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Apple Quality during Shelf-Life after Long-Term Storage and Simulated Transport

Maria Małachowska * and Kazimierz Tomala

Department of Pomology and Horticulture Economics, Institute of Horticultural Sciences, Warsaw University of Life Sciences (SGGW-WULS), ul. Nowoursynowska 159C, 02-787 Warsaw, Poland
* Correspondence: maria_malachowska@sggw.edu.pl; Tel.: +48-22-593-2080

Abstract: With the high production of apples in Poland, the priority actions include increasing their export volume. The main objective of the presented research was to maintain sufficient firmness in the apple cultivar Gala Schniga® SchniCo Red(s) transported to distant markets immediately after harvest or after long-term storage under ULO conditions (1.2% CO_2 and 1.2% O_2). In the study conducted during the 2021/2022 storage season on apples from the experimental orchard of the Warsaw University of Life Sciences (SGGW-WULS; Warsaw-52°14′ N, 21°1′ E), the effect of the pre- and post-harvest application of 1-MCP, harvest date, and simulated transport duration on the quality of apples in target retail trading conditions was evaluated. Apples collected on a given harvest date were divided into four samples: control (without the use of 1-MCP), Harvista™-sprayed, SmartFresh™-treated, and Harvista™-sprayed + SmartFresh™-treated. Immediately after harvest and after 9 months of storage, the apples were packed in boxes and stored at 1 °C for 6 and 8 weeks (simulated transport conditions). Directly after the simulated transport and after an additional 7 and 14 days at 25 °C (handling conditions in hot countries), the following parameters were determined: firmness, SSC, TA, and ethylene production. The study noted a significant effect of the use of 1-MCP, harvest time, and simulated transport period on all tested parameters. Apples from trees sprayed with Harvista™ maintained a firmness of >55 N for 14 days of shelf-life only if they were harvested at the optimal date and transported immediately after harvest, and if their shipping lasted 6 weeks. Such firmness could be preserved after 8 weeks of the transport of SmartFresh™-treated apples harvested at the optimal date, and of Harvista™-sprayed + SmartFresh™-treated apples harvested at a delayed date. In the latter combination, apples also maintained the desired firmness after 9 months of storage + 6 weeks of transport regardless of the harvest date.

Keywords: apples; 'Gala'; Harvista™; SmartFresh™; ethylene; firmness; SSC; TA

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1. Introduction

According to WAPA (the World Apple and Pear Association), Poland is the largest producer of apples in Europe and the third largest producer of apples in the world, after China and the USA. Poland's domestic apple production is growing [1], whereas domestic consumption is decreasing [2]. Therefore, it is crucial for Polish apple growers to acquire new markets and at the same time offer apple cultivars that meet high consumer requirements. Such requirements include, notably, flesh firmness. This is because consumers dislike the mealiness of overripe apples that results from the loss of firmness [3]. In the case of hard cultivars, such as 'Gala', consumers prefer apples with a firmness above 55 N [4]. Maintaining sufficiently high firmness is a big challenge, especially since apples must meet high market requirements after long-term storage and long-distance transport.

Apples are a climacteric fruit whose ripening process is regulated by ethylene [5]. Their maturation involves a significant increase in the production of ethylene [6–8] as well as physiological and biochemical changes, including, among other things, a change in skin base color, a decrease in flesh firmness, the production of aromatic compounds, and a change in fruit taste [9,10]. As ripening progresses, the shelf-life of apples becomes shorter, and thus their commercial value decreases. For this reason, it is important to know the level of ripeness of the fruit both at harvest and during storage [11].

It is very important to harvest apples in the right physiological stage because the harvest date has a key impact on their storage [12]. Apples harvested just after the start of climacteric ethylene production are characterized by the highest storage capacity [13]. Apples harvested too early lack the blush color typical of a given cultivar, and their taste does not fit into the preferences of consumers [14]. On the other hand, a too-late harvest results in faster firmness loss and greater susceptibility to watercore, internal breakdown, and bitter rot [15–17].

Maintaining sufficiently high quality in apples after long-term storage and long-distance transport is easier if the fruit is harvested at the optimal harvest date. However, this is not always possible due to factors independent of the fruit grower, such as unfavorable weather conditions (rainfall) or an insufficient number of seasonal workers. In such a case, special pre- and/or post-harvest treatments should be considered as a means to preserve the high quality of the fruit [18].

A popular method to achieve this is through the use of 1-methylcyclopropene (1-MCP), an inhibitor of ethylene synthesis with a 10-fold greater affinity for ethylene receptors than that of ethylene itself [19]. Available research results showing the effect of the post-harvest use of 1-MCP to reduce the ripening rate of apples transported to distant markets generally concern fruit harvested at the optimal harvest date and stored for only 5 months [20,21]. On the other hand, although studies on the pre-harvest use of 1-MCP do evaluate the fruit harvested both at the optimal and a delayed harvest date, they do not take into account the very long storage of apples prior to their shipment to a distant recipient [18,22].

Therefore, the objective of the experiment described in this paper was to determine the effect of the pre- and post-harvest application of 1-MCP on changes in the quality of Gala Schniga® SchniCo Red(s) apples collected at two harvest dates. In this study, special attention was paid to determining how the 1-MCP application, storage under ultra-low oxygen conditions (ULO; 1.2% CO_2 and 1.2% O_2), and length of transport affect the possibility to maintain apple firmness at above 55 N during a shelf-life of 7 and 14 days on a distant market.

2. Materials and Methods

2.1. Research Plan

The research was conducted in the 2021/2022 storage season on apples from the experimental orchard of the Warsaw University of Life Sciences (SGGW-WULS; Warsaw—52°14′ N, 21°1′ E). Some of the Gala Schniga® SchniCo Red(s) apples (from trees planted in 2014 on M.9 rootstock) collected at two harvest dates, 9 September 2021—the optimal harvest date (OHD) and 23 September 2021—delayed harvest (DH), were also studied in another experiment, the results of which have already been published [18]. In this cited paper, it is stated that 'Gala' apples for long-term storage should be harvested with a starch test value between 4 and 6 and a Streif index value between 0.20 and 0.14. It should be noted that weather conditions during the growing season in 2021 differed substantially compared to the long-term data (Table S1). Precipitation from April to June was close to the long-term averages, while July and August were very wet. Temperatures in April, May, and September were lower than the long-term average, while June and July were hot. For the purpose of the experiment described in this paper, 16 boxes of apples (15 kg per box) from both unsprayed and sprayed trees (7 days before OHD; Harvista™; AgroFresh Solutions Inc., Philadelphia, PA, USA; 150 $g \cdot ha^{-1}$) were collected at the two above-mentioned harvest dates. After 7 days, half of the fruit from both unsprayed and sprayed trees (8 boxes per harvest date) was treated with 1-MCP (SmartFresh ProTabs, AgroFresh™ Solutions Inc., Philadelphia, PA, USA; 0.65 ($\mu L \cdot L^{-1}$) for 24 h.

The experiment was designed in the same way as described in the previously published paper [18]. It involved the following eight treatments:

1. Control—OHD (fruit harvested at the optimal harvest date, not treated with 1-MCP either before or after harvest);
2. Harvista™—OHD (fruit harvested from Harvista™-sprayed trees at the optimal harvest date);
3. SmartFresh™—OHD (fruit harvested from Harvista™-non-sprayed trees at the optimal harvest date, and treated with SmartFresh™ 7 days after harvest);
4. Harvista™ + SmartFresh™—OHD (fruit harvested from Harvista™-sprayed trees at the optimal harvest date, and treated with SmartFresh™ 7 days after harvest);
5. Control—DH (fruit harvested at the delayed harvest date, not treated with 1-MCP either before or after harvest);
6. Harvista™—DH (fruit harvested from Harvista™-sprayed trees at the delayed harvest date);
7. SmartFresh™—DH (fruit harvested from Harvista™-non-sprayed trees at the delayed harvest date, and treated with SmartFresh™ 7 days after harvest);
8. Harvista™ + SmartFresh™—DH (fruit harvested from Harvista™-sprayed trees at the delayed harvest date, and treated with SmartFresh ™ 7 days after harvest).

After the post-harvest application of 1-MCP (SmartFresh™), the apples were split; half of the fruit from each treatment (4 boxes each) was placed under conditions that are present during long-distance transport, while the remaining fruit was stored for 9 months in ULO conditions (1.2% CO_2 and 1.2% O_2) at 1 °C and relative humidity of about 95%.

Directly after harvest and after 9 months of storage, the fruit was packed in a box (telescopic cardboard box closed from above) and kept for 6 and 8 weeks at 1 °C and in a normal atmosphere (78% N_2; 21% O_2; 0.05% CO_2).

The quality of apples after simulated transport was assessed three times: (1) immediately after 6 and 8 weeks, (2) after 7 days, and (3) after 14 days of keeping the apples in the conditions prevailing in trade in hot countries (temperature 25 °C, normal atmosphere). All measurements were made in 4 repetitions of 10 fruit per repetition. In the experiment, fruit of a typical size for the 'Gala' cultivar were used (140–150 g), which were grown under integrated fruit production methods.

2.2. Measurements

The procedure for measuring ethylene concentration in seed chambers was described in the previous paper [18]. A puncture was made with a syringe into the seed chamber of each fruit to draw 1 mL of air. Then, the ethylene concentration in the seed chamber was determined using a gas chromatograph (HP 5890, Hewlett Packard, Palo Alto, CA, USA). The results are expressed in $\mu L \cdot L^{-1}$.

The starch test was performed by spraying the transversely cut apples with Lugol liquid (solution I_2 in KI). The obtained pattern of starch disintegration in the flesh was compared with that in the standard table and scored from 1 to 10. The final result was the average of each repetition [20].

Flesh firmness was determined in accordance with the description given in the work of Tomala et al. [22]. The value of this characteristic was measured using the metal stem (diameter 11 mm) of the penetrometer (Instron 5542, Instron, Norwood, MA, USA), on two opposite sides of the fruit, after removing the skin. The results were expressed in Newtons (N). The results of the measurement of firmness, starch distribution. and SSC at harvest were used to calculate the Streif index, which is considered a good indicator of fruit ripeness [23,24].

Titratable acidity (TA) was measured using an automated titrator (TitroLine 5000, Xylem Analytics Germany GmbH, Weilheim, Germany). For this purpose, juice was extracted using a juicer (one section of flesh was taken along with the skin of each fruit). Then, 100 mL of distilled water and 10 mL of apple juice were placed in 150 mL flasks. The obtained solution was titrated with 0.1 M NaOH to achieve a pH of 8.1. The results were expressed as a percentage of malic acid (%).

For the determination of the soluble solids content (SSC), the remaining juice prepared for TA measurements was used. The SSC in the juice was determined using a refractometer (Atago, Palette PR-32, Atago, Co., Ltd., Tokyo, Japan). Results are expressed in Brix degrees (°Bx).

The intensity of ethylene production was recorded for 14 days at 25 °C. Individual fruit were weighed and closed in jars with a capacity of 1500 mL. After an hour, 1 mL of air was taken from a jar and injected into a gas chromatograph (HP 5890, Hewlett Packard, Palo Alto, CA, USA). Measurements were made for 6 apples from the combination, and the results were expressed in $\mu L \cdot kg^{-1} \cdot h^{-1}$.

2.3. Statistical Analysis

The Shapiro–Wilk test was used to verify the normal distribution of the results of individual parameters. The statistics were developed using a one-way analysis of variance, ANOVA, with Tukey's post hoc test. The effects of the experimental variables, i.e., harvest date (optimal and delayed harvest date), pre- and post-harvest treatment of fruit with 1-MCP (Control, Harvista™, SmartFresh™, and Harvista™ + SmartFresh™), and shelf-life (0, 7 and 14 days) on the physicochemical properties of apples were analyzed using multivariate analysis of variance − ANOVA, (Tables S2 and S3). Differences between means were assumed to be significant at $p \leq 0.05$. Statistical analyses were conducted using Statistica 13.3 (Statsoft Inc., Tulsa, OK, USA).

3. Results

The physiological condition of apples at harvest is shown in Table 1. The same data were published by Małachowska and Tomala [18]. It should be emphasized that apples harvested at the delayed harvest date (DH) had a lower firmness, acidity (TA) and Streif index value, while they contained more extract (SSC) and had a higher starch index value. Nevertheless, the ethylene concentration in the seed chambers of apples from Harvista™ trees remained below 0.5 ($\mu L \cdot L^{-1}$).

Table 1. Physiological condition of Gala Schniga® SchniCo Red(s) apples at optimal harvest date and delayed harvest.

Maturity Indices	Optimal Harvest Date (Harvest I)		Delayed Harvest (Harvest II)	
	Control	Harvista™	Control	Harvista™
	Mean ± SD			
Internal ethylene content ($\mu L \cdot L^{-1}$)	1.18 ± 0.17	0.48 ± 0.19	1.23 ± 0.64	0.42 ± 0.12
Starch index (-)	3.3 ± 0.3	4.1 ± 1.0 [1]	9.0 ± 0.4	6.8 ± 1.2
Soluble solids content (°Bx)	11.8 ± 0.2	10.8 ± 0.2	13.1 ± 0.3	11.5 ± 0.4
Firmness (N)	85.1 ± 1.8	85.3 ± 1.0	70.6 ± 3.7	75.9 ± 2.2
Titratable acidity (%)	0.409 ± 0.029	0.375 ± 0.032	0.333 ± 0.018	0.350 ± 0.015
Streif Index (IS) (-)	0.22 ± 0.02	0.20 ± 0.04	0.06 ± 0.01	0.10 ± 0.02

[1] No normal distribution (verified using Shapiro–Wilk test: $p \leq 0.05$). ™—trademark.

3.1. Ethylene Production

The intensity of ethylene production after 6 weeks of simulated transport immediately following the harvest is shown in Figure 1. The spraying of trees with Harvista™ together with post-harvest treatment of apples with SmartFresh™ ensured very low ethylene production up to day 6 at 25 °C, regardless of the harvest date. At that time, similarly low ethylene production was found in apples treated with SmartFresh™, but only in those collected at the optimal harvest date (OHD). On the other hand, apples from both control and Harvista™ -sprayed trees were characterized by similarly high ethylene production, regardless of harvest date. In these combinations, ethylene production usually gradually decreased over time, whereas the opposite relationship was noted for apples treated with SmartFresh™, regardless of whether or not the trees had previously been sprayed with Harvista™ and regardless of the harvest date.

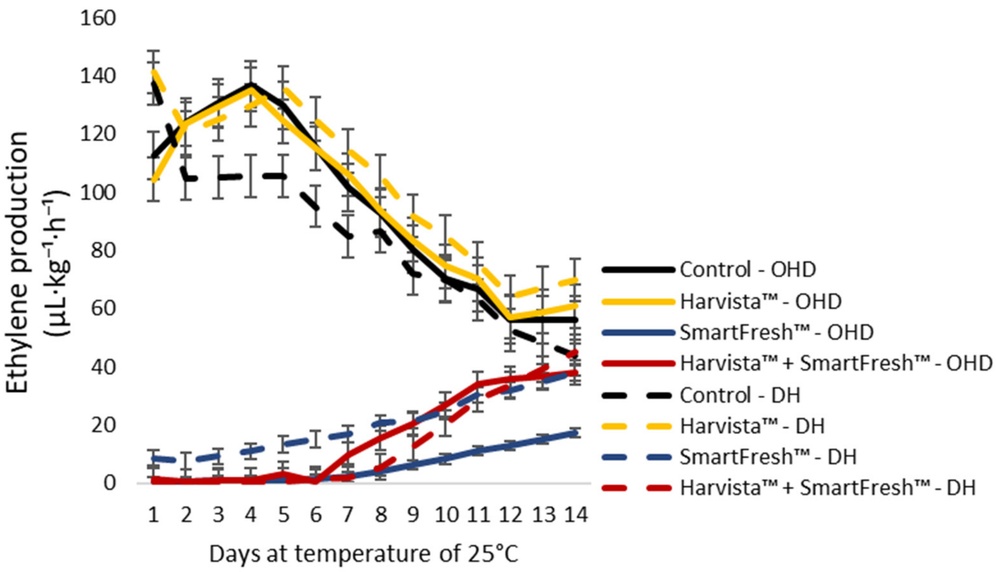

Figure 1. Ethylene production by Gala Schniga® SchniCo Red(s) apples kept at 25 °C after 6 weeks of simulated transport directly after harvest; OHD—optimal harvest date; DH—delayed harvest; ±, standard deviation; n = 48.

The curves illustrating the intensity of ethylene production after 8 weeks of transport were usually similar to the relationships recorded after 6 weeks (Figure 2). Interestingly, the extension of the transport period by 2 weeks resulted in a clear increase in ethylene production, especially in the first days on the target market at 25 °C, but only in the fruit treated with SmartFresh™, regardless of whether or not the trees had previously been sprayed with Harvista™ and regardless of the harvest date. As a rule, apples harvested at the delayed harvest date produced ethylene more intensively than did those harvested at the OHD.

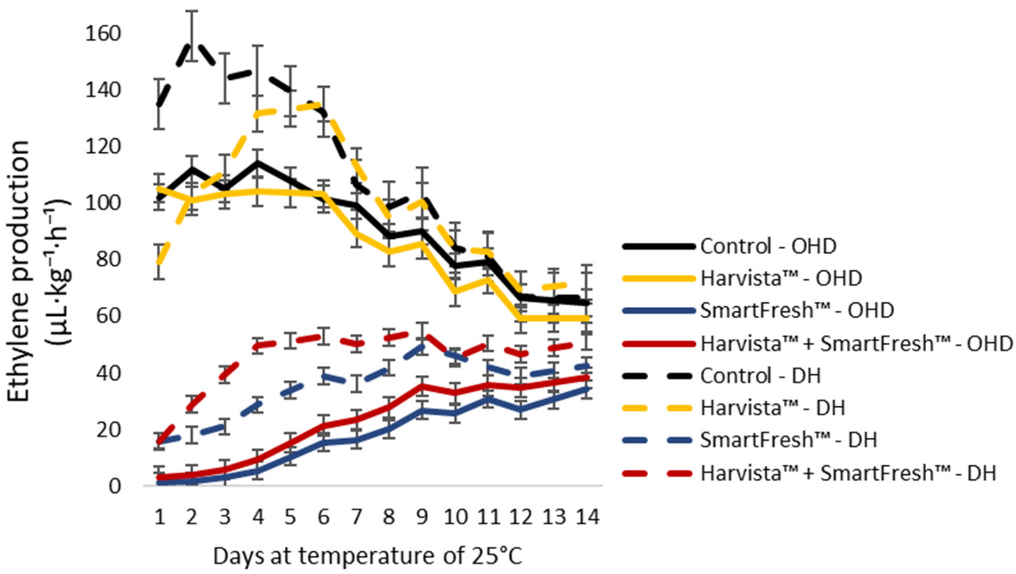

Figure 2. Ethylene production by Gala Schniga® SchniCo Red(s) apples kept at 25 °C after 8 weeks of simulated transport directly after harvest; OHD—optimal harvest date; DH—delayed harvest; ±, standard deviation; n = 48.

After 9 months of storage, apples from the control and Harvista™ combinations produced 2–3 times less ethylene than did apples transported immediately after harvest, regardless of the harvest date (Figures 3 and 4). After 6 weeks of transport, expressly lower ethylene production was ensured by treating apples exclusively with SmartFresh™, regardless of the harvest date. A similar relationship, although weaker, occurred after 8 weeks of transport.

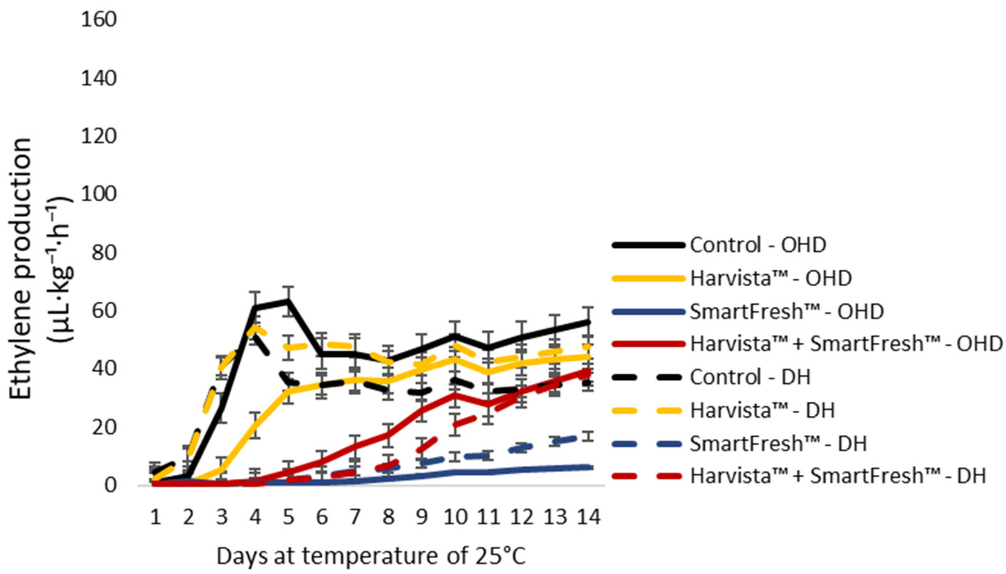

Figure 3. Ethylene production by Gala Schniga® SchniCo Red(s) apples kept at 25 °C after 9 months of storage plus 6 weeks of simulated transport; OHD−optimal harvest date; DH−delayed harvest; ±, standard deviation; n = 48.

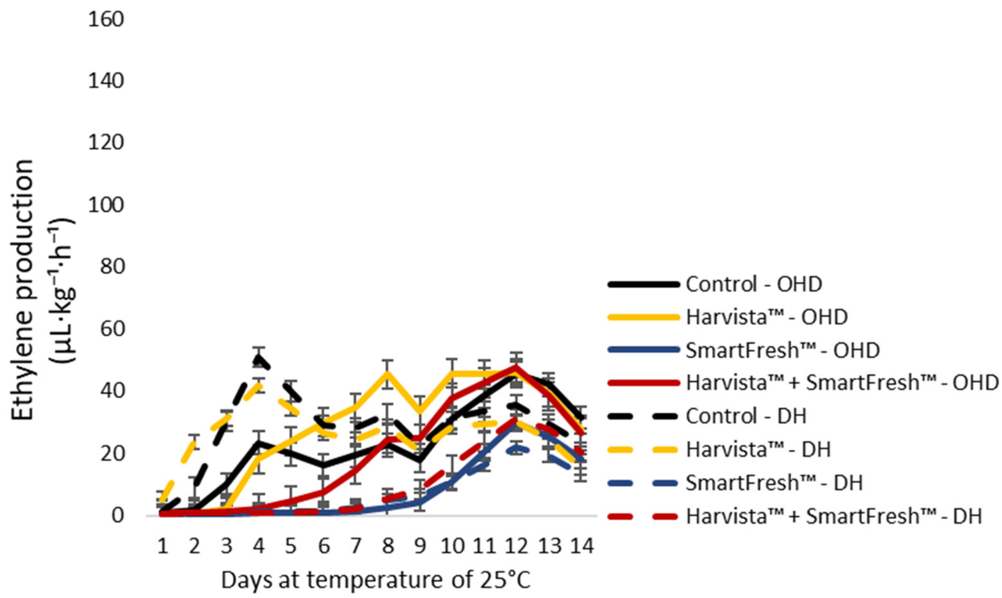

Figure 4. Ethylene production by Gala Schniga® SchniCo Red(s) apples kept at 25 °C after 9 months of storage plus 8 weeks of simulated transport; OHD−optimal harvest date; DH−delayed harvest; ±, standard deviation; n = 48.

3.2. Firmness

The delay in harvest was found to result in a significant decrease in the flesh firmness of 22 out of 24 evaluated apples transported 6 weeks immediately after harvest. After 8 weeks of transport, apples collected at DH were always characterized by a lower firmness than that of those collected at the OHD (Table 2). It should be also noted that apples not treated with 1-MCP either in the orchard or after harvest, especially if harvested at DH, lost firmness very rapidly under shelf-life conditions. Spraying trees with Harvista™ ensured the high quality of apples, with minimum firmness (55 N) for 14 days of shelf-life, regardless of the transport period, but only if the fruit was harvested at the optimal harvest date. On the other hand, apples collected from trees sprayed with Harvista™ and treated with SmartFresh™ after harvest were always firmer than 55 N, regardless of the harvest date, the transport period, and the length of the shelf-life.

Table 2. Flesh firmness (N) of Gala Schniga® SchniCo Red(s) apples shipped directly after harvest as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	**Treatment Applied/*p*-Value**	**Days of Shelf-Life**			***p*-Value for Shelf-Life**
		0	**7**	**14**	
		6 Weeks of Transport			
Harvest I (optimal harvest date)	Control	A^{b} 60.2 c	A^{b} 52.9 b	A^{b} 42.9 a	0.0002
	Harvista™	B^{b} 76.8 c	B^{b} 65.2 b	B^{b} 55.3 a	<0.0001
	SmartFresh™	B^{b} 79.7 c	C^{b} 74.3 b	C^{b} 66.9 a	<0.0001
	Harvista™ + SmartFresh™	B^{b} 80.0 c	C^{a} 73.6 b	C^{a} 63.2 a	0.0003
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 48.9 b	A^{a} 40.5 a	A^{a} 37.8 a	0.0005
	Harvista™	B^{a} 55.7 c	B^{a} 48.9 b	B^{a} 43.0 a	<0.0001
	SmartFresh™	C^{a} 64.1 b	C^{a} 59.7 a	C^{a} 61.7 a	<0.0001
	Harvista™ + SmartFresh™	D^{a} 75.8 c	D^{a} 71.3 b	C^{a} 63.7 a	0.0011
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.0396	0.0037	0.0064	
Harvista™		0.0006	0.0004	0.0008	
SmartFresh™		0.0007	0.0004	0.0088	
Harvista™ + SmartFresh™		0.0002	0.0066	0.1436	
		8 Weeks of Transport			
Harvest I (optimal harvest date)	Control	A^{b} 56.0 b	A^{b} 55.5 b	A^{b} 47.9 a	0.0306
	Harvista™	B^{b} 76.6 b	B^{b} 71.2 b	B^{b} 55.2 a	0.0050
	SmartFresh™	B^{b} 77.7 b	B^{b} 75.6 b	C^{b} 62.9 a	<0.0001
	Harvista™ + SmartFresh™	B^{b} 79.9 b	B^{b} 75.4 b	C^{b} 64.9 a	0.0007
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 46.5 b	A^{a} 43.6 ab	A^{a} 39.9 a	<0.0001
	Harvista™	A^{a} 51.7 b	AB^{a} 48.5 ab	AB^{a} 44.5 a	0.0529
	SmartFresh™	B^{a} 59.9 b	BC^{a} 56.6 ab	BC^{a} 49.7 a	0.0283
	Harvista™ + SmartFresh™	C^{a} 74.0 b	C^{a} 68.6 b	C^{a} 59.0 a	0.0015
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	<0.0001	0.0380	0.0262	
Harvista™		0.0004	0.0299	0.0203	
SmartFresh™		0.0049	0.0032	0.0010	
Harvista™ + SmartFresh™		<0.0001	0.0228	0.0241	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters are for comparing the impact of the length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

The firmness of apples transported after 9 months of storage is shown in Table 3. Apples, both from the control group and from trees sprayed with Harvista™, were usually characterized by much lower firmness than expected (55 N) under shelf-life conditions, regardless of the harvest date and transport period. The desired firmness value after the 14-day shelf-life period was achieved for apples harvested at the optimal harvest date, treated with SmartFresh™ after harvest, and transported to a distant market for 6 weeks after storage, as well as for apples from the Harvista™ + SmartFresh™ combination regardless of the harvest date, transported for 6 weeks. Taking into account the shorter, 7-day shelf-life on the target market, it was found that the post-harvest treatment of apples with SmartFresh™ (regardless of whether or not the trees had been sprayed with Harvista™) also ensured a firmness greater than 55 N after 8 weeks of transport; this also applied to apples harvested at the delayed harvest date (DH).

Table 3. Flesh firmness (N) of Gala Schniga® SchniCo Red(s) apples shipped after 9 months of storage as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	**Treatment Applied/*p*-Value**	**Days of Shelf-Life**			***p*-Value for Shelf-Life**
		0	**7**	**14**	
	6 Weeks of Transport				
Harvest I (optimal harvest date)	Control	A^{b} 54.8 b	A^{a} 41.4 a	A^{a} 37.5 a	0.0005
	Harvista™	A^{b} 59.3 c	B^{b} 51.0 b	B^{b} 45.1 a	<0.0001
	SmartFresh™	B^{b} 73.1 a	C^{b} 73.7 a	D^{b} 70.5 a	0.7185
	Harvista™ + SmartFresh™	B^{b} 78.8 b	C^{a} 76.1 b	C^{a} 62.4 a	0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 44.9 b	A^{a} 40.7 ab	A^{a} 37.1 a	<0.0001
	Harvista™	A^{a} 49.5 c	A^{a} 42.6 b	A^{a} 38.9 a	<0.0001
	SmartFresh™	B^{a} 61.2 b	B^{a} 56.2 b	B^{a} 44.9 a	0.0054
	Harvista™ + SmartFresh™	C^{a} 74.4 b	C^{a} 70.5 b	C^{a} 59.5 a	<0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.0004	0.0025	<0.0001	
Harvista™		<0.0001	0.0007	0.0096	
SmartFresh™		0.0812	0.0057	0.0002	
Harvista™ + SmartFresh™		0.0331	0.2063	0.1055	
	8 Weeks of Transport				
Harvest I (optimal harvest date)	Control	A^{a} 45.9 b	A^{a} 42.4 b	A^{a} 36.5 a	<0.0001
	Harvista™	B^{b} 51.7 c	A^{b} 44.9 b	A^{b} 41.6 a	0.0002
	SmartFresh™	C^{b} 71.4 b	B^{b} 67.6 b	B^{b} 53.0 a	<0.0001
	Harvista™ + SmartFresh™	D^{b} 76.3 c	B^{a} 65.7 b	B^{a} 53.2 a	<0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 44.5 b	A^{a} 40.4 a	A^{a} 37.8 a	0.0110
	Harvista™	A^{a} 46.7 c	A^{a} 42.3 b	A^{a} 37.4 a	<0.0001
	SmartFresh™	B^{a} 56.7 b	B^{a} 55.4 b	B^{a} 45.9 a	0.0083
	Harvista™ + SmartFresh™	C^{a} 66.8 b	C^{a} 63.2 b	C^{a} 52.5 a	0.0014
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.1664	0.0199	0.7489	
Harvista™		0.0017	0.0172	0.0052	
SmartFresh™		0.0143	0.0300	0.0676	
Harvista™ + SmartFresh™		0.0027	<0.0001	0.0297	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters are for comparing the impact of the length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

3.3. Soluble Solids Content (SSC)

The SSC values in apples transported immediately after harvest are presented Table 4. Apples harvested at the OHD and at DH most often did not differ in terms of SSC in simulated transport conditions, especially after 8 weeks of transport. However, as regards the fruit transported for 6 weeks, apples from trees sprayed with Harvista™ usually contained less SSC than did those treated with SmartFresh™ after harvest. Extending the shelf-life after 6 weeks of transport resulted in an increase in SSC in apples from the Harvista™ + SmartFresh™ treatment, whereas the opposite relationship was noted for apples treated only with one of the above preparations.

Table 4. Soluble solids content SSC (°Bx) of Gala Schniga® SchniCo Red(s) apples shipped directly after harvest as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	**Treatment Applied/*p*-Value**	**Days of Shelf-Life**			***p*-Value for Shelf-Life**
		0	**7**	**14**	
		6 Weeks of Transport			
Harvest I (optimal harvest date)	Control	B^{a} 12.4 a	B^{a} 12.5 a	A^{a} 12.0 a	0.0002
	Harvista™	B^{a} 12.4 a	B^{b} 12.6 a	AB^{b} 12.7 a	<0.0001
	SmartFresh™	C^{b} 14.6 b	C^{b} 15.0 b	B^{a} 13.4 a	<0.0001
	Harvista™ + SmartFresh™	A^{a} 11.4 a	A^{a} 11.4 a	B^{a} 13.3 b	0.0003
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 12.7 a	B^{a} 12.7 a	AB^{b} 12.7 a	0.0005
	Harvista™	A^{a} 12.5 b	A^{a} 11.4 a	A^{a} 11.6 a	<0.0001
	SmartFresh™	A^{a} 13.1 a	B^{a} 13.1 a	B^{a} 13.7 a	<0.0001
	Harvista™ + SmartFresh™	A^{b} 12.4 a	B^{b} 12.6 ab	B^{a} 13.4 b	0.0011
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.0396	0.0037	0.0064	
Harvista™		0.0006	0.0004	0.0008	
SmartFresh™		0.0007	0.0004	0.0088	
Harvista™ + SmartFresh™		0.0002	0.0066	0.1436	
		8 Weeks of Transport			
Harvest I (optimal harvest date)	Control	A^{a} 12.4 a	A^{b} 12.7 a	B^{a} 12.4 a	0.0306
	Harvista™	A^{a} 12.2 a	B^{a} 13.0 a	B^{a} 12.8 a	0.0050
	SmartFresh™	A^{a} 12.2 a	B^{b} 13.2 b	C^{b} 13.9 c	<0.0001
	Harvista™ + SmartFresh™	A^{a} 11.7 a	A^{a} 11.9 a	A^{a} 11.8 a	0.0007
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 12.4 a	A^{a} 11.8 a	A^{a} 12.5 a	<0.0001
	Harvista™	A^{a} 13.0 a	B^{a} 13.1 a	A^{a} 12.7 a	0.0529
	SmartFresh™	A^{a} 12.4 a	AB^{a} 12.4 a	A^{a} 12.3 a	0.0283
	Harvista™ + SmartFresh™	A^{b} 12.8 a	AB^{b} 12.8 a	A^{a} 12.3 a	0.0015
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	<0.0001	0.0380	0.0262	
Harvista™		0.0004	0.0299	0.0203	
SmartFresh™		0.0049	0.0032	0.0010	
Harvista™ + SmartFresh™		<0.0001	0.0228	0.0241	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters in the line are for comparing the impact of the length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

There were also significant fluctuations in the SSC in apples transported after 9 months of storage (Table 5). Apples collected at the OHD had a higher SSC than those harvested at DH, regardless of the length of shelf-life, but this was only observed for apples in the control combination after 6 weeks of transport, while the fruit from the other combinations usually had similar SSCs. On the other hand, apples treated with SmartFresh™ only and those treated with Harvista™ + SmartFresh™ usually contained more extract than did the fruit in the other two combinations (control and Harvista™) after 14 days shelf-life, regardless of the remaining experimental variables. At the same time, SmartFresh™-only and Harvista™ + SmartFresh™-treated apples showed a higher SSC value after 14 days of shelf-life than they did immediately after transport, but only if they were transported for 8 weeks.

Table 5. Soluble solids content SSC (°Bx) of Gala Schniga® SchniCo Red(s) apples shipped after 9 months of storage as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	**Treatment Applied/*p*-Value**	**Days of Shelf-Life**			***p*-Value for Shelf-Life**
		0	**7**	**14**	
	6 Weeks of Transport				
Harvest I (optimal harvest date)	Control	BC^{b} 13.2 a	B^{b} 13.5 a	B^{b} 13.1 a	0.0005
	Harvista™	AB^{a} 12.4 b	A^{a} 12.1 ab	A^{b} 11.9 a	<0.0001
	SmartFresh™	C^{a} 13.5 a	B^{a} 13.1 a	B^{a} 13.6 a	0.7185
	Harvista™ + SmartFresh™	A^{a} 11.9 a	A^{a} 11.8 a	A^{a} 11.7 a	0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 11.8 ab	AB^{a} 12.3 b	A^{a} 11.5 a	<0.0001
	Harvista™	AB^{a} 12.5 b	A^{a} 12.2 b	A^{a} 11.1 a	<0.0001
	SmartFresh™	B^{a} 13.2 a	B^{a} 13.1 a	B^{a} 13.2 a	0.0054
	Harvista™ + SmartFresh™	B^{b} 12.7 a	AB^{a} 12.4 a	B^{b} 12.6 a	<0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.0004	0.0025	<0.0001	
Harvista™		<0.0001	0.0007	0.0096	
SmartFresh™		0.0812	0.0057	0.0002	
Harvista™ + SmartFresh™		0.0331	0.2063	0.1055	
	8 Weeks of Transport				
Harvest I (optimal harvest date)	Control	BC^{a} 12.9 a	AB^{a} 12.1 a	B^{a} 12.3 a	<0.0001
	Harvista™	A^{a} 11.8 a	A^{a} 11.8 a	A^{a} 11.5 a	0.0002
	SmartFresh™	C^{a} 13.3 a	C^{a} 13.3 a	D^{a} 14.0 b	<0.0001
	Harvista™ + SmartFresh™	AB^{a} 12.2 a	BC^{b} 13.0 b	C^{a} 13.2 b	<0.0001
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	AB^{a} 12.1 a	A^{a} 12.1 a	AB^{a} 12.5 a	0.0110
	Harvista™	A^{a} 11.8 a	A^{a} 12.0 a	A^{a} 11.7 a	<0.0001
	SmartFresh™	B^{a} 12.8 a	B^{a} 13.6 ab	C^{a} 14.0 b	0.0083
	Harvista™ + SmartFresh™	AB^{a} 12.1 a	A^{a} 12.1 a	B^{a} 12.8 b	0.0014
	p-Value for the combinations with 1-MCP	<0.0001	<0.0001	<0.0001	
Control	*p*-Value for the harvest date	0.1664	0.0199	0.7489	
Harvista™		0.0017	0.0172	0.0052	
SmartFresh™		0.0143	0.0300	0.0676	
Harvista™ + SmartFresh™		0.0027	<0.0001	0.0297	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters are for comparing the impact of the length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

3.4. Titratable Acidity (TA)

The TA of apples transported immediately after harvest is presented in Table 6. The apples harvested at the OHD usually had a higher acidity than did the fruit harvested later, regardless of the 1-MCP treatment, the length of transport, and the shelf-life. On the other hand, apart from the apples assessed after 6 weeks of transport + 14 days of shelf-life, the effect of the 1-MCP treatment on TA was usually significant, regardless of the harvest date, although it showed some variability depending on the measurement date. The effect of 1-MCP on the TA value was found to be less stable after 6 weeks than after 8 weeks of simulated transport. During the shelf-life following the 8-week transportation period, the acidity of apples treated with SmartFresh™ and Harvista™ + SmartFresh was usually greater than that of control fruit. At that time, control and Harvista™-treated apples generally did not differ in terms of acidity. In the experiment, the rate of TA decline differed among the fruit samples as the shelf-life became longer. The exception was apples treated with Harvista™ and Harvista™ + SmartFresh™ and harvested at the delayed harvest date. The analysis carried out after the respective shelf-life periods following 6 weeks of transport did not reveal any differences between them in this respect.

Table 6. Titratable acidity, TA (%), of Gala Schniga® SchniCo Red(s) apples shipped directly after harvest as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	Treatment Applied/*p*-Value	Days of Shelf-Life 0	7	14	*p*-Value for Shelf-Life
		6 Weeks of Transport			
Harvest I (optimal harvest date)	Control	B^{a} 0.366 b	A^{b} 0.332 a	A^{b} 0.309 a	0.0013
	Harvista™	AB^{b} 0.364 b	A^{b} 0.350 b	A^{a} 0.306 a	0.0001
	SmartFresh™	C^{b} 0.427 b	B^{b} 0.397 b	A^{b} 0.322 a	0.0004
	Harvista™ + SmartFresh™	A^{b} 0.341 ab	AB^{b} 0.356 b	A^{b} 0.330 a	0.0073
	p-Value for the combinations with 1-MCP	<0.0001	0.0085	0.0516	
Harvest II (delayed harvest)	Control	C^{a} 0.356 c	B^{a} 0.297 b	A^{a} 0.263 a	0.0008
	Harvista™	A^{a} 0.286 a	A^{a} 0.254 a	A^{a} 0.286 a	0.0401
	SmartFresh™	C^{a} 0.360 c	B^{a} 0.305 b	A^{a} 0.273 a	<0.0001
	Harvista™ + SmartFresh™	B^{a} 0.310 a	B^{a} 0.293 a	A^{a} 0.281 a	0.2406
	p-Value for the combinations with 1-MCP	<0.0001	0.0024	0.3626	
Control	*p*-Value for the harvest date	0.2917	0.0298	0.0037	
Harvista™		0.0002	<0.0001	0.1134	
SmartFresh™		<0.0001	0.0019	0.0025	
Harvista™ + SmartFresh™		0.0331	0.0021	0.0093	
		8 Weeks of Transport			
Harvest I (optimal harvest date)	Control	AB^{b} 0.333 b	AB^{b} 0.321 b	A^{a} 0.218 a	<0.0001
	Harvista™	A^{b} 0.321 b	A^{b} 0.300 ab	B^{b} 0.287 a	0.0043
	SmartFresh™	C^{b} 0.387 b	B^{b} 0.334 a	B^{b} 0.319 a	0.0004
	Harvista™ + SmartFresh™	B^{b} 0.367 b	C^{b} 0.374 b	B^{b} 0.286 a	0.0008
	p-Value for the combinations with 1-MCP	0.0015	<0.0001	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 0.233 a	AB^{a} 0.273 b	A^{a} 0.232 a	<0.0001
	Harvista™	A^{a} 0.229 ab	A^{a} 0.256 b	A^{a} 0.215 a	0.0169
	SmartFresh™	B^{a} 0.304 ab	C^{a} 0.314 b	B^{a} 0.282 a	0.0224
	Harvista™ + SmartFresh™	B^{a} 0.311 b	B^{a} 0.297 b	A^{a} 0.234 a	0.0007
	p-Value for the combinations with 1-MCP	<0.0001	0.0006	0.0015	
Control	*p*-Value for the harvest date	<0.0001	0.0019	0.2440	
Harvista™		0.0001	0.0003	0.0008	
SmartFresh™		0.0007	0.0157	0.0135	
Harvista™ + SmartFresh™		0.0128	0.0010	0.0214	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters are for comparing the impact of length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

The TA results obtained for apples transported after 9 months of storage under ULO conditions are presented in Table 7. Surprisingly, the pre-existing differences in apple acidity associated with the harvest date mostly disappeared. At the same time, the impact of 1-MCP on the TA value was much more pronounced, regardless of the harvest date and the length of transport. Although the application of SmartFresh™ almost always resulted in higher acidity compared to that of the control combination, spraying trees with Harvista™ was only slightly less effective than was using SmartFresh™. Similarly to transport immediately after harvest, the shelf-life period had a significant impact on fruit acidity. Despite some differences between the fruit samples in the TA decline rate along with the increase in shelf-life, apples had always lower acidity after 14 days at 25 °C than they did immediately after transport (0 days of shelf-life). The exceptions to this rule were apples treated with SmartFresh™, collected at both harvest dates and transported for 6 weeks, as well as control apples harvested with a delay and transported for 8 weeks after storage. In those three cases, the apples did not differ in terms of TA at any time of measurement.

Table 7. Titratable acidity TA (%) of Gala Schniga® SchniCo Red(s) apples shipped after 9 months of storage as affected by 1-MCP treatment, harvest date, length of shelf-life, and transport period.

Harvest Date	**Treatment Applied/*p*-Value**	**Days Of Shelf-Life**			***p*-Value for Shelf-Life**
		0	**7**	**14**	
			6 Weeks of Transport		
Harvest I (optimal harvest date)	Control	A^{a} 0.228 c	A^{a} 0.196 b	A^{a} 0.165 a	<0.0001
	Harvista™	B^{a} 0.252 b	AB^{b} 0.237 b	B^{a} 0.189 a	0.0003
	SmartFresh™	B^{b} 0.260 a	B^{a} 0.252 a	C^{a} 0.217 a	0.1271
	Harvista™ + SmartFresh™	B^{b} 0.260 b	B^{a} 0.257 b	C^{a} 0.213 a	0.0007
	p-Value for the combinations with 1-MCP	0.0036	0.0251	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 0.206 b	A^{a} 0.184 ab	A^{a} 0.156 a	0.0066
	Harvista™	B^{a} 0.245 c	AB^{a} 0.199 b	A^{a} 0.173 a	<0.0001
	SmartFresh™	AB^{a} 0.230 a	B^{a} 0.236 a	B^{a} 0.220 a	0.6805
	Harvista™ + SmartFresh™	B^{a} 0.242 b	B^{a} 0.245 b	B^{a} 0.210 a	0.0004
	p-Value for the combinations with 1-MCP	0.0028	0.0055	<0.0001	
Control	*p*-Value for the harvest date	0.0790	0.2410	0.1477	
Harvista™		0.1805	0.0109	0.1029	
SmartFresh™		0.0251	0.4389	0.7299	
Harvista™ + SmartFresh™		0.0238	0.2417	0.6781	
			8 Weeks of Transport		
Harvest I (optimal harvest date)	Control	A^{a} 0.194 b	A^{a} 0.191 b	A^{a} 0.157 a	0.0128
	Harvista™	B^{a} 0.246 b	B^{b} 0.230 ab	B^{b} 0.200 a	0.0164
	SmartFresh™	B^{a} 0.265 b	AB^{a} 0.225 a	C^{a} 0.226 a	0.0085
	Harvista™ + SmartFresh™	B^{b} 0.278 c	B^{a} 0.254 b	C^{a} 0.220 a	0.0001
	p-Value for the combinations with 1-MCP	<0.0001	0.0037	<0.0001	
Harvest II (delayed harvest)	Control	A^{a} 0.193 a	A^{a} 0.190 a	B^{b} 0.205 a	0.4354
	Harvista™	B^{a} 0.271 b	A^{a} 0.199 a	A^{a} 0.175 a	<0.0001
	SmartFresh™	B^{a} 0.264 b	B^{a} 0.234 a	C^{a} 0.227 a	0.0051
	Harvista™ + SmartFresh™	B^{a} 0.256 b	B^{a} 0.245 b	BC^{a} 0.213 a	0.0006
	p-Value for the combinations with 1-MCP	0.0352	0.0005	<0.0001	
Control	*p*-Value for the harvest date	0.8475	0.9093	<0.0001	
Harvista™		0.1456	0.0178	0.0094	
SmartFresh™		0.9296	0.5402	0.8414	
Harvista™ + SmartFresh™		0.0130	0.2127	0.4140	

Tukey's HSD test; normal distribution (normality was checked using the Shapiro–Wilk test—$p \leq 0.05$); capital letters in the column are for comparing the impact of 1-MCP applied at a given harvest date, small letters are for comparing the impact of the length of shelf-life, and small letters in superscript are for comparing the impact of delayed harvest in respect of a given shipping period; ™—trademark.

4. Discussion

The increasing production of apples concurrent with a decline in their consumption in Poland [2,3] forces apple producers to search for new markets. Consumers are increasing their demands and expect apples to be well colored and have firm and juicy flesh all year round [25]. Therefore, the aim of the experiment described in this paper was to determine the effect of the pre- and post-harvest use of 1-MCP on changes in the quality of Gala Schniga® SchniCo Red(s) apples transported immediately after harvest or after storage in ULO conditions (1.2% CO_2 and 1.2% O_2). Particular attention was paid to the possibility of maintaining minimum firmness at above 55 N, which is the basic criterion for high-quality apples as assessed by consumers [4]. The study noted a significant effect of 1-MCP, harvest date, and shelf-life length on such parameters as ethylene production rate, firmness, SSC, and TA in apples subjected to simulated transport both immediately after harvest and after 9 months of storage, regardless of the shipping period.

It has been mentioned that firmness plays a key role in assessing the quality of apples [26,27]. This work proves that 1-MCP-treated apples harvested at the optimal harvest date (OHD) maintained firmness at above 55 N for 14 days after both 6 and 8 weeks of refrigerated transport, if the transport started immediately after harvest. The desired firmness could be maintained after 9 months of storage, for 14 days on the target market, if the apples were treated with 1-MCP before and after harvest, but this only applied to apples transported for 6 weeks, regardless of the harvest date. After 8 weeks of transport, the desired firmness could be maintained for only 7 days at 25 °C for apples treated with SmartFresh™ and those treated with Harvista™ + SmartFresh™, regardless of the harvest date. In the presented study, the firmness loss rate in apples as a climacteric fruit was associated with the intensity of ethylene production. Therefore, as also noted in the literature [19], the use of 1-MCP (ethylene inhibitor) had a clearly positive effect on the firmness and the shelf-life of apples.

Some researchers believe that fruit with ethylene receptors blocked by 1-MCP may not regain their ability to ripen after storage [28,29]. For example, pears [30], and bananas [31] did not ripen after 1-MCP was used in high concentrations. In this study, 1-MCP did not completely block the ripening of the 'Gala' apples. One of the signs of the post-harvest ripening of apples is a decrease in the firmness of fruit flesh, accompanied by increased ethylene production [10]. This relationship was also observed in this study, but the above processes were slow after the use of 1-MCP. Apples treated with 1-MCP after harvest produced less ethylene than did apples from trees sprayed with 1-MCP before harvest. It can therefore be concluded that apples remaining on the tree after 1-MCP treatment may form new ethylene receptors, and, consequently, produce more ethylene than apples treated with 1-MCP after harvest thus confirming the observations presented in other papers [32,33]. It is commonly known that a physiological reaction to ethylene requires the binding of ethylene to ethylene receptors. During the presented studies, it was found that applying 1-MCP twice (before and after harvest) effectively reduced deteriorations in fruit quality, which is consistent with the results of other studies [18,22,34].

In addition, it was shown that the delay in the harvest date also significantly affected the firmness decline rate of apples transported immediately after harvest. Thongkum et al. believe that the expression of genes involved in ethylene production depends on fruit maturity. Therefore, those genes are less expressed in unripe and overripe fruit than in fruit with optimal maturity, which is reflected in ethylene production [35]. In this study, fruit harvested at the delayed harvest date (DH) produced more ethylene than did fruit harvested at the optimal harvest date (OHD), but this was only the case for apples transported immediately after harvest. Apples untreated with 1-MCP (control) and apples from trees sprayed with Harvista™ produced less ethylene after 9 months of storage than they did when transported immediately after harvest.

According to consumers' perceptions, the firmness and juiciness of apple flesh are indicators of freshness [36], while SSC and TA are associated with nutritional values [7,37]. In our study, the post-harvest use of 1-MCP resulted in higher SSCs than did spraying trees with Harvista™. Błaszczyk and Gasparski [38] also noted an increase in SSC after the post-harvest use of 1-MCP. Of course, SSC and TA decrease as the fruit ripens, but the decrease rate is related to the length of storage [39]. Nevertheless, opinions are divided over the effect of 1-MCP on the course of changes in SSC in apples. Rupasinghe et al. argue that 1-MCP has no significant effect on SSC in apples [40,41]. Additionally, other studies conducted on apple cultivars, including those on 'Summer Prince' and 'Summer King' [42], and 'Hongkum' [43], have not shown a significant effect of 1-MCP on SSC. Other researchers believe that, SSC in apples after the use of 1-MCP can be either lower or higher, depending on, e.g., the cultivar or orchard location [44].

The harvest date significantly affected the acidity of the apples. The decrease in acidity associated with delayed harvest was recorded mainly in the apples harvested at DH and transported immediately after harvest. Organic acids, such as sugars, are the basic substrates in fruit respiration. For this reason, the loss of acidity was generally significant later into the shelf-life. The use of 1-MCP, especially after harvest, was visibly effective in maintaining higher acidity of apples. This can be explained by lower ethylene production, which, assumably, limited respiration, thus contributing to a lower consumption of organic acids in the respiration process, as reported by other authors [45–48]. Since consumers prefer fruit with a well-balanced sugar–acid ratio [4], the use of 1-MCP seems fully justified, especially if the fruit is to be transported to distant markets. This is particularly important for 'Gala' apples, which are characterized by relatively low acidity and which may be perceived by consumers as too sweet if their acidity significantly decreases.

5. Conclusions

Treatment with Harvista™ alone can only be recommended for apples intended for transport immediately after harvest. Then, only apples harvested at the optimal harvest date can be transported for 6 weeks, without the risk of an excessive reduction in their firmness when keeping them at 25 °C for the next 14 days. The double application of 1-MCP (Harvista™ + SmartFresh™) to Gala Schniga® SchniCo Red(s) apples, including the apples harvested 2 weeks after the optimal harvest date, ensured that the apples retained the desired firmness on the target market for 14 days after 6 weeks of transport preceded by 9 months of storage under ULO conditions. Apples from the delayed harvest, which were treated with SmartFresh™, stored for 9 months and transported for 8 weeks maintained the desired firmness during the shelf-life of 7 days. Changes in the values of this quality indicator showed some convergence with the production of ethylene.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/agriculture13112045/s1. Table S1. The weather conditions in the apple orchard in the year 2021 against the background of long-term data; Table S2. The *p*-value of the influence of individual experimental factors and interactions on the physicochemical properties of fruit shipped directly after harvest; Table S3. The *p*-value of the influence of individual experimental factors and interactions on the physicochemical properties of fruit shipped after 9 months of storage.

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