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The Effects of 1-Methylcyclopropene Treatment on the Fruit Quality of 'Idared' Apples during Storage and Transportation

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Abstract: 1-Methylcyclopropene (1-MCP) is applied as an inhibitor of ethylene action, which is widely used in postharvest technology to prolong the shelf life of many fruits. The aim of the study was to assess the possibility to apply 1-MCP treatment to maintain the quality of 'Idared' apples for long-distance transportation. The studied apples were assessed in three groups: (I) 1-MCP postharvest treatment; (II) 1-MCP postharvest treatment with Modified Atmosphere Packaging (MAP) selected gas permeability bags; and (III) control groups (with neither 1-MCP treatment, nor dedicated packaging). Apples were subjected to storage in the Ultra Low Oxygen (ULO) chamber that was applied for 0 weeks, 10 weeks and 20 weeks (three periods of storage); simulated long-distance transport (6 weeks); and simulated distribution, which was applied for 0 days, 5 days, 10 days, and 15 days (4 periods of distribution). The obtained 36 groups (three postharvest treatments per three periods of storage per four periods of distribution) were analyzed to assess firmness, total soluble solids (TSS) and titratable acidity (TA). There were differences between firmness values for control groups and those with 1-MCP applied, which were characterized by higher values of firmness ($p < 0.05$). Groups with 1-MCP and MAP applied combined were characterized by higher values of TSS than control groups ($p < 0.05$). The majority of groups with 1-MCP applied alone were characterized by higher values of TA than control groups ($p < 0.05$), but values for samples attributed to 1-MCP and MAP combined were not higher than for 1-MCP alone. It may be concluded that 1-MCP applied postharvest contributed to higher results of firmness and TA of 'Idared' apples after long-distance transportation, but combining 1-MCP with MAP did not contribute to further differences for TA. However, for TSS the observed influence was inconclusive. It may be stated that 1-MCP is a beneficial treatment for 'Idared' apples for long-distance transportation as it prolongs their shelf life and improves firmness.

Keywords: apples; 'Idared'; long-distance transportation; 1-Methylcyclopropene; 1-MCP; quality; firmness; total soluble solids; TSS; titratable acidity; TA

1. Introduction

The intake of fruits, similarly to intake of vegetables, has a positive effect on human health that was confirmed in a number of studies, indicating the possibility of weight maintenance or even loss [1], as well as the possibility of reducing the risk of metabolic syndrome [2], hypertension [3], and mental health problems [4]. As a result, the daily intake of five servings of fruit and vegetables is recommended to obtain a positive effect on human health [5]. However, for increasing fruit intake, there are numerous challenges, including inadequate fruit production, climate variability problems, short shelf life, and consumer expectations [6].

Taking this into account, it is indicated that sustainable food systems addressing public health concerns should include increased intake of fruit [7], but also proper fruit logistics [8] and fruit waste management [9]. It is associated with the fact that for perishable food products, in a supply chain, it is crucial to prevent product losses between producer and consumer, while effectively managing products [10]. The United Nations Sustainable Development Agenda presented an important aim to reduce food loss and waste by 50% by 2030, which may enable reducing the environmental impact of food systems [11].

One of the methods that may minimize losses is applying proper packaging systems combined with predicting expiry dates [12]. The controlled atmosphere is commonly applied in the case of fruit, as concentration of various gases and volatiles influences metabolic and physiological reactions and processes, so it has a potential to regulate the ripening process [13]. Especially 1-Methylcyclopropene (1-MCP) is applied as an inhibitor of ethylene action, which is widely used in postharvest technology to prolong the shelf life of many fruits and vegetables [14]. It is crucial in a long-distance transportation of fruit, as it may allow to prevent undesirable deterioration of the quality [15].

The 1-MCP could be applied both pre [16,17] and postharvest [18,19] as a treatment being non-toxic, stable over time and improving the quality of the products. In spite of the fact that it is applied mainly for apples, it may be used also for other fruit and vegetables, but the role of ethylene in ripening and senescence processes may differ, depending on the product, so also responses to 1-MCP are various [20]. As a result, its efficiency depends on specie and/or cultivar, but also on the stage of maturity of fruits [21,22]. At the same time, in the case of apples, for 'Jonagold' cultivar, it was stated that time from harvest to treatment was an even more important factor than maturity for 1-MCP efficacy, as a low 1-MCP blocking efficacy was shown to be the most likely cause of partial response for delayed 1-MCP treatment and 1-MCP treatment of late-picked apples [23].

The major application of 1-MCP in the case of apples is associated with the fact that, as an ethylene antagonist, it is routinely used to modulate the ripening progression, while increasing storage potential and shelf life [24]. However, not only for apples [25], but also other fruits such as banana [26], mango [27], plum [28], or tomato [29], there were some results published indicating that 1-MCP may be beneficial for the quality of fruits during extended periods after harvesting.

The increasing role of 1-MCP is reflected by the fact that by 2011, there were more than 50 countries that had the use of 1-MCP approved for fresh fruits and vegetables [30]. Also, in countries of the European Union, the 1-MCP is included in Directive 91/414/EEC (2005) [31] as an ingredient that could be used for fruits, including apples.

Taking into account the storage period of apples, it should be indicated that its availability and quality is determined by the storage conditions, and under proper conditions and harvested at optimum storage potential, apples may be stored even for 12 months [32]. However, in some countries in practice, a shorter storage is applied, as it is more affordable, as extending storage time is possible only while applying under near hypoxic conditions, controlled atmosphere, or by controlling ethylene (e.g., by using 1-MCP) [25]. Within possible methods of extending shelf life, 1-MCP is proven to be an affordable alternative to controlled atmosphere, especially if applied immediately after harvesting and combined with cold storage, to maintain the quality of fruits [33].

Within food products which are typically transported over a long distances within international food trade, there are apples [34], as according to the Eurostat data [35], apples are in the European

Union the most commonly produced fruit, with a quantity of 12.5 million tons harvested in 2016, while 29% of total apple production was harvested in Poland. Poland is the most important apple producer in European Union not only for the quantity of produced fruits, but also for the area devoted to apple orchards, as 34% (160,800 ha) of that area was in 2017 located in Poland [36]. The recent European Commission report, published in December 2019, and analyzing the period of the last 10 years, emphasized that the European Union apple stock for the fresh consumption is increasing, while it is highest also in Poland [37]. This situation resulted among others from the Russian import ban for various agricultural products from European Union, including apples, being in force since 2014 [38]. This situation and resultant increased competitiveness forced producers to rethink their production and export strategy, to obtain higher quality of their products and more sustainable production, to meet specific demands of consumers, as well as to keep their sales and prices at affordable levels [39]. Taking this into account, the aim of the presented study was to assess the possibility to apply 1-MCP treatment to maintain the quality of 'Idared' apples for long-distance transportation.

2. Materials and Methods

2.1. Experimental Procedures

The study was conducted to assess the quality of 'Idared' apples stored in the season of 2018/2019. Apples were obtained from the orchard in Julianów (51°46′ N 20°49′ E), in the district of Belsk Duży (23 October 2018), on 15 years old trees, planted at 4 m by 1.5 m (plant density—1667 trees/hectare). The harvesting time was indicated based on the Streif index assessment. Afterwards, during the experiment (which started directly after harvesting), the apples were stored in the experimental storage chambers of the Institute of Horticultural Sciences of the Warsaw University of Life Sciences (SGGW-WULS).

The obtained apples were divided into three groups to assess the influence of the 1-MCP treatment and selective gas permeability packaging, so the experiment included various methods of postharvest treatment: (I) control apples with neither 1-MCP treatment, nor packaging; (II) studied apples after 1-MCP postharvest treatment (SmartFresh ProTabs™, by AgroFresh Solutions Inc., Philadelphia, PA, USA, applied in the concentration of 0.65 µL/L), with no dedicated packaging; (III) studied apples after 1-MCP postharvest treatment (SmartFresh ProTabs™, by AgroFresh Solutions Inc., Philadelphia, PA, USA, applied in the concentration of 0.65 µL/L), with selected gas permeability bags applied (Xtend®, by StePac L.A. Ltd., Tefen, Israel) to provide Modified Atmosphere Packaging (MAP). The 1-MCP treatment was applied directly after harvesting, while MAP bags were applied before simulating long-distance transport, while both chosen 1-MCP treatment [40] and MAP bags are commonly used for fruits [41].

After preparing apples for three studied groups of postharvest treatment, they were subjected to storage in the Ultra Low Oxygen (ULO) chamber (1.2% CO_2, 1.2% O_2; temperature of 1 °C; humidity of 95%) that was applied for 0 weeks, 10 weeks and 20 weeks (three groups of postharvest treatment per three periods of storage, resulting in nine groups of postharvest treatment/storage).

After ULO storage, apples were subjected to the simulated long-distance transport, which was conducted in the storage chamber at a temperature of 1 °C for 6 weeks, being a typical period for long-distance transport.

After simulated long-distance transport, apples were subjected to simulated distribution, which was conducted at a temperature of 25 °C, that was applied for 0 days, 5 days, 10 days, and 15 days (nine groups of postharvest treatment/storage per four periods of distribution, resulting in 36 groups of postharvest treatment/storage/distribution). Each studied group consisted of four batches, 10 apples each and the procedures applied in the experimental groups are presented in Figure 1.

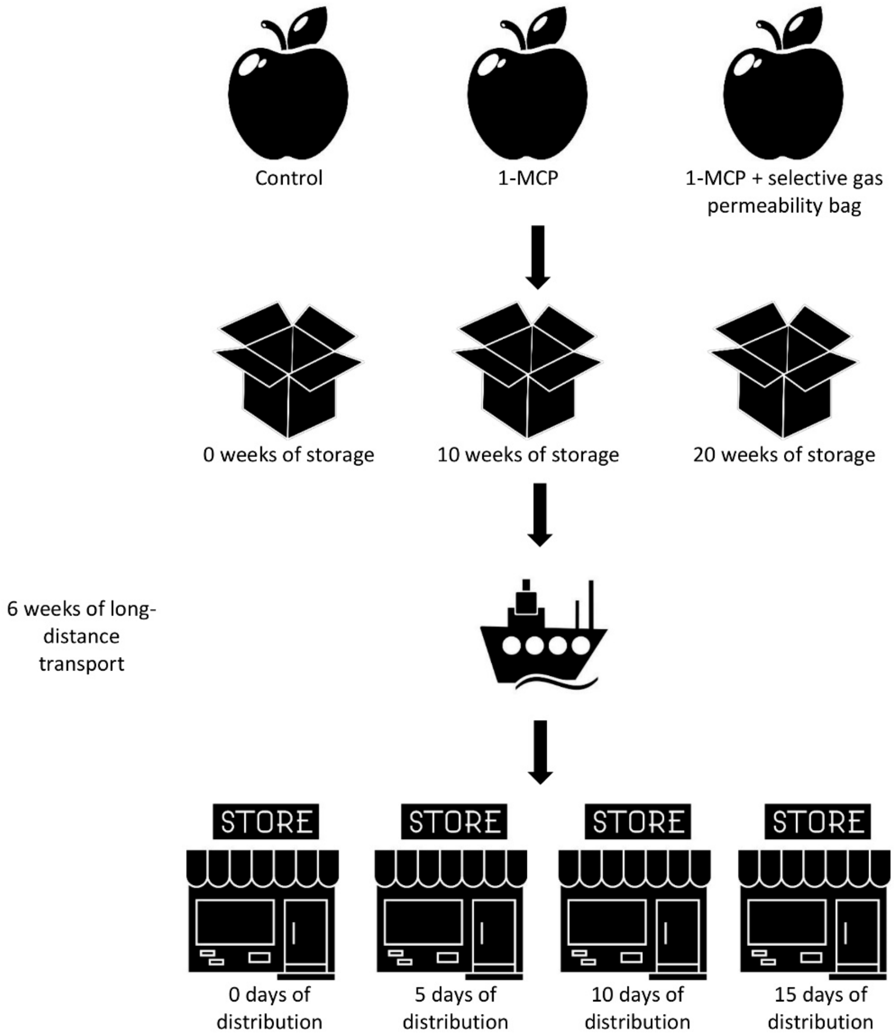

Figure 1. The procedures applied in the experimental groups of 'Idared' apples.

2.2. Conducted Measurements

The apples were studied after simulated distribution, to assess firmness, total soluble solids (TSS) and titratable acidity (TA) in 36 groups of postharvest treatment/storage/distribution.

The firmness of apples was assessed according to a widely applied methodology, similarly as in the previous own studies [16,17]. For each group, all apples were used to assess the firmness (four batches, 10 apples each). The measurement was conducted after removing the peel of apples and two opposite sides of each apple were analyzed. The universal testing machine was used (Instron 5542, Instron, Norwood, MA, USA), while the stainless steel plunger tips of 11 mm diameter were chosen and a speed of 4 mm/s was applied. The results of firmness measurement were expressed in N.

The TSS was assessed according to a widely applied methodology, similarly as in the previous own studies [16,17]. For each group, all apples were used to assess the TSS (four batches, 10 apples each), after the previous firmness analysis. The juice was pressed, while using a juice extractor, and the digital refractometer was used (Atago Palette PR-32, Atago Co., Ltd., Tokyo, Japan). The results of TSS measurement were expressed in °Bx.

The TA was assessed according to a widely applied methodology, similarly as in our own previous studies [16,17]. For each group, all apples were used to assess the TA (four batches, 10 apples each), after the previous firmness analysis. The juice was pressed, while using a juice extractor, and the automatic titrator was used (TitroLine 5000, Xylem Analytics Germany GmbH, Weilheim, Germany) to titrate it with NaOH solution (0.1 M) until obtaining the pH value of 8.1. Afterwards, the results were recalculated for malic acid content.

The internal ethylene content (IEC) [μL/L] was assessed according to a widely applied methodology, similarly as in the previous own studies [16,17]. It was measured in the core space of apples, while using 1 mL syringe to collect the samples of air. For each apple, 1 mL of air was injected and assessed while using the gas chromatography (HP 5890, Hewlett Packard, CA, USA) for ethylene analysis.

The starch index (SI) was assessed according to a widely applied methodology, similarly as in our own previous studies [16,17]. It was measured based on the reaction with the Lugol's solution and assessed visually in comparison with the 10-points scale standards.

The color of blush of apple was assessed according to a widely applied methodology, similarly as in our own previous studies [16,17]. It was assessed according to a widely applied methodology, in CIE L*a*b* system using spectrophotometer (Minolta CM-508i, Konica Minolta Co., Ltd., Tokyo, Japan). The calibration was made against a standard white tile.

2.3. Statistical Analysis

The statistical analysis was conducted while using Statistica, version 8.0 (Statsoft Inc., Tulsa, OK, USA). The normality of distribution was assessed while using the Shapiro–Wilk test. The groups were compared while using one-way ANOVA and post-hoc Tukey's honest significant difference test for multiple comparisons (for parametric distributions), as well as Kruskal–Wallis one-way ANOVA of ranks and post-hoc test (for nonparametric distributions). The value of $p \leq 0.05$ was interpreted as statistically significant.

3. Results

The characteristics of the quality parameters of 'Idared' apples assessed directly after harvesting are presented in Table 1.

Table 1. Characteristics of 'Idared' apples assessed directly after harvesting.

Characteristic	Mean ± SD	Median (IQR)
Internal ethylene content [μl/l]	2.90 ± 6.26	0.50 * (1.58)
Starch index [-]	8.3 ± 1.0	8.0 * (1.0)
Total soluble solids content [°Bx]	13.2 ± 0.3	13.2 (0.5)
Firmness [N]	59.0 ± 2.2	58.9 (3.7)
Titratable acidity [-]	0.51 ± 0.03	0.51 (0.05)
Streif index [-]	0.054 ± 0.004	0.053 (0.005)
L * component of color for blush	41.20 ± 0.22	41.15 (0.30)
a * component of color for blush	24.75 ± 0.59	24.95 (0.80)
b * component of color for blush	8.53 ± 0.27	8.52 (0.37)

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

The firmness values of 'Idared' apples are presented in Table 2. For all the studied periods of storage and periods of distribution, there were statistically significant differences between firmness values for control groups and those of groups with 1-MCP applied, which were characterized by significantly higher values of firmness ($p < 0.05$). At the same time, while comparing groups with MAP packaging applied and those with 1-MCP alone, the significant differences were observed only for samples without storage and without shelf life (with simulated long-distance transport only), as well as for samples with longest storage and longest shelf life (20 weeks of storage, 15 days of simulated distribution), as MAP contributed to higher values of firmness.

Table 2. The firmness [N] values of 'Idared' apples after Ultra Low Oxygen (ULO) storage, simulated long-distance transport, and simulated distribution, stratified by postharvest treatment, period of storage and period of distribution.

Postharvest Treatment		**Period of Simulated Distribution (Days)**			
		0	**5**	**10**	**15**
Period of Storage—0 Weeks					
Control	Mean ± SD	41.4 ± 1.6 ^{a}	36.8 ± 5.8 ^{a}	37.2 ± 1.7 ^{a}	35.7 ± 2.1 ^{a}
	Median (IQR)	41.6 (2.0)	39.1 (6.8)	37.4 (2.9)	35.6 (3.1)
1-MCP	Mean ± SD	53.2 ± 2.4 ^{b}	50.0 ± 1.4 ^{b}	47.2 ± 3.5 ^{b}	46.7 ± 2.5 ^{b}
	Median (IQR)	53.3 (3.8)	50.2 (2.5)	46.0 (4.6)	46.7 (4.1)
1-MCP + MAP	Mean ± SD	58.3 ± 1.3 ^{c}	54.1 ± 3.1 ^{b}	54.2 ± 4.5 ^{b}	52.2 ± 3.6 ^{b}
	Median (IQR)	57.9 (1.7)	54.5 (5.1)	53.9 (7.4)	53.9 * (3.9)
p-Value		<0.001	<0.001	<0.001	0.019
Period of Storage—10 Weeks					
Control	Mean ± SD	43.2 ± 2.5 ^{a}	40.1 ± 0.8 ^{a}	39.8 ± 1.4 ^{a}	38.2 ± 1.9 ^{a}
	Median (IQR)	43.9 (3.4)	40.1 (1.4)	39.7 (2.4)	38.8 (2.7)
1-MCP	Mean ± SD	53.0 ± 3.5 ^{b}	53.2 ± 3.4 ^{b}	53.1 ± 3.0 ^{b}	50.6 ± 2.7 ^{b}
	Median (IQR)	52.6 (5.0)	53.8 (5.6)	53.8 (3.8)	50.0 (4.2)
1-MCP + MAP	Mean ± SD	52.4 ± 2.6 ^{b}	51.2 ± 2.7 ^{b}	54.5 ± 2.7 ^{b}	52.2 ± 2.6 ^{b}
	Median (IQR)	52.7 (3.4)	51.1 (4.3)	54.8 (3.8)	52.8 (3.7)
p-Value		0.002	<0.001	<0.001	<0.001
Period of Storage—20 Weeks					
Control	Mean ± SD	40.1 ± 1.7 ^{a}	41.8 ± 1.2 ^{a}	38.3 ± 0.1 ^{a}	37.0 ± 1.9 ^{a}
	Median (IQR)	40.8 * (1.9)	42.1 (1.6)	38.3 (0.1)	37.5 (2.4)
1-MCP	Mean ± SD	52.0 ± 1.6 ^{b}	52.3 ± 3.1 ^{b}	50.7 ± 5.4 ^{b}	46.9 ± 2.8 ^{b}
	Median (IQR)	52.0 (2.6)	51.8 (4.8)	52.0 (6.9)	46.1 (4.4)
1-MCP + MAP	Mean ± SD	55.0 ± 4.0 ^{b}	57.1 ± 3.7 ^{b}	56.2 ± 1.6 ^{b}	54.2 ± 2.4 ^{c}
	Median (IQR)	54.3 (6.2)	58.1 (5.6)	56.3 (2.6)	54.1 (3.0)
p-Value		0.018	<0.001	<0.001	<0.001

* non-parametric distribution (verified using Shapiro–Wilk test—$p \leq 0.05$); 1-MCP—Methylcyclopropene; MAP—Modified Atmosphere Packaging; different superscript letters are attributed to statistically significant differences while comparing various postharvest treatments within period of storage and period of simulated distribution.

The TSS content values of 'Idared' apples are presented in Table 3. For the majority of the studied periods of storage and periods of distribution, there were no statistically significant differences between TSS values for control groups and those of groups with 1-MCP applied. Only for groups attributed to 10 weeks of storage (0 and 10 days of simulated distribution) and 20 weeks of storage (0, 10 and 15 days of simulated distribution) there were some differences between studied groups, while the majority of the groups with 1-MCP and MAP applied combined were characterized by significantly higher values of TSS than control groups ($p < 0.05$).

Table 3. The Total Soluble Solids (TSS) content [°Bx] values of 'Idared' apples after Ultra Low Oxygen (ULO) storage, simulated long-distance transport, and simulated distribution, stratified by postharvest treatment, period of storage and period of distribution.

Postharvest Treatment		**Period of Simulated Distribution (Days)**			
		0	**5**	**10**	**15**
		Period of Storage—0 Weeks			
Control	Mean ± SD	13.0 ± 0.2 ^{a}	12.8 ± 0.65 ^{a}	13.4 ± 0.4 ^{a}	13.3 ± 0.2 ^{a}
	Median (IQR)	13.0 (0.4)	12.9 (1.0)	13.4 (0.6)	13.4 (0.3)
1-MCP	Mean ± SD	13.0 ± 0.1 ^{a}	13.3 ± 0.5 ^{a}	13.6 ± 0.2 ^{a}	13.3 ± 0.3 ^{a}
	Median (IQR)	13.0 (0.2)	13.1 (0.6)	13.6 (0.3)	13.2 (0.5)
1-MCP + MAP	Mean ± SD	13.0 ± 0.1 ^{a}	13.4 ± 0.2 ^{a}	13.4 ± 0.2 ^{a}	13.6 ± 0.5 ^{a}
	Median (IQR)	13.0 * (0.1)	13.4 (0.20)	13.3 (0.20)	13.7 (0.9)
p-Value		0.920	0.232	0.416	0.425
		Period of Storage—10 Weeks			
Control	Mean ± SD	13.6 ± 0.2 ^{a}	13.2 ± 0.6 ^{a}	12.7 ± 0.2 ^{a}	12.9 ± 0.7 ^{a}
	Median (IQR)	13.5 (0.3)	13.2 (0.9)	12.6 (0.4)	13.0 (1.0)
1-MCP	Mean ± SD	12.7 ± 0.2 ^{b}	12.6 ± 0.3 ^{a}	12.7 ± 0.3 ^{a}	12.8 ± 0.4 ^{a}
	Median (IQR)	12.6 (0.4)	12.6 (0.5)	12.6 * (0.4)	13.0 (0.6)
1-MCP + MAP	Mean ± SD	12.9 ± 0.5 ^{b}	12.6 ± 0.3 ^{a}	13.7 ± 0.5 ^{b}	13.1 ± 0.8 ^{a}
	Median (IQR)	12.9 (0.7)	12.7 (0.4)	13.7 (0.9)	13.0 (1.2)
p-Value		0.009	0.103	0.035	0.851
		Period of Storage—20 Weeks			
Control	Mean ± SD	12.5 ± 0.1 ^{a}	12.8 ± 0.3 ^{a}	12.6 ± 0.2 ^{a}	12.2 ± 0.2 ^{a}
	Median (IQR)	12.5 (0.2)	12.9 (0.5)	12.7 (0.4)	12.2 (0.4)
1-MCP	Mean ± SD	13.2 ± 0.1 ^{b}	12.9 ± 0.3 ^{a}	12.9 ± 0.1 ^{ab}	12.9 ± 0.3 ^{a}
	Median (IQR)	13.2 (0.2)	12.9 (0.4)	13.0 (0.2)	13.0 (0.5)
1-MCP + MAP	Mean ± SD	13.0 ± 0.2 ^{b}	13.0 ± 0.3 ^{a}	13.1 ± 0.2 ^{b}	13.1 ± 0.3 ^{b}
	Median (IQR)	12.9 (0.2)	13.0 (0.4)	13.1 (0.2)	13.0 (0.4)
p-Value		<0.001	0.731	0.011	0.004

* non-parametric distribution (verified using Shapiro–Wilk test—$p \leq 0.05$); 1-MCP—Methylcyclopropene; MAP—Modified Atmosphere Packaging; different superscript letters are attributed to statistically significant differences while comparing various postharvest treatments within period of storage and period of simulated distribution.

The TA values of 'Idared' apples are presented in Table 4. For the majority of the studied periods of storage and periods of distribution, there were some statistically significant differences between TA values for control groups and those of groups with 1-MCP applied. While comparing control groups and those with 1-MCP applied alone, it may be indicated that in the majority of them (except for groups attributed to 0 weeks of storage for 0 days of simulated distribution, as well as 10 weeks of storage for 0, 5 and 15 days of simulated distribution), groups with 1-MCP applied were characterized by significantly higher values of TA than control groups ($p < 0.05$). At the same time, including MAP did not contribute to any further differences of TA values, as only for samples without storage and without shelf life (0 weeks of storage, 0 days of simulated distribution), the results for samples attributed to 1-MCP and MAP combined were significantly higher than those for 1-MCP alone.

Table 4. The Titratable Acidity (TA) [%] values of 'Idared' apples after Ultra Low Oxygen (ULO) storage, simulated long-distance transport, and simulated distribution, stratified by postharvest treatment, period of storage and period of distribution.

Postharvest Treatment		**Period of Simulated Distribution (Days)** 0	5	10	15
Period of Storage—0 Weeks					
Control	Mean ± SD	0.482 ± 0.020 [a]	0.423 ± 0.018 [a]	0.328 ± 0.020 [a]	0.329 ± 0.014 [a]
	Median (IQR)	0.483 (0.035)	0.423 (0.031)	0.334 (0.025)	0.330 (0.020)
1-MCP	Mean ± SD	0.478 ± 0.014 [a]	0.511 ± 0.019 [b]	0.484 ± 0.009 [b]	0.464 ± 0.012 [b]
	Median (IQR)	0.473 * (0.017)	0.511 (0.029)	0.482 (0.011)	0.468 (0.014)
1-MCP + MAP	Mean ± SD	0.435 ± 0.024 [b]	0.458 ± 0.021 [a]	0.456 ± 0.022 [b]	0.430 ± 0.006 [c]
	Median (IQR)	0.441 (0.034)	0.461 (0.030)	0.455 (0.033)	0.430 (0.010)
p-Value		0.025	<0.001	<0.001	<0.001
Period of Storage—10 Weeks					
Control	Mean ± SD	0.473 ± 0.020 [a]	0.421 ± 0.005 [a]	0.355 ± 0.021 [a]	0.377 ± 0.050 [a]
	Median (IQR)	0.477 (0.034)	0.422 (0.010)	0.363 (0.025)	0.383 (0.080)
1-MCP	Mean ± SD	0.418 ± 0.050 [ab]	0.414 ± 0.008 [ab]	0.434 ± 0.010 [b]	0.399 ± 0.032 [a]
	Median (IQR)	0.402 (0.070)	0.418 * (0.010)	0.431 (0.014)	0.392 (0.047)
1-MCP + MAP	Mean ± SD	0.411 ± 0.013 [b]	0.392 ± 0.007 [b]	0.341 ± 0.009 [a]	0.418 ± 0.012 [a]
	Median (IQR)	0.411 (0.022)	0.393 (0.011)	0.341 (0.015)	0.422 (0.015)
p-Value		0.043	0.150	<0.001	0.305
Period of Storage—20 Weeks					
Control	Mean ± SD	0.309 ± 0.007 [a]	0.345 ± 0.008 [a]	0.287 ± 0.021 [a]	0.273 ± 0.013 [a]
	Median (IQR)	0.308 (0.012)	0.344 (0.013)	0.285 (0.033)	0.275 (0.021)
1-MCP	Mean ± SD	0.417 ± 0.002 [b]	0.401 ± 0.005 [b]	0.371 ± 0.007 [b]	0.365 ± 0.007 [b]
	Median (IQR)	0.417 (0.004)	0.401 (0.010)	0.370 (0.012)	0.363 (0.010)
1-MCP + MAP	Mean ± SD	0.408 ± 0.011 [b]	0.341 ± 0.015 [a]	0.338 ± 0.011 [c]	0.348 ± 0.018 [b]
	Median (IQR)	0.407 (0.019)	0.346 (0.022)	0.341 (0.012)	0.347 (0.030)
p-Value		<0.001	<0.001	<0.001	<0.001

* non-parametric distribution (verified using Shapiro–Wilk test—$p \leq 0.05$); 1-MCP—Methylcyclopropene; MAP—Modified Atmosphere Packaging; different superscript letters are attributed to statistically significant differences while comparing various postharvest treatments within period of storage and period of simulated distribution.

4. Discussion

The studied 'Idared' apples were presented directly after harvesting, with characteristics being typical for this cultivar: TSS [42,43], firmness [42,43], TA [42] and components of color [44].

In the presented study, there were three major determinants of the quality of apples studied, namely the firmness, TSS and TA, while the influence of 1-MCP was visible mainly for firmness, which is a beneficial observation, taking into account the role of firmness in creating the quality of apples, as its firmness constitutes an important textural property and is one of the key parameters for ripening and shelf life [45]. Similarly, for the consumer preference of apple cultivars, firmness is the key determinant of acceptance [46]. In the study by Hoehn et al. [47], which was conducted for various apple cultivars, it was indicated that depending on the cultivar, the apples being rated by consumers as the most accepted are characterized by the firmness of 50–60 N. It indicates, that while compared with the values of firmness observed in the conducted study, only fruits subjected to 1-MCP treatment may be perceived by consumers as the most acceptable, as the other are too soft to be treated as those of the highest quality. It results from the fact that firmness decrease during storage is typical, being associated with ethylene, so its suppression causes the fruit to remain firmer [48]. Therefore, it should be emphasized that the results obtained in the presented study indicated that apples treated with 1-MCP treatment may have, for consumers, more attractive sensory parameters in the case of firmness, than other apples.

For the studied TSS content, the observed differences between compared groups were only minor. The main statement that may be formulated is associated with the fact that in the case of some samples, groups with 1-MCP and MAP applied combined were characterized by significantly higher values of TSS than control groups, but for other samples, such association was not observed, so it may be stated that the observations for TSS were diverse and inconclusive. Also, the results of other authors indicate that the influence of 1-MCP on TSS is much more dependent on the species and cultivars, as it was so far indicated that after 1-MCP application this parameter may be increased in papaya [49], but be decreased in strawberries [50], while for apples it may be increased [51], maintained [25], or decreased [52].

The differences observed for TA indicated that in the conducted experiment, 1-MCP applied alone may have contributed to obtaining significantly higher values of TA than for control groups, but values for samples attributed to 1-MCP and MAP combined were not significantly higher than for 1-MCP alone. It is comparable with the results observed by other authors, which indicated for apples treated with 1-MCP higher TA values than for their untreated samples [51,53]. It results from the fact that TA during natural fruit ripening is decreasing, so slowing the ripening process may result in obtaining higher TA results [54]. Interestingly, in the conducted experiment, the results of the controlled atmosphere were not observed in spite of the fact that in some studies it was concluded to allow to slow the ripening even more than 1-MCP applied alone [55]. However, it may be supposed that the relatively high results of TA observed for 1-MCP application could not possibly have been higher, even if MAP was combined with 1-MCP.

The conducted study did not indicate the most beneficial period of storage, as well as the most beneficial length of distribution, but those issues may be studied in the future and should be conducted for the treatment stated to be most promising, namely 1-MCP applied alone.

Taking into account the observed results, it may be summarized that the beneficial effects of 1-MCP are promising and in the studied conditions, applying MAP was not needed to influence the quality of 'Idared' fruits, as 1-MCP alone allowed to observe significant improvement of the quality of apples. Taking this into account, 1-MCP could be indicated as a good alternative or a good support for controlled atmosphere storage due to the fact that its application can maintain quality of apples on all the stages of the supply chain.

5. Conclusions

It may be concluded that 1-MCP applied postharvest contributed to significantly higher results of firmness and TA of 'Idared' apples after long-distance transportation, but combining 1-MCP with MAP did not contribute to further differences for TA. For TSS the observed influence was minor and inconclusive. It may be stated that 1-MCP is a beneficial treatment for 'Idared' apples for long-distance transportation to prolong their shelf life and improve firmness.

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