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Response of Nectarine Fruits to 1-Methylcyclopropene Treatments During Cold Storage Periods

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ABSTRACT: Maintaining maximum quality and minimizing physiological problems during extended storage is necessary for nectarine fruits. The aim of this work was to investigate the influence of 1-methylcyclopropene on the quality and storability of local nectarines cv. Misky during the cold storage durations. Fruits were picked at the optimum maturity with a green color background of 60 ± 10% and exposed to fumigation for 24 h with 0, 1, and 2 µL/L of 1-MCP, then maintained at 1 ± 1°C and 90 ± 5% RH in a cold room for 15, 30, 45, 60, and 75 days. Total soluble solids (TSS), TSS/TA ratio, titratable acidity (TA), vitamin C, carotene content, total phenol, polyphenol oxidase (PPO) activity, fruit weight loss, firmness, chilling injury (CI), and peel browning were measured following harvest and at the completion of each storage duration. The results revealed that fruit fumigated with 1-MCP, particularly at 2 µL/L, had significantly the maximum TA, total phenols, and firmness; moreover, it had the lowest TSS/TA ratio, PPO activity, fruit weight loss, CI, and peel browning; however, it was not significantly impacted in TSS and vitamin C in comparison with the control. In addition, TSS, TA, vitamin C, and firmness significantly decreased, while the TSS/TA ratio, total phenols, PPO activity, weight loss, and physiological disorders increased with prolonged storage durations. Findings indicate that 2 µL/L of 1-MCP effectively reduces physiological disorders and delays the decline of fruit firmness and nutritional quality in nectarines cv. Misky.

1. INTRODUCTION

Nectarine (Prunus persica var. nectarina), locally called Khokhi Lus, is a climacteric fruit, valued by consumers for its wonderful flavor, tender and juicy flesh, and nutritional constituents like vitamin C, amino acids, and carotenoids [39]. Peaches and nectarines rank as the 3rd highest commercially delectable and important crops of fruit worldwide, subsequent to apples and pears [17]. From an economic perspective, peaches are categorized into five pomological groups, which are yellow and white-fleshed peaches, yellow and white-fleshed nectarines, and percoche. Nectarines are essentially identical to peaches; they possess smooth skin due to the absence of trichomes and display slight differences in size and flavor relative to the fuzzy peach [29].

Nectarine fruits are very prone to fast quality degradation owing to their high perishability, rapid ripening (texture softening), and susceptibility to microbial spoiling [37]. Although cold storage can significantly mitigate fruit deterioration, nectarines are susceptible to low temperatures and face a risk of chilling injury (CI) with extended storage durations. CI signs include internal deterioration, like internal brown coloration and flesh mealiness [35]; leathery fruit with a firm texture and little juice; inability to ripen; growth suppression; loss of flavor; and becoming unappealing to consumers [41].

In recent years, the application of post-harvest development regulators has emerged as an important approach to reduce postharvest losses. The use of growth regulators, specifically 1-Methylcyclopropene (1-MCP), has been documented to

enhance cooling storage and shelf life by postponing post-harvest quality deterioration in many fruits and vegetables, including nectarines [10]. After being patented, 1-MCP was subsequently leading to quick registration and commercialization because of its perceived safety for the environment and humans, efficacy at low concentrations, and simplicity of application as a gas [35]. It is a primary method of inhibiting ethylene activity, which obstructs ethylene function in fruits and vegetables by blocking the binding sites of ethylene receptors [41]. Recently, numerous approaches have been applied to reduce chilling injury in peach and nectarine fruit, including near-freezing temperature storage and 1-MCP applications as an ethylene response blocker [39]. For instance, the treatment of peaches with 1−2 µL/L of 1-MCP demonstrated that it alleviated chilling damage, retarded softening, and inhibited the emission of aroma [12]. Authors [24] showed 1-MCP might be utilized as an efficient agent in nectarines concerning woolliness and acceptability, which affects customer preferences. Furthermore, the utilization of 1-MCP preserved the firmness of the plums while effectively lowering anthocyanin production during storage [33]. Additional study indicated that peaches subjected to 0.5 µL/L 1-MCP after 24 hours had decreased CI, extended storability, and preserved sensory quality and antioxidant characteristics [28].

In Iraqi Kurdistan region, peach and nectarine growers encounter significant challenges, particularly high losses in fruit quality and quantity from harvesting to market due to inadequate postharvest management practices and treatments. We performed searches using recognized search engines such as PubMed, IEEE Xplore, Web of Science, and IRAQI Academic Scientific Journals and found that no studies have been undertaken in the Kurdistan region and Iraq concerning the efficacy of 1-MCP on postharvest physiology and the extension of storage life for fruits and vegetables, including nectarines. So, the aim of our work is to determine the impact of 1-methylcyclopropene treatments on the quality, storability, and reduced losses of local nectarines cv. Misky during cold storage intervals.

2. MATERIALS AND METHODS

2.1 Orchard Site

Nectarine trees were grown in a commercial nectarine and peach orchard located in Xrapsahdon village, Duhok Governorate, at latitude 36.70° N and longitude 43.60° E, at an elevation of 418 meters above sea level. The orchard site region accumulates 701-800 chilling hours and 4001-5000 growing degree hours annually and has an annual average temperature of 20.2°C [16].

2.2 Plant Materials

The research was performed on the fruits of the local nectarine cultivar 'Misky' (yellow-fleshed and clingstone) [1]. Nectarine trees, 7 years old, were grafted onto local peach seedling rootstocks cv. 'Zerk', cultivated in a square arrangement (4 x 4 m), and trained to an open vase system. Healthy fruits that reached optimum maturity with a green background (60 ± 10%) [18] were hand-picked in the early morning (5-8 am) on 1 August 2024. Nectarines were placed in two layers within plastic padded crates and subsequently transported to the cold room for pre-cooling at 2 ± 1°C and 85-95% relative humidity (RH) for 24 hours to eliminate the field heat. Thereafter, fruits exhibiting a uniform color and weight of 130–150 g and an absence of visual defects, bruises, and diseases were selected and disinfected with sodium hypochlorite solution (100 ppm of active chlorine) [24] for 5 minutes, then air-dried.

2.3 Treatments

1-MCP concentrations were prepared and exposed to nectarine fruits following the methodology outlined in references [11, 26], with some changes; the fruits were fumigated with 0, 1, and 2 µL/L of 3.3% 1-MCP (Chesen BioChem Co., Ltd., China) after they were placed in plastic boxes, then put in airtight polystyrene-sealed boxes (93.5 L) in the presence of a glass jar containing 1-MCP and a mini charging fan for 24 hours at 2 ± 1°C. The selected fruits were randomly categorized into three distinct groups. (150 fruits per group) as follows: Fruits from the first group were used as a control (0 µL), and they were placed in a polystyrene-sealed box without fumigation; the second and third groups were fumigated with 1 and 2 µL/L of 1-MCP, respectively. When the fumigation period was completed, polystyrene boxes were opened for about 30 minutes to remove the gas, then the fruits of each treatment were randomly divided into five groups (each for a storage period). Thereafter, 10 fruits represented a replicate according to each treatment and storage duration and were packed in a 2 kg capacity perforated white polyethylene bag (each bag contains 12 pores with a 5 mm diameter). Finally, They were maintained at 1 ± 1°C and 90 ± 5% relative humidity in a cold room for 15, 30, 45, 60, and 75 days. After harvest and at the end of each

storage duration, fruits for each replicate were removed from cold storage and used for measuring changes in chemical, physical, and physiological parameters.

2.4 Measured Parameters

2.4.1 Total Soluble Solids (TSS %), Titratable Acidity (TA %), TSS|TA Ratio, and Vitamin C (mg/100 ml juice)

Total soluble solids (%) were determined by a digital handheld refractometer (Atago, PAL-3, Tokyo, Japan) [30]. Titratable acidity (%) was measured through titrating 10 mL of juice sample with 0.1 N NaOH as the method described by [24]. The TSS/TA ratio was obtained through dividing the TSS of each replicate by the TA of the same replicate. Vitamin C (mg/100 ml) in nectarine juice was determined using titration with 2,6-dichlorophenol indophenol blue pigment, as mentioned by [9].

2.4.2 Carotene Content (mg/100 ml)

The carotene content of the juice of nectarines was determined by blending 2 ml of the juice and 20 ml of acetone (80%) in a blender. Then 0.1 g of sodium bicarbonate was mixed in the solution to avoid carotene pigment oxidation. After that, the solution was then filtered and placed into a 100 ml volumetric flask and made up to the volume with 80% acetone and mixed well. Finally, the optical density of the samples was obtained using a UV/Vis spectrophotometer (JENWAY 6305, UK) at 480 nm [2, 7]. The carotene was determined according to Equation 1.

$$X = \frac{EY}{e \times 100} \times 1000 \quad (1)$$

Whereas:

X = carotene content in 100 ml of solution (mg/100 ml).
E = device reading at 480 nm.
Y = volume of the ultimate solution following dilution with acetone.
e = the specific extinction coefficient, which equal to 2300.

2.4.3 Total Phenol (mg/100 ml)

Total phenol was estimated from nectarines juice using alcoholic hydrochloric acid (95% ethyl alcohol and 1.5 N HCl) by UV/Vis spectrophotometer (JENWAY 6305, UK) at a wavelength of 480 nm as indicated in [15, 21].

2.4.4 Polyphenol Oxidase (PPO) Activity (U/mL)

Polyphenol oxidase activity was analyzed by the method of [8], with slight modifications. In brief, crude extract was made by mixing a 10 g fruit in extraction solution (50 ml of 0.1 M phosphate buffer with 5% PEG at pH 6.5 and 10 mM ascorbic acid) using blender for 5 min. The samples of crude extract were filtered and centrifuged for 20 min at 15000 g and at 4 °C in a refrigerated centrifuge (NUWIND Multi-Application Centrifuge, NU-C200R-E, USA). The PPO activity was determined spectrophotometrically by measuring the initial rate of rise in absorbance at 420 nm using a UV/Vis spectrophotometer (JENWAY 6305, UK).

2.4.5 Weight Loss (%)

Nectarines were weighed at the beginning of the study (Day 0) and at the end of each storage duration. The variance between the initial and final weight of the fruit was regarded as a total weight loss (WL), and the results were expressed as the percentage loss of the initial weight using the Equation 2 that follows [22]:

$$WL\ (\%) = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad (2)$$

2.4.6 Firmness (kg/cm²)

The firmness of nectarines (kg/cm²) was taken on the method used by [30] with few changes. Firmness for two fruits in each replicate was assessed on opposing sides after peeling at the equator of each fruit using a digital fruit hardness tester (Lutron, FR-5120, Taiwan) with an 8-mm penetrometer tip.

2.4.7 Physiological Disorders

Physiological disorders (chilling injury and peel browning %) were calculated on the basis of the number of physiologically damaged fruits, such as flesh mealiness or leathery texture, black pit cavity, and peel browning, as a proportion of the overall count for each replicate, according to the Equation 3 used by [23]:

$$\text{Physiological disorders (\%)} = \frac{\text{Number of damaged fruits}}{\text{Total number of fruits}} \times 100 \qquad (3)$$

2.5 Experimental Design and Statistical Analysis

The trial was organized factorially according to a complete randomized block design [26], including three 1-MCP concentrations (0, 1, and 2 µL/L) and five storage durations (15, 30, 45, 60, and 75 days) with three replications. The gathered data was analyzed utilizing the SAS 9.1 statistical software. Comparisons of means were conducted by using Duncan's multiple range test at $p \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Total Soluble Solids (TSS %), Titratable Acidity (TA %), TSS|TA Ratio, and Vitamin C (mg/100 ml juice)

As displayed in **Figure 1A**, no substantial variations exist among the means of total soluble solids (TSS) throughout the three treatments; however, fruits treated with 2 µL/L exhibited the slightly lowest percentage of TSS. In nectarines and other climacteric fruits, 1-MCP inhibits ethylene activity and reduces respiration rate, hence delaying ripening [10]. It interferes with metabolism associated with ripening, including sugar metabolism [43], resulting in constant TSS content. Similar results from previous studies showed that 1-MCP had no significant effect on the stability of TSS content in nectarines [10]. During the first storage period (15 days), TSS in fruits slightly increased and reached (14.37%), then gradually declined as storage periods advanced and attained (13.36%) at 75 days of storage. The early slight rise in TSS often results from the transformation of residual starch into sugars, whereas the subsequent decline is a consequence of sugar consumption during respiration and senescence. This phenomenon has been extensively documented in nectarines subjected to extended cold storage [24].

1-MCP treatments considerably enhanced the retention of fruit titratable acidity (TA) compared to the control, particularly at a concentration of 2 µL/L, which exhibited significantly the highest TA content (0.82%) relative to the control fruits, which had the lowest value (0.78%) **Figure 1B**. Organic acids are important respiratory substrates. Since 1-MCP blocks ethylene receptors, respiration slows and acids are consumed more slowly, leading to higher TA retention. Recent work confirmed that 1-MCP preserves TA in nectarines and delays ripening by reducing ethylene production [10]. Other research explained that 1-MCP had inhibitory effects on the breakdown of organic acids [4]. In addition, nectarines' content of TA significantly declined gradually as storage periods increased. This is expected as organic acids serve as substrates in respiration and metabolic processes during storage. The reduction in TA is a prominent sign of ripening advancement in climacteric fruits such as nectarines [10]. Our results align with those achieved by [11].

The lowest TSS/TA ratios were recorded in fruits treated with 1-MCP, especially at a concentration of 2 µL/L (18.41), which exhibited a considerable reduction in TSS/TA compared to the control treatment (20.61) **Figure 1C**. The reason behind obtaining the lower ratio was that TSS remained stable while acidity was preserved. This demonstrates that 1-MCP preserved freshness and postponed fruit maturation [10]. In addition, the results indicated that the TSS/TA ratios significantly increased with prolonged storage time. This alteration resulted from an acidity decline that was faster than that of TSS. Elevated ratios signify enhanced ripening, increased sweetness perception, and decreased freshness. Furthermore, the TSS/TA ratio, indicating the impression of sweetness and ripeness, increased significantly along storage periods.

The data that related to the vitamin C content of nectarines showed no statistical differences among the means of treatments **Figure 1D**. On the other hand, the quantity of vitamin C in fruits declined progressively with a prolonged storage duration. The breakdown of vitamin C is closely linked to enzymatic activity and processes of oxidation depending on the cultivar and length of storage. The considerable decrease was due to the oxidation of vitamin C by ascorbate oxidase, reactive oxygen species that are high, and the breakdown of membranes during storage [36]. These results were further confirmed by prior research [11].

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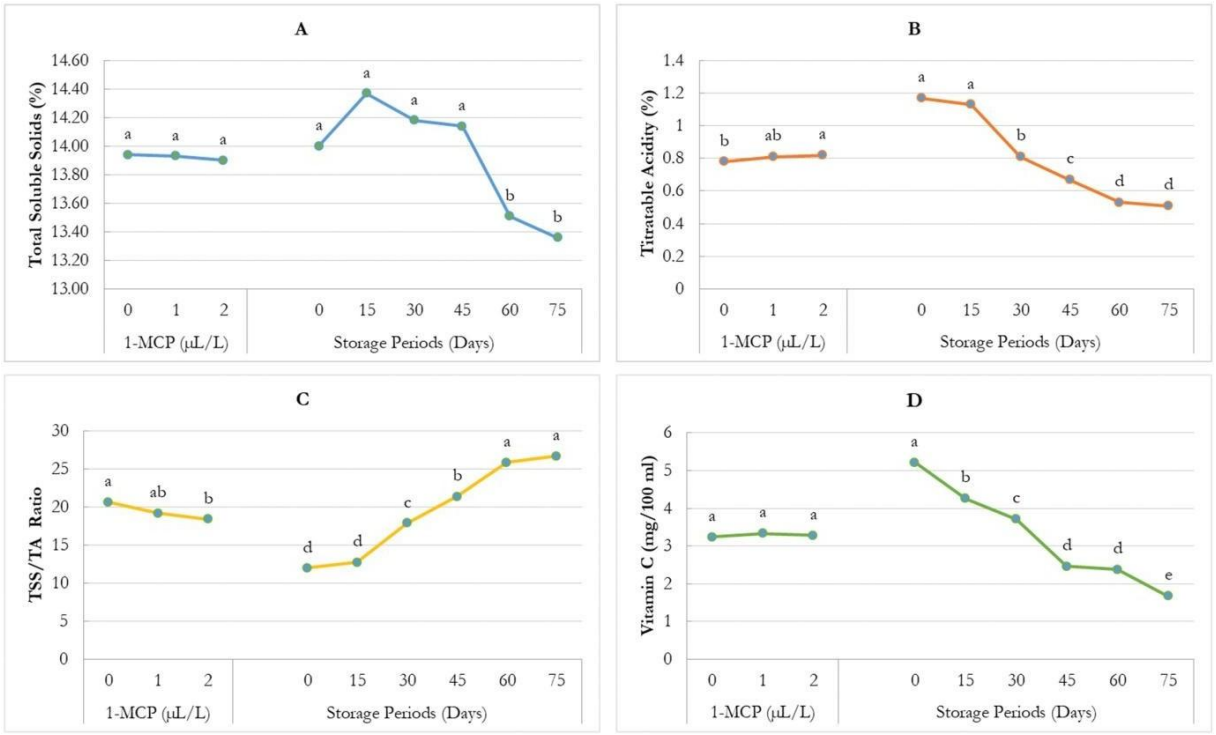


Figure (1): The separate effect of 1-MCP and storage periods on some chemical parameters of Misky nectarines during 75 days cold storage. (A) Total soluble solids, (B) Titratable acidity, (C) TSS/TA ratio, and (D) Vitamin C.

Means of each factor having the same letters in the same line are not significantly different from one another, as determined by Duncan's multiple range test at the 5% level.

3.2. Carotene Content (mg/100 ml)

Fruits fumigated at 1 µL/L recorded the highest mean of total carotene in nectarine fruits. The concentration of 2 µL/L had significantly the lowest mean of total carotene content, as shown in Table 1. The obtained results were primarily associated with 1-MCP's role as an ethylene-action inhibitor. 1-MCP permanently attaches to ethylene receptors, postponing ripening processes such as respiration and oxidative stress, hence maintaining cellular integrity and inhibiting carotenoid degradation during storage.

Prior research on nectarines during cold storage indicated that 1-MCP maintained flesh quality, postponed senescence, and decreased ethylene production [10]. However, the treatment with 1-MCP at 2 µL/L decreased the carotene content since high inhibition of ethylene can inhibit carotenoid biosynthesis pathways. Ethylene strongly regulates carotenoid-associated genes. This explanation was further confirmed by research on peaches, which found that ethylene increased total carotenoids and β-carotene production, while 1-MCP displayed the opposite effect by preventing carotenoid metabolism [32].

Regarding the effect of storage times, there is a significant variation of total carotene amounts during storage. The increase of total carotene content in nectarines during the advanced storage period, particularly at the last interval, can be attributed to ongoing pigment manufacture during progressive ripening and concentration effects resulting from moisture loss [10]. The interaction between 1-MCP and storage intervals significantly influenced the mean of total carotene levels. The maximum carotene concentration was recorded in nectarines subjected to 1 µL/L of 1-MCP after 75 days of storage (0.071 mg/100 mL). The lowest means were seen in the treatment of 2 µL/L during the second storage period.

Table 1. Impact of 1-MCP, Storage Periods, and Their Interactions on Misky Nectarines' Content of Carotene (mg/100 ml) During 75 Days Cold Storage.

1-MCP (µL/L)	Storage Periods (Days)						1-MCP Means
	0	15	30	45	60	75	
0	0.056 c-g	0.064 a-d	0.052 d-g	0.046 efg	0.062 a-d	0.070 ab	0.058 a
1	0.056 c-g	0.067 abc	0.053 d-g	0.044 fg	0.062 a-d	0.071 a	0.059 a
2	0.057 c-f	0.063 a-d	0.043 g	0.048 efg	0.052 d-g	0.058 b-e	0.054 b
Storage Periods Means	0.056 c	0.065 ab	0.049 d	0.046 d	0.059 bc	0.066 a	

Means of every factor and their interactions that have identical letters are not significantly varying, as determined by Duncan's multiple range test at the 5% level.

3.3. Total Phenol (mg/100 ml)

The higher doses of 1-MCP lead to a higher retention of phenols. The nectarines treated with the highest dose (2 µL/L) had a statistically significant higher mean (41.52 mg/100 ml) compared to the control and the 1 µL/L dose (38.77 and 39.21 mg/100 ml) Table 2. The obtained results demonstrate the importance of 1-MCP on phenolic metabolism. 1-MCP is an ethylene action inhibitor, which postpones ripening and senescence [10]. Ethylene inhibition leads to the accumulation of phenolic compounds during storage by postponing their degradation. The same study also reported that the total phenolic content in 1-MCP-treated nectarines exceeded that of the control group [24]. Furthermore, 1-MCP inhibits phenolic degradation, maintains cell membrane integrity of nectarines, and diminishes the activity of oxidation-related enzymes, including PPO [36].

In addition, total phenol content increases progressively during storage, reaching maximum value at 60 days. However, by Day 75, there is a rapid, significant drop down to 36.97 mg/100 ml. The increase in total phenols during the storage of nectarines for up to 60 days might be associated with stress-induced biosynthesis due to cold storage. To alleviate this stress, nectarines produce secondary metabolites, particularly phenolic compounds. While the reasons behind the rapid decline in total phenols during the final storage duration may be due to the nectarines entering aging and cellular breakdown along with residual enzymatic oxidation by PPO. This interpretation is further supported by researchers [24] who showed that the reduction in phenolics was recorded at extended storage of nectarines. Regarding the interaction effect between 1-MCP and storage periods, the treatment of 2 µL/L of 1-MCP worked best in maintaining and improving total phenols across the 2nd to 3rd periods, but its impact declines at very long storage times. Following 75 days, phenols dropped in all treatments, but 1 -MCP remained at relatively higher levels.

Table 2. Impact of 1-MCP, Storage Periods, and Their Interactions on Misky Nectarines' Content of Total Phenols (mg/100 ml) During 75 Days Cold Storage.

1-MCP (µL/L)	Storage Periods (Days)						1-MCP Means
	0	15	30	45	60	75	
0	30.04 f	37.90 de	37.39 de	41.36 cde	49.96 a	35.95 e	38.77 b
1	30.05 f	37.96 de	45.83 abc	40.88 cde	42.99 bcd	37.56 ed	39.21 b
2	30.04 f	38.55 de	47.76 ab	48.19 ab	47.19 ab	37.39 de	41.52 a

Storage Periods Means	30.04 d	38.14 c	43.66 b	43.48 b	46.71 a	36.97 c	

Means of every factor and their interactions that have identical letters are not significantly varying, as determined by Duncan's multiple range test at the 5% level.

3.4 Polyphenol Oxidase (PPO) Activity (U/mL)

Table 3 indicated that 1-MCP treatments, especially at 2 µL/L, significantly inhibited PPO activity in nectarine fruits compared to the control. The fumigation of fruits with 1-MCP decreases PPO activity in nectarines through acting as an ethylene action inhibitor, which delays the ripening of climacteric fruits. This result is performed by slowing respiration, softening, membrane degradation, and oxidative stress, which in turn reduces enzymatic browning and PPO activation. Recent research demonstrated that 1-MCP also inhibits soluble quinone accumulation and decreases PPO and POD activities; consequently, reduced browning and enhanced aroma quality in nectarines [36].

In addition, PPO activity declined during the thirty-day period, then increased significantly with prolonged storage, especially at a period of 75 days, where its peak value was recorded. PPO activity increases during prolonged storage due to senescence, leading to cellular compartment disruption. The PPO enzyme, commonly located in plastids, combines with phenolic substrates in vacuoles, initiating oxidation reactions that convert o-diphenols into o-quinones, which then polymerize to brown pigments [19]. Concerning the interaction impact between the two studied factors on PPO activity in Misky fruits, as in Table 3, both 1-MCP treatments significantly suppressed PPO activity at the final storage time, especially the concentration of 1 µL/L, which was most efficacious (98.67 U/mL), while the control showed the highest mean (198.00 U/mL). The elevated PPO enzyme activity in the control group during the last storage time indicates tissue senescence and oxidative stress.

Table 3. Impact of 1-MCP, Storage Periods, and Their Interactions on Polyphenol Oxidase Activity (U/mL) of Misky Nectarines During 75 Days Cold Storage.

1-MCP (µL/L)	**Storage Periods (Days)**					**1-MCP Means**
	0	**15**	**45**	**60**	**75**	
0	38.00 ef	13.33 h	37.33 ef	26.67 fg	198.00 a	62.67 a
1	38.00 ef	36.67 ef	34.00 ef	54.00 d	98.67 c	52.27 b
2	38.01 ef	17.33 gh	12.00 h	42.67 de	136.00 b	49.20 b
Storage Periods Means	38.00 b	22.44 c	27.78 c	41.11 b	144.22 a	

Means of every factor and their interactions that have identical letters are not significantly varying, as determined by Duncan's multiple range test at the 5% level.

3.5 Weight Loss (%) and Firmness (kg/m²)

The results displayed in **Figure 2** confirm that both 1-MCP treatment and storage duration significantly impacted the physical properties of nectarine fruit. Increasing 1-MCP levels leads to a significant reduction in fruits' weight loss. The 2 µL/L treatment was the most efficient, lowering the nectarine loss from (2.82%) at control to (2.33%). Weight loss is mainly influenced by reductions in water vapor pressure [13]; however, 1-MCP exhibits a considerable affinity for ethylene receptors, inhibiting ethylene sensing and thus postponing climacteric ripening, respiration, membrane degradation, softening, and oxidative stress [3]. The decreased fruit respiration diminishes the use of internal sugars and organic acids, indirectly postponing the decline of total wax content, conserved n-alkanes, and primary alcohols in cuticular wax, which enhances

moisture retention and mitigates postharvest water loss [20]. A recent study by researchers [24] confirmed that 1-MCP-treated nectarines show reduced weight loss compared to the control fruits. On the other hand, fruit weight loss gradually increased with prolonged storage time, attaining 4.16% at 75 days of storage. This increase was due to gradual water loss through transpiration, respiration, and other internal physiological processes throughout the storage time [6]. A study by [24] explained that nectarines' weight loss elevated with advanced storage time.

The 1-MCP treatment significantly maintained fruit firmness compared to the control. The higher firmness was observed in treated fruit with 1-MCP, while the lower mean was recorded in the control treatment **(Figure 2)**. 1-MCP works as an ethylene action inhibitor, consequently postponing ripening, respiration, softening, membrane breakdown, and oxidative damage [3]. This leads to improved maintenance firmness for nectarines. As appeared by researchers [34], 1-MCP maintains fruit firmness by inhibiting the activity of cell wall-degrading enzymes, including polygalacturonase, cellulase, and pectin methyl esterase, thus decreasing pectin solubilization and tissue softening. A recent study by [24] confirmed that 1-MCP-treated nectarines display higher firmness compared to control treatment. Furthermore, the firmness of nectarines declined as storage time increased until 60 days of storage and then suddenly increased at 75 days. The reason for the gradual decline in fruit firmness during prolonged storage is a general trend. As explained by [31], fruit softening emerges as a result of ripening and a breakdown of cell walls. A sudden slight increase in firmness at the final storage time might be due to elevated fruit infection from chilling injury. As appeared in [41], CI leads to leathery fruit with a firm texture.

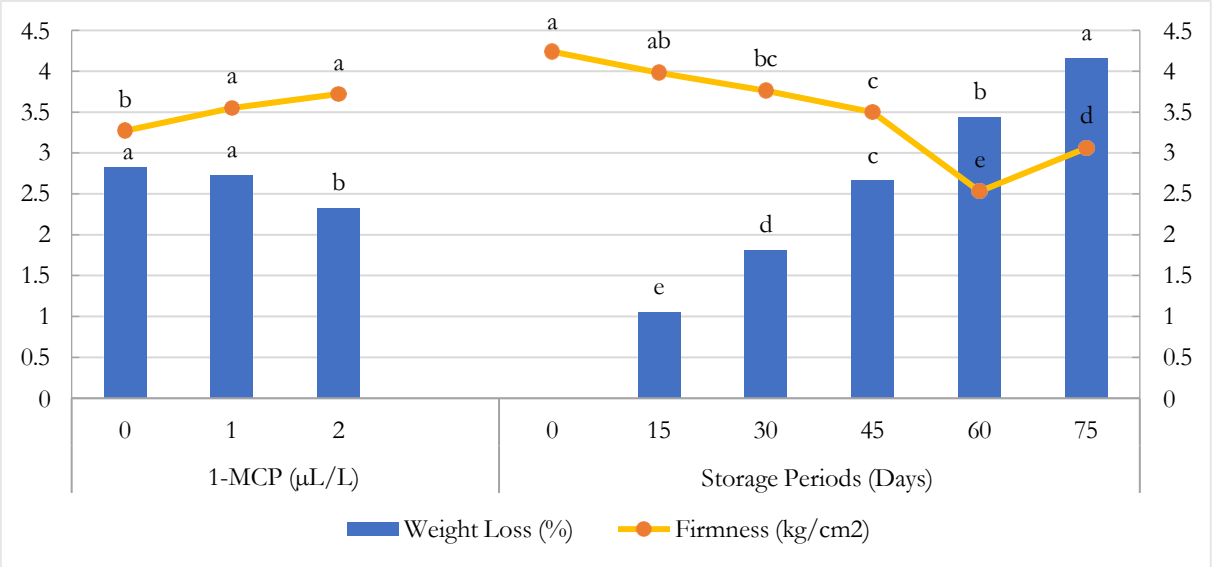


Figure (2): The separate effect of 1-MCP and storage periods on weight loss and firmness of Misky nectarines during 75 Days cold storage.

The means of every factor for each parameter with identical letters are not significantly different from one another, as determined by Duncan's multiple range test at 5% level.

3.6 Physiological Disorders

The results displayed in **Figure 3** demonstrate that both studied factors significantly affected the physiological disorders of fruits. 1-MCP significantly minimized chilling injury (CI) and the percentage of peel browning compared to the control. CI incidence in nectarine fruit is directly associated with the peroxidation of membrane lipids and the oxidative stress caused by low-temperature storage [25]. The reasons behind recording the lower CI in fumigated fruits were explained by [10]; that 1-MCP improves cellular susceptibility to stress from cold, potentially by enhancing antioxidant defense mechanisms and the stability of membrane structures. [42] explained that 1-MCP decreases ROS accumulation and maintains elevated activities of antioxidant enzymes such as superoxide dismutase. The findings were supported by previous investigations [40], indicating that fruits fumigated with 1-MCP markedly reduced the incidence of CI in fruits. Regarding the incidence of peel browning of fruits, it is chiefly induced by the enzymatic oxidation of phenolic substances facilitated by PPO and POD [27]. Fumigated fruits had recorded lower peel browning, and this related to the role of 1-MCP, which either directly or indirectly suppresses

these enzymatic activities by preserving membrane integrity and diminishing substrate-enzyme interaction. The same study also indicated that 1-MCP lowered browning by about 30% through the regulation of PPO and POD activities, as well as a decrease in ROS and soluble quinone buildup [36]. Thus, directly supporting our results on peel browning.

Figure 3 illustrated that no indications of CI were detected in nectarines until 30 days, with minor symptoms emerging at 45 days (3.17%) and developing to 47.22% by the end of the final storage period. Prolonged storage of fruits leads to increased CI resulting from membrane disruption and oxidative stress [5]. A modern study by [38] revealed that symptoms of chilling injury manifest following prolonged cold storage and progress over time.

Moreover, incidence of peel browning elevated with extended storage duration. At the third storage time, it reached (1.11%) and then elevated to (23.67%) at the final storage time **(Figure 3)**. Similarly to chilling injury, peel browning increased substantially at the final period, likely due to raised membrane permeability, elevated phenolic oxidation, and increased enzymatic activity, which induces the oxidation of phenolic compounds and brown pigment [14] and makes fruits unappealing to consumers.

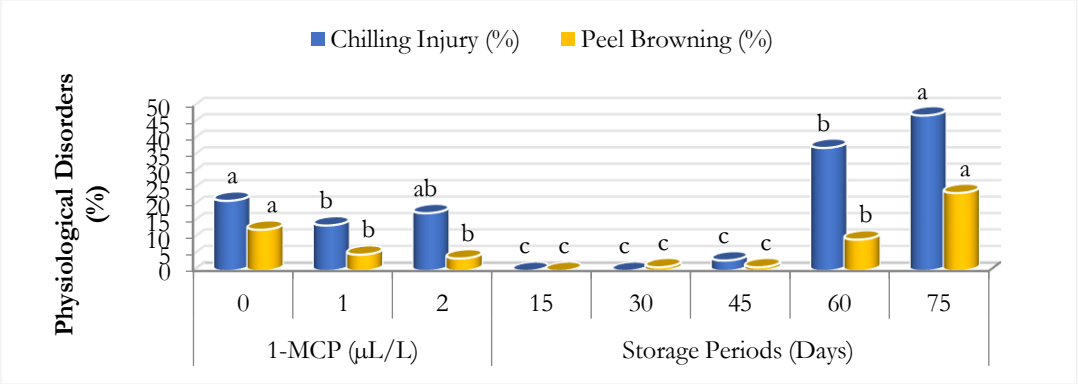


Figure (3): The separate effect of 1-MCP and storage periods on chilling injury and peel browning (%) of Misky nectarines during 75 days cold storage.

Means of each factor followed by the same letters are not significantly different from each other, according to Duncan's multiple range test at the 5% level.

1-MCP treatments employed in this work revealed significant efficacy in postponing the deterioration of fruit quality, mitigating physiological problems, and finally reducing losses in nectarines cv. Misky.

The limitation of this study, generally, is that we faced challenges due to insufficient laboratories, modern apparatus, and chemical materials. We did not measure the respiration rate and ethylene production of nectarines, which were strongly influenced by 1-MCP and play an important role, both directly and indirectly, in fruit quality and storage ability due to the unavailability of suitable apparatus to measure these parameters. If we measured, they would strongly support our results.

4. CONCLUSION

Based on the findings of this investigation, we concluded that 1-MCP fumigation treatments for nectarines cv. Misky, especially the 2 µL/L treatment, are highly effective in retarding declines in fruit weight, firmness, and nutritional quality, as well as in reducing physiological disorders compared to unfumigated nectarines, thereby enhancing marketability. In addition, fruits fumigated with 1-MCP could be stored for 45 days without any signs of peel browning and chilling injuries (at 1 µL/L) and maintain fruit quality. Future researches are needed on the effect of 1-MCP from other origin on local cultivars of fruits including peaches and nectarines, as well as on the maturity stages of nectarines cv. Misky to identify the optimal stage for harvesting. This will help extend storage and shelf life while improving customer acceptance.

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AUTHOR CONTRIBUTIONS

Azad H. Yonis: Methodology, Laboratory Analysis, Data Collection and Curation, Writing.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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