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The Effects of Preharvest 1-Methylcyclopropene (1-MCP) Treatment on the Fruit Quality Parameters of Cold-Stored 'Szampion' Cultivar Apples

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Abstract: Postharvest treatment by 1-methylcyclopropene (1-MCP) for 'Szampion' cultivar apples inhibits ripening of climacteric fruit by blocking ethylene receptors, preventing ethylene from binding and eliciting its action. It is also possible to apply 1-MCP preharvest, which so far has not been studied for the 'Szampion' cultivar. The aim of this study was to assess the effects of preharvest 1-MCP treatment on the fruit quality parameters of cold-stored 'Szampion' cultivar apples in a Polish experiment. Two identical groups of apple trees (6 years, experimental orchard in Warsaw) were included, to obtain studied apples (preharvest 1-MCP treatment with Harvista^{TM}, 150 g/ha, 7 days before the optimum harvesting window, OHW) and control apples (1-MCP not applied). Apples for the studied group were harvested twice—on 28 September (OHW) and 24 October (delayed harvesting)—and for control group once—on 28 September, as before 24 October the majority of apples fell from trees. Afterwards, apples were stored in an Ultra Low Oxygen chamber (1.2% CO_2, 1.2% O_2). Apples were assessed in the preharvest period (weekly, six measurements for the studied group, and five measurements for the control group) and postharvest period (monthly, three measurements separately for each harvest time for the studied group and control group). The following parameters were assessed: internal ethylene content (IEC), firmness, total soluble solids (TSS) content, starch index, Streif index, titratable acidity (TA), and color for blush. For the preharvest period, statistically significant differences between the studied group and the control group were observed for IEC, the a* coordinate of color ($p < 0.05$; for apples treated with 1-MCP lower results), firmness, Streif index, TA ($p < 0.05$; higher results), and starch index ($p < 0.05$; no defined trend). For the postharvest period, statistically significant differences between the studied group and the control group were observed for apples harvested in the OHW for firmness ($p < 0.05$; for apples treated with 1-MCP higher results) and IEC ($p < 0.05$; no defined trend), while for delayed harvesting the differences were only minor. It may be concluded, that preharvest 1-MCP application makes it possible not only to obtain better results for 'Szampion' cultivar apples' quality parameters, but also allows delayed harvesting without deterioration in quality.

Keywords: 1-methylcyclopropene; 1-MCP; preharvest; 'Szampion'; quality; ethylene production; starch index; total soluble solids; titratable acidity; firmness; Streif index; color

1. Introduction

'Szampion' is a hybrid cultivar crossing 'Golden Delicious' and 'Cox Orange Pippin' and is almost exclusively grown in Poland. Such high production of 'Szampion' in Poland may be a chance for Polish export, as the apple prices are in Poland relatively low (38 EUR/100kg for November 2019, based on statistics of European Commission), as compared with other countries (European Union average price of 63 EUR/100kg) [1].

In order to increase the quality of produced 'Szampion' cultivar apples, various actions are taken, including spraying trees [2], modified atmosphere storage [3], and edible coatings [4], but also postharvest treatment by 1-methylcyclopropene (1-MCP) [5]. 1-MCP is commonly used in postharvest treatment also for other cultivars, such as 'Aroma', 'Red Gravenstein', 'Summered Norvegian' [6], 'Idared' [5], 'Granny Smith' [7], 'Red Delicious' [8], 'Cripps Pink' [9], and 'Jonah King' cultivars [10]. It inhibits ripening of climacteric fruit by blocking ethylene receptors, preventing ethylene from binding and eliciting its action [11]. In the study of Kolniak-Ostek [5], which evaluated the effect of postharvest 1-MCP treatment on apple physicochemical quality, after 6 months of storage, authors stated that the content of dry matter in apple increased, while total soluble solids content and acidity decreased slightly. In this study, the authors concluded that, when used postharvest in the production of 'Szampion' apples, 1-MCP is promising for maintaining the eating quality [5].

However, there is also a possibility of using 1-MCP preharvest, being a quite novel option, studied so far only for few a cultivars, including 'McIntosh', 'Empire' [12], and 'Fuji' cultivars when combined with 1-MCP postharvest treatment [13], or alone for 'Delicious', 'Empire', 'Gala', 'Jonagold', 'Macoun', 'McIntosh' [14], 'Honeycrisp' [14,15], 'Golden Delicious' [16,17], 'Law Rome' [17], 'Scarletspur Delicious', 'Cameo' [18], 'Imperial Gala', and 'Royal Gala' cultivars [19], but not studied so far for 'Szampion' cultivar. Taking this into account, the aim of the present study was to assess the effects of preharvest 1-MCP treatment on the fruit quality parameters of cold-stored 'Szampion' apples in the Polish experiment.

2. Materials and Methods

2.1. Experiment

The study was conducted based on the cultivation in the experimental orchard of the Warsaw University of Life Sciences, located in Warsaw (52°14′ N, 21°1′ E). The research was conducted both in-orchard (preharvest period) and in the experimental Ultra Low Oxygen (ULO) chamber (1.2% CO_2, 1.2% O_2; temperature of 1 °C) of the Institute of Horticultural Sciences (postharvest period) during the 2017/2018 storage season.

Within the Shampion group (classification based on the Regulation of the European Parliament and of the Council No 1337/2011 [20]), the 'Szampion' cultivar was chosen for assessment (classification based on the Regulation No 1337/2011 [21], in agreement with 2008/690/EC Commission Decision [22]).

The orchard was planted in an area of fertile soil [23] of the highest valuation quality (1st class in the Polish soil classification) characterized by a share of humus higher than 2% [24]. The 'Szampion' trees were planted at 3.5 meters by 1 meter as a tall spindle system. In 2017, when the experiment was conducted, the trees were of 6 years of age and they were not higher than 3 meters. Due to low temperatures in April–May 2017 for Warsaw and the risk of subzero temperatures during a frost night (the lowest temperature in April was −3.9 °C, based on the data of Institute of Meteorology and Water Management—National Research Institute [25]), standard over-plant sprinklers were used to obtain an active protection [26].

The scheme of the experiment is presented in Figure 1. There were two identical groups of apple trees, to obtain the studied apples (applied preharvest 1-MCP treatment) and control apples (preharvest 1-MCP treatment not applied), which were assessed in the preharvest and postharvest periods.

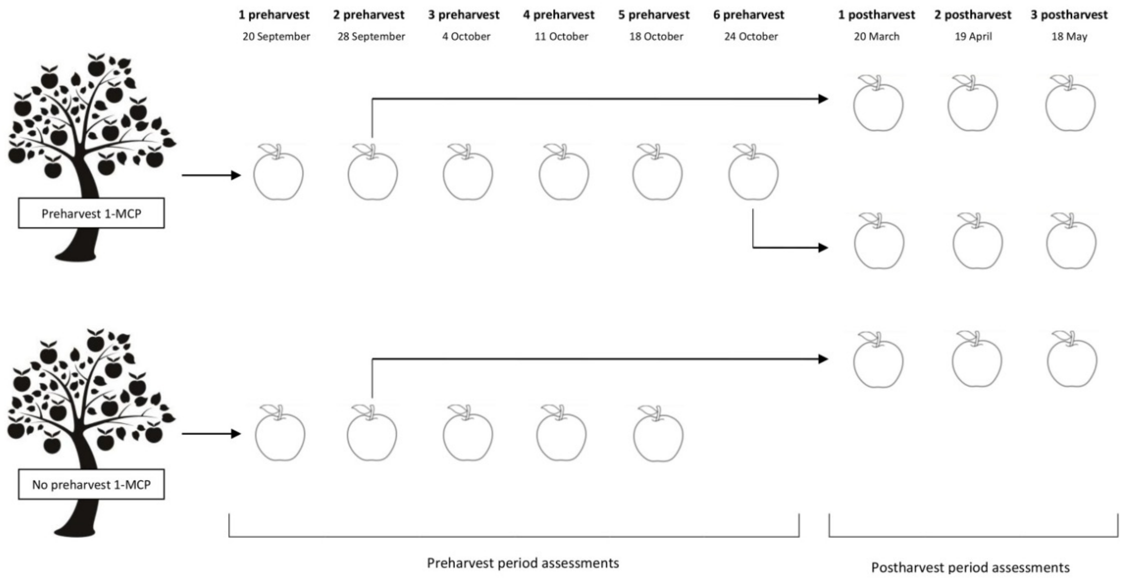

Figure 1. The scheme of the experiment.

1-MCP was applied as a sprayable formulation for preharvest use on horticultural products (Harvista™, by AgroFresh Solutions Inc., Philadelphia, PA, USA, being the only 1-MCP formulation for preharvest use); this makes it possible to obtain better postharvest fruit firmness retention and reduced ethylene production [27]. It was applied 7 days before the optimum harvesting window (OHW) (for Poland, for 'Szampion' apples, 28 September), namely 20 September. The applied dose was 150 g/ha, as doses of 100 g/ha, or higher than 100 g/ha, were found to be the most positive for preventing fruit drop and minimizing the changes of quality parameters of fruits [16,28]; 400 L of water were used to apply the solution, and the application was made in the morning.

In order to verify the harvesting time, the assessment of ethylene production was conducted each week in the preharvest period and once a month in the postharvest period after 5, 6 and 7 months of storage [29]. The analysis was conducted for the sample of 1500 g of apples, which were placed in a hermetically sealed container for 7 days with hydrated lime (reacting with carbon dioxide). Every 24 hours, 1 ml of air was analyzed using gas chromatography (HP 5890, Hewlett Packard, Palo Alto, CA, USA) to specify the amount of ethylene produced per 1 kg of apples in 1 hour.

The apples from the studied group were harvested twice—on 28 September (OHW) and 24 October (delayed harvesting). For the control group, apples were harvested only once (28 September, OHW), as before 24 October (delayed harvesting possible after preharvest 1-MCP treatment only) the majority of apples fell from the trees (89.3% until 18 October). Afterwards, apples were stored in a ULO chamber, for 5, 6 and 7 months.

2.2. Measurements

The measurements were conducted in the preharvest period (six measurements for studied group, five measurements for control group) and postharvest period (3 measurements, measurements separately for each harvest time of studied group and control group). In the preharvest period, the following parameters were assessed: internal ethylene content (IEC), firmness, total soluble solids (TSS) content, starch index, Streif index, titratable acidity (TA), and CIE L*a*b* coordinates of color for blush, while in the postharvest period, the following parameters were assessed: IEC, firmness, TSS, TA. The starch index was not assessed in postharvest period, as it is a parameter used to specify the stage of development (maturity) of apple fruit [30] and, as a result, to predict the OHW [31]. At the same time, as for Streif index and L*a*b* coordinates of color for blush the differences in the preharvest period were only minor and inconclusive, or they were not observed, so the indicated parameters were no longer monitored in the postharvest period.

The internal ethylene content [μl/l] was measured in the core space of the apples, using a 1 ml syringe to collect the samples of air. For each apple, 1 ml of air was withdrawn by a syringe from the apple's core and analyzed using gas chromatography (HP 5890, Hewlett Packard, Palo Alto, CA, USA). Measurements were conducted in four replications using 10 apples each time.

The firmness [N] was measured with the peel removed, on the two opposite sides of the fruit, using a universal testing machine (Instron 5542, Instron, Norwood, MA, USA), and stainless steel plunger tips of 11 mm diameter with a speed of 4 mm/s. Measurements were conducted in four replications.

The total soluble solids (TSS) content] (°Bx) was measured for the pressed juice, using a digital refractometer (Atago Palette PR-32, Atago Co., Ltd., Tokyo, Japan). Measurements were conducted in four replications.

The starch index was measured based on the reaction with Lugol's iodine solution (I_3K), after visual analysis of the color of the flesh, in comparison with standards, using a dedicated 10-points scale. Measurements were conducted in four replications using 10 apples each time.

The Streif index was calculated based on the results of firmness, total soluble solids content and starch index [32].

The titratable acidity (TA), recalculated per malic acid content, was measured for the pressed juice, by titration with 0.1 M NaOH to pH 8.1, while using automatic titrator (TitroLine 5000, Xylem Analytics Germany GmbH, Weilheim, Germany). Measurements were conducted in four replications.

The color was measured in a CIE L*a*b* system for the blush of the apples, using a portable spectrophotometer (Minolta CM-508i, Konica Minolta Co., Ltd., Tokyo, Japan), calibrated against a standard white tile. Measurements were conducted in five replications using four apples each time.

Ethylene production was analyzed as the amount of ethylene produced by 1000 g of apples in 1 hour ($\mu L \cdot kg^{-1} \cdot h^{-1}$). Immediately after harvesting, 1500 grams of apples were sealed in airtight containers with calcium hydroxide to bind the carbon dioxide produced. Over 7 days, the measurements were conducted using a 1 mL syringe to collect the samples of air. 1 mL of air was withdrawn by a syringe from the containers and analyzed using gas chromatography (HP 5890, Hewlett Packard, Palo Alto, CA, USA). Measurements were conducted in two batches, 1500 g of apples each.

2.3. Statistical Analysis

The distribution of data was verified while using the Shapiro–Wilk test. To compare results obtained for the studied group and the control group, a Student's t-test (for parametric distributions), and Mann–Whitney U test (for nonparametric distributions) were applied. A value of $p \leq 0.05$ was accepted as a significant difference between groups. Statistical analysis was conducted using the Statgraphics Plus for Windows 5.1 (Statgraphics Technologies Inc., The Plains, VA, USA).

3. Results

The results for IEC in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 1. Statistically significant differences between the studied group and the control group were observed for preharvest period for first assessment (directly after applying 1-MCP; $p = 0.0171$) and afterwards for the fourth ($p < 0.0001$; lower IEC for apples treated with 1-MCP) and fifth assessment ($p < 0.0001$; lower results of IEC for apples treated with 1-MCP).

Table 1. Results for internal ethylene content (µl/l) measured in the core space for 'Szampion' cultivar apples in the pre- and postharvest periods, compared for groups treated with 1-MCP and a control group not treated with 1-MCP.

Assessment		No Preharvest 1-MCP Treatment	Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD	0.20 ± 0.24	0.15 ± 0.11	0.0171
	Median (min–max)	0.07 * (0.04–0.77)	0.12 * (0.07–0.74)	
2nd preharvest	Mean ± SD	0.24 ± 0.25	0.2 ± 0.23	0.0531
	Median (min–max)	0.16 * (0.09–1.07)	0.13 * (0.08–0.98)	
3rd preharvest	Mean ± SD	1.70 ± 2.16	1.88 ± 4.15	0.1449
	Median (min–max)	0.42 * (0.11–10.80)	0.16 * (0.06–23.60)	
4th preharvest	Mean ± SD	10.96 ± 6.79	1.31 ± 3.14	<0.0001
	Median (min–max)	9.15 * (2.04–26.00)	0.67 * (0.09–19.60)	
5th preharvest	Mean ± SD	30.95 ± 13.81	3.22 ± 6.28	<0.0001
	Median (min–max)	30.95 (3.15–60.38)	0.95 * (0.03–29.00)	
6th preharvest	Mean ± SD	-	3.81 ± 5.00	-
	Median (min-max)	-	0.89 * (0.14-17.70)	
OHW harvesting				
1st postharvest	Mean ± SD	14.44 ± 5.53	2.06 ± 0.31	0.0006
	Median (min–max)	17.46 * (4.71–18.93)	2.07 (1.52–2.48)	
2nd postharvest	Mean ± SD	21.08 ± 15.12	6.35 ± 4.73	0.0301
	Median (min–max)	16.48 (5.54–41.89)	3.40 (2.28–14.09)	
3rd postharvest	Mean ± SD	10.39 ± 7.89	30.85 ± 9.76	0.0010
	Median (min–max)	6.88 (1.86–22.26)	32.29 (11–39.80)	
Delayed harvesting				
1st postharvest	Mean ± SD	14.44 ± 5.53	16.74 ± 8.55	0.7493
	Median (min–max)	17.46 * (4.71–18.93)	16.87 (4.63–28.74)	
2nd postharvest	Mean ± SD	21.08 ± 15.12	19.88 ± 11.80	0.8712
	Median (min–max)	16.48 (5.54–41.89)	15.04 (6.29–36.28)	
3rd postharvest	Mean ± SD	10.39 ± 7.89	25.53 ± 7.36	0.0060
	Median (min–max)	6.88 (1.86–22.26)	26.59 * (10.03–31.68)	

* non-parametric distribution (verified using Shapiro-Wilk test—$p \leq 0.05$); OHW—optimum harvesting window; 1-MCP—1-methylcyclopropene.

Statistically significant differences between the studied group and the control group were observed for apples harvested in the OHW for the first ($p = 0.0006$; lower IEC for apples treated with 1-MCP), second ($p = 0.0301$; lower IEC for apples treated with 1-MCP) and third assessment ($p = 0.0010$; higher IEC for apples treated with 1-MCP), as well as for delayed harvesting for the third assessment ($p = 0.0060$; higher IEC for apples treated with 1-MCP).

The results of firmness measured for 'Szampion' cultivar apples in the pre- and postharvest periods, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 2. Statistically significant differences between the studied group and the control group were observed for preharvest period only for the fifth assessment ($p = 0.0003$; higher firmness for apples treated with 1-MCP).

Table 2. Results for firmness [N] measured in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for groups treated with 1-MCP and a control group not treated with 1-MCP.

Assessment		No Preharvest 1-MCP Treatment	Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD	65.7 ± 1.6	68.0 ± 3.2	0.1489
	Median (min–max)	65.1 (64.7–68.0)	66.6 * (66–72.7)	
2nd preharvest	Mean ± SD	64.8 ± 2.5	67.4 ± 1.4	0.1066
	Median (min–max)	64.3 (62.4–68.0)	67.5 (65.9–68.9)	
3rd preharvest	Mean ± SD	64.9 ± 1.8	63.7 ± 3.6	0.5839
	Median (min–max)	64.9 (62.9–67.0)	64.3 (59.6–66.7)	
4th preharvest	Mean ± SD	61.4 ± 1.1	63.5 ± 3.5	0.3034
	Median (min–max)	61.7 (59.9–62.3)	64.3 (58.9–66.3)	
5th preharvest	Mean ± SD	53.6 ± 2.8	67.7 ± 2.4	0.0003
	Median (min–max)	53.2 (50.7–57.4)	67.2 (65.2–71)	
6th preharvest	Mean ± SD	–	58.5 ± 2.7	-
	Median (min–max)	–	57.8 (56.1–62.3)	
OHW harvesting				
1st postharvest	Mean ± SD	60.4 ± 0.7	70.1 ± 2.5	0.0003
	Median (min–max)	60.4 (59.7–61.1)	69.7 (67.7–73.3)	
2nd postharvest	Mean ± SD	58.4 ± 2.6	69.9 ± 1.7	0.0003
	Median (min–max)	58.4 (55.5–61.2)	70.4 (67.6–71.2)	
3rd postharvest	Mean ± SD	57.2 ± 2.1	64.4 ± 2.1	0.0003
	Median (min–max)	57.9 (54.2–58.6)	65.1 (61.4–66.0)	
Delayed harvesting				
1st postharvest	Mean ± SD	60.4 ± 0.7	56.0 ± 4.8	0.1165
	Median (min–max)	60.4 (59.7–61.1)	55.2 (51.2–62.2)	
2nd postharvest	Mean ± SD	58.4 ± 2.6	50.9 ± 5.9	0.0592
	Median (min–max)	58.4 (55.5–61.2)	50.4 (44.3–58.6)	
3rd postharvest	Mean ± SD	57.2 ± 2.1	54.6 ± 4.2	0.3067
	Median (min–max)	57.9 (54.2–58.6)	53.7 (50.6–60.3)	

* non-parametric distribution (verified using Shapiro-Wilk test—$p \leq 0.05$); OHW—optimum harvesting window; 1-MCP—1-methylcyclopropene.

Statistically significant differences between the studied group and the control group were observed for apples harvested in the OHW for the first ($p = 0.0003$; higher firmness for apples treated with 1-MCP), second ($p = 0.0003$; higher firmness for apples treated with 1-MCP) and third assessments ($p = 0.0003$; higher firmness for apples treated with 1-MCP).

The results for TSS content measured in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 3. No statistically significant differences between the studied group and the control group were observed for preharvest period ($p > 0.05$).

Statistically significant differences between the studied group and the control group were observed for apples from delayed harvesting for the second assessment ($p = 0.0407$; lower TSS content for apples treated with 1-MCP).

Table 3. Results for total soluble solids content (°Bx) measured in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for groups treated with 1-MCP and a control group not treated with 1-MCP.

Assessment		No Preharvest 1-MCP Treatment	Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD Median (min–max)	12.6 ± 0.1 12.6 (12.4–12.7)	12.6 ± 0.3 12.7 (12.2–12.9)	0.7970
2nd preharvest	Mean ± SD Median (min–max)	13.1 ± 0.3 13.2 (12.8–13.4)	12.7 ± 0.1 12.7 (12.6–12.8)	0.2147
3rd preharvest	Mean ± SD Median (min–max)	13.1 ± 0.4 13.0 (12.8–13.6)	12.9 ± 0.2 12.9 (12.6–13.2)	0.3903
4th preharvest	Mean ± SD Median (min–max)	13.0 ± 0.5 13.2 (12.3–13.4)	12.9 ± 0.2 12.9 (12.6–13.1)	0.5415
5th preharvest	Mean ± SD Median (min–max)	14.0 ± 0.4 14.0 (13.6–14.5)	13.3 ± 0.3 13.3 (12.9–13.5)	0.1421
6th preharvest	Mean ± SD Median (min–max)	– –	13.3 ± 0.1 13.3 * (13.2–13.4)	–
OHW harvesting				
1st postharvest	Mean ± SD Median (min–max)	13.5 ± 0.6 13.5 (12.8–14.3)	13.4 ± 0.6 13.5 (12.6–14.0)	0.8662
2nd postharvest	Mean ± SD Median (min–max)	13.2 ± 0.2 13.2 (13.0–13.4)	13.0 ± 0.1 13.0 (12.8–13.1)	0.7545
3rd postharvest	Mean ± SD Median (min–max)	12.7 ± 0.2 12.6 * (12.6–13.0)	12.6 ± 0.3 12.5 (12.3–13.0)	0.1939
Delayed harvesting				
1st postharvest	Mean ± SD Median (min–max)	13.5 ± 0.6 13.5 (12.8–14.3)	13.0 ± 0.5 12.9 (12.5–13.7)	0.2771
2nd postharvest	Mean ± SD Median (min–max)	13.2 ± 0.2 13.2 (13.0–13.4)	12.9 ± 0.2 12.9 (12.7–13.1)	0.0407
3rd postharvest	Mean ± SD Median (min–max)	12.7 ± 0.2 12.6 * (12.6–13.0)	12.5 ± 0.5 12.3 (12.0–13.2)	0.2482

* non-parametric distribution (verified using Shapiro–Wilk test—$p \leq 0.05$); OHW—optimum harvesting window; 1-MCP—1-methylcyclopropene.

The results for TA measured in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 4. Statistically significant differences between the studied group and the control group were observed for preharvest period for the second ($p = 0.0100$; higher TA for apples treated with 1-MCP), fourth ($p = 0.0461$; higher TA for apples treated with 1-MCP) and fifth assessment ($p = 0.0021$; higher TA for apples treated with 1-MCP).

Statistically significant differences between the studied group and the control group were observed for apples harvested in the OHW for the second assessment ($p = 0.0264$; higher TA for apples treated with 1-MCP).

The results for starch index measured in 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 5. Statistically significant differences between the studied group and the control group were observed for the first assessment (directly after applying 1-MCP; $p = 0.0098$) and afterwards for the second ($p = 0.0004$; lower results of starch index for apples treated with 1-MCP), third ($p = 0.0005$; higher results of starch index for apples treated with 1-MCP), fourth ($p = 0.0008$; lower results of starch index for apples treated with 1-MCP) and fifth assessment ($p < 0.0001$; lower results of starch index for apples treated with 1-MCP).

Table 4. Results for titratable acidity measured in 'Szampion' cultivar apples in the pre- and postharvest periods, compared for groups treated with 1-MCP and a control group not treated with 1-MCP.

Assessment		No Preharvest 1-MCP Treatment	Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD	0.488 ± 0.027	0.547 ± 0.048	0.0833
	Median (min–max)	0.500 * (0.448–0.504)	0.545 (0.498–0.603)	
2nd preharvest	Mean ± SD	0.432 ± 0.038	0.540 ± 0.044	0.0100
	Median (min–max)	0.432 (0.386–0.476)	0.536 (0.499–0.586)	
3rd preharvest	Mean ± SD	0.418 ± 0.021	0.453 ± 0.046	0.2094
	Median (min–max)	0.418 (0.396–0.437)	0.455 (0.396–0.506)	
4th preharvest	Mean ± SD	0.446 ± 0.034	0.520 ± 0.048	0.0461
	Median (min–max)	0.446 (0.408–0.482)	0.510 (0.471–0.587)	
5th preharvest	Mean ± SD	0.381 ± 0.015	0.429 ± 0.011	0.0021
	Median (min–max)	0.383 (0.362–0.396)	0.426 (0.420–0.444)	
6th preharvest	Mean ± SD	–	0.483 ± 0.042	-
	Median (min–max)	–	0.474 (0.441–0.540)	
OHW harvesting				
1st postharvest	Mean ± SD	0.398 ± 0.030	0.407 ± 0.063	0.8079
	Median (min–max)	0.386 (0.378–0.442)	0.415 (0.327–0.470)	
2nd postharvest	Mean ± SD	0.334 ± 0.025	0.423 ± 0.055	0.0264
	Median (min–max)	0.334 (0.309–0.361)	0.427 (0.351–0.485)	
3rd postharvest	Mean ± SD	0.305 ± 0.008	0.358 ± 0.099	0.3255
	Median (min–max)	0.304 (0.295–0.316)	0.332 (0.278–0.490)	
Delayed harvesting				
1st postharvest	Mean ± SD	0.398 ± 0.030	0.380 ± 0.022	0.3745
	Median (min–max)	0.386 (0.378–0.442)	0.374 (0.361–0.410)	
2nd postharvest	Mean ± SD	0.334 ± 0.025	0.345 ± 0.027	0.6000
	Median (min–max)	0.334 (0.309–0.361)	0.335 (0.325–0.383)	
3rd postharvest	Mean ± SD	0.305 ± 0.008	0.283 ± 0.051	0.4456
	Median (min–max)	0.304 (0.295–0.316)	0.297 (0.211–0.328)	

* non-parametric distribution (verified using Shapiro-Wilk test—$p \leq 0.05$); OHW—optimum harvesting window; 1-MCP—1-methylcyclopropene.

Table 5. Results for starch index measured in 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and a control group not treated with 1-MCP.

Assessment		Preharvest 1-MCP Treatment	No Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD	4.4 ± 1.1	3.8 ± 0.7	0.0098
	Median (min–max)	4.0 * (2–7)	4.0 * (2–5)	
2nd preharvest	Mean ± SD	5.4 ± 0.9	6.7 ± 1.1	0.0004
	Median (min–max)	5.0 * (4–7)	6.5 * (5–8)	
3rd preharvest	Mean ± SD	8.1 ± 1.2	7.3 ± 1.2	0.0005
	Median (min–max)	8.0 * (6–10)	7.0 * (5–10)	
4th preharvest	Mean ± SD	9.5 ± 0.6	9.8 ± 0.4	0.0008
	Median (min–max)	10.0 * (8–10)	10.0 * (9–10)	
5th preharvest	Mean ± SD	8.9 ± 1.1	10.0 ± 0.0	<0.0001
	Median (min–max)	9.0 * (6–10)	10.0 * (10–10)	
6th preharvest	Mean ± SD	9.2 ± 0.9	–	–
	Median (min–max)	9.5 * (7–10)	–	

* non-parametric distribution (verified using Shapiro-Wilk test—$p \leq 0.05$); 1-MCP—1-methylcyclopropene.

The results for Streif index measured in 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Table 6. Statistically significant differences between the studied group and the control group were observed for the second ($p = 0.0008$; higher results of Streif index for apples treated with 1-MCP) and fifth assessment ($p = 0.0008$; higher results of Streif index for apples treated with 1-MCP).

Table 6. Results of Streif index measured for 'Szampion' cultivar apples in the preharvest period compared for the group treated with 1-MCP and the control group not treated with 1-MCP.

Assessment		Preharvest 1-MCP Treatment	No Preharvest 1-MCP Treatment	*p*
1st preharvest	Mean ± SD	0.126 ± 0.020	0.141 ± 0.019	0.3063
	Median (min–max)	0.125 (0.103–0.148)	0.14 (0.119–0.166)	
2nd preharvest	Mean ± SD	0.100 ± 0.006	0.074 ± 0.005	0.0008
	Median (min–max)	0.102 (0.091–0.104)	0.073 (0.070–0.082)	
3rd preharvest	Mean ± SD	0.061 ± 0.005	0.070 ± 0.014	0.2814
	Median (min–max)	0.060 (0.056–0.068)	0.067 (0.058–0.086)	
4th preharvest	Mean ± SD	0.052 ± 0.003	0.048 ± 0.003	0.1087
	Median (min–max)	0.053 (0.048–0.055)	0.047 (0.046–0.052)	
5th preharvest	Mean ± SD	0.058 ± 0.006	0.038 ± 0.001	0.0008
	Median (min–max)	0.057 (0.051–0.067)	0.038 (0.037–0.040)	
6th preharvest	Mean ± SD	0.048 ± 0.003	–	–
	Median (min–max)	0.048 (0.045–0.051)	–	

1-MCP—1-methylcyclopropene.

The results for the lightness L* coordinate of color of blush measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Supplementary Materials Table S1. No statistically significant differences between the studied group and the control group were observed ($p > 0.05$).

The results for the a* coordinate of color of blush measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Supplementary Materials Table S2. Statistically significant differences between the studied group and control group were observed for the fifth assessment ($p = 0.0007$; lower results of a* for apples treated with 1-MCP).

The results for the b* coordinate of color of blush measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP, are presented in Supplementary Materials Table S3. Statistically significant differences between the studied group and the control group were observed for the first assessment (directly after applying 1-MCP; $p = 0.0058$).

The results of ethylene production (μL kg^{-1} h^{-1}) measured for 7 days for each preharvest period for 'Szampion' cultivar apples, compared for the groups treated with 1-MCP and the control group not treated with 1-MCP, are presented in Supplementary Materials Table S4. Statistically significant differences between the studied group and the control group were observed for the 1st and 7th days for the first assessment ($p < 0.05$); for the 1st, 2nd, 5th, 6th and 7th days for the second assessment ($p < 0.05$); for all days, except for the 1st, for the third assessment ($p < 0.05$); for the 5th, 6th and 7th days for the fourth assessment ($p < 0.05$); as well as for the 2nd and 3rd days for the fifth assessment ($p < 0.05$).

4. Discussion

In the conducted experiment, it was observed that the characteristics of apples treated with 1-MCP differed in the preharvest period from the characteristics of the control ones. Such observations were indicated mainly for IEC, firmness, starch index and TA, while for Steif index and coordinates of color for blush, the differences were only minor and inconclusive.

Similar observations were indicated by other authors who applied 1-MCP in the preharvest period in cases of different cultivars. As 'Szampion' is a hybrid cultivar crossing 'Golden Delicious' and

'Cox Orange Pippin', studies conducted for 'Golden Delicious' and other 'Delicious' cultivars may be especially meaningful for comparison. In the study by Sakaldas & Gundogdu [16], conducted for 'Golden Delicious', it was observed that 1-MCP applied in the doses of 100–200 g/ha (similar to in the present study) also contributed to a lower IEC, as well as higher firmness and TA of apples. Similarly, in the study by McArtney et al. [17], conducted for 'Golden Delicious', it was observed that 1-MCP, applied in doses of 75–150 mg/L, also contributed to a lower IEC, as well as higher firmness of apples. At the same time, the indicated studies also confirm the lack of a defined trend for starch index [16,17], as depending on the studied group, and time, it may be higher, lower, or not differ compared with control groups. Such a situation is, by other authors, attributed to the fact that starch index may change due to natural inconsistent development and ripening associated with the cultivar [15].

In the study by Elfving et al. [18], conducted for 'Scarletspur Delicious', similar observations were made, as 1-MCP in the preharvest period contributed to a lower IEC and a higher firmness of apples, but did not influence TSS, or TA. Likewise, in the study by Watkins et al. [14], for 'Delicious', 1-MCP in the preharvest period contributed to a lower IEC and higher firmness of apples, but it did not influence TSS. Additionally, in the studies by DeEl & Ehsani-Moghaddam, conducted for 'McIntosh' and 'Empire' [12] and 'Honeycrisp' cultivars [15], as well as by Yoo et al. for 'Hongro' [33] and 'Fuji' cultivars [20], the higher firmness of apples was the major observation, except for the IEC.

The similar observations in the indicated studies are the result of a reduced amount of ethylene being produced, being typical after 1-MCP application [34–36], which prolongs harvest maturity—as stated by Sakaldas & Gundogdu [16]—for 21–28 days. In consequence, some parameters of apple, including firmness and TA, are typical for lower maturity and their changes are prevented, which allows minimizing changes of quality. At the same time, fruit drop is not observed within the experimental period, as stated both in our own study and in other studies [16,17], so delayed harvesting is possible. It is in general indicated that 1-MCP application within 7 days of anticipated harvesting time (as in the presented own study, applied 7 days before OHW) allows continued fruit growth both for normal and delayed harvesting [17]. As apple harvesting and storage are currently of the main interest of researchers in a lot of countries, and in Poland this problem is becoming vital, especially for 'Szampion' cultivar [37], the possibility to influence it is of a great value. However, it should be mentioned that the average percentage of bitter rot defects for all harvesting and storage periods was 3.6% (data not shown) for apples without preharvest 1-MCP applied and 4.9% (data not shown) for apples with preharvest 1-MCP applied for OHW. At the same time, for delayed harvesting, the percentage of apples with bitter rot defects was significantly higher, as it was 19.9% (data not shown).

As, in the presented study, during the postharvest period, the quality parameters of apples treated with 1-MCP in the preharvest period, after delayed harvesting, did not differ from those of control apples after OWH harvesting, the applied treatment creates a possibility of not harvesting in the moment of OWH, but delaying. As, without 1-MCP, delayed harvesting is associated with decreased quality of apples [38], and cannot be extended due to fruit drop, the conducted study indicates that preharvest 1-MCP application allows harvesting in late October, while the quality is still at the level required by consumers. However, based on the previous studies of other authors, other issues associated with 1-MCP application should be mentioned. If apples are harvested too early, or ripening after fruit storage is lacking [39], 1-MCP application can adversely affect ripening, including firmness, color and aroma formation [40]. The mechanism for aroma formation in such cases was described in the review study by Espino-Díaz et al. [41]; they indicated that 1-MCP suppresses ethylene production, so, as a result, it causes a decrease in the production of adenosine triphosphate molecules and reduces the synthesis of fatty acids, the main precursors of volatile compounds. A similar influence of 1-MCP was also observed for other fruits; e.g., in the study of Lia et al. [42], an application of 1-MCP changed the aroma components in 'Ruanerli' and 'Alexander Lucas' pears. Therefore, it must be emphasized that the proper harvesting time and other conditions of storage are crucial for the quality of fruits.

It is generally observed that potential postharvest benefits, associated with preharvest application of 1-MCP, depend on cultivar, fruit maturity, days between application and harvest, and storage conditions [14]. However, other potentially influential factors may be indicated, such as, e.g., weather conditions for the season. Taking this into account, further studies are necessary, as the presented study is the first conducted so far for the 'Szampion' cultivar.

In spite of the fact that interesting observations were made for the preharvest use of 1-MCP for 'Szampion' cultivar, which has not been studied so far, some limitations of the conducted study should be mentioned. The most important limitation is associated with the fact that the study was conducted during one harvest and storage season only, so it should be reproduced to verify the observations made. It would also be meaningful to include other variables, such as respiration rate, which is an important parameter for climacteric products such as apples. Last, but not least, sensory analysis would also make it possible to observe the consumer acceptability of the obtained apples.

5. Conclusions

It may be concluded that preharvest 1-MCP application makes it possible not only to obtain better results for 'Szampion' cultivar apples' quality parameters, but also allows delayed harvesting without deterioration in quality. There is a need for further studies to analyze the observed effect, considering characteristics of trees and fruits, weather conditions, season, and applied procedures, including 1-MCP concentration.

Supplementary Materials: The following are available online at http://www.mdpi.com/2077-0472/10/3/80/s1, Table S1. Results for the lightness L* coordinate of color of blush measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP (assessments conducted weekly); Table S2. Results for the a* coordinate of color measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP (assessments conducted weekly). Table S3. Results for the color parameter (b*) [-] measured for 'Szampion' cultivar apples in the preharvest period, compared for the group treated with 1-MCP and the control group not treated with 1-MCP (assessments conducted weekly). Table S4. Results for ethylene production [$\mu L/\cdot kg^{-1}\cdot h^{-1}$] measured over 7 days in each of the preharvest periods for 'Szampion' cultivar apples, compared for groups treated with 1-MCP and the control group not treated with 1-methylcyclopropene.

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