Research Article

Received: 20 June 2026
Accepted: 30 October 2026
Published: 04 November 2026

The Impact of Methyl Jasmonate, Chitosan, and Storage Period on the Storability of Local Orange Fruits (*Citrus sinensis* L. Osbeck)

Nahla Mohammed Rasheed Hasan
Department of Horticulture, College of Agriculture Engineering Sciences, Duhok University, Duhok, Kurdistan Region Iraq; nahla.hasan@uod.ac

Sarfaraz Fatah Ali Al-Bamarny
Department of Horticulture, College of Agriculture Engineering Sciences, Duhok University, Duhok, Kurdistan Region Iraq

Cite this article:

N. M. R. Hasan and S. F. A. Al-Bamarny (2026). The Impact of Methyl Jasmonate, Chitosan, and Storage Period on the Storability of Local Orange Fruits (*Citrus sinensis* L. Osbeck). Revista Cultura Científica, (24), pp. 2340–2356.
https://doi.org/10.70517/revcc2624189

2026 © The Author(s). Published by Revista Cultura Científica. This article is published as open access under the Creative Commons Attribution 4.0 International (CC BY 4.0) license (http://creativecommons.org/licenses/by/4.0/).

Abstract

This study was carried out on fruit of local Diyala orange (*Citrus sinensis* L. Osbeck). The fruit were obtained from a private orchard in Buhriz village, Diyala governorate, Iraq, to study the impact of (control, 0.5, 1, and 1.5 mM) methyl jasmonate dipped for 3 min and chitosan (control, 1, 2, and 4% w/v) for 5 min on the fruit quality of orange in terms of (fruit weight loss (%), Total soluble solids (%), titratable acidity (%), ascorbic acid content, Total phenol content, chilling injury (%), decay (%), and catalase enzyme) during 30, 60, and 120 days storage at 5±1°C with 85-90% RH. Results showed that all treatments of (Methyl jasmonate and chitosan) significantly decreased the fruit weight loss (%). Furthermore, fruit treated with (1, and 1.5 mM) methyl jasmonate significantly reduced chilling injury (%), and decay (%), respectively, compared with the control. The titratable acidity (%), ascorbic acid content, total phenols, and enzyme catalase significantly increased in fruit treated with 0.5 mM methyl jasmonate compared to other treatments. On the other hand, the untreated fruits caused a significant increase in total soluble solids of both methyl jasmonate and chitosan compared with all other treatments. Dipping fruit in 2% chitosan effectively reduced chilling injury and decay compared with the control. There was a significant increase in ascorbic acid and total phenols when fruit were treated with (2, and 4%) chitosan, respectively. Consequently, all chitosan concentrations were superior to the untreated fruit in catalase activity. Prolonging the storage period from 30 to 60 and 120 days markedly increased the fruit weight loss (%), total soluble solids (%), chilling injury (%), and decay (%), while the titratable acidity (%), ascorbic acid content, and total phenol content substantially decreased. The interaction among both dipped treatments and storage period had a significantly positive influence on the quality parameters of orange fruit.

Key words: Methyl jasmonate, chitosan, post-harvest, orange fruits and storage periods

1. INTRODUCTION

Orange (*Citrus sinensis* L. Osbeck) belongs to the genus Citrus in the family Rutaceae and grows as an evergreen fruit tree. Orange trees are long-lived perennial crops, and their fruit represents one of the most important, highly valued, and commercially profitable horticultural products worldwide. Their economic importance is demonstrated by their extensive geographical distribution and large-scale commercial production [1, 2].

Citrus fruits are predominantly cultivated in tropical and subtropical areas of the world. The effective cultivation of citrus in diverse climatic conditions is due to its adaptation to a wide range of environmental settings [3]. The production of orange fruit in Iraq is about 508 metric tons, according to data gathered by [4]. According to the Food and Agriculture Organization [5] the yield of oranges is 1253.8 kg/ha.

Citrus fruits are non-climacteric, so they are only harvested when they are at their best edible ripening stage; they must also meet the expectations of today's consumers, who want fruit that has good appearance, flavor, taste, and nutritional properties, as well as fruit that is safe, traceable, and grown in an environmentally friendly way [6, 7]. Also, fruits contain a significant concentration of nutritive, non-nutritive, and bioactive substances, including phenolics, flavonoids, phytochemicals, and anthocyanins, with nutritive components such as essential oils, sugars, carotenoids, vitamin C, and minerals. They possess a unique flavor and taste, exceptional therapeutic properties, and healthcare functions [1].

Fresh fruit quality is influenced by how it is handled, transported, and stored after harvest. Storage is considered a critical operation; inadequate storage leads to losses in both quantity and quality of fruits. Therefore, to maintain the high quality of the harvested fruits, it is important to store them correctly [8].

Appropriate post-harvest technologies are necessary to mitigate the adverse impact of biotic and abiotic stresses to preserve the nutritional value and storage longevity of the product. The use of synthetic chemicals in the postharvest management of horticultural crops has raised concerns about food safety and environmental effects, encouraging investigation of alternative preservation treatments and defense elicitors [9]. There has been increasing interest in preservation approaches that include coatings based on chitosan, beeswax, and carboxymethyl cellulose [10]; hot-water treatments [11]; modified-atmosphere packaging using cling films and shrink wrapping; and essential oils [12]. Methyl jasmonate and 1-methylcyclopropene have also attracted attention as postharvest treatments intended to maintain fruit quality and extend storage life [13]. The safety and regulatory status of each treatment must be evaluated for its particular formulation, concentration, and intended application. These environmentally oriented techniques are currently regarded as a novel alternative to chemical methods [9].

Methyl jasmonate (MJ) is synthesized from jasmonic acid through the catalysis of S-adenosyl-L-methionine by jasmonic acid carboxyl methyltransferase. Methyl jasmonate is a compound utilized in plant defense mechanisms and several developmental processes, including seed germination, root development, blooming, fruit ripening, and senescence. Plants synthesise methyl jasmonate and jasmonic acid in response to various biotic and abiotic stressors and wounds [14]. Methyl jasmonate is a signaling molecule that regulates numerous developmental processes and defense mechanisms in response to biotic and abiotic stressors. Furthermore, it enhances resistance to both disease and chilling injury during postharvest storage [15, 16]. Post-harvest methyl jasmonate can maintain and even improve the nutritional and therapeutic quality of fruits [17]. Khajehyar et al. [18] reported that a postharvest treatment of methyl jasmonate (0.3, and 0.4 mM), distilled water as a control, on the orange cv. 'Valencia' during cold storage at 2 °C for 1.5 months. Reduce of fruit weight loss, chilling injury, decay, and physiological decay as compared with the control fruits reported. Habibi *et al*., [19] investigated the blood orange cv. 'Moro' treated with methyl jasmonate at (50 and 100 μmol^{-1}), alongside untreated control fruit, stored for 150 days at 3 °C, and 90% RH. The results showed that MeJA at 50 μmol^{-1} significantly decreased the weight loss (%), TSS (%), and TSS/TA ratio, while TA (%), VC content, total phenol content, and enzyme catalase significantly increased compared to untreated fruits. Vithana *et al*., [20] reported the post-harvest treatments of methyl jasmonate at (0, 0.5, 1, and 1.5 Mm), on 'Tarocco lippolito' in blood orange, and stored for 45 days at 6 ± 1 °C with 85± 5% RH. The results indicated that methyl jasmonate at (0.5mM) significantly increased the total phenols, and vitamin C at (1.5 mM) compared to other treatments. A previous study [21] examined a postharvest treatment of methyl jasmonate (Distilled water,10 and 20 μM) on sweet lime fruit, and stored at 9°C with 85±5%RH for 120 days. The treatments were observed to reduce weight loss in all treatments during the storage period compared to the control, while titratable acidity, vitamin C, phenolic content, and antioxidant activity significantly increased at 10μM methyl jasmonate compared with the control.

Chitosan (CHI) is a cationic polysaccharide of high molecular weight that is derived from the deacetylation of chitin, which is extracted from crustacean and insect exoskeletons and fungal cell walls. It has numerous applications in agriculture and horticulture due to its remarkable capacity to form an antimicrobial and antifungal film that is biocompatible, biodegradable, and non-toxic to humans. This coating possesses antibacterial characteristics [22, 23]. Chitosan coating is thought to be the best edible and safe preservation coating for different kinds of fruits. It has functional benefits, including slowing down respiration, increasing the storage duration, keeping the firmness of the fruits, and reducing microbial pathogens [24]. Rappussi *et al*., [25] found that chitosan can be used as a coating of orange 'Pêra Rio' fruits. The

treatments included control, chitosan 2% (v/v), fungicides imazalil (100 Ml a.i./100 L), thiabendazole (480 g a.i./100 L), and chitosan combined with both fungicides. After that fruits were stored for 7 days at 25°C with 80% RH. The TSS and TSS/Acid ratio decreased, while the titratable acidity, and vitamin C increased compared with the control fruits. It was reported [26] that Chitosan coatings for citrus are distinguished by their capacity to minimize weight loss and sustaining fruit quality by preserving total soluble solids, titratable acidity, and vitamin C during storage. Baswal et al. [27] reported the impact of coating treatments such as chitosan (0.5, 1.0, and 1.5 g L^{-1}), with uncoated fruit serving as the control, on 'Kinnow' mandarin fruits, and stored for 75 days at 5–7 °C with 90–95% RH. Among the coating treatments evaluated, carboxymethylcellulose at 2.0 g L^{-1} was identified as the most effective treatment for retaining total phenols and sugars during cold storage relative to the uncoated control fruit. Al Zahrani *et al*., [28] evaluated nano-chitosan and nano-chitosan combined with wax on mandarin fruits "Murcott" at (50 and 100 mg L^{-1}) and 100 mg L^{-1}, respectively, alongside uncoated control fruit, then stored for 4 months at 5°C and 90-95%RH. The authors found that the 100 mg.l^{-1} of nano chitosan reduced fruit weight loss, kept vitamin C, and preserved superior levels of total acidity and TSS, the total antioxidant and enzyme compared to untreated fruit.

This experiment was conducted to determine how methyl jasmonate and an edible chitosan coating influence the storage characteristics of local Diyala orange fruit. These treatments were investigated as potential alternatives within postharvest preservation practices, with the specific objectives of prolonging fruit storability, maintaining measured quality characteristics, and controlling or reducing physiological injury during cold storage under the experimental conditions described below.

2. MATERIALS AND METHODS

Fully mature, medium-sized fruit with a yellow or orange color from local Diyala orange (*Citrus sinensis* L. Osbeck), were harvested manually from 10-year-old trees at a private orchard in Buhriz village, Diyala governorate, Iraq, during the early morning of 14 December 2024. Harvested fruits were directly transported to the Central Laboratory of the College of Agricultural Engineering Sciences, University of Duhok. To study the impact of three factors (methyl jasmonate, chitosan and storage period) on the quality and storability of local Diyala orange fruit, healthy fruit of similar size and appearance were selected and randomly divided into two groups. Orange fruit in the first group were dipped for 3 minutes in {Distilled water (control), 0.5, 1, and 1.5 mM} methyl jasmonate. The second group of fruit were dipped in {Distilled water (control), 1, 2, and 4% w/v}chitosan solution for 3 minutes. After dipping, fruits were spread on a cloth to air-dry, after which the fruit were packed in perforated white plastic bags, which were tied securely (each bag represents an experimental unit). Subsequently, all fruits were stored in cold storage at 5±1°C and 85-90% RH for 120 days. After each period of storage (30, 60, and 120) days, the fruits were taken out for analysis. The experiment was laid out as a factorial experiment in a completely randomized design (CRD), including three factors: methyl jasmonate, chitosan, and storage period (4*4*3) with 3 replicates. Data were tabulated and statistically analyzed utilizing the SAS program [29]. The differences among various treatment averages were tested using the Duncan multiple-range test at the 0.05 level [30]. The parameters measured during the experiment are described in detail below:

Fruit weight loss (%): The starting weights of the fresh fruits were measured before storage, and the weights of the same fruits were recorded after each storage period [18].

Total soluble solids (TSS): The total soluble solids were measured using a hand refractometer ([31]).

Titratable acidity (TA%) and Ascorbic acid content (mg. 100 ml^{-1} juice fruit), were determined as recommended in [32]. The (TA%) was determined based on citric acid by titrating clear juice with (0.1N NaOH) utilizing phenolphthalein as indicator. Ascorbic acid content was measured using the titration method with 2,6-Dichlorophenol indophenol.

Total phenol content: Phenol was extracted from juice using an ethanolic hydrochloric acid solution (85% ethanol, 15% 1N HCl). The mixture was refrigerated at 4°C for 24 hours, then centrifuged at 3000 rpm for 15 minutes.

Phenol content was measured with a UV-1700 spectrophotometer at 280 nm, presented as mg of total phenol per 100g of fresh juice [33].

Fruit disorder (%): Any signs of deterioration (decay) and visual disorder (chilling injury) on the fruits were recorded. The percentage of decayed fruits was determined based on the total number of fruits [34].

Enzyme catalase ($mmol.min^{-1}.mg^{-1}$):

A 2 ml aliquot of plant extract was incubated with a reaction mixture containing 65 mM hydrogen peroxide and 60 mM sodium-potassium phosphate buffer at pH 7.4 for 4 minutes at 25 °C. The concentration of the yellow complex of molybdate and hydrogen peroxide was measured at 405 nm after the enzymatic process was terminated by 1 ml of 32.4 mM ammonium molybdate [35].

3. RESULTS AND DISCUSSION

3.1. FRUIT WEIGHT LOSS (%)

As indicated by the results presented in Table 1, all concentrations (0.5,1,1.5 mM MeJA and 1, 2, 4% CHI) lowered the fruit weight loss (%) significantly in comparison with untreated fruits of the MeJA and CHI which recorded the maximum fruit weight loss. This result can be attributed to fruit transpiration, which involves water diffusion through the peel surface and is a critical element influencing the water loss of fruit during cold storage. Moreover, weight loss is caused by metabolic processes, including respiration and cellular degradation resulting from chilling injury damage at low temperature [36]. MeJA treatment may modify physiological processes associated with water loss during storage. Nevertheless, a mechanism involving stomatal closure and free-radical production cannot be established from the measurements reported here and requires direct experimental evidence before it can be asserted as an explanation [19]. It has been reported that the capacity of chitosan to create a semipermeable barrier against oxygen, carbon dioxide, and moisture might be the reason for the significant reduction in weight loss observed whenever it is used as an edible coating during storage. As a result, coated fruits may therefore lose less water and exhibit less dehydration and shrinkage [37, 38]. The highest fruit weight loss, observed at the end of the storage period, may have been caused by a faster metabolism and ripening, which accelerated the breakdown of cell walls, and increased membrane permeability, which exposed the cell wall for easy evaporation [39]. The results of the present study are in agreement with those found by [19, 40] on blood orange fruits cv. ʿMoroʾ and on lime fruits respectively. On the other hand, the triple interaction treatments showed that the lowest fruit weight loss (%) was noticed when the fruit was dipped in 0.5 mM MeJA+ 0% CHI + 30 days storage compared with the highest fruit weight loss (%) found from the untreated fruits during 120 days.

Table 1. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit weight loss (%) of local orange stored at* $5 \pm 1\,^{\circ}C$

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	1.601 mn	5.096 fg	10.552 a	5.750 a	3.838 a
	1	0.918 no	2.491 j-l	8.270 bc	3.893 b	
	2	0.985 no	2.418 kl	4.734 g	2.712 ef	
	4	1.115 no	2.800 i-l	5.080 fg	2.998 e	
0.5	0	0.761 o	2.602 j-l	2.826 i-l	2.063 g	2.602 c
	1	1.142 no	3.121 ij	2.944 i-k	2.402 fg	
	2	1.097no	2.986 i-k	7.493 d	3.859 b	
	4	0.998 no	2.609 j-l	2.644 j-l	2.084 g	
1	0	0.862 o	3.824 h	5.598 f	3.428 c	3.618 b
	1	0.812 o	2.160 lm	6.245 e	3.072 de	
	2	0.950 no	2.479 j-l	8.458 b	3.962 b	
	4	1.091 no	3.142 ij	7.800 cd	4.011 b	
1.5	0	1.321 no	3.139 ij	8.135 bc	4.198 b	3.646 b
	1	1.076 no	2.758 i-l	8.573 b	4.136 b	
	2	1.019 no	2.844 i-l	4.757 g	2.873 e	
	4	1.090 no	3.414 hi	5.629 f	3.378 cd	
Mean of Storage Periods		1.052 c	2.993 b	6.233 a		
MeJA*Storage periods	0	1.155 f	3.201 d	7.159 a	Mean of CHI	
	0.5	0.999 f	2.830 e	3.977 c		
	1	0.929 f	2.901 de	7.025 ab		
	1.5	1.126 f	3.039 de	6.773 b		
CHI*Storage periods	0	1.136 g	3.665 d	6.778 a	3.860 a	
	1	0.987 g	2.633 f	6.508 ab	3.376 b	
	2	1.013 g	2.682 f	6.360 b	3.352 b	
	4	1.073 g	2.992 e	5.288 c	3.118 c	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

3.2. TOTAL SOLUBLE SOLIDS (TSS)

The results presented in Table 2 showed that total soluble solids (TSS, %) were significantly higher in untreated fruit than in fruit dipped in 1 mM MeJA. The elevated TSS content of the control fruit might have arisen from the concentration of fruit juice associated with water loss and storage-related changes in soluble constituents. Al-Hajani et al. also reported that

total soluble solids and fruit weight loss increased as cold storage was prolonged [41]. However, in MeJA-treated fruit, the decrease in TSS might be due to delayed ripening and senescence processes, thereby indirectly delaying an increase in TSS (%) during storage [19]. A similar study [42] observed that the increase in TSS (%) of Murcott mandarins was diminished in treated fruits compared to the control fruit. In addition, the present data show that TSS (%) was significantly increased when the storage period was prolonged from 30, 60 to 120 days. This pattern might reflect the substantial quantities of polysaccharides in the cell wall, primarily pectin and cellulose, which are degraded by cell wall-degrading enzymes, resulting in a slight increase in total soluble solids content during storage [43]. The present results can be compared with earlier observations on grapefruit [44]. In navel orange fruit, Youssef et al. reported that soluble solids increased initially and subsequently declined during storage, while several coating treatments retained higher soluble solids than the control. Their findings therefore demonstrate treatment-dependent changes rather than direct agreement with every trend observed here [45]. Meanwhile, the combination among 0 mM MeJA+ 0% CHI+120 day storage recorded significantly higher TSS (%) compared to all other interaction treatments, except the interaction among (0 mM MeJA+ 0% CHI+ 60 day storage) and (0.5 mM MeJA+1%CHI +120 day), while the minimum value TSS (%) in fruit was recorded by the interaction among (0 mM MeJA+1% CHI and 30 day storage).

Table 2. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit total soluble solid (TSS%) of local orange stored at* $5 \pm 1\,^{\circ}C$

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	11.667 c-f	12.500 ab	12.833 a	12.333 a	11.625 a
	1	10.667 h	11.333 d-h	11.833 b-e	11.278 bc	
	2	11.000 f-h	11.333 d-h	12.000 b-d	11.444 bc	
	4	10.833 gh	11.500 c-g	12.000 b-d	11.444 bc	
0.5	0	10.833 gh	11.333 d-h	11.500 c-g	11.222 c	11.486 ab
	1	11.000 f-h	11.667 c-f	12.167 a-c	11.611 bc	
	2	11.000 f-h	11.667 c-f	12.000 b-d	11.556 bc	
	4	11.000 f-h	11.667 c-f	12.000 b-d	11.556 bc	
1	0	11.000 f-h	11.167 e-h	11.667 c-f	11.278 bc	11.403 b
	1	11.000 f-h	11.500 c-g	11.833 be	11.444 bc	
	2	11.000 f-h	11.333 d-h	12.000 b-d	11.444 bc	
	4	11.167 e-h	11.333 d-h	11.833 b-e	11.444 bc	
1.5	0	11.000 f-h	11.333 d-h	11.667 c-f	11.333 bc	11.486 ab
	1	11.333 d-h	11.833 b-e	12.000 b-d	11.722 b	
	2	11.000 f-h	11.333 d-h	11.667 c-f	11.333 bc	
	4	11.333 d-h	11.500 c-g	11.833 b-e	11.556 bc	
Mean of Storage periods		11.052 c	11.521 b	11.927 a	Mean of CHI	
MeJA*Storage periods	0	11.042 fg	11.667 b-d	12.167 a		
	0.5	10.958 g	11.583 b-d	11.917 ab		
	1	11.042 fg	11.333 d-f	11.833 a-c		
	1.5	11.167 e-g	11.500 c-e	11.792 bc		
CHI*Storage	0	11.125 de	11.583 bc	11.917 ab	11.542 a	
	1	11.000 e	11.583 bc	11.958 a	11.514 a	
	2	11.000 e	11.417 cd	11.917 ab	11.444 a	
	4	11.083 e	11.500 c	11.917 ab	11.500 a	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

3.3. TITRATABLE ACIDITY (TA%)

The data in Table 3 show that fruit treated with 0.5 mM MeJA had significantly higher titratable acidity than fruit receiving the other MeJA concentrations. The lower acidity in untreated fruit might reflect the utilization of organic acids in respiration or other metabolic changes occurring in the fruit during storage [46]. The higher organic acid content in treated fruit may be associated with slower respiratory consumption and delayed senescence, helping to preserve acidity during storage. As related evidence from another fruit system, Valero et al. found that salicylic, acetylsalicylic, and oxalic acid treatments delayed postharvest ripening in sweet cherry. Their results provide a comparative physiological context and should not be interpreted as a direct test of MeJA or chitosan in orange fruit [47]. Our results were similar to those reported by Geransayeh et al. [48], who showed that titratable acidity (%) was higher in strawberry fruit treated with different postharvest applications of MeJA compared with the control. Additionally, the titratable acidity (%) of fruit substantially

decreased when the storage period was extended from 30 to 60 and 120 days. The titratable acidity (%) correlates with the concentration of organic acids, which significantly influence fruit quality, while their decline during cold storage is associated with their utilization as primary respiratory substrates for energy generation during storage [36]. Also, among all of the interaction treatments, the highest significant titratable acidity (%) was recorded in fruits treated with 0.5 mM MeJA + 0% CHI + 30 days storage compared with the control fruit during 120 days storage, which was higher than all other interactions, demonstrating that this triple combination was most efficacious in preserving acidity.

Table 3. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit titratable acidity (TA%) of local orange stored at* $5 \pm 1\,^{\circ}C$.

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	0.872 e-g	0.765 kl	0.603 q	0.747 f	0.805 b
	1	0.999 ab	0.905 d-f	0.709 lm	0.869 b	
	2	0.978 ac	0.785 i-k	0.683 m-o	0.815 cd	
	4	0.956 a-d	0.781 jk	0.628 o-q	0.788 de	
0.5	0	1.012 a	0.961 a-d	0.762 kl	0.911 a	0.842 a
	1	0.965 a-d	0.858 f-h	0.675 m-p	0.830 c	
	2	0.944 b-d	0.850 f-i	0.649 m-q	0.814 cd	
	4	0.965 a-d	0.803 h-k	0.674 m-p	0.814 cd	
1	0	0.978 ac	0.777 jk	0.615 pq	0.790 de	0.804 b
	1	0.922 c-e	0.840 g-j	0.696 mn	0.820 cd	
	2	0.961 a-d	0.807 h-k	0.632 n-q	0.800 c-e	
	4	0.935 b-d	0.824 g-k	0.657 m-q	0.805 c-e	
1.5	0	0.973 ac	0.824 g-k	0.666 m-q	0.821 cd	0.804 b
	1	0.926 b-e	0.781 jk	0.615 pq	0.774 ef	
	2	0.958 a-d	0.769 kl	0.687 m-o	0.805 c-e	
	4	0.978 ac	0.815 g-k	0.654 m-q	0.816 cd	
Mean of Storage periods		0.957 a	0.822 b	0.663 c	Mean of CHI	
MeJA*Storage periods	0	0.950 a	0.809 c	0.656 e		
	0.5	0.969 a	0.868 b	0.690 d		
	1	0.949 a	0.812 c	0.650 e		
	1.5	0.959 a	0.797 c	0.655 e		
CHI*Storage periods	0	0.959 a	0.832 bc	0.661 d	0.817 a	
	1	0.949 a	0.846 b	0.674 d	0.823 a	
	2	0.960 a	0.803 c	0.663 d	0.808 a	
	4	0.958 a	0.806 c	0.653 d	0.806 a	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

3.4. ASCORBIC ACID CONTENT (MG. 100 ML $^{-1}$ JUICE FRUIT)

The results presented in Table 4 clearly indicate that MeJA had a positive effect on fruit juice ascorbic acid, the highest ascorbic acid content was recorded in fruit dipped in (0.5 mM MeJA), but the lowest ascorbic acid in orange juice was found in fruit treated with (1.5 mM MeJA). MeJA helps to postpone the ascorbic acid oxidation process during metabolic activities [49]. MeJA can increase the transcription of genes involved in the de novo production of ascorbic acid in fruits, according to reports from studies conducted on plant cells [50]. Furthermore, fruits dipped in CHI concentration at (2%) significantly increased ascorbic acid compared to untreated fruits. The higher ascorbic acid content was caused by coatings, possibly because they slow down the gas exchange rate with the environment, preventing ascorbic acid from being exposed to oxygen and helping to retain it within the fruit [26]. Every coating procedure postponed the deterioration of the vitamin C content of the fruit [51]. Chitosan can elicit antioxidant defense responses that influence the balance between reactive oxygen species and antioxidant activity in harvested fruit. These responses provide a plausible physiological context for interpreting the retention of antioxidant compounds during storage [52, 53]. The results showed that a prolonged storage period from 30 to 120 days induced a significant reduction in fruit juice ascorbic acid. This might be due to the quick conversion of L-ascorbic acid into dehydroascorbic acid in the presence of L-ascorbic acid oxidase and the enhanced respiration process [54, 55]. Our data are in agreement with the findings of these studies [43] on lemon fruit, [56] on mandarin fruits cv. 'Murcott', and [20] on blood orange fruit. The combination of 0.5 mM MeJA, 0% CHI, and 30 days of storage was effective for preserving ascorbic acid in orange juice as compared with the untreated fruit during 120 days storage, which recorded the lowest ascorbic acid.

Table 4. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit ascorbic acid content (mg. 100 ml^{-1} juice fruit) of local orange stored at* $5 \pm 1\,^{\circ}C$.

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	70.630 e	49.177 t	47.160 u	55.656 j	61.140 b
	1	73.367 b	58.900 h	56.520 i	62.929 c	
	2	72.503 bc	64.657 f	53.713 k-n	63.624 b	
	4	72.937 bc	59.833 gh	54.287 kl	62.352 c	
0.5	0	75.103 a	64.873 f	56.377 i	65.451 a	61.885 a
	1	72.503 bc	55.873 i	52.847 n-q	60.408 f	
	2	72.577 bc	60.553 g	51.193 rs	61.441 ed	
	4	72.433 bc	56.307 i	51.983 qr	60.241 f	
1	0	72.650 bc	56.087 i	52.490 o-q	60.409 f	59.483 c
	1	71.353 de	52.150 p-r	50.757 s	58.087 hi	
	2	73.007 bc	55.440 ij	54.143 k-m	60.863 ef	
	4	72.937 bc	51.950 qr	50.833 s	58.573 gh	
1.5	0	72.937 bc	51.120 rs	49.103 t	57.720 i	59.271 c
	1	72.073 cd	59.257 h	53.137 m-p	61.489 d	
	2	73.443 b	54.650 jk	48.820 t	58.971 g	
	4	74.690 a	53.353 l-o	48.673 t	58.906 g	
Mean of Storage periods		72.821 a	56.511 b	52.002 c	Mean of CHI	
MeJA*Storage periods	0	72.359 b	58.142 d	52.920 g		
	0.5	73.154 a	59.402 c	53.100 g		
	1	72.487 b	53.907 f	52.056 h		
	1.5	73.286 a	54.595 e	49.933 i		
CHI*Storage periods	0	72.830 ab	55.314 e	51.283 h	59.809 c	
	1	72.324 b	56.545 d	53.315 f	60.728 b	
	2	72.883 a	58.825 c	51.968 g	61.225 a	
	4	73.249 a	55.361 e	51.444 h	60.018 c	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

3.5. TOTAL PHENOLS CONTENT (MG 100G^{-1} JUICE)

As shown by the results in Table 5, MeJA at 0.5 mM, CHI at 4% and 2% produced significantly higher total phenol content in orange fruits compared with the control fruits, which recorded the lowest value. The increase in total phenols in treated fruits might be attributed to activation of the secondary metabolic pathway leading to the buildup of phenolic compounds in the fruits [57]. MeJA activates many defense signaling pathways and induces the synthesis of numerous secondary metabolites, including phenolic substances [58] and [59]. The postharvest administration of MeJA postponed the depletion of polyphenols, including total phenols, likely due to the enhancement of phenylalanine ammonia lyase activity by these compounds, which facilitates the accumulation of elevated levels of total phenols [60]. By lowering the oxygen permeability and loss of water in fruit, chitosan coating can inhibit oxidative stress and enzymatic browning, which break down phenolic compounds [61]. These observations suggest that chitosan coatings create a protective barrier on the fruit surface, hence reducing the availability of oxygen responsible for the enzymatic oxidation of phenolic components [62]. The results clearly showed that total phenol content was significantly affected by the duration of the cold storage period. Consequently, it is evident that fruit stored for 30 days had significantly elevated total phenol levels in comparison to those stored for 60 and 120 days storage. Also, the reduction of total phenols during cold storage in orange fruits has been related to their enzymatic oxidation mainly due to peroxidase (POD), and polyphenol oxidase (PPO) activities [37, 63]. The reduction in phenolic content at the end of cold storage might result from the breakdown of phenolic compounds attributed to enzymatic activity [64]. The results from our study are similar to those of [49] who demonstrated that preharvest application of MeJA had higher total phenols in 'Kinnow' mandarin (*Citrus reticulata* Blanco) fruits. Additionally, the best interaction was observed in (0.5 mM MeJA+ 0% CHI + 30 days storage), which was the most effective interaction for obtaining a significantly higher total phenol content. However, the lowest total phenol in the orange fruit juice was noted in the fruit of (0 mM MeJA+ 0% CHI and stored for 120 days) interaction.

Table 5. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit total phenols content (mg 100g^{-1} juice) of local orange stored at* $5 \pm 1\,^{\circ}C$.

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	69.401 q	50.692 w-y	33.902 B1	51.332 l	66.754 c
	1	103.101 f	56.314 t	40.375 A2	66.597 h	
	2	109.149 e	70.057 pq	54.717 tu	77.974 d	
	4	99.397 gh	64.982 r	48.957 y	71.112 g	
0.5	0	144.305 a	100.794 g	80.436 lm	108.512 a	94.429 a
	1	96.660 i	72.196 p	49.841 x-y	72.899 f	
	2	140.627 b	82.118 l	77.713 n	100.153 b	
	4	135.880 c	81.640 l	70.941 pq	96.154 c	
1	0	82.161 l	59.507 s	50.782 w-y	64.150 i	67.144 c
	1	71.854 pq	56.670 t	52.350 u-w	60.291 j	
	2	93.381 j	64.925 r	51.495 v-x	69.933 g	
	4	98.570 g-i	82.204 l	41.829 a-Z	74.201 e	
1.5	0	77.071 n	74.705 o	43.754 z	65.176 i	72.117 b
	1	113.319 d	97.829 hi	79.181 mn	96.776 c	
	2	70.037 pq	52.394 u-w	53.634 uv	58.688 k	
	4	89.446 k	70.699 pq	43.340 z	67.828 h	
Mean of Storage periods		99.647 a	71.108 b	54.578 c	Mean of CHI	
MeJA*Storage periods	0	95.262 b	60.511 h	44.488 k		
	0.5	129.368 a	84.187 d	69.733 f		
	1	86.491 c	65.826 g	49.114 j		
	1.5	87.468 c	73.907 e	54.977 i		
CHI*Storage periods	0	93.235 d	71.424 f	52.218 j	72.292 c	
	1	96.234 c	70.752 f	55.437 i	74.141 b	
	2	103.298 b	67.373 g	59.390 h	76.687 a	
	4	105.823 a	74.881 e	51.267 j	77.324 a	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

3.6. CHILLING INJURY (%)

Table 6 clarified that chilling injury (%) in fruit significantly decreased in fruit dipped at all concentrations of MeJA and CHI compared to the control, the lowest value obtained from (1 mM MeJA and 2% CHI) respectively. MeJA plays an important function in signaling defense in chilled plants, and the establishment of tolerance has frequently been linked to the accumulation of defense-related enzymes and compounds [65]. MeJA is proposed to function via augmenting antioxidant activity, and enhances tolerance to chilling injury by increasing antioxidant activity in the flavedo, hence improving its reactive oxygen species (ROS) scavenging capability [66]. Chitosan coating reduced chilling injury. This response may be associated with the protective coating on the fruit surface and the elicitation of defense mechanisms that help maintain cellular integrity during storage. Chitosan is a chitin-derived polymer, and the proposed explanation therefore concerns chitosan-mediated protection rather than a membrane formed from hydrolyzed starch [52, 67]. Overall, coated fruits were of higher quality than uncoated ones; this enhancement in quality might be ascribed to an increase in organic acids during senescence [68]. On the other hand, the present findings showed that chilling injury (%) significantly increased on orange fruits when the storage period was prolonged from 30, 60 to 120 days storage, while during 30 days there were no symptoms of chilling injury (%). Our results are similar to previous findings of [18] on orange fruits cv.'Valencia', [69] on mango fruits, and [70] who illustrated that the physiological disorder in mandarin fruits increased after storage duration of 62 days. Furthermore, the best triple interaction was recorded at both (0 mM MeJA+ 4% CHI + 60 days), and (1 mM MeJA+ 1% CHI+ 60 days) because no chilling injury was observed in these fruit. In addition, no chilling injury was observed on the peel of the fruit treated with all concentrations of MeJA + CHI during the first period of storage.

3.7. FRUIT DECAY (%)

Table 7 showed that the fruit decay (%) decreased significantly when the fruit was treated with all dipping concentration treatments of both MeJA and CHI compared with the control fruits, the minimum value was obtained from fruits treated at (1.5 mM MeJA and 2% CHI) each alone. MeJA has been demonstrated to stimulate the synthesis and expression of specific stress proteins, including heat-shock proteins and pathogenesis-related proteins, resulting in enhanced resistance to infections and reduced decay incidence [71, 72].

Table 6. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit chilling injury (%) of local orange stored at* $5 \pm 1\,^{\circ}C$.

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	0.000 c	33.333 a	37.500 a	23.611 a	10.060 a
	1	0.000 c	8.333 bc	16.667 b	8.333 b	
	2	0.000 c	4.167 bc	8.333 bc	4.167 b	
	4	0.000 c	0.000 c	12.500 bc	4.167 b	
0.5	0	0.000 c	4.167 bc	16.667 b	6.944 b	6.047 b
	1	0.000 c	12.500 bc	4.167 bc	5.556 b	
	2	0.000 c	4.167 bc	15.625 b	6.597 b	
	4	0.000 c	11.111 bc	4.167 bc	5.093 b	
1	0	0.000 c	8.333 bc	4.167 bc	4.167 b	4.340 b
	1	0.000 c	0.000 c	6.250 bc	2.083 b	
	2	0.000 c	12.500 bc	4.167 bc	5.556 b	
	4	0.000 c	12.500 bc	4.167 bc	5.556 b	
1.5	0	0.000 c	8.333 bc	12.500 bc	6.944 b	6.019 b
	1	0.000 c	16.667 b	4.167 bc	6.944 b	
	2	0.000 c	6.250 bc	5.555 bc	3.935 b	
	4	0.000 c	10.417 bc	8.333 bc	6.250 b	
Mean of Storage periods		0.000 b	9.549 a	10.308 a		
MeJA*Storage periods	0	0.000 d	11.458 b	18.750 a		
	0.5	0.000 d	7.986 bc	10.156 bc		
	1	0.000 d	8.333 bc	4.688 cd		
	1.5	0.000 d	10.417 bc	7.639 bc		
CHI*Storage periods	0	0.000 d	13.542 ab	17.708 a	10.417 a	
	1	0.000 d	9.375 bc	7.813 bc	5.729 b	
	2	0.000 d	6.771 c	8.420 bc	5.064 b	
	4	0.000 d	8.507 bc	7.292 c	5.266 b	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

The lower incidence of decay in MeJA-treated fruit may be associated with induced disease resistance and changes in protective antioxidant and phenolic compounds. These potential mechanisms offer a basis for interpreting the observed treatment response, although they do not independently establish the causal pathway in the present orange fruit experiment [15, 73]. Chitosan has been extensively utilized in antimicrobial films to create an edible protective coating for food by spraying and immersing because of its antibacterial properties [22, 52]. The fruits can be better protected against postharvest decay by applying an edible coating that partially restricts gas exchange through the fruit peel and inhibits the activity of ethylene [74]. Data about storage period demonstrated that no decay was observed in fruit at the first and second period (30 and 60 days storage), but after extending the storage period to 120 days, some fruits showed signs of decay. The increase in fruit decay at the end of storage is mostly caused by fruit weight loss, which results in shriveling and degradation, it is known that immersed treatments lower the rate of weight loss, which in turn lowers the percentage of decay [75]. Our results are consistent with [51] on navel orange fruit, and [76] on Murcott tangor. Moreover, the combination of 1.5 mM MeJA and 4% CHI preserved orange fruit without observed decay after 120 days of storage. This treatment combination therefore maintained fruit quality over the longest storage interval assessed in the present experiment. By comparison, untreated fruit stored for 120 days had the highest value of decay (%) in comparison with all other triple interactions.

3.8. CATALASE ENZYME

As illustrated in Table 8, MeJA at 0.5 mM and CHI at all tested concentrations significantly increased catalase activity in orange fruit juice compared with the untreated control fruit. Catalase enzyme (CAT) is an anti-oxidative detoxification enzyme that plays a crucial role in the scavenging of reactive oxygen species [77]. Externally applied MeJA can act as an inducer of signaling pathways that regulate the production of reactive oxygen species (ROS), including H_2O_2, and activate defense and stress responses [78]. Moreover, MeJA can upregulate genes associated with catalase and increase CAT activity [73, 79]. The elevation of the catalase enzyme might be due to MeJA, which increases the activity of the antioxidant enzyme. On the other hand, fruit treated with MeJA increases antioxidant enzymes such as catalase enzyme, and other defense systems to prevent ROS damage [66]. According to reviews, MeJA frequently causes the production of defense genes and ROS, which trigger the activation of the antioxidant system as a compensatory protective response [80].

Table 7. *Effect of methyl jasmonate (MeJA), chitosan (CHI), storage period and their interaction on fruit decay (%) of local orange stored at* $5 \pm 1\,^{\circ}C$

MeJA (mM)	CHI (%)	Storage periods (days)			MeJA*CHI	Mean of MeJA
		30	60	120		
0	0	0.000 c	0.000 c	29.167 a	9.722 a	4.861 a
	1	0.000 c	0.000 c	12.500 b	4.167 b	
	2	0.000 c	0.000 c	4.167 c	1.389 b	
	4	0.000 c	0.000 c	12.500 b	4.168 b	
0.5	0	0.000 c	0.000 c	14.063 b	4.688 b	2.734 b
	1	0.000 c	0.000 c	6.250 bc	2.083 b	
	2	0.000 c	0.000 c	6.250 bc	2.083 b	
	4	0.000 c	0.000 c	6.250 bc	2.083 b	
1	0	0.000 c	0.000 c	8.333 bc	2.778 b	2.778 b
	1	0.000 c	0.000 c	12.500 b	4.167 b	
	2	0.000 c	0.000 c	4.167 c	1.389 b	
	4	0.000 c	0.000 c	8.333 bc	2.778 b	
1.5	0	0.000 c	0.000 c	4.167 c	1.389 b	1.389 b
	1	0.000 c	0.000 c	8.333 bc	2.778 b	
	2	0.000 c	0.000 c	4.167 c	1.389 b	
	4	0.000 c	0.000 c	0.000 c	0.00 b	
Mean of Storage periods		0.00 b	0.00 b	8.822 a	Mean of CHI	
MeJA*Storage periods	0	0.000 d	0.000 d	14.583 a		
	0.5	0.000 d	0.000 d	8.203 b		
	1	0.000 d	0.000 d	8.333 b		
	1.5	0.000 d	0.000 d	4.167 c		
CHI*Storage periods	0	0.000 d	0.000 d	13.932 a	4.644 a	
	1	0.000 d	0.000 d	9.896 b	3.299 ab	
	2	0.000 d	0.000 d	4.688 c	1.563 b	
	4	0.000 d	0.000 d	6.771 bc	2.257 b	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

In addition, MeJA treatments have been associated with increased catalase activity during cold storage of citrus fruit, including mandarins and blood oranges [66] and [13]. The catalase enzyme increased in the fruit juice of local Diyala orange when treated with chitosan, which might be due to stimulating the antioxidant defense system as a biological elicitor [52]. Chitosan might produce a regulated ROS signal that triggers defense mechanisms. In response, the fruit produces more catalase and associated enzymes to detoxify H_2O_2 and preserve ROS equilibrium [67, 81]. Nevertheless, Chitosan coatings may sustain increased catalase activity and delay fruit senescence by reducing ROS generation and concurrently stimulating the antioxidant enzyme system [53, 82]. The chitosan-related findings can be compared with research on coated strawberry fruit [83]. Separately, Elatafi et al. investigated methyl jasmonate and storage temperature in Shine Muscat table grapes and reported effects on antioxidant activity and fruit quality. That grape study provides context for the MeJA treatment discussed here, rather than direct evidence for a chitosan coating effect [84]. The interaction between MeJA and CHI further showed that fruit dipped in 0.5 mM MeJA and 4% CHI had significantly higher catalase activity in orange juice than most other treatment combinations. The lowest value of catalase enzyme was found at (0 mM MeJA+ 0% CHI).

Table 8. *Effect of methyl jasmonate (MeJA), chitosan (CHI), and their interaction on enzyme catalase of local orange stored for 60 days at* $5 \pm 1\,^{\circ}C$.

MeJA (mM)	CHI (%)				Mean of MeJA
	0	1	2	4	
0	4.340 f	5.927 b-d	5.610 de	5.960 b-d	5.459 b
0.5	6.170 a-d	5.977 b-d	6.370 ab	6.807 a	6.331 a
1	5.670 c-e	5.787 b-d	5.677 c-e	5.670 c-e	5.701 b
1.5	5.620 de	6.347 a-c	5.957 b-d	5.110 e	5.758 b
Mean of CHI	5.450 b	6.009 a	5.903 a	5.887 a	

Means of each factor and their interactions followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at 0.05 level.

4. CONCLUSION

Based on the data, it can be concluded that local Diyala orange fruits treated with methyl jasmonate and edible coating of chitosan during the cold storage period, whether applied alone or in combination, were effective in prolonging the storage period and reducing (fruit weight loss, chilling injury, and decay, in addition to preserving titratable acidity, ascorbic acid, and total phenol content) compared with the control after 120 days in cold storage. Moreover, the treatments preserved catalase activity relative to untreated fruit after 60 days of cold storage. Overall, the postharvest application of methyl jasmonate and chitosan demonstrated efficacy in preserving the postharvest quality and prolonging the storability of local Diyala orange fruits.

Author Contributions

Both authors contributed equally to this research and approved the final manuscript.

Conflict of Interest

The authors declare no conflicts of interest.

Funding

This research received no external funding.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] Saini, Ramesh Kumar, Arina Ranjit, Kavita Sharma, Parchuri Prasad, Xiaomin Shang, Karekal Girinur Mallikarjuna Gowda, and Young-Soo Keum. "Bioactive Compounds of Citrus Fruits: A Review of Composition and Health Benefits of Carotenoids, Flavonoids, Limonoids, and Terpenes." *Antioxidants*, vol. 11, no. 2, 2022, article 239. https://doi.org/10.3390/antiox11020239.

[2] Al-Janabi, Atheer Mohammed Ismail. "Effect of Shading, Rootstock Type and Foliar Spraying with Amino Acids on Some Growth Traits of Sweet Orange (*Citrus sinensis* L. Osbeck) Saplings." *Biochemical and Cellular Archives*, vol. 20, no. 1, 2020, pp. 1735–44.

[3] El-Gioushy, Sherif Fathy Eid El-Sayed. *Physiological and Anatomical Studies on Some Factors Affecting Productivity and Nutritional Status of Navel Orange*. 2012. Benha University, PhD dissertation.

[4] United States Department of Agriculture, Foreign Agricultural Service. *Citrus: World Markets and Trade*. Jan. 2026, https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf.

[5] Food and Agriculture Organization of the United Nations. "Crops and Livestock Products." *FAOSTAT*, 2023, https://www.fao.org/faostat/en/#data/QCL.

[6] Lado, Joanna, et al. "Maturity Indicators and Citrus Fruit Quality." *Stewart Postharvest Review*, vol. 10, no. 2, 2014, pp. 1–6.

[7] Cavaco, Ana M., et al. "Nondestructive Assessment of Citrus Fruit Quality and Ripening by Visible–Near Infrared Reflectance Spectroscopy." *Citrus—Research, Development and Biotechnology*, edited by Muhammad Sarwar Khan and Iqrar Ahmad Khan, IntechOpen, 2021, ch. 13, https://www.intechopen.com/chapters/75090.

[8] Abd Asl, Khalid Naji, and Abdulmuhsen Jaber Ahmed. "Effect of Cold Storage and Packaging to Improve the Quality of Local Orange Fruits after Harvest." *Euphrates Journal of Agricultural Science*, vol. 14, no. 2, 2022, pp. 202–210. https://iasj.rdd.edu.iq/journals/uploads/2025/05/11/bdd6cd8ff1236c82a0156bffd48847d5.pdf.

[9] Terry, Leon A., and Daryl C. Joyce. "Elicitors of Induced Disease Resistance in Postharvest Horticultural Crops: A Brief Review." *Postharvest Biology and Technology*, vol. 32, no. 1, 2004, pp. 1–13.

[10] Baswal, A. K., H. S. Dhaliwal, Zora Singh, B. V. C. Mahajan, Anu Kalia, and K. S. Gill. "Influence of Carboxy Methylcellulose, Chitosan and Beeswax Coatings on Cold Storage Life and Quality of Kinnow Mandarin Fruit." *Scientia Horticulturae*, vol. 260, 2020, article 108887. https://doi.org/10.1016/j.scienta.2019.108887.

[11] Singla, Rachna, et al. "Storage Performance of Hot Water Treated Kinnow Fruits under Ambient Conditions." *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 6, 2018, pp. 3775–82.

[12] Castillo, S., et al. "The Essential Oils Thymol and Carvacrol Applied in the Packing Lines Avoid Lemon Spoilage and Maintain Quality during Storage." *Food Control*, vol. 35, no. 1, 2014, pp. 132–36.

[13] Baswal, A. K., H. S. Dhaliwal, Zora Singh, and B. V. C. Mahajan. "Post-harvest Application of Methyl Jasmonate, 1-Methylcyclopropene and Salicylic Acid Elevates Health-Promoting Compounds in Cold-Stored 'Kinnow' Mandarin (*Citrus nobilis* Lour. × *C. deliciosa* Tenora) Fruit." *International Journal of Fruit Science*, vol. 21, no. 1, 2021, pp. 147–157. https://doi.org/10.1080/15538362.2020.1860865.

[14] Cheong, Jong-Joo, and Yang Do Choi. "Methyl Jasmonate as a Vital Substance in Plants." *Trends in Genetics*, vol. 19, no. 7, 2003, pp. 409–13.

[15] Guo, Jun, et al. "Inhibition of Green Mold Disease in Mandarins by Preventive Applications of Methyl Jasmonate and Antagonistic Yeast *Cryptococcus laurentii*." *Postharvest Biology and Technology*, vol. 88, 2014, pp. 72–78.

[16] Gómez, Carlos A., et al. "Efecto de 1-metilciclopropeno en la poscosecha de mandarina (*Citrus reticulata* L.) var. Arrayana." *Revista Facultad Nacional de Agronomía Medellín*, vol. 67, no. 2, suppl. 2, 2014, pp. 1159–62.

[17] Buraphaka, Hathairat, and Waraporn Putalun. "Stimulation of Health-Promoting Triterpenoids Accumulation in *Centella asiatica* (L.) Urban Leaves Triggered by Postharvest Application of Methyl Jasmonate and Salicylic Acid Elicitors." *Industrial Crops and Products*, vol. 146, 2020, article 112171.

[18] Khajehyar, R., et al. "Methyl Jasmonate and Polyamines Reduce Chilling Injury Symptoms of Orange (*Citrus sinensis*) Fruit during Cold Storage." *Journal of Applied Horticulture*, vol. 18, no. 2, 2016, pp. 135–37.

[19] Habibi, Fariborz, et al. "Blood Oranges Maintain Bioactive Compounds and Nutritional Quality by Postharvest Treatments with γ-Aminobutyric Acid, Methyl Jasmonate or Methyl Salicylate during Cold Storage." *Food Chemistry*, vol. 306, 2020, article 125634.

[20] Vithana, Mekhala Dinushi Kananke, et al. "Pre- and Post-harvest Elicitation with Methyl Jasmonate and Salicylic Acid Followed by Cold Storage Synergistically Improves Red Colour Development and Health-Promoting Compounds in Blood Oranges." *Journal of Plant Growth Regulation*, vol. 43, no. 5, 2024, pp. 1657–71.

[21] Assar, Pedram, and Leila Taghipour. "Enhancing Postharvest Quality and Storability of Sweet Lime Using Methyl Jasmonate and Salicylic Acid Treatments." *Agriculturae Conspectus Scientificus*, vol. 90, no. 1, 2025, pp. 55–62.

[22] Dutta, P. K., et al. "Perspectives for Chitosan Based Antimicrobial Films in Food Applications." *Food Chemistry*, vol. 114, no. 4, 2009, pp. 1173–82.

[23] Muzzarelli, Riccardo A. A., et al. "Current Views on Fungal Chitin/Chitosan, Human Chitinases, Food Preservation, Glucans, Pectins and Inulin: A Tribute to Henri Braconnot, Precursor of the Carbohydrate Polymers Science, on the Chitin Bicentennial." *Carbohydrate Polymers*, vol. 87, no. 2, 2012, pp. 995–1012.

[24] Vilaplana, Rosa, et al. "Chitosan Coatings to Control Soft Mold on Fresh Blackberries (*Rubus glaucus* Benth.) during Postharvest Period." *Scientia Horticulturae*, vol. 262, 2020, article 109049.

[25] Rappussi, Maria Cristina Canale, et al. "Chitosan and Fungicides on Postharvest Control of *Guignardia citricarpa* and on Quality of 'Pêra Rio' Oranges." *Summa Phytopathologica*, vol. 37, no. 3, 2011, pp. 142–44.

[26] Plácido, Geovana Rocha, et al. "Effect of Chitosan-Based Coating on Postharvest Quality of Tangerines (*Citrus deliciosa* Tenore): Identification of Physical, Chemical, and Kinetic Parameters during Storage." *African Journal of Agricultural Research*, vol. 11, no. 24, 2016, pp. 2185–92.

[27] Baswal, Arvind Kumar, Harvinder Singh Dhaliwal, Zora Singh, Bal Vipan Chander Mahajan, and Anu Kalia. "Edible Coatings Maintain the Phytochemicals in Cold-Stored 'Kinnow' Mandarin (*Citrus nobilis* Lour. × *C. deliciosa* Tenora) Fruit." *Australian Journal of Crop Science*, vol. 15, no. 10, 2021, pp. 1332–1338. https://doi.org/10.21475/ajcs.21.15.10.p3335.

[28] Al Zahrani, Nourah A., et al. "Efficacy of Chitosan Nanoparticles and Wax Coatings on Maintaining Post-harvest Quality of 'Murcott' Mandarins." *Saudi Journal of Biological Sciences*, vol. 31, no. 2, 2024, article 103894.

[29] *SAS*. Version 9.1, SAS Institute, 2003.

[30] Duncan, David B. "Multiple Range and Multiple F Tests." *Biometrics*, vol. 11, no. 1, 1955, pp. 1–42.

[31] AOAC. *Official Methods of Analysis.* 17th ed., edited by William Horwitz, AOAC International, Gaithersburg, Maryland, 2000.

[32] Chen, Chuying, et al. "Physiological and Biochemical Responses in Cold-Stored Citrus Fruits to Carboxymethyl Cellulose Coating Containing Ethanol Extract of *Impatiens balsamina* L. Stems." *Journal of Food Processing and Preservation*, vol. 41, no. 4, 2017, article e12999.

[33] Ranganna, S. *Handbook of Analysis and Quality Control for Fruit and Vegetable Products*. 2nd ed., Tata McGraw-Hill, 1986.

[34] Abd-Elghany, N. A., et al. "Effects of Polyolefin Film Wrapping and Calcium Chloride Treatments on Postharvest Quality of 'Wonderful' Pomegranate Fruits." *Journal of Horticultural Science & Ornamental Plants*, vol. 4, no. 1, 2012, pp. 7–17.

[35] Luhová, L., et al. "Activities of Amine Oxidase, Peroxidase and Catalase in Seedlings of *Pisum sativum* L. under Different Light Conditions." *Plant, Soil and Environment*, vol. 49, no. 4, 2003, pp. 151–57.

[36] Habibi, Fariborz, and Asghar Ramezanian. "Vacuum Infiltration of Putrescine Enhances Bioactive Compounds and Maintains Quality of Blood Orange during Cold Storage." *Food Chemistry*, vol. 227, 2017, pp. 1–8.

[37] Valero, Daniel, et al. "Effects of Alginate Edible Coating on Preserving Fruit Quality in Four Plum Cultivars during Postharvest Storage." *Postharvest Biology and Technology*, vol. 77, 2013, pp. 1–6.

[38] Arnon, Hadar, et al. "Effects of Carboxymethyl Cellulose and Chitosan Bilayer Edible Coating on Postharvest Quality of Citrus Fruit." *Postharvest Biology and Technology*, vol. 87, 2014, pp. 21–26.

[39] Lee, Laurence, et al. "A Review on Modified Atmosphere Packaging and Preservation of Fresh Fruits and Vegetables: Physiological Basis and Practical Aspects—Part II." *Packaging Technology and Science*, vol. 9, no. 1, 1996, pp. 1–17.

[40] Aghaei Dargiri, Soheila, et al. "Chitosan Based Coating Enriched with *Spirulina platensis* and Moringa Leaf Extracts Preserved the Postharvest Quality of Mexican Lime (*Citrus aurantifolia*)." *Journal of Horticulture and Postharvest Research*, vol. 8, no. 1, 2025, pp. 105–24.

[41] Al-Hajani, Rezan M. A., N. N. F. Haded, and S. F. A. Al Bamarny. "Influence of Citric Acid, Ginger Extract and Storage Period on Fruit Quality of Local Orange (*Citrus sinensis* L. Osbeck)." *Iraqi Journal of Agricultural Sciences*, vol. 53, no. 4, 2022, pp. 850–856. https://doi.org/10.36103/ijas.v53i4.1597.

[42] Ennab, Hassan A., et al. "Salicylic Acid and Putrescine to Reduce Post-Harvest Storage Problems and Maintain Quality of Murcott Mandarin Fruit." *Agronomy*, vol. 10, no. 1, 2020, article 115.

[43] Nasrin, Taslima Ayesha Aktar, et al. "Effect of Novel Coconut Oil and Beeswax Edible Coating on Postharvest Quality of Lemon at Ambient Storage." *Journal of Agriculture and Food Research*, vol. 2, 2020, article 100019.

[44] Ahmed, W., et al. "Pre Harvest Foliar Application of Methyl Jasmonate on Fruit Quality and Quality Enzymes and Phenolic Compounds Changes during Storage of Grapefruit." *Pakistan Journal of Chemistry*, vol. 5, no. 3, 2015, pp. 126–37.

[45] Youssef, Aml R. M., Enas A. M. Ali, and Hala E. Emam. "Influence of Postharvest Applications of Some Edible Coating on Storage Life and Quality Attributes of Navel Orange Fruit during Cold Storage." *International Journal of ChemTech Research*, vol. 8, no. 4, 2015, pp. 2189–2200. https://sphinxsai.com/2015/ch_vol8_no4/4/(2189-2200)V8N4.pdf.

[46] Maftoonazad, Neda, et al. "Shelf-Life Extension of Peaches through Sodium Alginate and Methyl Cellulose Edible Coatings." *International Journal of Food Science & Technology*, vol. 43, no. 6, 2008, pp. 951–57. https://academic.oup.com/ijfst/article/43/6/951/7864797.

[47] Valero, Daniel, Huertas M. Díaz-Mula, Pedro Javier Zapata, Salvador Castillo, Fabián Guillén, Domingo Martínez-Romero, and María Serrano. "Postharvest Treatments with Salicylic Acid, Acetylsalicylic Acid or Oxalic Acid Delayed Ripening and Enhanced Bioactive Compounds and Antioxidant Capacity in Sweet Cherry." *Journal of Agricultural and Food Chemistry*, vol. 59, no. 10, 2011, pp. 5483–5489. https://doi.org/10.1021/jf200873j.

[48] Geransayeh, Mahsa, Sadegh Sepahvand, Vahid Abdossi, and Vahid Zarrinnia. "Effect of Methyl Jasmonate Treatment on Decay, Post-Harvest Life and Quality of Strawberry (*Fragaria ananassa* L. cv. Gaviota) Fruit." *International Journal of Current Science*, vol. 15, 2015, pp. E123–E131. https://rjpn.org/ijcspub/papers/IJCSP10A1288.pdf.

[49] Dhami, K. S., et al. "Pre-harvest Methyl Jasmonate Spray Maintains Postharvest Quality of Kinnow Mandarin (*Citrus reticulata*) Fruits." *The Indian Journal of Agricultural Sciences*, vol. 91, no. 10, 2021, pp. 1495–99. https://epubs.icar.org.in/index.php/IJAgS/article/view/117514.

[50] Wolucka, Beata A., et al. "Methyl Jasmonate Stimulates the *de novo* Biosynthesis of Vitamin C in Plant Cell Suspensions." *Journal of Experimental Botany*, vol. 56, no. 419, 2005, pp. 2527–38. https://academic.oup.com/jxb/article/56/419/2527/532050.

[51] Gao, Yang, et al. "Quality and Biochemical Changes of Navel Orange Fruits during Storage as Affected by Cinnamaldehyde-Chitosan Coating." *Scientia Horticulturae*, vol. 239, 2018, pp. 80–86. https://www.sciencedirect.com/science/article/pii/S0304423818303388.

[52] El Hadrami, Abdelbasset, et al. "Chitosan in Plant Protection." *Marine Drugs*, vol. 8, no. 4, 2010, pp. 968–87.

[53] Wang, Shiow Y., and Haiyan Gao. "Effect of Chitosan-Based Edible Coating on Antioxidants, Antioxidant Enzyme System, and Postharvest Fruit Quality of Strawberries (*Fragaria x aranassa* Duch.)." *LWT—Food Science and Technology*, vol. 52, no. 2, 2013, pp. 71–79.

[54] Abdel-Salam, Maha M. "Improving Grapefruit Quality during Storage Life by Using Some Coating Materials on Different Temperature." *Middle East Journal of Agriculture Research*, vol. 5, no. 1, 2016, pp. 29–36. https://www.curresweb.com/mejar/mejar/2016/29-36.pdf.

[55] Atrash, Sara, et al. "Antifungal Effects of Savory Essential Oil, Gum Arabic, and Hot Water in Mexican Lime Fruits." *HortScience*, vol. 53, no. 4, 2018, pp. 524–30. https://journals.ashs.org/view/journals/hortsci/53/4/article-p524.xml.

[56] Niu, Chenyu, et al. "Coating of Layer-by-Layer Assembly Based on Chitosan and CMC: Emerging Alternative for Quality Maintenance of Citrus Fruit." *Horticulturae*, vol. 9, no. 6, 2023, article 715. https://www.mdpi.com/2311-7524/9/6/715.

[57] De Geyter, Nathan, et al. "Transcriptional Machineries in Jasmonate-Elicited Plant Secondary Metabolism." *Trends in Plant Science*, vol. 17, no. 6, 2012, pp. 349–59. https://www.sciencedirect.com/science/article/pii/S1360138512000532.

[58] Kim, Hyun-Jin, et al. "Effect of Methyl Jasmonate on Secondary Metabolites of Sweet Basil (*Ocimum basilicum* L.)." *Journal of Agricultural and Food Chemistry*, vol. 54, no. 6, 2006, pp. 2327–32. https://pubmed.ncbi.nlm.nih.gov/16536615/.

[59] Heredia, J. Basilio, and Luis Cisneros-Zevallos. "The Effect of Exogenous Ethylene and Methyl Jasmonate on PAL Activity, Phenolic Profiles and Antioxidant Capacity of Carrots (*Daucus carota*) under Different Wounding Intensities." *Postharvest Biology and Technology*, vol. 51, no. 2, 2009, pp. 242–249. https://doi.org/10.1016/j.postharvbio.2008.07.001.

[60] Yao, Hongjie, and Shiping Tian. "Effects of Pre- and Post-harvest Application of Salicylic Acid or Methyl Jasmonate on Inducing Disease Resistance of Sweet Cherry Fruit in Storage." *Postharvest Biology and Technology*, vol. 35, no. 3, 2005, pp. 253–62. https://www.sciencedirect.com/science/article/abs/pii/S092552140400225X.

[61] Sarengaowa, et al. "Screening of Essential Oils and Effect of a Chitosan-Based Edible Coating Containing Cinnamon Oil on the Quality and Microbial Safety of Fresh-Cut Potatoes." *Coatings*, vol. 12, no. 10, 2022, article 1492. https://www.mdpi.com/2079-6412/12/10/1492.

[62] Zhang, Donglin, and Peter C. Quantick. "Effects of Chitosan Coating on Enzymatic Browning and Decay during Postharvest Storage of Litchi (*Litchi chinensis* Sonn.) Fruit." *Postharvest Biology and Technology*, vol. 12, no. 2, 1997, pp. 195–202. https://www.sciencedirect.com/science/article/abs/pii/S0925521497000574.

[63] Rapisarda, Paolo, et al. "Effect of Cold Storage on Vitamin C, Phenolics and Antioxidant Activity of Five Orange Genotypes [*Citrus sinensis* (L.) Osbeck]." *Postharvest Biology and Technology*, vol. 49, no. 3, 2008, pp. 348–54. https://www.sciencedirect.com/science/article/abs/pii/S0925521408000689.

[64] Baltacıoğlu, Cem, et al. "Changes in Total Phenolic and Flavonoid Contents of Rowanberry Fruit during Postharvest Storage." *Journal of Food Quality*, vol. 34, no. 4, 2011, pp. 278–83.

[65] Creelman, Robert A., and John E. Mullet. "Biosynthesis and Action of Jasmonates in Plants." *Annual Review of Plant Physiology and Plant Molecular Biology*, vol. 48, 1997, pp. 355–81.

[66] Habibi, Fariborz, et al. "Postharvest Treatments with γ-Aminobutyric Acid, Methyl Jasmonate, or Methyl Salicylate Enhance Chilling Tolerance of Blood Orange Fruit at Prolonged Cold Storage." *Journal of the Science of Food and Agriculture*, vol. 99, no. 14, 2019, pp. 6408–17.

[67] Nie, Zhengpeng, et al. "Chitosan Coating Alleviates Postharvest Juice Sac Granulation by Mitigating ROS Accumulation in Harvested Pummelo (*Citrus grandis* L. Osbeck) during Room Temperature Storage." *Postharvest Biology and Technology*, vol. 169, 2020, article 111309.

[68] Baldwin, Elizabeth A. "Edible Coatings for Fresh Fruits and Vegetables: Past, Present, and Future." *Edible Coatings and Films to Improve Food Quality*, edited by John M. Krochta et al., Technomic Publishing, 1994, pp. 25–64.

[69] Chien, Po-Jung, et al. "Effects of Edible Chitosan Coating on Quality and Shelf Life of Sliced Mango Fruit." *Journal of Food Engineering*, vol. 78, no. 1, 2007, pp. 225–29.

[70] Acharya, Bibek, et al. "Effect of Plant Extracts and Packaging Materials on Prolonging Shelf Life and Maintaining Quality of Mandarin (*Citrus reticulate* Blanco.)." *International Journal of Horticulture, Agriculture and Food Science*, vol. 4, no. 2, 2020, pp. 29–39.

[71] Ding, Chang-Kui, et al. "Reduction of Chilling Injury and Transcript Accumulation of Heat Shock Proteins in Tomato Fruit by Methyl Jasmonate and Methyl Salicylate." *Plant Science*, vol. 161, no. 6, 2001, pp. 1153–59.

[72] Ding, Chang-Kui, et al. "Jasmonate and Salicylate Induce the Expression of Pathogenesis-Related-Protein Genes and Increase Resistance to Chilling Injury in Tomato Fruit." *Planta*, vol. 214, no. 6, 2002, pp. 895–901.

[73] Pan, Liuyi, et al. "Methyl Jasmonate Induces Postharvest Disease Resistance to Decay Caused by *Alternaria alternata* in Sweet Cherry Fruit." *Scientia Horticulturae*, vol. 292, 2022, article 110624.

[74] Hassan, Z. H., et al. "Effects of Wax Coating Applications and Storage Temperatures on the Quality of Tangerine Citrus (*Citrus reticulata*) var. Siam Banjar." *International Food Research Journal*, vol. 21, no. 2, 2014, pp. 641–48.

[75] El-Eryan, E. E., and M. E. Tarabih. "Extending Storability of Egyptian Banzahir Lime Fruits by Aqueous Ozone Technology with Edible Coating." *Journal of Environmental Science and Technology*, vol. 13, no. 1, 2020, pp. 9–21.

[76] Elnaggar, I. A., et al. "Effect of Some Postharvest Treatments with Edible Coating Materials on Storability and Quality of Murcott Tangor Fruits during Cold Storage." *Al-Azhar Journal of Agricultural Research*, vol. 46, no. 1, 2021, pp. 16–27.

[77] Duan, Xuewu, et al. "Effect of Pure Oxygen Atmosphere on Antioxidant Enzyme and Antioxidant Activity of Harvested Litchi Fruit during Storage." *Food Research International*, vol. 44, no. 7, 2011, pp. 1905–11.

[78] Ho, Thanh-Tam, et al. "Methyl Jasmonate Induced Oxidative Stress and Accumulation of Secondary Metabolites in Plant Cell and Organ Cultures." *International Journal of Molecular Sciences*, vol. 21, no. 3, 2020, article 716.

[79] Huang, Ting, et al. "Mitigation of Chilling Injury in Mango Fruit by Methyl Jasmonate Is Associated with Regulation of Antioxidant Capacity and Energy Homeostasis." *Postharvest Biology and Technology*, vol. 211, 2024, article 112801.

[80] Reyes-Díaz, Marjorie, et al. "Methyl Jasmonate: An Alternative for Improving the Quality and Health Properties of Fresh Fruits." *Molecules*, vol. 21, no. 6, 2016, article 567.

[81] Li, Yurong, et al. "Effect of Polyethoxylated Flavonoids (PMFs)-Loaded Citral and Chitosan Composite Coatings on Citrus Preservation: From the Perspective of Fruit Resistance." *Food Chemistry: X*, vol. 22, 2024, article 101417.

[82] Badawy, Mohamed E. I., et al. "Strawberry Shelf Life, Composition, and Enzymes Activity in Response to Edible Chitosan Coatings." *International Journal of Fruit Science*, vol. 17, no. 2, 2017, pp. 117–36.

[83] Bahmani, Reza, et al. "Evaluation of Proline-Coated Chitosan Nanoparticles on Decay Control and Quality Preservation of Strawberry Fruit (cv. Camarosa) during Cold Storage." *Horticulturae*, vol. 8, no. 7, 2022, article 648.

[84] Elatafi, Essam, Abdelmonem Elshahat, Yu Xue, Li Shaonan, Lu Suwen, Dong Tianyu, and Jinggui Fang. "Effects of Different Storage Temperatures and Methyl Jasmonate on Grape Quality and Antioxidant Activity." *Horticulturae*, vol. 9, no. 12, 2023, article 1282. https://doi.org/10.3390/horticulturae9121282.