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RESEARCH ON THE EFFECTS OF 1-METHYLCYCLOPROPENE AND MODIFIED ATMOSPHERE PACKAGES ON STORAGE OF NECTARINE FRUITS

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ABSTRACT

The study aimed to determine the effects of 1-methylcyclopropene (1-MCP) and two modified atmosphere packages (MAP) on major quality parameters of 'Sunny' nectarine variety during storage. The experiment was designed to test the six following variables: a) Non-treated in MAP accepted as the control group b) 1-MCP treatment without MAP, c) MAP1 (Lifepack®) d) 1-MCP+MAP1, e) 1-MCP+MAP2 (RipeLock™, closed bag) and f) MAP2 with 1-MCP generator. In all treatments, fruits were stored for 56 days at 0°C and 90% RH. Sampling was done at 14 days intervals, and samples were then kept at for 2 days as shelf life (20°C and 70% RH). During storage, the weight loss significantly increased in applications without MAP, and fruits lost their marketable value due to water loss after 28 days of storage with 2 days shelf life. Combined treatments showed slight decreases in fruit flesh firmness during storage. 1-MCP+MAP treated samples reduced the ethylene production during shelf life after cold storage. The effects of MAP and 1-MCP on total soluble solids, titratable acidity, total phenolic content, and antioxidant activity parameters were insignificant. The results showed that MAP1 and 1-MCP+MAP treatments maintained quality of nectarine fruit and provided longer storage and shelf life.

KEYWORDS :
Prunus persica, decay, ethylene, quality, shelf life, water loss

INTRODUCTION

The rising demand for nectarine (*Prunus persica* var. nectarina Maxim.) fruits both in domestic and foreign markets raised attention in Turkey. The longer postharvest life and higher resistance to transportation of nectarines compared to peaches, increases export opportunities to distant markets [1].

Nectarine fruits are climacteric. Major factors that limit the storage period are fruit softening [2], physiological and pathological disorders [3, 4] and weight loss [5]. Delaying senescence has significant role in extending the storage and shelf life periods. Softening is linked to the increase in ethylene and begins prior to maturation therefore; ethylene production needs to be controlled [6]. Reducing fruit temperature, increasing CO_2 and/or decreasing O_2 concentration and applying 1-MCP (ethylene inhibitor) help control ethylene production [5].

Many postharvest technologies are developed to prolong the storage period and preserve quality of stone fruits. Modified atmosphere (MA) packaging is reported to extend storage periods of stone fruits and preserve their quality [7, 8, 9]. MA packages delay senescence by changing the composition of the atmosphere inside the package and reducing the moisture loss. Thus, MA packages are widely used in post-harvest handling of many fruit and vegetables in order to maintain quality and extend postharvest life [10, 11]. One of the methods that reduce adverse effects of ethylene is the use of 1-MCP known to block the activity of ethylene and slow down ethylene linked biochemical reactions. Various research works are carried out on 1-MCP due to its valued properties such as high efficiency even at very low concentrations, being odorless, commercial availability, easy application, and no toxicity [12]. It is reported that stone fruits treated with 1-MCP preserve their quality better during the storage [13, 14, 15, 16, 17]. Similarly, stone fruits treated with 1-MCP and packed in MAP stored successfully [6, 18, 19, 20]. Studies that investigate the single or combined effects of 1-MCP and MAP treatments on the storability of nectarine fruits are very limited.

This study aimed to determine the effects of 1-MCP and two MAPs on preservation of major quality parameters of 'Sunny' nectarine variety during storage and shelf life.

MATERIALS AND METHODS

Materials. The study was carried out in an orchard established in 2012 with 'Sunny' nectarine variety, (*Prunus persica* var. nectarina, Maxim.) in

İzmir province, western Turkey. The cultural practices as pruning, soil tillage, nutrition, and pest and disease management of the orchard were performed according to the standard practices recommended by the state extension office. The nectarines were harvested at firm maturity stage, and immediately transported to the postharvest laboratory of the Department of Horticulture at Ege University for treatments and analyses.

Two different MAP packages, MAP1 (Lifepack®, Aypek Ambalaj Co., Bursa, Turkey) and MAP2 (RipeLock™, AgroFresh, USA), were used in the study. 1-MCP applied as a special formulation (SmartFresh™, AgroFresh Inc., Dow AgroSciences, USA) at a concentration of 625 ppb in 1 m^3 volume gas-tight cabins. 1-MCP generator (sheet, each 0.625 g), which supplies ca 625 ppb concentration, was installed in RipeLock™ package (AgroFresh Inc., Dow AgroSciences, USA).

Treatments and storage. Six different treatments were applied to pre-cooled nectarine fruits as follows; a) control (non-treated in MAP), b) 1-MCP treatment (625 ppb treatment for 24 hours at 2°C, without MAP), c) MAP1 package, d) 1-MCP+MAP1 (625 ppb was applied to open MAP1 packages at 2°C for 24 hours and then packages were sealed), e) 1-MCP + MAP2 (RipeLock™) (625 ppb was applied to pre-sealed MAP2 packages at 2°C for 24 hours), f) MAP2 (RipeLock™) + 1-MCP generator (1-MCP generator was placed into packages and then packages were sealed).

Both treated and non-treated 'Sunny' nectarine fruits were stored at 0°C and 90 % relative humidity for 56 days [21]. Sample fruits were taken out at 14 days intervals to assess quality. Then, MAP packages were open, and fruits were stored for an additional 2 days at shelf-life conditions (20°C and 70% RH). After shelf-life period, below mentioned measurements and analyses were performend for quality assessment. The study was designed as randomized parcels experimental design with four replicates. Each box having 5 kg of nectarine fruits was accepted as one replicate.

Quality analysis. The nectarine samples were weighted on a precision scale (XB12100; Presica Instruments Ltd., Switzerland) at the initial phase, during storage and after the 2-days shelf life. Weight loss was determined and expressed as percent lost from the initial weight. Fruit firmness was determined using a texture analyzer (GS-15, GÜSS Manufacturing Ltd., South Africa) with a 7.9 mm diameter tip on opposite sides of 15 fruits after removing the peels. The data were calculated as the means of the measurements and expressed in Newton (N). Fruit skin color was determined at the equator on both sides of 15 fruit using a colorimeter (CR-400; Minolta Co., Osaka, Japan), which measured CIE L*, a*, b* values. These values were then used to calculate Chroma ($C^* = [a^{*2} + b^{*2}]^{1/2}$) and hue angle ($h° = \tan^{-1} [b^*/a^*]$) [22]. The total soluble solid (TSS) content of the nectarine juice was determined using a digital refractometer (PR-1; Atago, Tokyo, Japan) and expressed as percent. The titratable acidity (TA) content was determined by titrating 10 mL of extracted juice with 0.1 N NaOH up to pH 8.1. The results were expressed as gram malic acid per 100 mL of fruit juice [5].

Fruit extracts were prepared using methods described by Thaipong *et al.* (2006) [23], with some modifications for total phenolic content and antioxidant activity (in methanol extract) analysis. Total phenolic content was determined by using the Folin–Ciocalteu method based on the methods of Zheng and Wang (2001) [24]. The FRAP assay was performed as previously described by Benzie and Strain (1996) [25]. In this method, antioxidants in the sample reduce Fe (III)/tripyridyltriazine complex to its blue ferrous form, increasing absorbance at 593 nm.

Sensory quality of nectarine fruits was evaluated by a panelist group of 6 according to their overall appearance ranked as 1 to 5 scale (1: Unacceptable, 2: Bad, 3: Medium, 4: Good, 5: Very Good) [26].

Respiration rate and ethylene production. For each measurement, five nectarines per replicates were enclosed in a 1.9 L glass jar for 3 h at 20°C. 5 mL of headspace gas sample was withdrawn from the jar and injected into the gas chromatography device (Agilent Technologies, 6890 N, USA). GS-GASPRO column (30 m 0.32 mm, 0.5 mm film thickness, Agilent J&W GC Columns, USA), TCD and FID detector were used in the measurements. The respiration rate and ethylene production are expressed as mL CO_2/kg.h and as nL/kg.h respectively.

Statistical analysis. All data were subjected to analyses of variance (ANOVA) by using the IBM® SPSS® Statistics 19 statistical software (IBM, NY, USA). Significant differences between the means for each storage period were determined by Duncan's multiple range tests at $P \leq 0.05$.

RESULTS AND DISCUSSION

Changes in weight loss and flesh firmness of nectarine fruits during storage subjected to different treatments are displayed in Figure 1. The effect of treatments on weight loss and flesh firmness was statistically significant ($P \leq 0.01$). The weight loss in nectarines in MAP was lower than the control and 1-MCP treated nectarines after 2 days at shelf life (20°C) after all sampled storage periods (14, 28, 42 and 56 days at 0°C). It was clear that MAP decreased moisture loss of the product as it was reported for many fruit species [7, 9, 10,]. The weight loss rate was similar in control and 1-MCP treated nectarines

after the shelf-life period following 14 days of storage. As the storage is prolonged, the weight loss of 1-MCP treated nectarines was slightly reduced compared to the control. This is compatible with the effect of 1-MCP delaying senescence [27]. The weight loss of control and 1-MCP treated nectarines was determined as 21.36% and 18.52%, respectively, after the shelf life following 56 days of storage. The weight loss ranged between 1.76% and 2.84 % in other tested treatments. During the storage period of 56 days, fruit weight loss increased steadily, and this increase was quite limited in MAP treatments.

Fruit flesh firmness of 1-MCP+MAP1 treated nectarines was the highest after the shelf life following 14 days of storage, while firmness was the lowest in control fruit. The flesh firmness in MAP treatments was similar to MAP1+1-MCP treatment. The fruit flesh firmness in MAP and MAP+1-MCP treatments was evidently higher than the control and 1-MCP treatments after the shelf life following 14, 28 and 56 days of storage. Single MAP and MAP+1-MCP treatments retarded fruit softening by slowing down the senescence process. Similar results were identified in Tegan Blue [28], Autumn Giant, Black [19] and Angeleno [20] plum varieties, and Monroe and Blake peach varieties [9]. The flesh firmness of 1-MCP treated nectarines was higher than the control after the shelf life following 28 days of storage. However, this difference dimished during the later storage periods sampled. The retarding effect of 1-MCP on softening during the early stages of the storage is in line with the effect of 1-MCP on senescence. There are numerous studies that report effectiveness of 1-MCP on retaining of fruit flesh firmness [13, 14, 16, 17]. However, during the later storage periods towards senescence, this effect decreased. As the storage period advanced, flesh firmness decreased steadily in all treatments, however this decrease was more prominent in the control treatment (80%).

Changes in fruit peel color C* and h° values of different treatments during the storage period are shown in Table 1. Tested treatments had significant effects on peel C* and h° values of nectarines ($P \leq 0.05$) after the shelf life following 28 days of storage. As the storage period extends, the differences diminish. The peel C* value of control and 1-MCP treated nectarine fruits was lower than the 1-MCP+MAP2 treated fruits after the shelf life following 14 days of storage. The peel C* value of control and 1-MCP treated nectarine fruits was lower than the 1-MCP+MAP1 and 1-MCP+MAP2 treated fruits after the shelf life following 28 days of storage. Such differences among the treatments disappeared during the later storage periods, and the peel C* value ranged within narrower limits as 28.93 and 31.29. Changes in peel C* value of nectarine fruits were limited.

The peel h° value of MAP2+1-MCP treated nectarines was higher than the control after the shelf life following 2 and 28 days of storage. Some studies reported that 1-MCP treatment delays color changes in apricot and plum [14, 16, 17, 29], whereas some other studies reported the opposite effect [4, 20], thus the effect of 1-MCP treatment on color is not fully unveiled. During the later storage periods, the peel h° value of nectarine fruits were similar (22.83-24.95). At the end of the storage, the peel h° value was slightly decreased in comparison to the first measurements (29.18).

The TSS and TA contents of nectarine fruits measured in different treatments are presented in Table 2. Effect of treatments on TSS and TA contents was not significant during the storage period. The TSS content varied between 13.3% and 15.4% during the storage period, which was initially 15.4%. The TA contents of nectarine fruits varied between 0.22 and 0.26 g malic acid 100 mL^{-1}, after 2 days at shelf life conditions following 42 days of storage. Studies on plums stated that 1-MCP does not have any impact on TSS and TA contents [13, 20]. However, Erkan and Eski (2012) [19] reported that the TA and TSS contents of 1-MCP+MAP treated Autumn Giant and Black plum fruits were higher than the control fruit. The effect of 1-MCP treatment on these parameters may vary due to various factors as variety, storage conditions or concentration of the treatments [27]. A steady decrease was observed in TA content of nectarine fruits during the storage period.

Changes in total phenolic content and antioxidant activity of nectarine fruits in storage are shown in Table 3. During the storage period, treatments exerted similar effects on the total phenol content and antioxidant activity of nectarine fruits. The total phenolic contents varied between 51.24-57.34, 49.10-58.24 and 46.36-54.44 mg GAE 100/g, respectively, in samples analyzed after 2 days of shelf life following 2, 4 and 42 days of cold storage. The antioxidant activity of nectarine fruits varied between 4.35 and 4.94 µmol TE/g after shelf-life following 42 days of storage, which was initially 6.49 µmol TE/g. The total phenolic content and antioxidant activity of nectarines declined at the end of the storage period if compared to the initial values. However, no differences were observed among the tested treatments. Factors such as variety, growing conditions and practices, maturity stage, climate and seasonal conditions and extraction methods may affect the total phenolic content and antioxidant activity of nectarine fruits overshadowing the effect of treatments [30].

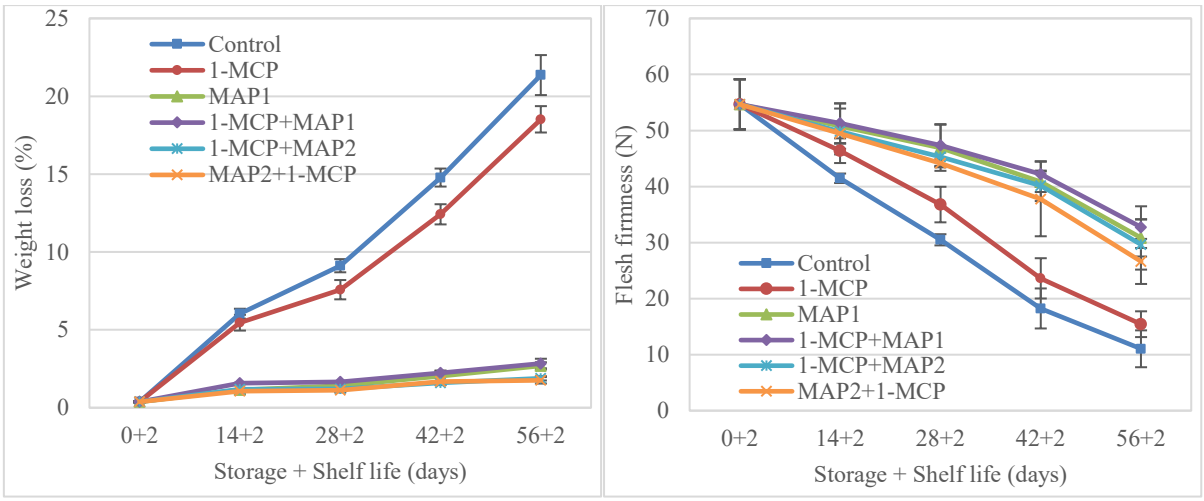

FIGURE 1
Effects of different treatments on weight loss (%) and flesh firmness (N) of nectarine fruits during the cold storage period followed by shelf-life.

TABLE 1
Effects of different treatments on peel color C* and h° values of nectarine fruits sampled during storage period

	Treatments	Storage + Shelf life (days)				
		0+2	14+2	28+2	42+2	56+2
Peel C* value	Control	26.10	29.24 b^{z}*	28.53 c*	28.93^{NS}	
	1-MCP	26.10	28.73 b	29.50 bc	29.24	
	MAP1	26.10	31.65 ab	32.26 ab	31.29	30.57^{NS}
	1-MCP+MAP1	26.10	32.61 ab	33.96 a	30.01	30.54
	1-MCP+MAP2	26.10	34.70 a	33.69 a	29.45	30.63
	MAP2+1-MCP	26.10	31.53 ab	31.36 ab	29.73	28.98
Peel h° value	Control	29.18	26.84 b^{z}*	23.47 c*	22.83^{NS}	
	1-MCP	29.18	27.84 ab	26.83 ab	23.84	
	MAP1	29.18	30.51 ab	29.36 ab	24.90	24.95^{NS}
	1-MCP+MAP1	29.18	29.22 ab	28.64 ab	23.97	23.60
	1-MCP+MAP2	29.18	30.90 a	29.44 a	24.28	24.16
	MAP2+1-MCP	29.18	28.98 ab	27.95 ab	24.10	23.32

^{z}Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.
^{NS}, *, Nonsignificant or significant at $P \leq 0.05$.

TABLE 2
Effects of different treatments on TSS and TA contents of nectarine fruits sampled during storage period

	Treatments	Storage + Shelf life (days)				
		0+2	14+2	28+2	42+2	56+2
TSS content (%)	Control	15.40	15.17^{NS}	14.23^{NS}	14.67^{NS}	
	1-MCP	15.40	15.43	15.17	14.60	
	MAP1	15.40	14.93	15.07	14.30	13.97^{NS}
	1-MCP+MAP1	15.40	14.60	14.47	14.53	14.07
	1-MCP+MAP2	15.40	14.47	14.60	13.70	13.10
	MAP2+1-MCP	15.40	14.53	14.10	14.03	13.30
TA content (g malic acid/ 100 mL)	Control	0.46	0.40^{NS}	0.3^{NS}	0.25^{NS}	
	1-MCP	0.46	0.42	0.33	0.26	
	MAP1	0.46	0.40	0.29	0.24	0.24^{NS}
	1-MCP+MAP1	0.46	0.36	0.33	0.22	0.22
	1-MCP+MAP2	0.46	0.34	0.29	0.23	0.22
	MAP2+1-MCP	0.46	0.36	0.29	0.23	0.23

^{NS}, Nonsignificant.

TABLE 3
Effects of different treatments on the total phenol content and antioxidant activity of nectarine fruits sampled during storage period

	Treatments	Storage + Shelf life (days)				
		0+2	14+2	28+2	42+2	56+2
Total phenol content (mg GAE/ 100 g)	Control	56.14	54.58^{NS}	49.10^{NS}	53.26^{NS}	
	1-MCP	56.14	57.34	52.64	54.44	
	MAP1	56.14	51.24	51.76	49.68	43.64^{NS}
	1-MCP+MAP1	56.14	55.32	56.04	48.26	46.60
	1-MCP+MAP2	56.14	57.44	58.24	49.16	40.14
	MAP2+1-MCP	56.14	55.73	50.66	46.36	40.44
Antioxdant activity (µmol TE/g)	Control	6.49	6.34^{NS}	4.93^{NS}	4.89^{NS}	
	1-MCP	6.49	6.50	4.93	4.56	
	MAP1	6.49	5.28	4.76	4.94	3.63^{NS}
	1-MCP+MAP1	6.49	5.79	5.31	4.46	3.94
	1-MCP+MAP2	6.49	6.18	5.49	4.76	3.21
	MAP2+1-MCP	6.49	5.03	5.16	4.35	3.34

^{NS}, Nonsignificant.

Sensory evaluation scores of nectarines subjected to different treatments are presented in Table 4. Effect of tested treatments on sensory scores was non-significant after 2-days at shelf life following 14 days of storage. However, the effect of different treatments was significant in fruit stored for 28, 42 and 56 days. Control and 1-MCP treated nectarine fruits had lower scores than the other treatments after the shelf life following 28, 42 and 56 days of storage. The marketability of control and 1-MCP treated nectarines was lost after the shelf life following 6 and 56 days of storage, and the scores ranged between 1.17 and 2.33. The nectarine fruits treated with MAP had significantly higher appearance scores (3.67-4.00) at the end of the storage period (56 days at 0°C+2 days at 20°C). A steady decrease was observed in the appearance of control and 1-MCP treated nectarines during the storage period, while the changes remained limited in the other treatments. The overall appearance scores of control and 1-MCP treated nectarines were low due to shriveling related to water loss and softening of fruit flesh related to senescence. MAP alone or in combination with 1-MCP treatments displayed limited water loss and senescence [9, 10, 19, 20, 27, 28].

The respiration rate and of ethylene production in the nectarine fruits exhibited a typical climacteric pattern in control and MAP-stored samples, whereas the 1-MCP+MAP treated samples had reduced ethylene production during shelf life in addition to storage (Figure 2) as reported in several fruits [31].

Nectarine fruit in control treatment had higher respiration rates than 1-MCP+MAP samples after the shelf life following 56 days of storage. Additionally, during the shelf-life simulation, the respiration rate of the controls was similar to 1-MCP+MAP treated fruit up to days 42. This situation is typical of climacteric fruits and has also been reported for Honey peaches [32].

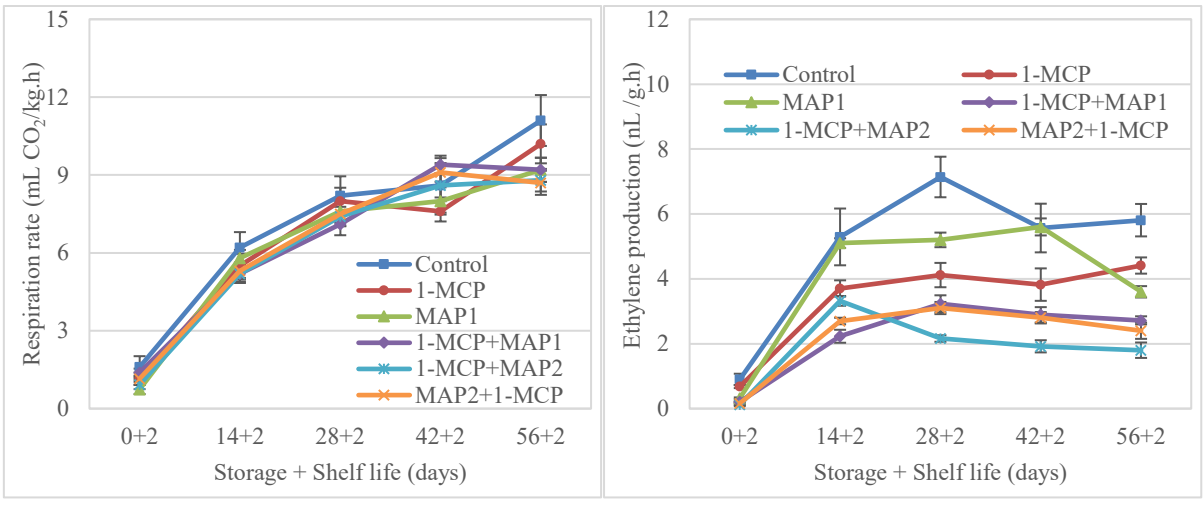

FIGURE 2
Effects of different treatments on respiration rate and ethylene production of nectarine fruits during thecold storage period followed by shelf-life.

TABLE 4
Effects of different treatments on overall appearance (1-5 scale) of nectarine fruits sampled during storage period

Treatments	Storage + Shelf life (days)				
	0+2	14+2	28+2	42+2	56+2
Control	5.0	3.7^{NS}	2.8 b^{z}*	1.7 b**	1.2 b**
1-MCP	5.0	3.8	3.2 b	2.3 b	1.3 b
MAP1	5.0	4.5	4.3 a	4.2 a	3.7 a
1-MCP+MAP1	5.0	4.8	4.5 a	4.2 a	4.2 a
1-MCP+MAP2	5.0	4.8	4.7 a	4.3 a	4.0 a
MAP2+1-MCP	5.0	4.7	4.3 a	4.0 a	3.8 a

^{z}Mean separation within columns by Duncan's multiple range test, $P \leq 0.05$.
^{NS}, *, **, Nonsignificant or significant at $P \leq 0.05$, or 0.01, respectively.

CONCLUSION

The non-treated control and 1-MCP treated nectarine fruits lost their marketability due to weight loss and softening as the storage period extended. On the other hand, results show that nectarine fruits could be successfully stored with MAP and 1-MCP treatment for 42 days+2 days at shelf-life conditions. 1-MCP + RipeLock™ (MAP2) treatment in nectarine storage may be preferred due to its ease in application and lower water loss rates.

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