Turkish Journal of Agriculture and Forestry

Volume 48 | Number 1 Article 8

2-1-2024

Influence of storage technology and 1-methylcyclopropene on postharvest behaviorof ‘Ankara’ pear

ÖZGE HORZUM
ozupek@agri.ankara.edu.tr

NURDAN TUNA GÜNEŞ
tuna@agri.ankara.edu.tr

TÜBİTAK

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2024) 48: 81-94

doi:10.55730/1300-011X.3164

Influence of storage technology and 1-methylcyclopropene on postharvest behavior of 'Ankara' pear

Özge HORZUM, Nurdan TUNA GÜNEŞ*

Department of Horticulture, Faculty of Agriculture, Ankara University, Ankara, Turkiye

Received: 26.05.2023 • **Accepted/Published Online:** 07.11.2023 • **Final Version:** 01.02.2024

Abstract: This study was carried out in order to gain a better understanding of the effects of 1-methylcyclopropene (1-MCP) and controlled atmosphere (CA) storage on the quality of 'Ankara' pears after 210 days of cold storage at 0 °C plus 14 days of shelf life at 20 °C. Fruits were harvested at commercial harvest time (flesh firmness of 75–80 N, soluble solids content of 14%–16%) and stored in regular air (RA) or CA storage (3% O_2 + 1.5% CO_2) after treatment with or without 1-MCP (300 nL L^{-1}). Ripening was delayed by 1-MCP treatment and CA storage as evidenced by lower ethylene production, respiration rate, fermentative products, and sensory evaluation scores and slower softening compared to fruits stored in RA. 1-MCP and CA also affected the amounts of sucrose and glucose, but not the fructose contents of the fruits. The results show that the positive effects of 1-MCP and CA storage for 'Ankara' pear fruits are individual, especially regarding quality parameters. This could be taken into account with the commercial use of these promising postharvest technologies for 'Ankara' pears.

Key words: Controlled atmosphere storage, ethylene, respiration, sugar, sensory evaluation

1. Introduction

Winter pears need postharvest chilling to ripen properly (Villalobos-Acuña and Mitcham, 2008). However, there are difficulties in the storage of winter pears due to the increase in pear production and insufficient cold storage capacity around the world. In order to preserve the quality of winter pear fruits during long-term storage successfully, it is crucial that postharvest techniques focus on the requirements of winter pears and the factors that affect storability (Sugar, 2007).

Controlled atmosphere (CA) storage is an eco-friendly postharvest technology. It allows European pears to be stored at low temperatures with limited quality loss (Saquet et al., 2017) by delaying fruit ripening (Guo et al., 2020). However, since it is a high-capital technique, it cannot be used in many parts of the world. Therefore, in recent years, 1-methylcyclopropene (1-MCP) has become widespread as an alternative to CA storage technology (Rizzolo et al., 2015). 1-MCP is an organic compound that can block and prevent the negative effects of ethylene during storage and shelf life (Watkins, 2015). The action of 1-MCP is a result of its binding to ethylene receptors and the blocking of ethylene connections in that region, thereby slowing down the physiological response and respiration rate. It retards acidity loss, softening, skin yellowing, scald, and flesh browning in many European pear cultivars (Vanoli et al., 2016; Guo et al., 2020). Moreover, it has positive effects in terms of maintaining quality during the postharvest period in Turkish pear cultivars (Bakoğlu and Tuna Gunes, 2018; Kurubaş and Erkan, 2018). On the other hand, 1-MCP sometimes blocks the regaining of the ripening ability of fruits after long-term cold storage in European pear cultivars such as 'Alexander Lucas' and 'd'Anjou' (Hewitt et al., 2020; Dias et al., 2021). The effectiveness of 1-MCP for pear fruits varies depending on the cultivar, growing conditions, maturity stage, 1-MCP dose, storage type, and storage conditions (Watkins, 2015; Vanoli et al., 2016). Today in the fruit industry, 1-MCP may be used in combination with CA storage technology in order to extend the keeping quality of pear fruit (Ribeiro et al., 2008). However, pears treated with 1-MCP may demonstrate different postharvest characteristics during their periods after regular air (RA) and CA storage depending on the cultivar. Some cultivars react positively to 1-MCP treatment, with increases in their storability periods, while others either cannot regain their ripening ability or become sensitive to certain physiological disorders after different types of storage conditions (Saquet, 2019).

The 'Ankara' pear cultivar is one of the winter-type European pear (*Pyrus communis* L.) cultivars of Türkiye.

* Correspondence: tuna@agri.ankara.edu.tr

It is very sweet and juicy and has a buttery texture at the ripening stage. The harvest window of this cultivar occurs in September and October (Dumanoğlu et al., 2021). As is seen for other European pears (Saquet and Almeida, 2017; Dias et al., 2022), the 'Ankara' cultivar shows climacteric characteristics with increases in respiration rate and ethylene production during ripening. Consequently, the inhibition of ethylene biosynthesis slows its ripening and allows for a longer storage period (Tuna Güneş et al., 2007). However, there is no research to date focusing on the combined effects of 1-MCP treatment and CA storage on 'Ankara' pear fruits. In the present study, we investigated the effects of 1-MCP treatment and CA storage technology on the storability of 'Ankara' pears during their shelf life after certain durations of cold storage.

2. Materials and methods

2.1. Fruit material, 1-MCP treatment, and storage conditions

'Ankara' pear fruits were harvested from a commercial orchard in Yenikent-Sincan in Ankara Province, Türkiye (Central Anatolian Region; 40°00′19.0″N, 32°31′29.0″E), at commercial maturity (firmness of 75–80 N, soluble solids content of 14%–16%) and were immediately transported to the Postharvest Laboratory. A group of fruits were then treated with 300 nL L^{-1} 1-MCP (SmartFresh™, AgroFresh Solutions, Inc., Philadelphia, PA, USA) at 20 ± 1 °C under gas-tight conditions for 24 h as suggested by the distributor company of 1-MCP. A similar quantity of fruit not exposed to 1-MCP was held under the same conditions. Fruits treated and not treated with 1-MCP were stored in RA and CA (3% O_2 + 1.5% CO_2) storage conditions at 0 ± 1 °C and 85%–90% relative humidity for 210 days. The gas composition inside the gas-tight CA cabinets (Fruit Control C.A. Technologies, Milan, Italy) were digitally monitored. Fruit were transported to room conditions (20 ± 1 °C) for 7 to 14 days after a certain duration of cold storage in order to observe changes during shelf life.

2.2. Respiration rate and ethylene production

Previously weighed fruits were sealed in a jar for 1 h and the headspace gas composition was measured with an infrared CO_2 analyzer (PA 404, Servomex, East Sussex, UK). The respiration rate was calculated using CO_2, time, and the weight and volume of the fruit as mL CO_2 kg^{-1} h^{-1} (Klein and Lurie, 1990).For ethylene production, a gas sample of 1 mL from the same headspace was injected into a gas chromatography device (ThermoQuest 2000, Thermo Fisher Scientific, Waltham, MA, USA) equipped with a flame ionization detector. An activated alumina stainless steel column (1 m, 80/100 mesh, Supelco 120-99, Sigma-Aldrich, St. Louis, MO, USA) and nitrogen (99.9%) at a flow rate of 40 mL min^{-1} as a carrier gas were used during analysis. The oven, injection, and detector temperatures were 100, 100, and 120 °C, respectively. Results were calculated by comparisons to an external ethylene standard (Alltech, Nicholasville, KY, USA) as μL C_2H_4 kg^{-1} h^{-1} (Bangerth, 1978; Dong et al., 2018).

2.3. Flesh firmness

Flesh firmness was evaluated at three different points of the equatorial region of the fruit using a hand penetrometer (FT 327, Effegi, Milan, Italy) equipped with a plunger of 7.9 mm in diameter after removing the skin of the fruit with a peeler (Larrigaudière et al., 2004).

2.4. Soluble solids and titratable acidity content

Soluble solids content was determined with a digital Abbe refractometer (Leica 10480, Leica Camera, Wetzlar, Germany) using fruit juices obtained by squeezing and filtering.

Fruit juice (5 mL) with the addition of 50 mL of double deionized water (DDW) was titrated with 0.1 N NaOH solution (Merck 106462, Merck, Darmstadt, Germany) until pH 8.1 using an automatic titrator (DL 50 Graphix, Mettler Toledo, Columbus, OH, USA) and the titratable acidity results were expressed as malic acid %.

2.5. Sugar content

Pear samples of about 10 g were homogenized (Janke & Kunkel, Ultraturrax 725, IKA, İstanbul, Türkiye) in 20 mL of DDW for 1 min at 24,000 rpm and were then centrifuged (Sigma 3K30, Sigma-Aldrich) at 15,000 rpm at 1 °C for 30 min. The supernatant was filtered (Millex®-HV, SLHV013NK, Millipore, Merck) and then taken up into screw vials (SV-15B, AIM , Prospect, SA, Australia). Separation of individual sugars was achieved with an Aminex column (Phenomenex Rezex RCM-Monosaccharide, Bio-Rad, Hercules, CA, USA) with a high-pressure liquid chromatography device (LC10-ATVPi, Shimadzu, Kyoto, Japan) equipped with a refractive index detector (RID 10A, Shimadzu). During analysis, the automatic sampler and oven temperatures were set to 4 and 80 °C, respectively. DDW was used as the carrier phase at a flow rate of 0.6 mL min^{-1}. Sucrose (Sigma, S7903), glucose (Sigma, G7528), and fructose (Sigma, F2543) standards were used for the identification and quantification of sugar peaks (Tuna Gunes and Poyrazoğlu, 2022).

2.6. Fermentative products

Fermentative products were determined in the fruit juices of 'Ankara' pears according to the method of Ke et al. (1994) with slight modifications. Briefly, 5 mL of fruit juice in a sealed vacuum test tube (16 × 100 mm, Hema Tube, Hemalab, Ankara, Türkiye) was incubated at 45 °C for 15 min in a water bath (BM 402, Nüve, Ankara, Türkiye). Gas samples taken from the headspace of the tubes were analyzed by gas chromatography (ThermoQuest 2000, Thermo Fisher Scientific) equipped with a flame ionization detector and a Carbopack column (Carbowax 5%, 60/80 mesh, Supelco, Sigma-Aldrich). The temperatures of the

oven, injection, and detector were set to 80, 100, and 150 °C, respectively. Nitrogen (99.9%) was used as the carrier gas at a flow rate of 40 mL min^{-1}. Identification and quantification of the peaks were performed using regression lines plotted for different concentrations of acetaldehyde (PubChem CID: 177, Merck 800004), ethanol (PubChem CID: 702, Merck 100983), and methanol (PubChem CID: 887, Merck 106007) standards.

2.7. Cuticular wax content

Fruits were completely immersed in a solution of chloroform (PubChem CID: 6212, Merck 102445) and methanol (PubChem CID: 887, Merck 106007) (v/v, 3/1) at room temperature for 2 min under a fume hood, and then the solution including the cuticular waxes was transferred to a preweighed round-bottomed flask and all of the solution was evaporated at 40 °C on a rotary evaporator (Laborota 4000, Heidolph, Schwabach, Germany). The cuticular wax quantity was then recorded by weighing the flask after the evaporation procedure (Lurie et al., 1996).

2.8. Sensory evaluations

Sensory evaluations were performed according to the method of Predieri and Gatti (2009) with some modifications. Slices of 5 mm in thickness from each fruit were put into previously numbered separate plates for 10 trained assessors. These slices were served with water and unsalted bread. The juiciness, sweetness, bitterness, and alcohol flavor of the fruits were determined as sensory parameters. These properties were scored on a range from 1 point (very bad, not marketable) to 10 points (very good, marketable).

2.9. Data analysis

This study was based on completely randomized experimental design with 3 replications and 10 randomly selected fruits were used in each replication. Analysis of variance (ANOVA) was performed on the data at an error level of $p \leq 0.05$ using MINITAB 17 software (trial version). Storage period, shelf life, storage type, and 1-MCP treatment were taken into consideration as independent variables or factors in this experiment. Means were compared with Tukey's test using MSTAT-C software (Michigan State University, East Lansing, MI, USA) and significant differences among means were marked with letters in tables.

3. Results

3.1. Respiration rate and ethylene production

The respiration rate (RR) of 'Ankara' pear fruits increased according to the cold storage period (Table 1). It was lower in fruits treated with 1-MCP than in nontreated fruits and RA storage conditions caused higher RR values (Figure 1). Climacteric conditions in RR occurred on the 150 + 7th day in RA-stored fruit without 1-MCP treatment, but in CA-stored fruit without 1-MCP treatment, this was delayed by 1 week during the shelf life period (Figure 1). In the CA + 1-MCP and RA + 1-MCP treatments, a sharp increase in RR was observed after the 180th day of cold storage. During the storage period, differences in the average RR values became significant after 90 days and the highest average RR was observed on the 210th day as 10.70 mL CO_2 kg^{-1} h^{-1}. Based on these average values, CA conditions and 1-MCP treatment prevented an increase in RR. In the fruits treated with 1-MCP, a statistical difference in RR was not observed between the fruit stored in RA (5.21 mL CO_2 kg^{-1} h^{-1}) and CA (5.30 mL CO_2 kg^{-1} h^{-1}) conditions, while in both storage conditions, 1-MCP treatments resulted in lower RR values. Our results showed that 1-MCP and CA storage were effective independently of each other in slowing the RR of the fruits (Table 1).

The ethylene production (EP) of 'Ankara' pear fruits increased in parallel with the progression of the cold storage period and shelf life (Table 1; Figure 1). The highest ethylene production was observed on the 150 + 14th day. Based on the average values, CA storage (23.15 µL C_2H_4 kg^{-1} h^{-1}) and 1-MCP treatment (18.85 µL C_2H_4 kg^{-1} h^{-1}) individually delayed an increase and slowed the EP by at least twofold in the pears during the storage and shelf life periods (Table 1). When we considered the effect of 1-MCP for each storage method, it was seen that fruits treated with 1-MCP had lower EP values. In fruits treated with 1-MCP, CA storage caused an EP value of 19.25 µL C_2H_4 kg^{-1} h^{-1}, while this was 18.45 µL C_2H_4 kg^{-1} h^{-1} for fruit stored in RA conditions, representing a statistically insignificant difference (Table 1). This demonstrated that CA technology and 1-MCP treatment could each be used alone to inhibit EP during the shelf life of 'Ankara' pears.

3.2. Flesh firmness

The firmness of the fruit significantly decreased throughout the storage and shelf life periods. At the beginning of storage, this value was recorded as 79.78 N, and at the end, it reached 29.98 N (Table 1). During the shelf life period, the firmness value for the 14th day (49.26 N) was significantly lower than the value for the 7th day (49.26). It is also possible to discuss the protective effect of CA conditions as fruit stored under CA conditions showed higher firmness (50.21 N). A similar situation was valid for fruits treated with 1-MCP (54.30 N). 1-MCP treatment was effective in maintaining fruit firmness in both RA (54.40 N) and CA (54.19 N) storage conditions and the differences were not significant between these two storage technologies. Thus, the effect of 1-MCP is more pronounced than that of CA storage (Table 2).

3.3. Soluble solids content and titratable acidity

Soluble solids content (SSC) and titratable acidity (TA) values of 'Ankara' pear fruits were recorded as 15.20% and 0.40% malic acid at the beginning of the cold storage period and as 13.77% and 0.22% malic acid at the end of the storage period, continuously decreasing (Table 2). The decline in these parameters continued with the extension of

Table 1. Effects of different variables on respiration rate and ethylene production of 'Ankara' pear fruits.

Significant effects[1]	Respiration rate (mL CO_2 kg^{-1} h^{-1})	Ethylene production (µL kg^{-1} h^{-1})
SP (days)		
0	3.64 ± 0.05 C[2]	0.45 ± 0.03 F[2]
90	4.66 ± 0.32 C	16.67 ± 4.90 E
120	6.34 ± 0.55 B	21.60 ± 6.17 D
150	6.74 ± 0.57 B	36.54 ± 9.48 C
180	6.99 ± 0.56 B	52.60 ± 5.51 B
210	10.70 ± 0.61 A	66.47 ± 2.40 A
SL (days)		
7	6.31 ± 0.39 ns[2]	29.40 ± 3.77 B[2]
14	6.72 ± 0.37 ns	35.38 ± 4.45 A
ST		
RA	7.24 ± 0.44 A[2]	41.63 ± 4.65 A[2]
CA	5.79 ± 0.29 B	23.15 ± 3.19 B
T		
–1-MCP	7.77 ± 0.42 A[2]	45.93 ± 4.53 A[2]
+1-MCP	5.25 ± 0.27 B	18.85 ± 2.93 B
ST × T		
RA × –1-MCP	9.26 ± 0.64 A, a[3]	64.81 ± 6.29 A, a[3]
CA × –1-MCP	6.28 ± 0.40 B, a	27.06 ± 4.83 B, a
RA × +1-MCP	5.21 ± 0.37 A, b	18.45 ± 4.19 A, b
CA × +1-MCP	5.30 ± 0.39 A, b	19.25 ± 4.15 A, b

[1] SP: Storage period; SL: shelf life; ST: storage type; RA: regular air storage; CA: controlled atmosphere storage; T: treatment.
[2] Data are presented as mean ± standard error of mean (SEM); different letters in the same column are significantly different; ns: nonsignificant at $p \leq 0.05$ error level.
[3] Capital letters of the same color show differences among storage types for each treatment and lowercase letters of the same color show differences between treatments for each storage type at $p \leq 0.05$ error level according to Tukey's test.

the shelf life periods. CA storage conditions maintained the SSC (14.61%) and TA (0.30% malic acid) values better than RA storage. However, RA storage + 1-MCP treatment (14.69% and 0.31% malic acid, respectively) was more effective for maintaining these parameters than RA without 1-MCP (14.235% and 0.27% malic acid, respectively). Moreover, 1-MCP treatment largely prevented the decrease in SSC (14.71%) and TA (0.3% malic acid) in both storage conditions. However, under CA conditions, there was no clear distinction between fruits treated with 1-MCP (0.31% malic acid) and nontreated fruits (0.30% malic acid) (Table 2).

3.4. Sugar content

During the storage period, sucrose contents gradually decreased, while glucose and fructose contents increased within 90 days and showed lower values in the last two analysis periods (Table 3). The highest glucose values were recorded on the 90th and 120th days as 5.36 g 100 g^{-1} FW and 5.16 g 100 g^{-1} FW, respectively. The highest fructose amounts were attained on the 90th (6.76 g 100 g^{-1} FW), 120th (6.81 g 100 g^{-1} FW), and 150th (6.59 g 100 g^{-1} FW) days of the cold storage period. In general, all individual sugars had the lowest values at the end of the entire storage period. Fructose was the dominant sugar in 'Ankara' pear fruits, followed by glucose and sucrose. The shelf life period significantly affected only sucrose contents; after a shelf life period of 7 days, the fruits had higher sucrose contents (1.75 g 100 g^{-1} FW). Storage type and 1-MCP treatment were effective on only sucrose and glucose contents. CA storage conditions caused higher sucrose (1.76 g 100 g^{-1} FW) and glucose (4.78 g 100 g^{-1} FW) contents in the fruits than RA storage (1.70 g 100 g^{-1} FW and 4.54 g 100 g^{-1} FW,

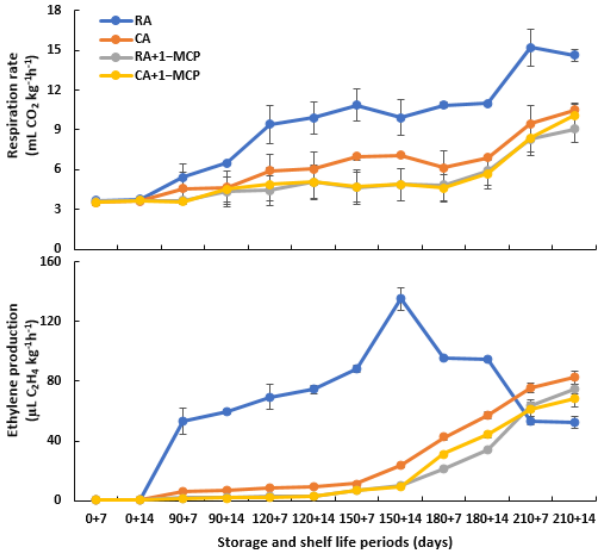

Figure 1. Changes in respiration rate and ethylene production in 'Ankara' pears during storage and shelf life periods. RA: Regular air storage; CA: controlled atmosphere storage. Vertical lines are the standard errors of mean values.

Table 2. Effects of different variables on flesh firmness, soluble solid contents, and titratable acidity of 'Ankara' pear fruits.

Significant effects[1]	Flesh firmness (N)	Soluble solid contents (%)	Titratable acidity (% malic acid)
SP (days)			
0	79.78 ± 0.32 A[2]	15.20 ± 0.03 A[2]	0.40 ± 0.01 A[2]
90	54.51 ± 2.31 B	15.22 ± 0.02 A	0.33 ± 0.01 B
120	46.16 ± 2.38 C	14.53 ± 0.04 B	0.32 ± 0.01 C
150	39.16 ± 2.22 D	14.27 ± 0.05 C	0.26 ± 0.02 D
180	34.57 ± 1.72 E	14.25 ± 0.03 C	0.23 ± 0.01 E
210	29.98 ± 1.70 F	13.77 ± 0.11 D	0.22 ± 0.01 F
SL (days)			
7	49.26 ± 2.20 A[2]	14.63 ±0.07 A[2]	0.31 ± 0.01 A[2]
14	45.47 ± 2.26 B	14.45 ±0.07 B	0.29 ± 0.01 B
ST			
RA	44.51 ± 2.45 B[2]	14.47 ± 0.08 B[2]	0.29 ± 0.01 B[2]
CA	50.21 ± 1.95 A	14.61 ± 0.06 A	0.31 ± 0.01 A
T			
–1-MCP	40.42 ± 2.36 B[2]	14.38 ± 0.08 B[2]	0.29 ± 0.01 B[2]
+1-MCP	54.30 ± 1.77 A	14.71 ± 0.05 A	0.31 ± 0.01 A
ST × T			
RA × –1-MCP	34.63 ± 3.53 B, b[3]	14.25 ± 0.13 B, b[3]	0.27 ± 0.01 B, b[2]
CA × –1-MCP	46.22 ± 2.86 A, b	14.50 ± 0.08 A, b	0.30 ± 0.01 A, a
RA × +1-MCP	54.40 ± 2.52 A, a	14.69 ± 0.07 A, a	0.31 ± 0.01 A, a
CA × +1-MCP	54.19 ± 2.53 A, a	14.72 ± 0.07 A, a	0.31 ± 0.01 A, a

[1] SP: Storage period; SL: shelf life; ST: storage type; RA: regular air storage; CA: controlled atmosphere storage; T: treatment.
[2] Data are presented as mean ± standard error of mean (SEM); different letters in the same column are significantly different.
[3] Capital letters of the same color show differences among storage types for each treatment and lowercase letters of the same color show differences between treatments for each storage type at $p \leq 0.05$ error level according to Tukey's test.

Table 3. Effects of different variables on sugar contents of 'Ankara' pear fruits.

Significant effects[1]	Sucrose (g 100 g^{-1} FW)	Glucose (g 100 g^{-1} FW)	Fructose (g 100 g^{-1} FW)
SP (days)			
0	2.20 ± 0.02 A[2]	4.66 ± 0.05 B[2]	6.17 ± 0.11 B[2]
90	1.82 ± 0.01 B	5.36 ± 0.07 A	6.76 ± 0.08 A
120	1.71 ± 0.02 C	5.16 ± 0.07 A	6.81 ± 0.09 A
150	1.64 ± 0.02 D	4.69 ± 0.11 B	6.59 ± 0.14 A
180	1.61 ± 0.02 E	4.29 ± 0.12 C	5.94 ± 0.13 B
210	1.43 ± 0.03 F	3.82 ± 0.09 D	5.81 ± 0.09 B
SL (days)			
7	1.75 ± 0.02 A[2]	4.66 ± 0.07 ns[2]	6.37 ± 0.07 ns[2]
14	1.71 ± 0.03 B	4.67 ± 0.08 ns	6.32 ± 0.08 ns
ST			
RA	1.70 ± 0.03 B[2]	4.54 ± 0.09 B[2]	6.27 ± 0.08 ns[2]
CA	1.76 ± 0.02 A	4.78 ± 0.06 A	6.41 ± 0.07 ns
T			
–1-MCP	1.68 ± 0.03 B[2]	4.59 ± 0.09 B[2]	6.32 ± 0.08 ns[2]
+1-MCP	1.79 ± 0.02 A	4.74 ± 0.06 A	6.37 ± 0.07 ns
ST × T			
RA × –1-MCP	1.63 ± 0.50 B, b[3]	4.33 ± 1.59 B, b[3]	6.20 ± 1.35 ns[2]
CA × –1-MCP	1.74 ± 0.38 A, b	4.85 ± 0.83 A, a	6.43 ± 0.10 ns
RA × +1-MCP	1.79 ± 0.39 A, a	4.76 ± 0.79 A, a	6.34 ± 0.10 ns
CA × +1-MCP	1.79 ± 0.37 A, a	4.72 ± 0.90 A, b	6.40 ± 0.09 ns

[1] SP: Storage period; SL: shelf life; ST: storage type; RA: regular air storage; CA: controlled atmosphere storage; T: treatment.
[2] Data are presented as mean ± standard error of mean (SEM); different letters in the same column are significantly different; ns: nonsignificant at $p \leq 0.05$ error level.
[3] Capital letters of the same color show differences among storage types for each treatment and lowercase letters of the same color show differences between treatments for each storage type at $p \leq 0.05$ error level according to Tukey's test.

respectively). The effects of shelf life, storage type, and 1-MCP treatment on fructose contents were insignificant. The interactive effect of storage type and 1-MCP treatment was significant for only sucrose and glucose contents. Without 1-MCP treatment, CA conditions resulted in the fruits having higher sucrose (1.74 g 100 g^{-1} FW) and glucose (4.85 g 100 g^{-1} FW) contents compared to fruits under RA conditions (1.63 g 100 g^{-1} FW and 4.32 g 100 g^{-1} FW). However, after 1-MCP treatment, neither RA nor CA conditions created significant differences in sucrose or glucose contents. A similar effect was not observed for the fructose contents of 'Ankara' pear fruits (Table 3).

3.5. Fermentative products

In this study, we determined acetaldehyde, methanol, and ethanol concentrations as fermentative products (Table 4). Among these products, the levels of ethanol were the highest, followed by methanol and acetaldehyde. During the storage period, these products tended to increase up the 180th day and then decreased significantly. The highest acetaldehyde, methanol, and ethanol concentrations were respectively recorded as 24.41 µL L^{-1}, 67.70 µL L^{-1}, and 136 µL L^{-1}. In general, the levels of fermentative products determined on the 7th day of the shelf life period were lower than those on the 14th day. 1-MCP treatment inhibited the production of all fermentative products determined in the current study. Methanol concentration was not affected by the interaction of storage technology and 1-MCP, while acetaldehyde and ethanol production levels were highest under RA conditions without 1-MCP treatment at 18.36 µL L^{-1} and 134.70 µL L^{-1}, respectively. RA storage with 1-MCP treatment caused higher levels of acetaldehyde production (17.87 µL L^{-1}) than CA storage (16.28 µL L^{-1}).

Table 4. Effects of different variables on fermentative products of 'Ankara' pear fruits.

Significant effects[1]	Acetaldehyde (μL L^{-1})	Methanol (μL L^{-1})	Ethanol (μL L^{-1})
SP (days)			
0	13.48 ± 0.04 C[2]	4.51 ± 0.37 D[2]	17.53 ± 0.36 C[2]
90	18.23 ± 0.90 B	36.34 ± 4.48 C	57.61 ± 6.84 B
120	17.79 ± 0.89 B	37.78 ± 5.25 C	53.50 ± 5.32 B
150	24.10 ± 1.94 A	53.15 ± 8.95 B	116.50 ± 18.00 A
180	24.41 ± 1.80 A	67.70 ± 12.70 A	136.90 ± 22.40 A
210	19.09 ± 1.46 B	25.68 ± 5.60 C	69.10 ± 13.40 B
SL (days)			
7	18.18 ± 0.74 B[2]	27.28 ± 2.63 B[2]	63.74 ± 7.33 B[2]
14	20.86 ± 0.98 A	47.76 ± 5.99 A	86.60 ± 10.20 A
ST			
RA	19.46 ± 0.73 ns[2]	39.85 ± 5.53 ns[2]	84.70 ± 10.70 A[2]
CA	19.58 ± 1.01 ns	35.20 ± 3.87 ns	65.66 ± 6.66 B
T			
–1-MCP	23.73 ± 0.99 A[2]	56.03 ± 5.77 A[2]	115.90 ± 10.60 A[2]
+1-MCP	15.31 ± 0.30 B	19.02 ± 1.67 B	34.53 ± 1.99 B
ST × T			
RA × –1-MCP	23.04 ± 1.09 A, a[3]	58.47 ± 9.87 ns[2]	134.70 ± 17.80 A, a[3]
CA × –1-MCP	24.42 ± 1.66 B, a	53.59 ± 6.12 ns	97.00 ± 10.70 B, a
RA × +1-MCP	15.89 ± 0.55 A, b	21.22 ± 2.64 ns	34.73 ± 2.67 A, b
CA × +1-MCP	14.72 ± 0.17 B, b	16.81 ± 2.02 ns	34.33 ± 3.00 A, b

[1] SP: Storage period; SL: shelf life; ST: storage type; RA: regular air storage; CA: controlled atmosphere storage; T: treatment.
[2] Data are presented as mean ± standard error of mean (SEM); different letters in the same column are significantly different; ns: nonsignificant at $p \leq 0.05$ error level.
[3] Capital letters of the same color show differences among storage types for each treatment and lowercase letters of the same color show differences between treatments for each storage type at $p \leq 0.05$ error level according to Tukey's test.

The same effect was not observed for ethanol production, while the level of ethanol production in the RA + 1-MCP group (97.00 μL L^{-1}) was higher than that obtained for CA + 1-MCP (34.33 μL L^{-1}), the difference was not statistically significant (Table 4).

3.6. Cuticular wax quantity

We observed the highest wax content values on the 150th (1.60 mg g^{-1}) and 180th (1.62 mg g^{-1}) days and it decreased after the 180th day (Figure 2A). CA storage and 1-MCP treatment led to lower wax contents (1.10 mg g^{-1}) on the skins of the pears. However, 1-MCP treatment under both RA and CA conditions helped the fruit in terms of lower wax contents (1.11 mg g^{-1}). The shelf life periods alone did not cause significant changes in this parameter. Nevertheless, it had an interactive effect with other variables (Figure 2B). It seems that 1-MCP treatment and CA conditions alone can both help to reduce the wax production on the skins of 'Ankara' pears.

3.7. Sensory evaluation

In this study, we considered juiciness, sweetness, bitterness, and alcohol flavor as sensory evaluation parameters for 'Ankara' pear fruits (Table 5). All of these parameters increased linearly during cold storage and the shelf life periods. Pears stored under CA conditions were found to be less juicy (5.81 points) than those stored under RA (6.13 points). In addition, 1-MCP treatment caused the fruits to be less juicy (5.79 points). However, the effect of CA and 1-MCP treatment subsequently disappeared, especially in the later storage periods. Sweetness increased with the cold storage period for all shelf life durations. Without 1-MCP treatment, RA (6.29 points) and CA (5.71 points) storage conditions alone caused sweeter fruit. Differences between

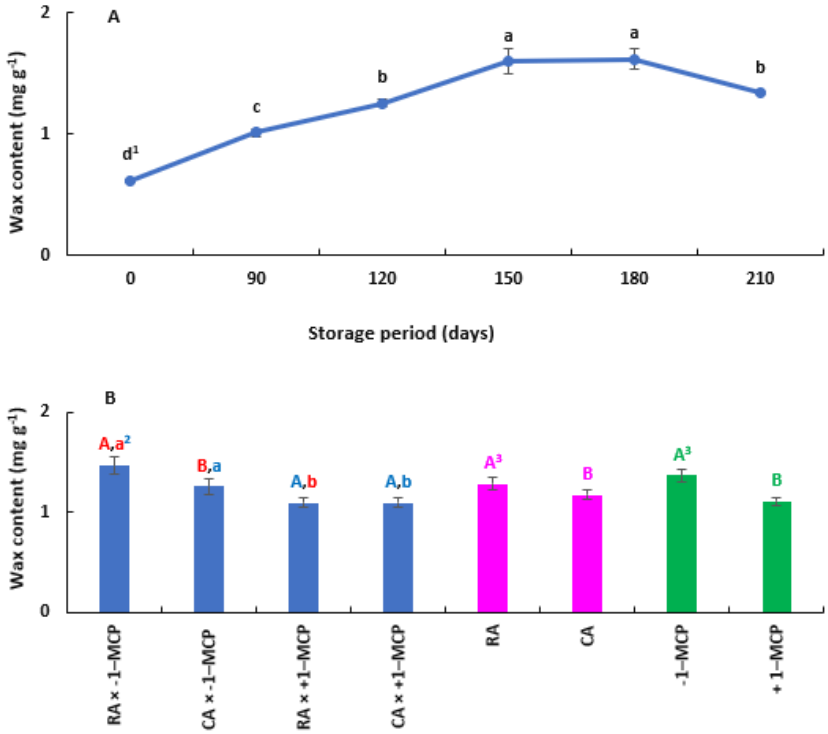

Figure 2. Changes in skin wax contents in 'Ankara' pears: A) during cold storage period, B) effect of storage types and 1-MCP treatments. Vertical lines are the standard errors of mean values.

[1]Letters show differences among cold storage periods.
[2]Capital letters of the same color show differences among storage types in each treatment and lowercase letters of the same color show differences between treatments in each storage type.
[3]Letters of the same color show differences between storage types and treatments at $p \leq 0.05$ error level; RA: regular air; CA: controlled atmosphere storage.

RA + 1-MCP and CA + 1-MCP with respect to sweetness, bitterness, and alcohol flavor were not significant, but they greatly inhibited the formation of a bitter taste (1.04 and 1.07 points, respectively). CA storage and 1-MCP treatment resulted in lower average sweetness scores. However, this effect disappeared along with the storage and shelf life periods and all pears had similar sweetness scores. Remarkable increases were observed in the alcohol flavor of 'Ankara' pear fruits and the fruits treated with 1-MCP had the lowest values (1.06 points). 1-MCP treatment strongly inhibited the occurrence of alcohol flavor during the shelf life periods after both RA (1.06 points) and CA (1.05 points) storage. CA storage alone (1.20 points) caused fruits to have lower levels of alcohol flavor than RA storage (1.61 point).

4. Discussion

The RR values of 'Ankara' pear fruits followed fluctuations during the cold storage and shelf life. In fruits stored under RA and CA conditions without 1-MCP treatment, RR increased up to the 150 + 7th day (10.87 mL CO_2 kg^{-1} h^{-1}) and up to the 150 + 14th day (7.10 mL CO_2 kg^{-1} h^{-1}), respectively. Both RA and CA conditions with 1-MCP treatment generally inhibited RR (Figure 1; Table 1). It was previously reported that the RR values of pear fruits were lower with 1-MCP treatments (Watkins, 2015) and proper CA storage techniques helped to reduce RR (Thompson et al., 2019). Despite studies claiming that 1-MCP treatments strengthen the effects of CA storage (Rizzolo et al., 2015), we found independent effects of 1-MCP treatment and CA storage in slowing the RR of 'Ankara' pears, as noted in some previous reports (Zhi et al., 2019). The observations of Bakoğlu (2014) and Kurubaş and Erkan (2018) working with 'Ankara' pear and those of Escribano et al. (2016) and Villalobos-Acuña et al. (2011) for 'Bartlett' pear support our findings about the effect of 1-MCP in slowing the RR of the fruits. On the other hand, comparing the effects of different storage technologies such as RA and CA storage used in the current study, it is possible to note the stronger effect of CA storage on slowing down the RR of 'Ankara'

Table 5. Effects of different variables on sensory evaluation scores of 'Ankara' pear fruits.

Significant effects[1]	Sweetness (1–10 points)	Bitterness (1–10 points)	Alcohol flavor (1–10 points)	Juiciness (1–10 points)
SP (days)				
0	4.16 ± 0.06 F[2]	1.00 ± 0.00 E[2]	1.00 ± 0.00 D[2]	4.00 ± 0.03 F[2]
90	5.19 ± 0.05 E	1.00 ± 0.00 E	1.00 ± 0.00 D	5.18 ± 0.09 E
120	5.75 ± 0.12 D	1.15 ± 0.05 D	1.00 ± 0.00 D	5.91 ± 0.11 D
150	6.07 ± 0.15 C	1.66 ± 0.14 C	1.22 ± 0.05 C	6.54 ± 0.14 C
180	6.58 ± 0.07 B	2.23 ± 0.26 B	1.45 ± 0.12 B	6.97 ± 0.06 B
210	6.70 ± 0.05 A	2.48 ± 0.31 A	1.75 ± 0.12 A	7.18 ± 0.06 A
SL (days)				
7	5.63 ± 0.11 B[2]	1.55 ± 0.12 B[2]	1.21 ± 0.05 B[2]	5.83 ± 0.13 B[2]
14	5.85 ± 0.12 A	1.63 ± 0.13 A	1.27 ± 0.06 A	6.11 ± 0.15 A
ST				
RA	5.89 ± 0.12 A[2]	1.70 ± 0.14 A[2]	1.34 ± 0.07 A[2]	6.13 ± 0.14 A[2]
CA	5.60 ± 0.11 B	1.48 ± 0.09 B	1.14 ± 0.03 B	5.81 ± 0.13 B
T				
-1-MCP	6.00 ± 0.12 A[2]	2.12 ± 0.15 A[2]	1.41 ± 0.07 A[2]	6.14 ± 0.13 A[2]
+1-MCP	5.49 ± 0.11 B	1.06 ± 0.02 B	1.06 ± 0.02 B	5.79 ± 0.14 B
ST × T				
RA × –1-MCP	6.29 ± 0.17 A, a[3]	2.36 ± 0.24 A, a[3]	1.61 ± 0.11 A, a[3]	6.37 ± 0.19 A, a[3]
CA × –1-MCP	5.71 ± 0.14 B, a	1.87 ± 0.16 B, a	1.20 ± 0.03 B, a	5.91 ± 0.19 B, a
RA × +1-MCP	5.48 ± 0.15 A, b	1.04 ± 0.01 A, b	1.06 ± 0.02 A, b	5.88 ± 0.20 A, b
CA × +1-MCP	5.49 ± 0.16 A, b	1.07 ± 0.02 A, b	1.05 ± 0.02 A, b	5.70 ± 0.19 B, b

[1] SP: Storage period; SL: shelf life; ST: storage type; RA: regular air storage; CA: controlled atmosphere storage; T: treatment.
[2] Data are presented as mean ± standard error of mean (SEM); different letters in the same column are significantly different.
[3] Capital letters of the same color show differences among storage types for each treatment and lowercase letters of the same color show differences between treatments for each storage type at $p \leq 0.05$ error level according to Tukey's test.

pears. Similarly, Mattheis et al. (2013) observed that the RR of CA-stored 'd'Anjou' pear fruits was lower than that of fruits kept with air storage. 1-MCP in combination with CA was found to be effective for the RR of climacteric fruit because it can abate fruit metabolic activity and 1-MCP can support the effects of CA on RR (Watkins, 2015). However, in the current study, very similar RR values measured in the RA + 1-MCP (5.21 mL CO_2 $kg^{-1} h^{-1}$) and CA + 1-MCP (5.30 mL CO_2 $kg^{-1} h^{-1}$) groups suggested that 1-MCP cannot support CA storage for the 'Ankara' pear cultivar. With a similar approach, Guo et al. (2020) noted that the unified effect of 1-MCP and CA was not always considerable for RR in all climacteric fruit species and the outcomes can vary across different cultivars.

All variables in the current study significantly affected the EP of 'Ankara' pear fruits. It has been argued that the regulation of ripening, especially in climacteric fruit species such as pears, is linked to ethylene-related patterns (Wang S et al., 2018). Thus, the importance of ethylene inhibitors and different storage methods comes to the fore in this respect. In our study, 1-MCP and CA delayed ethylene production. Under RA conditions, EP was measured as 64.81 µL C_2H_4 $kg^{-1} h^{-1}$ and 18.45 µL C_2H_4 $kg^{-1} h^{-1}$ in the groups without and with 1-MCP treatment, respectively. This shows that, under RA conditions, 1-MCP can be successful in obstructing EP. Likewise, 1-MCP treatment alone inhibited EP in 'Passe Crassane' pears during their shelf life (Cocetta et al., 2016). On the other hand, Guo et al. (2020) stated that the combination of 1-MCP and CA storage was more effective in inhibiting EP in 'd'Anjou' pears. According to the same researchers, this unified effect might be due to lower levels of interaction of O_2 and ethylene. It can be said that the combined effect of these postharvest technologies on EP, which are effective when examined individually, varies among pear cultivars. In the

current study, we could not determine a superior effect of CA + 1-MCP treatment (19.25 µL C_2H_4 kg^{-1} h^{-1}) on EP (Table 1).

1-MCP and CA storage technologies can be used to delay the loss of firmness that occurs during the ripening of 'Ankara' pear fruits. Mattheis et al. (2013) noted that fruit softening in 'd'Anjou' pears was reduced by CA storage, and according to Escribano et al. (2016), 1-MCP maintained the flesh firmness of 'Bartlett' pears. However, the effect of 1-MCP was more pronounced than CA storage in the current study. In many studies, greater firmness loss in pear fruits was associated with higher ethylene biosynthesis (Lindo-García et al., 2020; He et al., 2023). In our study, firmness loss was notable in the RA group without 1-MCP (34.63 N), which had the highest EP, and fruits in the RA + 1-MCP group (54.40 N) remained firmer with lower EP values (Tables 1 and 2). Our results are similar to previous findings suggesting that 1-MCP treatment (Li et al., 2013; Bakoğlu, 2014; Kurubaş and Erkan, 2018) and CA storage (Horak et al., 2015) are effective in preserving flesh firmness in pears. On the contrary, however, 'Blanquilla' pears treated with 1-MCP softened faster than control fruits during their shelf life (Cucchi and Regiroli, 2011).

In the current study, SSC values decreased in all groups during the storage and shelf life. The decrease of SSC with the progression of the storage and shelf life periods may be due to the breakdown of sugars, which make up a very large part of the SSC, in relation to the RR and fruit metabolism. Łysiak et al. (2021) and Híc et al. (2023) reported similar situations for the 'Conference' and 'Yali' pear cultivars. In our study, it was clearly seen that 1-MCP prevented decreases in SSC with both storage technologies and SSC was measured as 14.69% and 14.72% under RA and CA conditions, respectively. A similar protective effect was also achieved with CA storage (14.50%) regardless of the use of 1-MCP. Supporting our findings, Rizzollo et al. (2015) determined that CA-stored and 1-MCP-treated 'Abbe Fetel' pears had higher SSC contents than control fruits after 20 weeks + 7 days of shelf life. Moreover, Łysiak et al. (2021) obtained similar results for 'Conference' pears. However, Cucchi and Regiroli (2011) obtained conflicting findings as they could not determine any differences between 1-MCP-treated and control fruits with respect to the SSC values of 'Conference' and 'Abbé Fétel' pears.

The TA values of the fruits in all groups in the current study decreased during the storage and shelf life. Flaherty et al. (2018) noted that TA in pears was mainly due to malic acid and tended to decrease during the postharvest storage and shelf life. This decrease may be because of the oxidation of organic acids to meet energy requirements in respiration during ripening (Híc et al., 2023). In the CA + 1-MCP and RA + 1-MCP groups (0.31% malic acid), losses of TA were mostly prevented (Table 2). Gago et al. (2015) determined that the overall decrease in malic acid and thus TA levels could be delayed and reduced by 1-MCP and CA storage. Rizzolo et al. (2015) found higher TA in 'Abbe Fetel' pears treated with 1-MCP with and without CA storage, stored for 20 weeks + 7 days of shelf life. Likewise, Vanoli et al. (2008) reported that 1-MCP-treated 'Abbé Fétel' pears had higher TA values than control fruits when stored in both air and CA conditions. These previous studies support our results.

Sugar content have prominent effects on pear fruit quality and an important role in pear ripening (Wang L et al., 2018). While fructose and glucose levels increased at first and then decreased in our study, Itai and Tanahashi (2008) determined a continuous increase in the glucose contents of pears during the storage period. Similarly to our study, the fructose and glucose contents of pears stored at 0 °C increased from the 1st month of the storage period to the 3rd month, and then decreased to the end of storage. Nevertheless, there was a general decline in sucrose content for 5 months of cold storage. This situation was explained by the disintegration of sucrose to fructose and glucose during storage (Chen et al., 2006). These differences are thought to have originated from the differences between the ripening metabolisms of European and Japanese pears. Itai and Tanahashi (2008) noted that 1-MCP regulated the genes controlling the sucrose metabolism of 'Gold Nijisseiki' and 'Hosui' cultivars and, in parallel with our study, it was argued that the effect of 1-MCP was evident in RA storage conditions. Similarly, we determined significantly higher sucrose contents in fruits stored under RA + 1-MCP (1.78 g 100 g^{-1} FW) conditions (Table 3). However, the determination of similar sucrose values in the CA + 1-MCP group shows that the unified effect of CA storage and 1-MCP treatment on carbohydrate metabolism is still not clear and should be explored using molecular techniques in further studies. A similar situation is valid for the interactive effects of storage technologies and 1-MCP treatments on glucose metabolism.

Acetaldehyde and ethanol production with small amounts of methanol are the natural biochemical stages in pear ripening. These fermentative products possibly contribute to the flavor and aroma at low concentrations. However, at high concentrations these products cause fermentative aroma and off-flavor in pear fruits (Ke et al., 1994). In our previous studies, we determined that long storage periods of more than 4 months were responsible for a bitter and alcoholic taste during the shelf life in 'Ankara' pear fruits (Bakoğlu, 2014). Kreuzwieser et al. (1999) demonstrated that poplar plant tissues could recover carbon from ethanol produced under hypoxic conditions with the metabolization of ethanol to acetaldehyde and then acetate. Additionally, this could be a reason for the higher ethanol values than acetaldehyde found in the current study. Na-

nos et al. (1992) demonstrated that during the ripening period, pear fruits produced acetaldehyde and ethanol. These compounds are normal metabolic products and their concentrations increased with the storage and shelf life periods in our study. Nevertheless, 1-MCP and storage type can have positive or negative effects on the biosynthesis of these substances during storage and shelf life. For example, in 'Spadona' pears 1-MCP treatment (Feygenberg et al., 2015) and in 'Conference' pears 1-MCP treatment + CA storage (Rizzollo et al., 2015) prevented acetaldehyde production during storage. Similarly, Lara et al. (2003) reported that RA-stored 'Doyenne du Comice' pears showed higher levels of acetaldehyde production than CA-stored fruits after 5 months of cold storage and 4 days of shelf life. In our study, 1-MCP treatment generally caused lower acetaldehyde (15.31 μL L^{-1}), methanol (19.02 μL L^{-1}), and ethanol (34.53 μL L^{-1}) levels and CA storage resulted in lower ethanol accumulation (65.66 μL L^{-1}) (Table 4). Likewise, Horak et al. (2015) found that CA storage conditions slowed the ethanol and methanol production of 'Zaosuli' pears during shelf life. In contrast to our results, Rizzollo et al. (2015) noted that the 1-MCP treatment of 'Conference' pears did not inhibit ethanol production under RA storage conditions but did inhibit ethanol production under CA conditions. This finding is in contrast to our results because we determined significantly lower levels of ethanol production in the RA + 1-MCP group (34.73 μL L^{-1}) (Table 4). These contrasting results could be the result of differences in the genetic structures of the cultivars. Shu et al. (2020) studying the 'Laiyang' cultivar and Ahmad et al. (2023) studying the 'Shughri' cultivar reported that 1-MCP treatment effectively controlled alcohol dehydrogenase activities and prevented the production of ethanol and acetaldehyde, which are the main causes of off-flavor in pear fruits. Thus, 1-MCP treatments might significantly prevent increases in fermentative products in 'Ankara' pear fruits during the shelf life period. On the other hand, similar to the findings of Rizzollo et al. (2015), CA conditions alone (97.00 μL L^{-1}) and in combination with 1-MCP treatment (34.33 μL L^{-1}) decreased ethanol production in our study.

Similarly to our study, significant increases in wax contents during storage and shelf life were reported by Wang et al. (2021) for 'Korla' and Mao et al. (2022) for 'Fragrant' pear cultivars under different storage conditions. However, for some Asian pear cultivars such as 'Kuerle,' 'Xuehua,' and 'Yuluxiang,' Wu et al. (2017) observed a steady decline in epicuticular waxes during a cold storage period of 7 months. In the current study, CA-stored and 1-MCP-treated 'Ankara' pears had significantly lower wax contents on their skins (Figure 2). Mao et al. (2022) noted the preventive effect of 1-MCP treatment on wax biosynthesis in 'Fragrant' pears during storage, and this result is in line with our findings. Moreover, Curry (2008) reported a similar effect of 1-MCP treatment during the progression of maturity in apples. In the current study, CA storage alone without 1-MCP treatment also reduced the wax biosynthesis of 'Ankara' pears (Figure 2). However, 1-MCP treatment under both RA and CA conditions helped the fruits in terms of lower wax content. Li et al. (2023) explained that with ethylene production, the wax contents in pear peels are increased, whereas 1-MCP inhibits these changes. In our study, the inhibiting effect of 1-MCP treatment and CA storage on cuticular wax formation in 'Ankara' pear skins could have been due to the suppression of ethylene production. Therefore, it can be suggested that 1-MCP and CA storage may play an active role in the regulation of wax biosynthesis in the skins of 'Ankara' pears.

1-MCP treatment and CA storage significantly influenced the sensory characteristics of 'Ankara' pears during shelf life (Table 5). Our results highlight the effects of storage and shelf life periods, storage technology, and 1-MCP treatment on the sensory properties of 'Ankara' pears. While the pears that were not treated with 1-MCP and stored in RA conditions had higher juiciness and sweetness levels in the initial storage and shelf life periods, the fruits of the CA + 1-MCP group showed values similar to those of control fruits during the later storage and shelf life periods. This is in agreement with the results of Vanoli et al. (2015), who reported less juicy 'Abbé Fetél' fruits in the 1-MCP + CA storage group compared to control fruits. On the other hand, Kurubaş and Erkan (2018) reported that 'Ankara' pear fruits treated with 1-MCP were sweeter than untreated fruits during all considered shelf life periods, while Vanoli et al. (2015) described 1-MCP-treated 'Conference' and 'Abbé Fétel' pears as firmer and less juicy, sweet, and aromatic than untreated fruits. The difference in our study may have resulted from the initial low oxygen stress applied after 1-MCP treatment by Vanoli et al. (2015), which could cause some irregularities in the ripening processes of these cultivars.

5. Conclusions

This is the first study to evaluate the effects of important postharvest factors such as 1-MCP treatment (300 nL L^{-1}) and RA and CA (3% O2 + 1.5% CO2) storage on the quality parameters of an important European pear cultivar, 'Ankara,' in Türkiye. In this research, the individual and combined effects of these factors on certain physiological characteristics and quality parameters were evaluated. RA storage was the most ineffective technology in terms of maintaining quality parameters and inhibiting fruit metabolism based on RR and EP values. RA and CA storage with 1-MCP treatment had similar inhibiting effects on RR, EP, loss of firmness, SSC, TA, sucrose and glucose contents, skin wax contents, and ethanol formation. CA +

1-MCP significantly inhibited only acetaldehyde production and caused less juicy fruits. There was no significant difference between the RA + 1-MCP and CA + 1-MCP groups in terms of sweetness, bitterness, and alcohol flavor. CA storage alone was more successful in maintaining quality parameters than RA storage.

Overall, 'Ankara' pear fruits can be successfully stored for a cold storage period of 210 days + 14 days of shelf life with treatment by only 1-MCP at a concentration of 300 nL L^{-1} when CA storage is not possible. In the case of CA storage, 1-MCP treatment did not have a greater effect on quality parameters or the inhibition of RR and EP values of the fruits compared to RA + 1-MCP treatment.

Acknowledgments

The authors thank the Scientific Research Project Office of Ankara University for financial support with Project Number 14L0447006. Some data from the PhD thesis titled "The effect of controlled atmosphere storage and 1-methylcyclopropane (1-MCP) treatment on some quality parameters of 'Ankara' pear (*Pyrus communis* L. cv. Ankara)" were used in this article.

References

Ahmad A, Hashmi MS, Durrani Y, Khan NA, Khan MR et al. (2023). Synergy of 1-MCP and hypobaric treatments prevent fermented flavour and improve consumers' acceptability of 'Shughri' pear. Journal of Food Science and Technology 60: 200-210. https://doi.org/10.1007/s13197-022-05605-y

Bakoğlu N (2014). The effect of postharvest 1-methylcyclopropane treatments on storage of Ankara pear cultivar. MSc, Ankara University, Türkiye.

Bakoğlu N, Tuna Gunes N (2018). The effect of 1-MCP concentration on skin and flesh color polyphenol oxidase activity during cold storage and shelf life periods in 'Ankara' pear (*Pyrus communis* L.). Acta Horticulturae 1275: 221-228. https://doi.org/10.17660/ActaHortic.2020.1275.31

Bangerth F (1978). The effect of a substituted amino acid on ethylene biosynthesis, respiration, ripening and preharvest drop of apple fruits. Journal of the American Society for Horticultural Science 103: 401-404. https://doi.org/10.21273/JASHS.103.3.401

Chen JL, Wu JH, Wang Q, Deng H, Hu XS (2006). Changes in the volatile compounds and chemical and physical properties of Kuerle Fragrant pear (Pyrus serotina Reld) during storage. Journal of Agricultural and Food Chemistry 54: 8842-8847. https://doi.org/10.1021/jf061089g

Cocetta G, Mignani I, Spinardi A (2016). Ascorbic acid content in Passe-Crassane winter pear as affected by 1-methylcyclopropene during cold storage and shelf life. HortScience 51: 543-548. https://doi.org/10.21273/HORTSCI.51.5.543

Cucchi A, Regiroli G (2011). Temperature and ethylene: two useful tools to be used in combination with Smartfresh℠ (1-MCP) for delivering optimal quality pears. Acta Horticulturae 909: 679-686. https://doi.org/10.17660/ActaHortic.2011.909.83

Curry E (2008). Effects of 1-MCP applied postharvest on epicuticular wax of apples (Malus domestica Borkh.) during storage. Journal of the Science of Food and Agriculture 88: 996-1006. https://doi.org/10.1002/jsfa.3180

Dias C, Ribeiro T, Rodrigues AC, Ferrante A, Vasconcelos MW et al. (2021). Improving the ripening process after 1-MCP application: implications and strategies. Trends in Food Science & Technology 113: 382-396. https://doi.org/10.1016/j.tifs.2021.05.012

Dias C, Ribeiro T, Rodrigues AC, Ferrante A, Vasconcelos MW et al. (2022). Cold storage demand for 'Rocha' pear ripening: a comparison between a shorter and longer cold period. Scientia Horticulturae 299: 111033. https://doi.org/10.1016/j.scienta.2022.111033

Dong Y, Wang Y, Einhorn TC (2018). Postharvest physiology, storage quality and physiological disorders of Gem pear (*Pyrus communis* L.) treated with 1-methylcyclopropene. Scientia Horticulturae 240: 631-637. https://doi.org/10.1016/j.scienta.2018.06.073

Dumanoğlu H, Tuna Güneş N, Horzum Ö (2021). Important Turkish winter pear cultivar: Ankara pear (*Pyrus communis* L.). In: Kunter B, Keskin N (editors). Agricultural and Natural Research & Reviews. Lyon, France: Livre de Lyon Publishing, pp. 1-18.

Escribano S, Lopez A, Sivertsen H, Biasi WV, Macnish AJ et al. (2016). Impact of 1-methylcyclopropene treatment on the sensory quality of 'Bartlett' pear fruit. Postharvest Biology and Technology 111: 305-313. https://doi.org/10.1016/j.postharvbio.2015.09.015

Feygenberg O, Goldenberg L, Nerya O, Ben Arie R, Pesis E (2015). Pre-storage treatment with hypoxia or 1-MCP to maintain Spadona pear quality after cold storage. Acta Horticulturae 107: 589-596. https://doi.org/10.17660/ActaHortic.2015.1071.76

Flaherty EJ, Lum GB, DeEll JR, Subedi S, Shelp BJ et al. (2018). Metabolic alterations in postharvest pear fruit as influenced by 1-methylcyclopropene and controlled atmosphere storage. Journal of Agricultural and Food Chemistry 66: 12989-12999. https://doi.org/10.1021/acs.jafc.8b04912

Gago CML, Miguel MG, Cavaco AÖ, Almeida DPF, Antunes MDC (2015). Combined effect of temperature and controlled atmosphere on storage and shelf life of Rocha pear treated with 1-methylcyclopropene. Journal of Food Science and Technology 21: 94-103. https://doi.org/10.1177/1082013213511808

Guo J, Wei X, Lü E, Wang Y, Deng Z (2020). Ripening behavior and quality of 1-MCP treated d'Anjou pears during controlled atmosphere storage. Food Control 117: 107364. https://doi.org/10.1016/j.foodcont.2020.107364

He J, Feng Y, Cheng Y, Guan J (2023). Effects of preharvest aminoethoxyvinylglycine (AVG) treatment on fruit ripening, core browning and related gene expression in Huangguan pear (*Pyrus bretschneideri* Rehd.). Horticulturae 9: 179. https://doi.org/10.3390/horticulturae9020179

Hewitt SL, Ghogare R, Dhingra A (2020). Glyoxylic acid overcomes 1-MCP-induced blockage of fruit ripening in *Pyrus communis* L. var. 'D'Anjou.' Scientific Reports 10: 7084. https://doi.org/10.1038/s41598-020-63642-z

Híc P, Kožíšková J, Omastová P, Balík J, Goliáš J (2023). Physiochemical changes of European pear cv. Conference and Asian pear cv. Yali during cold storage. Horticulturae 9: 378. https://doi.org/10.3390/horticulturae9030378

Horak M, Golias J, Balik J, Snurkovic P, Nemcova A (2015). Effect of controlled atmosphere storage on qualitative parameters of Asian pear cultivar 'Zaosuli.' Acta Horticulturae 1079: 567-572. https://doi.org/10.17660/ActaHortic.2015.1079.76

Itai A, Tanahashi T (2008). Inhibition of sucrose loss during cold storage in Japanese pear (Pyrus pyrifolia Nakai) by 1-MCP. Postharvest Biology and Technology 48: 355-363. https://doi.org/10.1016/j.postharvbio.2007.10.015

Ke D, Yahia E, Mateos M, Kader A (1994). Ethanolic fermentation of Bartlett pears as influenced by ripening stage atmospheric composition. Journal of the American Society for Horticultural Science 119: 976-982. https://doi.org/10.21273/JASHS.119.5.976

Klein JD, Lurie S (1990). Prestorage heat treatment as a means of improving poststorage quality of apples. Journal of the American Society for Horticultural Science 115: 265-269. https://doi.org/10.21273/JASHS.115.2.265

Kreuzwieser J, Schnitzler JP, Steinbrecher R (1999). Biosynthesis of organic compounds emitted by plants. Plant Biology 1: 149-159. https://doi.org/10.1055/s-2007-978501

Kurubaş MS, Erkan M (2018). Impacts of 1-methylcyclopropene (1-MCP) on postharvest quality of Ankara pears during long-term storage. Turkish Journal of Agriculture and Forestry 42: 88-96. https://doi.org/10.3906/tar-1706-72

Lara I, Miró RM, Fuente T, Sayez G, Graell J et al. (2003). Biosynthesis of volatile aroma compounds in pear fruit stored under long-term controlled-atmosphere conditions. Postharvest Biology and Technology 29: 29-39. https://doi.org/10.1016/S0925-5214(02)00230-2

Larrigaudière C, Vilaplana R, Soria Y, Recasens I (2004). Oxidative behaviour of Blanquilla pears treated with 1-methylcyclopropene during cold storage. Journal of the Science of Food and Agriculture 84: 1871-1877. https://doi.org/10.1002/jsfa.1850

Li D, Li X, Cheng Y, Guan J (2023). Effect of 1-methylcyclopropene on peel greasiness, yellowing, and related gene expression in postharvest Yuluxiang pear. Frontiers in Plant Science 13: 1082041. https://doi.org/10.3389/fpls.2022.1082041

Li F, Zhang X, Song B, Li J, Shang Z et al. (2013). Combined effects of 1-MCP and MAP on the fruit quality of pear (*Pyrus bretschneideri* Reld cv. Laiying) during cold storage. Scientia Horticulturae 164: 544-551. https://doi.org/10.1016/j.scienta.2013.10.018.

Lindo-García V, Larrigaudière C, Duaigües E, López ML, Echeverria G et al. (2020). Elucidating the involvement of ethylene and oxidative stress during on-and off-tree ripening of two pear cultivars with different ripening patterns. Plant Physiology and Biochemistry 155: 842-850. https://doi.org/10.1016/j.plaphy.2020.08.018

Lurie S, Fallik E, Klein JD (1996). The effect of heat treatment on apple epicuticular wax and calcium uptake. Postharvest Biology and Technology 8: 271-277. https://doi.org/10.1016/0925-5214(96)00007-5

Łysiak GP, Rutkowski K, Walkowiak-Tomczak D (2021). Effect of storage conditions on storability and antioxidant potential of pears cv. Conference. Agriculture 11: 545. https://doi.org/10.3390/agriculture11060545

Mao H, Lv Y, Chen G, Jiang Y (2022). Effects of cuticular wax on the postharvest physiology in fragrant pear at different storages. Journal of the Science of Food and Agriculture 102: 4425-4434. https://doi.org/10.1002/jsfa.11796

Mattheis JP, Felicetti D, Rudell DR (2013). Pithy brown core in 'd'Anjou' pear (*Pyrus communis* L.) fruit developing during controlled atmosphere storage at pO_2 determined by monitoring chlorophyll fluorescence. Postharvest Biology and Technology 86: 259-264. https://doi.org/10.1016/j.postharvbio.2013.07.006

Nanos GD, Romani RJ, Kader AA (1992). Metabolic and other responses of Bartlett pear fruit and suspension-cultured Passe Crassane pear fruit cells held in 0.25% O2. Journal of the American Society for Horticultural Science 117: 934-940. https://doi.org/10.21273/JASHS.117.6.934

Predieri S, Gatti E (2009). Effects of cold storage and shelf life on sensory quality and consumer acceptance of Abate Fetel pear. Postharvest Biology and Technology 51: 342-348. https://doi.org/10.1016/j.postharvbio.2008.09.006

Ribeiro CJO, Cavalheiro JT, Santos ASA, Meireles O, Ponteira D (2008). Preliminary characterization of Portuguese pear cultivars after cold storage. Acta Horticulturae 800: 1077-1084. https://doi.org/10.17660/ActaHortic.2008.800.147

Rizzolo A, Grassi M, Vanoli M (2015). Influence of storage (time, temperature, atmosphere) on ripening, ethylene production and texture of 1-MCP treated Abbe Fetel pears. Postharvest Biology and Technology 109: 20-29. https://doi.org/10.1016/j.postharvbio.2015.06.003

Saquet AA (2019). Storage of pears. Scientia Horticulturae 246: 1009-1016. https://doi.org/10.1016/j.scienta.2018.11.091

Saquet AA, Almeida DPF (2017). Ripening physiology and biochemistry of 'Rocha' pear affected by ethylene inhibition. Postharvest Biology and Technology 125: 161-167. https://doi.org/10.1016/j.postharvbio.2016.11.008

Saquet AA, Streif J, Almeida DP (2017). Responses of Rocha pear to delayed controlled atmosphere storage depend on oxygen partial pressure. Scientia Horticulturae 222: 17-21. https://doi.org/10.1016/j.scienta.2017.05.006

Shu P, Min D, Zhou J, Ai W, Li J et al. (2020). The synergism of 1-methylcyclopropene and ethephon preserves quality of Laiyang pears with recovery of aroma formation after long-term cold storage. Frontiers in Plant Science 11: 490. https://doi.org/10.3389/fpls.2020.00490

Sugar D (2007). Postharvest handling of winter pears. In: Mitcham E, Elkins R (editors). Pear Production and Handling Manual. Davis, CA, USA: University of California Agriculture and Natural Resources Publications, pp. 171-174.

Thompson AK, Prange RK, Bancroft R, Puttongsiri T (2019). Controlled Atmosphere Storage of Fruit and Vegetables. Wallingford, UK: CABI.

Tuna Gunes N, Poyrazoğlu ES (2022). Influence of hot water and 1-methylcyclopropane treatments on air-stored quince fruit. Agronomy 12: 458. https://doi.org/10.3390/agronomy12020458

Tuna Güneş N, Şan B, Aygün A, Erdoğan V, Kotlarla A et al. (2007). Ümitvar 'Ankara' armudu klonlarında meyvelerin soğukta muhafazası. In: Türkiye V. Ulusal Bahçe Bitkileri Kongresi; Erzurum, Türkiye. pp. 469-473 (in Turkish).

Vanoli M, Grassi M, Bianchi G, Buccheri M, Rizzolo A (2015). 'Conference' and 'Abbé Fétel' pears treated with 1-methylcyclopropene: physiological and quality implications of initial low oxygen stress and controlled atmosphere storage. Advances in Horticultural Science 29: (2-3): 84-96. https://doi.org/10.13128/ahs-22685

Vanoli M, Grassi M, Eccherzerbini P, Rizzolo A (2008). Fluorescence, conjugated trienes, α-farnesene and storage disorders in Abbé Fétel pears cooled with different speeds and treated with 1-MCP. Acta Horticulturae 58: 191-198. https://doi.org/10.17660/ActaHortic.2010.858.25

Vanoli M, Grassi M, Rizzolo A (2016). Ripening behavior and physiological disorders of Abate Fetel pears treated at harvest with 1-MCP and stored at different temperatures and atmospheres. Postharvest Biology and Technology 111: 274-285. https://doi.org/10.1016/j.postharvbio.2015.09.017

Villalobos-Acuña M, Mitcham EJ (2008). Ripening of European pears: The chilling dilemma. Postharvest Biology and Technology 49: 187-200. https://doi.org/10.1016/j.postharvbio.2008.03.003

Villalobos-Acuña MG, Biasi VW, Mitcham EJ, Holcroft D (2011). Fruit temperature and ethylene modulate 1-MCP response in Bartlett pears. Postharvest Biology and Technology 60: 17-23. https://doi.org/10.1016/j.postharvbio.2010.11.005

Wang L, Chen Y, Wang S, Xue H, Su Y et al. (2018). Identification of candidate genes involved in the sugar metabolism and accumulation during pear fruit post-harvest ripening of 'Red Clapp's Favorite' (*Pyrus communis* L.) by transcriptome analysis. Hereditas 155: 11. https://doi.org/10.1186/s41065-017-0046-0

Wang S, Saito T, Ohkawa K, Ohara H, Suktawee S et al. (2018). Abscisic acid is involved in aromatic ester biosynthesis related with ethylene in green apples. Journal of Plant Physiology 221: 85-93. https://doi.org/10.1016/j.jplph.2017.12.007

Wang Y, Mao H, Lv Y, Chen G, Jiang Y (2021). Comparative analysis of total wax content, chemical composition and crystal morphology of cuticular wax in Korla pear under different relative humidity of storage. Food Chemistry 339: 128097. https://doi.org/10.1016/j.foodchem.2020.128097

Watkins CB (2015). Advances in the use of 1-MCP. In: Wills RBH, Golding JB (editors). Advances in Postharvest Fruit and Vegetables Technology. Boca Raton, FL, USA: CRC Press, pp. 117-147.

Wu X, Yin H, Chen Y, Li L, Wang Y et al. (2017). Chemical composition, crystal morphology and key gene expression of cuticular waxes of Asian pears at harvest and after storage. Postharvest Biology and Technology 132: 71-80. https://doi.org/10.1016/j.postharvbio.2017.05.007

Zhi H, Dong Y, Wang Y (2019). Effects of controlled atmosphere, edible coating, and 1-methylcyclopropene on improving storage quality of pears after long-term storage. The Journal of Horticultural Science and Biotechnology 94: 94-101. https://doi.org/10.1080/14620316.2018.1450098