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INFLUENCE OF 1-METHYLCYCLOPROPENE (1-MCP) ON THE QUALITY AND STORABILITY OF 'RED JONAPRINCE' APPLES STORED IN DIFFERENT CONDITIONS

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ABSTRACT

The research was carried out on apples of the cultivar 'Red Jonaprince' in two storage seasons of 2015/2016 and 2016/2017. Both 1-MCP-treated and untreated apples were stored for 120 and 150 days at 2°C and 90–92% relative humidity in a regular cold store (NA) and in two atmospheric controlled storages, i.e. 2% CO_2 and 2% O_2 (CA) and 2% CO_2 and 1.2% O_2 (ULO). Apples were evaluated directly after the storage and after 7 days of simulated shelf-life. It was shown that storage conditions had significant impact on the value of apple quality traits. The effectiveness of the post-harvest 1-MCP treatment of apples manifested in different manner depending on the tested trait and storage conditions. 1-MCP delayed the softening of apples, but only those stored in CA and ULO. It effectively limited the decrease in titratable acidity, especially of apples from NA and ULO. A positive effect of 1-MCP in NA conditions on the soluble solids content was observed, as well as a reduction in the natural loss of weight and the percentage of fruits with the symptoms of fungal decay.

Key words: apples, 1-MCP, storage, shelf life, storability, quality

INTRODUCTION

The condition for maintaining good quality of apples after harvest is to limit the production of ethylene, and it is achieved by choosing the proper date of harvest and storage at low temperature and in a controlled atmosphere [Saquet and Streif 2008, Ho et al. 2013, Kweon et al. 2013]. This effect can also be obtained with 1-methylcyclopropene (1-MCP), which interacts with ethylene receptors, and as a result effectively blocks its synthesis [Sisler and Serek 1997]. According to Watkins and Miller [2005] and Pre-Aymard et al. [2005], the production of ethylene and fruit respiration is strongly inhibited by 1-MCP action, and thus reduces the rate of their maturation. The compound delays changes in the primary color of the skin [Bulens et al. 2012], reduces the skin's fatness and apple weight loss [DeEll et al. 2007, Akbudak et al. 2009]. The positive effect of 1-MCP on limiting apple softening [Zanella 2003, Tang et al. 2004, Pang et al. 2006, Jung and Watkins 2011, Bulens et al. 2012] and retaining high apple acidity [Mir et al. 2001, Pre-Aymard et al. 2003, Zanella 2003, Akbudak et al. 2009] have been often emphasized. According to Watkins et al. [2000] and Toivonen [2012], 1-MCP may have a beneficial effect on the content of apple soluble solids. In turn, Mir et al. [2001], Zanella [2003], Bai et al. [2005] and Argenta et al. [2007] believe that 1-MCP generally does not significantly affect the value of this trait. Many publications indicated the positive impact of 1-MCP on limiting the occurrence of physiological disorders of apples, such as superficial scald,

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senescent breakdown or core browning [Watkins et al. 2000, DeLong et al. 2004, Golding et al. 2005, Moran 2006, Sabban-Amin et al. 2011, Lu et al. 2012, Lu et al. 2013]. It has also been shown that 1-MCP may limit [Mitcham et al. 2001, Dauny and Joyce 2002] or increase the occurrence of fungal decay [Akbudak et al. 2009, McArtney et al. 2011]. The use of 1-MCP, in addition to many advantages, may also have negative consequences. The compound may increase the sensitivity of certain apple cultivars to elevated CO_2 concentrations [DeEll et al. 2003, Zanella 2003, Fawbush et al. 2008]. Additionally, 1-MCP may cause damage to fruit skin in the form of russet browning [McCormick and Streif 2008, Lallu et al. 2010]. The action of 1-MCP depends on the physiological state of the fruit. Too late apple harvest reduces the effective action of 1-MCP, which is associated with rapid loss of firmness [De Long et al. 2004, Fawbush et al. 2008]. When the compound is applied to prematurely harvested apples, it may disturb or prevent further ripening [Huber 2008]. The storage of fruits at low temperatures is the condition for the effective action of 1-MCP [Mir et al. 2001]. Apples stored in a regular cold store with 1-MCP retain high quality from 2 to even 6 months, depending on the cultivar [De Long et al. 2004]. 1-MCP works even longer on apples' quality if they are stored under KA conditions [Watkins et al. 2000, De Long et al. 2004, Akbudak et al. 2009].

The aim of the study was to evaluate the effect of 1-methylcyclopropene on the quality of apples of the cultivar 'Red Jonaprince' both after storage and after a shelf life.

MATERIALS AND METHODS

The research was carried out on apples of the cultivar 'Red Jonaprince' in two storage seasons of 2015/2016 and 2016/2017. The fruits were derived from the Experimental Orchard of the Department of Pomology and Apiculture, located in Garlica Murowana (50°08'25", 19°55'39"E). Trees grafted on the M.9 rootstock were planted in the spring of 2013, at a 4 × 1 m spacing. The harvest date was determined based on the measurement of apple flesh firmness, soluble solids content and starch index value and the value of the calculated Streif index. Chemical measurements and analyses were carried out directly after the harvest on a sample of 40 fruits. The following parameters were determined: flesh firmness, soluble solids contents, titratable acidity and respiration rate. In addition, 12 fruits from each combination were weighed to determine the size of the natural weight losses after storage. Fruit samples representative for storage conditions (combinations) were divided into 4 replicates, each representing about 10 kg of apples. After 7 days from harvest, half of the apples were treated for 24 hours with 1-methylcyclopropene (1-MCP) at a concentration of 0.65 μl l^{-1} at 2°C in the form of a SmartFresh™ formulation. The apples were stored at 2°C and 90–92% relative humidity in a regular cold store (with normal atmosphere, NA) and in a controlled atmosphere containing 2% CO_2 and 2% O_2 (CA) and 2% CO_2 and 1.2% O_2 (ULO). Storage time was 120 and 150 days. After removing the fruits from the cold store, they were stored for an additional 7 days at 17°C – the period of shelf life. The occurrence of fungal decay and physiological disorders was assessed on the basis of observations made after taking fruit out of the cold store. Measurements and analyses, on a sample of 40 fruits from each combination, were performed after 120 and 150 days of storage and after additional 7 days of simulated shelf life. Measurements of flesh firmness were carried out using a TA 500 Lloyd Texture Analyzer (tip with a 11 mm diameter). The measurement was performed twice in each fruit. The results are given in Newton (N). The soluble solids content was determined in apple juice using an ATAGO PR 100 refractometer. The results are given as a percentage (%). Titratable acidity was determined in apple juice by titrating a solution consisting of 5 ml of juice and 100 ml of distilled water with 0.1 N NaOH to pH 8.1, considered the neutralization point. Measurements were carried out using a CX 501 pH meter. The results are presented as a percentage (%) in malic acid equivalent. Fruit respiration intensity was measured using an Air Tech 2500P CO_2 analyzer. The measurements were carried out at 20°C in 12 fruits from each combination. The results are expressed in mg of CO_2 released by 1 kg of apples in 1 hour (mg CO_2 kg^{-1} h^{-1}). The size of natural fruit weight losses due to respiration and transpiration was calculated based on the difference in apple weight before and after storage. The results are given as a percentage (%). The occurrence of fungal decay and physiological disorders was assessed on the basis of observations made after taking fruit out of the cold store and after 7 days of simulated shelf life. The results are given as a percentage. The results obtained were statistically analyzed using one-way analysis of variance. Storage conditions were the factor analyzed. Data regarding the percentage of apples with symptoms of fungal diseases and physiological disorders were converted according to the Bliss function ($y = \arcsin \sqrt{x}$). Other indices were calculated using actual values. The Tukey test was used to assess the significance of differences between means, at the significance level, $\alpha = 0.05$. Calculations were conducted using the Statistica 12 program (Statsoft Inc.)

RESULTS

The physiological state of apples evaluated immediately after harvest is shown in Table 1. The date of apple harvest was determined each year of testing on the basis of flesh firmness, soluble solids content as well as starch index value and Streif index that corresponded to the recommended values of these indices for the optimal date of apple harvest of the Jonagold cultivar group. The effect of 1-MCP on apple firmness was only visible in the CA and ULO combinations both immediately after storage and after a 7-day period of shelf life (Tab. 2). Compound-treated apples showed greater firmness (from 13.9 to 27.6 N) than fruits stored without using this compound. The significant effect of 1-MCP on the described trait was not recorded in apples stored under NA conditions. Apples from the ULO/1-MCP combination were distinguished by the highest firmness at each measurement time points. In turn, fruits stored in NA with or without 1-MCP application were always characterized by lower firmness compared to apples from other combinations. Post-harvest 1-MCP-treated apples usually contained more soluble solids content than untreated fruits under all storage conditions (Tab. 3). Such a correlation was not observed only in apples stored in CA and ULO in the first study season, after 150 days of storage and after an additional period of simulated shelf life. The positive effect of 1-MCP on apple titratable acidity was generally observed in fruits stored under NA and ULO conditions (Tab. 4). The beneficial effect of the compound on the discussed trait was visible only in the second season of research

Table 1. Fruit quality of ‘Red Jonaprince’ apples at harvest

Year	Date of fruit harvesting	Flesh firmness (N)	Soluble solids content (%)	Titratable acidity (mg 100 g $^{-1}$)	Respiration rate (mg CO_2 kg^{-1} h^{-1})	Starch index (1−10)	Streif index
2015	22.09	73.0	12.3	0.56	1.6	8.7	0.07
2016	23.09	74.1	13.8	0.59	3.1	7.6	0.07

Table 2. Flesh firmness (N) of ‘Red Jonaprince’ apples as affected by storage conditions

Storage condition	2015/2016				2016/2017			
	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life	After 120-day storage	After 120-day storage and 7 day helf-life	After 150-day storage	After 150-day storage and 7 day shelf-life
NA	35.6 ±5.4 a	34.4 ±5.2 a	34.5 ±4.0 a	33.1 ±2.2 a	37.5 ±4.8 a	36.5 ±4.2 a	35.8 ±4.2 a	35.1 ±5.1 a
NA/1-MCP	38.2 ±7.6 a	37.3 ±4.9 a	37.6 ±5.2 a	35.1 ±4.9 a	38.4 ±4.0 a	37.1 ±3.4 a	36.2 ±4.7 a	35.9 ±5.8 a
CA	50.6 ±6.6 b	43.8 ±7.0 b	47.0 ±6.6 b	42.3 ±3.7 b	42.4 ±4.3 b	40.2 ±3.4 b	40.4 ±5.0 b	40.2 ±3.1 b
CA/1-MCP	64.5 ±9.1 d	64.0 ±11.8 d	63.4 ±10.4 c	61.8 ±9.7 c	69.1 ±6.8 d	67.8 ±9.5 d	67.2 ±8.6 d	65.3 ±9.4 d
ULO	55.1 ±6.5 c	48.1 ±6.9 c	48.5 ±6.2 b	44.7 ±4.2 b	51.7 ±5.4 c	45.0 ±4.2 c	46.3 ±6.1 c	45.0 ±11.6 c
ULO/1-MCP	70.0 ±5.7 d	69.8 ±5.2 e	68.0 ±8.3 d	66.8 ±10.1 d	72.5 ±4.9 e	71.6 ±4.9 e	70.3 ±5.3 e	69.6 ±8.8 e

* Means followed by the same letter within column, for each analyzed date and storage season, are not significantly different at $\alpha = 0.05$

Table 3. Soluble solids content (%) of 'Red Jonaprince' apples as affected by storage conditions

Storage condition	2015/2016				2016/2017			
	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life
NA	11.9 ±0.3 a	12.0 ±0.4 a	11.8 ±0.1 a	12.0 ±0.1 a	13.0 ±0.6 a	13.0 ±0.3 a	12.6 ±0.8 a	12.7 ±0.5 a
NA/1-MCP	12.6 ±0.3 b	12.5 ±0.1 b	12.7 ±0.4 b	12.5 ±0.4 b	13.6 ±0.4 b	13.3 ±0.3 b	12.9 ±0.3 b	13.1 ±0.4 b
CA	12.7 ±0.5 b	12.6 ±0.3 b	12.7 ±0.1 b	12.5 ±0.4 b	13.9 ±0.3 c	13.8 ±0.1 c	13.8 ±0.5 cd	13.8 ±0.6 d
CA/1-MCP	12.9 ±0.4 bc	12.8 ±0.1 bc	12.8 ±0.2 b	12.6 ±0.1 b	14.5 ±0.2 d	14.7 ±0.2 d	14.1 ±0.1 e	14.2 ±0.6 e
ULO	12.7 ±0.1 b	12.6 ±0.2 b	12.6 ±0.2 b	12.5 ±0.3 b	13.6 ±0.5 b	13.4 ±0.7 b	13.6 ±0.3 c	13.5 ±0.7 c
ULO/1-MCP	13.0 ±0.2 c	13.0 ±0.2 c	12.6 ±0.5 b	12.7 ±0.3 b	14.1 ±0.7 cd	13.9 ±0.5 c	14.0 ±0.7 de	14.2 ±0.5 e

* Explanations: see Table 2

Table 4. Titratable acidity (mg 100 g $^{-1}$) of 'Red Jonaprince' apples as affected by storage conditions

Storage condition	2015/2016				2016/2017			
	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life
NA	0.40 ±0.02 a	0.34 ±0.01 a	0.28 ±0.02 a	0.27 ±0.00 a	0.38 ±0.04 a	0.37 ±0.04 a	0.39 ±0.03 a	0.30 ±0.00 a
NA/1-MCP	0.43 ±0.06 b	0.40 ±0.02 b	0.37 ±0.02 b	0.34 ±0.04 b	0.43 ±0.02 b	0.43 ±0.05 b	0.42 ±0.03 b	0.32 ±0.02 a
CA	0.48 ±0.03 c	0.44 ±0.01 c	0.42 ±0.01 c	0.41 ±0.01 c	0.48 ±0.03 c	0.47 ±0.02 c	0.49 ±0.01 c	0.42 ±0.02 b
CA/1-MCP	0.49 ±0.03 c	0.45 ±0.01 c	0.44 ±0.01 cd	0.42 ±0.03 c	0.52 ±0.04 d	0.51 ±0.01 d	0.51 ±0.03 c	0.46 ±0.02 c
ULO	0.50 ±0.01 c	0.46 ±0.04 c	0.46 ±0.01 de	0.43 ±0.03 c	0.48 ±0.04 c	0.48 ±0.03 c	0.50 ±0.04 c	0.45 ±0.02 c
ULO/1-MCP	0.53 ±0.03 d	0.50 ±0.03 d	0.48 ±0.02 e	0.46 ±0.01 d	0.57 ±0.01 e	0.56 ±0.02 e	0.56 ±0.03 d	0.53 ±0.05 d

* Explanations: see Table 2

Table 5. Respiration rate (mg CO_2 kg^{-1} h^{-1}) of 'Red Jonaprince' apples as affected by storage conditions

Storage condition	2015/2016				2016/2017			
	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life	After 120-day storage	After 120-day storage and 7 day shelf-life	After 150-day storage	After 150-day storage and 7 day shelf-life
NA	9.65 ±1.80 d	9.77 ±2.40 c	9.18 ±0.20 c	9.72 ±0.96 b	8.85 ±2.36 b	9.16 ±1.18 c	5.45 ±0.74 b	10.79 ±4.13 c
NA/1-MCP	7.10 ±0.56 c	7.37 ±0.56 b	8.89 ±0.16 c	9.11 ±0.53 b	7.20 ±1.00 b	7.74 ±1.74 bc	3.63 ±0.56 ab	8.58 ±3.45 bc
CA	4.14 ±0.73 b	6.64 ±0.14 b	4.62 ±0.24 b	6.32 ±0.43 ab	6.70 ±2.09 b	7.75 ±0.98 bc	5.17 ±0.10 b	6.97 ±2.52 abc
CA/1-MCP	2.76 ±0.62 ab	3.95 ±0.40 a	4.37 ±0.10 ab	5.18 ±0.40 a	2.58 ±0.71 a	2.57 ±0.23 a	3.07 ±1.05 ab	3.12 ±1.23 ab
ULO	2.90 ±0.15 ab	4.37 ±1.76 a	2.34 ±0.18 a	4.33 ±0.56 a	4.14 ±0.27 a	5.73 ±2.05 b	4.51 ±1.49 b	5.22 ±1.00 ab
ULO/1-MCP	2.25 ±0.80 a	2.88 ±1.16 a	2.67 ±0.69 a	3.52 ±0.39 a	2.04 ±0.57 a	2.08 ±0.44 a	1.74 ±0.21 a	2.67 ±1.51 a

* Explanations: see Table 2

Table 6. Natural weight losses (%) of 'Red Jonaprince' apples as affected by storage conditions

Storage condition	2015/2016		2016/2017	
	After 120-day storage	After 150-day storage	After 120-day storage	After 150-day storage
NA	5.5 c	6.2 c	5.6 c	6.5 c
NA/1-MCP	4.9 b	5.5 b	4.8 b	5.4 b
CA	0.9 a	1.3 a	0.9 a	1.5 a
CA/1-MCP	1.0 a	1.3 a	0.9 a	1.5 a
ULO	0.7 a	1.1 a	1.0 a	1.5 a
ULO/1-MCP	1.1 a	1.5 a	0.6 a	1.1 a

* Explanations: see Table 2

Table 7. Percent of 'Red Jonaprince' apples with fungal decay symptoms as affected by storage conditions

Storage condition	2015/2016		2016/2017	
	After 120-day storage and 7 day shelf-life	After 150-day storage and 7 day shelf-life	After 120-day storage and 7 day shelf-life	After 150-day storage and 7 day shelf-life
NA	3.8 c	2.5 c	4.9 b	4.7 b
NA/1-MCP	1.3 b	1.4 b	0.7 a	0.7 a
CA	0.4 a	0.8 a	0.0 a	0.0 a
CA/1-MCP	0.0 a	0.0 a	0.8 a	0.6 a
ULO	0.9 ab	0.0 a	0.8 a	0.4 a
ULO/1-MCP	0.0 a	0.0 a	0.8 a	0.6 a

* Explanations: see Table 2

Table 8. Percent of 'Red Jonaprince' apples with bitter pit symptoms as affected by storage conditions

Storage condition	2015/2016		2016/2017	
	After 120-day storage and 7 day shelf-life	After 150-day storage and 7 day shelf-life	After 120-day storage and 7 day shelf-life	After 150-day storage and 7 day shelf-life
NA	6.0 c	5.1 c	5.5 d	5.4 d
NA/1-MCP	6.3 c	5.0 c	3.3 c	2.6 c
CA	1.6 a	0.8 a	3.1 c	2.6 c
CA/1-MCP	1.7 a	0.8 a	0.0 a	0.0 a
ULO	3.0 b	2.6 b	1.3 b	1.0 b
ULO/1-MCP	1.7 b	2.5 b	0.0 a	0.0 a

* Explanations: see Table 2

for apples from CA; the exception was the result of the analysis after 150 days of storage. As in the case of flesh firmness, the titratable acidity of apples stored in NA conditions, which were treated and not treated after harvest with 1-MCP, was significantly lower compared to fruits from other storage conditions. Assessing the effect of 1-MCP on the intensity of apple respiration, it was shown that the compound effectively limited the intensity of fruit respiration only in certain combinations and measurement time points (Tab. 5). In turn, the influence of storage conditions on the value of the discussed trait was clearly visible. Respiration intensity of apples stored in ULO with or without the use of 1-MCP was generally lower than those from NA and NA/1-MCP conditions. Post-harvest 1-MCP treatment of apples, which were stored in NA, significantly reduced their weight loss (Tab. 6). There was no effect of the compound on the value of this trait for CA and ULO, but the apple weight losses from these storage conditions were significantly lower compared to the fruits from NA and NA/1-MCP. Similar relationships, as for the above discussed trait, were found by analyzing the effect of 1-MCP on the percentage of apples showing signs of fungal decay, such as gloeosporium rot (*Gloeosporium* sp.) and blue mold (*Penicillium expansum*) (Tab. 7). The only difference was the higher percentage of infected apples from NA conditions compared to other combinations observed in the second storage season. The storage of apples with the use of 1-MCP had an impact on the limitation of the percentage of fruits with bitter pit symptoms, but only in the second storage season (Tab. 8). In addition, it was demonstrated that in general the most damaged fruits came from the NA and NA/1-MCP combinations.

DISCUSSION

Storing apples with 1-MCP, with the exception of those stored in the NA, allowed to maintain their high firmness, exceeding 60 N, throughout the storage period and during the simulated shelf life. In contrast, softening rate of apples stored without the use of the compound was rapid, their firmness after removal from the cold store was less than 55 N – the value characterizing the firmness threshold accepted by consumers for apples considered hard [DeEll et al. 2001]. The only exception was apples stored for 120 days in ULO in the first research season. The results of the present experiments did not confirm previous reports of Zanella [2003] about the higher firmness of apples treated with 1-MCP and stored in NA compared to the apple firmness in CA. Fast softening of apples, especially those stored under NA conditions (with and without 1-MCP), and those untreated with 1-MCP in CA and ULO suggests that the harvest should be performed earlier, when the fruit flesh firmness of this cultivar is higher. In addition to flesh firmness, soluble solids content and titratable acidity are important features that characterize fruit quality. The effect of 1-MCP on the value of these indices is usually favorable [Watkins et al. 2000, Zanella 2003, DeLong et al. 2004, Akbudak et al. 2009, Toivonen 2012]. The results of our research demonstrated that regardless of storage conditions, there was often a lower decrease in titratable acidity, and the content of soluble solids in apples was usually greater under 1-MCP conditions. However, information on the effect of 1-MCP on the soluble solids content in apples is contradictory. According to Fan et al. [1999] and Rupasinghe et al. [2000] 1-MCP did not affect soluble solids content in apples. On the other hand, Watkins et al. [2000], Bai et al. [2005], Akbudak et al. [2009] and Toivonen [2012] were of opposite opinion. In the conducted experiments, a constant drop in the titratable acidity of apples was observed with prolonged storage time. This relationship was observed directly after storage and after the period of shelf life. However, the rate of this process was much higher for fruits stored in NA than in CA and ULO conditions. The results presented in the current work confirmed the opinion of Johnson [2008] and James et al. [2010], who believed that the conditions of controlled atmosphere effectively inhibited the acidity decrease in fruits. Many publications emphasized the effectiveness of 1-MCP in limiting ethylene synthesis and the intensity of fruit respiration [Rupasinghe et al. 2000, Ferenczi et al. 2006, Mao et al. 2007]. The results of the present research did not unambiguously confirm this view. The use of 1-MCP did not always significantly reduce the intensity of apple respiration. Fruit storage conditions, especially in ULO, had a greater impact on the value of the discussed trait. The process of respiration and transpiration leads to a natural loss of apple weight.

Fruits stored under NA conditions showed up to 5−6 times higher weight loss compared to CA and ULO. The application of 1-MCP gave a positive effect only in this combination of storage conditions, significantly reducing apple weight loss, as previously reported by DeEll et al. [2007] and Akbudak et al. [2009]. Low weight loss of apples from CA and ULO stored with and without 1-MCP, which after 5 months of storage did not exceed 1.5% should be noted. The occurrence of fungal decay and physiological diseases can cause large losses during fruit storage. 1-MCP is believed to maintain better wholesomeness of stored fruits. The studies of Lafer [2003] and Akbudak et al. [2009] proved a lower occurrence of fungal diseases when 1-MCP was applied. In the current study, the use of 1-MCP allowed to significantly reduce the percentage of apples with symptoms of fungal decay only in NA conditions. No effect of the compound on the occurrence of fungal decay was observed in the CA and ULO combination. It should be emphasized that under these storage conditions, either all fruits were healthy, or the percentage of rotten fruits was negligible. The bitter pit was the only physiological disorders observed in the stored apples. Many reports confirmed fewer physiological disorders of fruits under the influence of 1-MCP [Watkins et al. 2000, Zanella 2003, DeLong et al. 2004, Akbudak et al. 2009]. In our research, the positive effect of 1-MCP in reducing the occurrence of bitter pit was noted in all storage combinations, but only in the second year of the study. In addition, it was shown that the percentage of apples with bitter pit symptoms was always higher under NA conditions than in CA and ULO. Similar results were obtained by Akbudak et al. [2009], who found that the reduction of storage disease occurrence was lower under the influence of 1-MCP than in a controlled atmosphere, and the best results were obtained by combining the application of 1-MCP with fruit storage in a controlled atmosphere.

CONCLUSIONS

The result of the present study showed that storage conditions had a significant impact on the value of apple quality traits, while, the post-harvest effect of 1-MCP fruit treatment was varied. The compound generally had a positive effect on limiting the acidity decrease of apples and soluble solids content. 1-MCP effectively reduced the size of natural weight losses and the percentage of fruits with symptoms of fungal decay in apples stored under NA conditions. The problem associated with storing apples of the cultivar 'Red Jonaprince' was their relatively fast softening, even when stored in CA and ULO. However, the application of 1-MCP in these combinations effectively delayed this process. However, this effect was not observed in apples stored in NA.

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