 490 <https://doi.org/10.1016/j.postharvbio.2023.112491>

491 Kader AA (2005) Increasing food availability by reducing post-harvest losses of fresh produce.
 492 *Acta Horticulturae* 682:2169–2176. <https://doi.org/10.17660/ActaHortic.2005.682.263>

493 Kaur K, Dhillon WS (2015) Influence of maturity and storage period on physical and biochemical
 494 characteristics of pear during post-cold storage at ambient conditions. *Journal of Food*
 495 *Science and Technology* 52:5352–5356. <https://doi.org/10.1007/s13197-014-1620-3>

496 Kebede M, Admassu S (2019) Application of antioxidants in food processing industry: options to
 497 improve the extraction yields and market value of natural products. *Advances in Food*
 498 *Technology and Nutritional Sciences* 5:38–49. <https://doi.org/10.17140/aftnsoj-5-155>

499 Khademi O, Ashtari M, Razavi F (2019) Effects of salicylic acid and ultrasound treatments on
 500 chilling injury control and quality preservation in banana fruit during cold storage. *Scientia*
 501 *Horticulturae* 249:334–343. <https://doi.org/10.1016/j.scienta.2019.02.018>

502 Kumar N, Pratibha, Petkoska AT, Khojah E, Sami R, Al-Mushhin AAM (2021) Chitosan edible
 503 films enhanced with pomegranate peel extract: study on physical, biological, thermal, and
 504 barrier properties. *Materials* 14:3305. <https://doi.org/10.3390/ma14123305>

505 Li P, Yu X, Xu B (2017) Effects of UV-C light exposure and refrigeration on phenolic and
 506 antioxidant profiles of subtropical fruits (litchi, longan, and rambutan) in different fruit
 507 forms. *Journal of Food Quality* 2017:785121. <https://doi.org/10.1155/2017/8785121>

508 Lim J (2011) Hedonic scaling: a review of methods and theory. *Food Quality and Preference*
 509 22:733–747. <https://doi.org/10.1016/j.foodqual.2011.05.008>

510 Lufu R, Ambaw A, Opara UL (2019) The contribution of transpiration and respiration processes
 511 in the mass loss of pomegranate fruit (cv. Wonderful). *Postharvest Biology and Technology*
 512 157:110982. <https://doi.org/10.1016/j.postharvbio.2019.110982>

513 Madhav JV, Sethi S, Sharma RR, Rudra SG (2016) Impact of salicylic acid on the physiological
 514 and quality attributes of guava (*Psidium guajava*) fruits during storage at low temperature.
 515 *Indian Journal of Agricultural Sciences* 86:1172–1174.
 516 <https://doi.org/10.56093/ijas.v86i9.61512>

517 Midzi J, Jeffery DW, Baumann U, Rogiers S, Tyerman SD, Pagay V (2022) Stress-induced volatile
 518 emissions and signalling in inter-plant communication. *Plants* 11:2566.
 519 <https://doi.org/10.3390/plants11192566>

520 Opara UL, Atukuri J, Fawole OA (2015) Application of physical and chemical postharvest
 521 treatments to enhance storage and shelf life of pomegranate fruit: a review. *Scientia*
 522 *Horticulturae* 197:41–49. <https://doi.org/10.1016/j.scienta.2015.10.046>

523 Orabi SA, El-Motty EZA (2018) The effect of salicylic acid and aspirin treatments on enzyme
 524 activity and fruit quality of Clementine mandarin fruits during different cold storage periods.
 525 *Middle East Journal of Agriculture Research* 7:583–593.
 526 <https://www.curreweb.com/mejar/mejar/2018/583-593.pdf>

527 Ramezani A, Dadgar R, Habibi F (2018) Postharvest attributes of ‘Washington Navel’ orange as
 528 affected by preharvest foliar application of calcium chloride, potassium chloride, and
 529 salicylic acid. *International Journal of Fruit Science* 18:68–84.
 530 <https://doi.org/10.1080/15538362.2017.1377669>

531 Ranganna S (1994) *Handbook of analysis and quality control for fruit and vegetable products*, 2nd
 532 edn. Tata McGraw-Hill Publishing Company Ltd., New Delhi, India, p 1112.

533 Rasouli M, Koushesh Saba M, Ramezani A (2019) Inhibitory effect of salicylic acid and aloe
 534 vera gel edible coating on microbial load and chilling injury of orange fruit. *Scientia*
 535 *Horticulturae* 247:27–34. <https://doi.org/10.1016/j.scienta.2018.12.004>

536 Razo-Belman R, Ozuna C (2023) Volatile organic compounds: a review of their current
 537 applications as pest biocontrol and disease management. *Horticulturae* 9:441.
 538 <https://doi.org/10.3390/horticulturae9040441>

539 Reddy VR, Sharma RR, Srivastav M, Kaur C (2016) Effect of pre-harvest application of salicylic
 540 acid on postharvest behaviour of ‘Amrapali’ mango fruits during storage. *Indian Journal of*
 541 *Horticulture* 73:405–409. <https://doi.org/10.5958/0974-0112.2016.00086.4>

542 Sabir FK, Sabir A (2017) Postharvest quality maintenance of table grapes cv. ‘Alphonse Lavallée’
 543 by exogenous applications of salicylic acid, oxalic acid and MAP. *Erwerbs-Obstbau* 59:211–
 544 219. <https://doi.org/10.1007/s10341-016-0314-6>

545 Sayyari M, Babalar M, Kalantari S, Martínez-Romero D, Guillén F, Serrano M, Valero D (2011)
 546 Vapour treatments with methyl salicylate or methyl jasmonate alleviated chilling injury and
 547 enhanced antioxidant potential during postharvest storage of pomegranates. *Food Chemistry*
 548 124:964–970. <https://doi.org/10.1016/j.foodchem.2010.07.036>

549 Shanbehpour F, Rastegar S, Ghasemi M (2020) Effect of preharvest application of calcium
 550 chloride, putrescine, and salicylic acid on antioxidant system and biochemical changes of
 551 two Indian jujube genotypes. *Journal of Food Biochemistry* 44:e13474.
 552 <https://doi.org/10.1111/jfbc.13474>

553 Srivastava MK, Dwivedi UN (2000) Delayed ripening of banana fruit by salicylic acid. *Plant*
 554 *Science* 158:87–96. [https://doi.org/10.1016/S0168-9452\(00\)00304-6](https://doi.org/10.1016/S0168-9452(00)00304-6)

555 Taher MA, Lo’ay AA, Gouda M, Limam SA, Abdelkader MFM, Osman SO, Fikry M, Ali EF,
 556 Mohamed SY, Khalil HA, El-Ansary DO, El-Gioushy SF, Ghazzawy HS, Ibrahim AM,
 557 Maklad MF, Abdein MA, Hikal DM (2022) Impacts of gum arabic and polyvinylpyrrolidone
 558 (PVP) with salicylic acid on peach fruit (*Prunus persica*) shelf life. *Molecules* 27:2595.
 559 <https://doi.org/10.3390/molecules27082595>

560 Valko M, Leibfritz D, Moncol J, Cronin MT, Mazur M, Telser J (2007) Free radicals and
 561 antioxidants in normal physiological functions and human disease. *International Journal of*
 562 *Biochemistry and Cell Biology* 39:44–84. <https://doi.org/10.1016/j.biocel.2006.07.001>

- Varatharajan K, Pushparani DS (2018) Screening of antioxidant additives for biodiesel fuels. Renewable and Sustainable Energy Reviews 82:2017–2028. <https://doi.org/10.1016/j.rser.2017.07.020>
- Vyas PB, Rao Tadapaneni VR, Thakkar VR (2016) Chemical elicitors improve the shelf life of phalsa (*Grewia asiatica* L.) by inducing antioxidants and controlling microbes. Fruits 71:307–317. <https://doi.org/10.1051/fruits/2016018>
- Vyas PB, Rao TR, Thakkar VR (2015) Combined effects of chemical and physical elicitors on postharvest quality of custard apple (*Annona squamosa* L., cv. Balanagar). Scientia Horticulturae 187:50–57. <https://doi.org/10.1016/j.scienta.2015.02.040>
- Wang J, Liu X, Zhang H, Allan AC, Wang W, Yin X (2022) Transcriptional and post-transcriptional regulation of ethylene biosynthesis by exogenous acetylsalicylic acid in kiwifruit. Horticulture Research 9:uhac116. <https://doi.org/10.1093/hr/uhac116>
- Yang H, Fang R, Luo L, Yang W, Huang Q, Yang C, Wang J (2023) Uncovering the mechanisms of salicylic acid-mediated abiotic stress tolerance in horticultural crops. Frontiers in Plant Science 14:1226041. <https://doi.org/10.3389/fpls.2023.1226041>
- Zhang H, Zhao L, Fan C, Wang P, Cui M, Liu L, Yang H, Wang J (2020) Impact of methyl salicylate on storage quality, ethylene action, and protein profiling of ‘Zaosu’ pear (*Pyrus bretschneideri*). Scientia Horticulturae 264:109196. <https://doi.org/10.1016/j.scienta.2020.109196>
- Zhao P, Ndayambaje JP, Liu X, Xia X (2022) Microbial spoilage of fruits: a review on causes and prevention methods. Food Reviews International 38:225–246. <https://doi.org/10.1080/87559129.2020.1858859>