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Evaluation of Storage Quality of Hardy Kiwifruit (*Actinidia arguta*): Effect of 1-MCP and Maturity Stage

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Abstract: Hardy kiwifruit fits into consumer expectations, especially in terms of taste and nutritional value. The main reason for the loss of quality is that the fruit softens too quickly, but storage at low temperatures (0–1 °C) is not effective enough in maintaining high fruit quality. Two cultivars were evaluated for storage quality, i.e., 'Geneva' and 'Ananasnaya'. Minikiwi were harvested at two stages of maturity. The fruit were treated with 1-methylcyclopropene at a concentration of 0.65 µL/L and then stored under common cold storage, ULO, and CA conditions. Fruit evaluation was carried out for 12 weeks, and firmness, soluble solids content, and titratable acidity were evaluated. Post-harvest treatments, as well as the conditions under which the fruit is stored, determine its quality after storage. The application of 1-MCP decisively inhibits the softening of mini kiwi even under normal atmospheric conditions.

Keywords: mini kiwi; 'Geneva'; 'Ananasnaya'; *Actinidia arguta*; 1-MCP; controlled atmosphere; fruit quality

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1. Introduction

The best-known species of the genus Actinidia (Actinidia Lindl.) is Actinidia deliciosa (A. Chev.) C. F. Liang & A. R. Ferguson) and its fruit has been commonly known as 'Kiwi' since the 1950s [1,2]. The globalization of trade and changes in consumer preferences imply a search for new species with fruits distinguished by their appearance, taste as well as nutritional properties. Hardy kiwifruit fits into consumer expectations, especially in terms of taste [3] and nutritional properties [4–6]. A major advantage of the mini kiwi is that the whole fruit can be eaten, including the skin, which, as with other fruits, contains significantly more health-promoting compounds than the flesh itself [7–9]. In addition, due to the small size of the berries, they can be treated as a convenient and easily accessible snack for children or adults.

The high nutritional qualities of mini kiwi are winning it more and more admirers worldwide. Dynamic development of cultivation can be seen in European countries, but also New Zealand and China [1,2]. Many research facilities are breeding new varieties with more favorable characteristics [10]. The search is on for varieties with larger sizes, higher nutrient content, or storability [11,12]. It is the short distribution period of the fruit that is currently the main problem in plantation development and fruit marketing. A characteristic feature of mini kiwi is the harvesting of the fruit at the harvest maturity stage when it is not suitable for consumption [13]. A commonly used determinant of the harvesting stage of the fruit is the soluble solids content [13,14], although other, more accurate indicators are being sought [15,16]. Fruits harvested when the soluble solids content (SSC) reaches 6–7 °Brix have the highest storability so that the distribution period of mini kiwi can be extended. It should be noted that the quality of mini kiwi, like other fruits, is influenced by more factors: plant fertilization [17], pruning and plant formation [18], varietal [10,11] or environmental characteristics [19], and the conditions under which the fruit is stored [20–22]. Previous research and practice indicate that storage at low temperatures (0–1 °C) is not sufficiently effective in maintaining the high quality of mini kiwi [23]. The main reason for the loss of consumer acceptability is that the fruit softens too quickly [24]. A reason for the loss of firmness of mini kiwi is the activation of the enzymes exo-polygalacturonase, endo-polygalacturonase, pectin esterase, and endo-1,4β-D-glucanase by ethylene, produced even in small quantities [25]. The inhibition of endogenous ethylene synthesis, e.g., by increasing the CO_2 content in the air surrounding the fruit, is one of the long-established methods of slowing fruit ripening [21,26]. A high CO_2 concentration can be achieved by adding synthetic carbon dioxide to the cold chambers or, as a result of the respiration of the fruit, by enclosing the mini kiwi in MAP packaging (Modified Atmosphere Packaging) [27,28]. Another method is using synthetic ethylene inhibitors such as 1-methylcyclopropene and its homologs [29–31]. 1-Methylcyclopropene (1-MCP) blocks the binding of ethylene to its receptor and thus slows ethylene production and the ripening processes affected by this phytohormone [32]. The efficacy of 1-MCP treatment to prolong storage life has been widely demonstrated on 'Hayward' kiwifruit [32–34], but despite the promising results observed to date, few studies have evaluated the effect of 1-MCP treatment on mini kiwi [29,30].

Mini kiwi is a climacteric fruit, so the initiation of ethylene synthesis means that the process continues autocatalytically. Results of previous studies indicate high efficiency of 1-MCP application in reducing fruit softening [35,36]; however, the blocking of aroma synthesis and deterioration of flavor of fruit treated with 1-MCP is unexplained. The aim of this study was to evaluate the effects of the post-harvest application of 1-methylcyclopropene on the physicochemical quality of hard kiwifruit depending on the stage of fruit maturity at harvest. An additional objective was to verify the validity of the application of 1-MCP for mini kiwi fruit stored under air storage versus controlled atmosphere conditions.

2. Materials and Methods

2.1. Outline of the Experiment

The experiment was conducted on the fruit of two cultivars of mini kiwi obtained from an experimental plantation located on the university campus of Warsaw University of Life Science (WULS) located in central Poland (52°15′ N, 21°02′ E). Two cultivars were evaluated for storage quality, i.e., 'Geneva'—an early mini kiwi variety, commonly grown in Poland [14] and 'Ananasnaya'—s. 'Anna' is the most widely grown mini kiwi fruit in the world [37]. Mini kiwi plants were grown in a T-shape at a spacing of 4 m × 4 m. Fruits were harvested from 7-year-old hardy kiwi (*Actinidia arguta* (Sieb. & Zucc.) Planch. ex Miq.) plants, managed according to good agricultural practice. Fruits were harvested twice; the first harvest was carried out when the fruit reached harvest maturity (6–7 °Brix) based on guidelines from the literature and own previous studies [10,38]. The first harvest was carried out on the dates: 'Geneva'—24 August 2016, and 'Anansnaya'—18 September 2016. The second collection was made after 7 days after the mini kiwi had reached approximately 9 °Brix. The berries were harvested by hand, placing the cut fruit in PVC packs (Best Opakowania, Pniewy, Poland) with ventilation holes to allow free air exchange, with a capacity of 250 g. Immediately after harvesting, the fruit packages were transported to the cold store of the WULS, Institute of Horticultural Sciences, where they were placed under refrigeration at 1 °C, Rh = 75–80%, to cool the berries. Approximately 24 h after fruit harvest, half of the fruit packs were placed in an airtight 1 m^3 experimental container, where the fruit was treated with 1-methylcyclopropene (SmartFresh ProTabs™, AgroFresh Solutions Inc., Philadelphia, PA, USA) at a concentration of 0.65 µL/L, for 24 h, as recommended in the literature [26,28,39]. The remaining fruit (the other half) was left under refrigeration. Subsequently, all fruit were divided into three groups (separately for 1-MCP-treated and untreated fruit) and placed in three experimental containers (area 1 m^3) equipped with an Oxystat 200 automatic gas control system (David Bishop Ltd., Heathfield, United Kingdom) providing continuous monitoring of CO_2 and O_2 content. The conditions in the experimental containers corresponded to those of a conventional cold store (0.1% CO_2:21%

O_2), ULO—ultra low oxygen (1.5% CO_2:1.5% O_2), and CA—controlled atmosphere (5% CO_2:1.5% O_2). The fruit in the experimental containers was stored at a temperature of 1 °C and a relative humidity of approximately 95%. Systematically, the fruit of both cultivars was sampled every 2 weeks for 12 weeks for physicochemical analyses. The experiment was replicated three times, each on 0.25 kg of fruit (approx. 40–50 fruits).

2.2. Analytical Methods

Physicochemical indices were used to assess the fruit, describing the parameters most relevant to consumer preferences. Fruit firmness, extract content and titratable acidity were assessed, and analyses were carried out immediately after harvesting and at any time after storage.

Fruit firmness (FF) is estimated as the value of the force required for the probe to penetrate the fruit, according to a previously described method [14]. FF was determined using an Instron 5542 penetrometer (Instron, High Wycombe, UK). Twenty fruits were used in triplicate, and each fruit was tested twice (on opposite sides). The tests were carried out with the following parameters: stem diameter 4.5 mm, stem speed at compression 240 mm^{-1}, and penetration to a depth of 5 mm. The FF value was expressed in Newtons (N).

The content of soluble solids (SSC) was determined refractometrically, according to Polish Standard PN-EN 12,143:2000 [40] (developed by the Polish Committee for Standardization) according to the previously described method [10]. For the determination, juice squeezed from 20 fruits (previously used for FF determination) was used using a simple extractor. SSC was analyzed using an Atago Palette PR-32 alpha digital refractometer (Atago, Tokyo, Japan), and measurements were taken at 20 °C. Results were expressed in °Brix.

Titratable acidity (TA) was determined in accordance with Polish Standard PN-EN 12,147:2000 [41], according to a previously described method [10]. The juice obtained from the SSC analysis, diluted with distilled water at a ratio of 1:10 (*v:v*), was used to assess TA. This was measured in the aqueous extract by titration with 0.1 N sodium hydroxide (NaOH) to a pH endpoint of 8.1. The test was performed using a TitroLine 5000 system (Si Analytics, Mainz, Germany). Results are expressed as a percentage of anhydrous citric acid equivalent.

2.3. Statistical Analysis

The results were analyzed statistically in the Statistica 12.5 program (StatSoft Polska, Krakow, Poland). The effect of experimental variables, i.e., post-harvest treatment of fruit with 1-MCP (+/− 1-MCP), harvest date (Harvest I and II), storage conditions (NA, ULO, CA), and storage duration on quality parameters of mini kiwi were analyzed using multifactor analysis of variance (ANOVA). A Newman–Keuls test was used to evaluate the significance of differences between the means, accepting the significance level as 5% or 1%. Mean and standard deviation were also reported for all measured parameters.

3. Results

The characteristics of the physicochemical indices of the fruit immediately after harvest of the cultivars 'Geneva' and 'Ananasnaya' are shown in Table 1.

Fruit firmness was statistically affected by all analyzed investigated factors (Supplementary Tables S1 and S2). Analyzing the results of the averages for the entire storage period, it can be concluded that mini kiwi fruit of both cultivars from the first harvest date were significantly firmer than the fruit harvested seven days later (Figures 1 and 2). The relationship was proven after storing the fruit under all storage conditions and independently of the post-harvest treatment with 1-MCP. The effect of technology and the application of 1-MCP on the fruit of both cultivars was as expected. It turned out that fruit stored in NA, irrespective of 1-MCP treatment and harvest time, had lower firmness than mini kiwi stored in CA (with or without 1-MCP), on average, for the storage period.

'Geneva' fruit stored in CA was characterized by higher firmness than those from ULO after four weeks of storage (without 1-MCP) or after 8 (with 1-MCP). A significant effect of 1-MCP application and storage conditions on the firmness of the 'Ananasnaya' fruit was noted in the second week of storage. The 1-MCP-treated fruit were firmer, and this trait was evidenced on each of the analysis dates for fruit stored in NA and ULO. In contrast, differences in firmness between 'Geneva' fruit stored in CA and determined by the application of 1-MCP were proven after six weeks for fruit from the first harvest and eight weeks for fruit from the second harvest (Table 2). For the 'Ananasnaya' fruit, the softening process proceeded slightly faster. The effect of 1-MCP on the firmness of mini kiwi was observed already after two weeks of storage in all technologies except for fruit from the second harvest—after two weeks of storage in CA and after twelve weeks of storage in ULO (Table 3). The application of 1-MCP caused the firmness of the fruit of both cultivars to be almost two times higher at the end of the storage period than that of fruit on which this ethylene inhibitor was not applied. It should be noted that fruit stored in NA without 1-MCP after eight weeks, irrespective of their harvest date, were characterized by very low firmness, which led to the decision to terminate further testing in NA. Fruits of both cultivars harvested on the second harvest date softened significantly faster than those of the first harvest date and attained 'consumable' softness already after approximately six, eight, and twelve weeks of storage in NA, ULO, and CA, respectively. The application of 1-MCP delayed this process, causing the fruit from the second harvest to be perfectly edible even after 12 weeks of storage at CA and ULO. An even stronger effect of 1-MCP was observed with fruit from the first harvest, which were too hard for consumption after twelve weeks at CA and ULO, with the exception of 'Ananasnaya' fruit, which was softer than 'Geneva' after storage under comparable ULO conditions.

Table 1. Characteristics of 'Geneva' and 'Ananasnaya' mini kiwi assessed directly after harvest.

Characteristics	Harvest I	Harvest II
	'Geneva'	
Firmness (N)	38.4	35.0
Soluble solids content (°Brix)	6.9	8.8
Titratable acidity (%)	1.277	1.151
	'Ananasnaya'	
Firmness (N)	53.1	47.8
Soluble solids content (°Brix)	7.1	9.4
Titratable acidity (%)	0.930	0.902

In general, it can be concluded that mini kiwi harvested at the late time had a higher SSC after storage than from the first harvest date, on average, for the storage period (Figures 3 and 4). This relationship was confirmed for the 'Ananasnaya' fruit in all combinations of storage technology and 1-MCP application. On the other hand, 'Geneva' fruits after storage in NA and ULO and treated with 1-MCP were characterized by the same value of the parameter from the second harvest as from the first harvest. Evaluating the effect of storage technology, it was noted that fruits stored in NA (not treated with 1-MCP) were characterized by higher SSC. However, in the case of 'Ananasnaya', the SSC value was similar after storage in NA and ULO (Figure 4). The data obtained in the study indicated that the combinations of 1-MCP treatment and storage conditions used in the experiment slightly modified the average soluble solids content of the fruit, except for the NA condition mentioned earlier. Analysis of the detailed data confirmed the general trends (Tables 4 and 5). For the fruit of both cultivars stored in NA, large differences were noted when comparing the SSC values for fruit from the first and second harvest, showing that higher 'sweetness' was achieved by fruit harvested later, regardless of the application of 1-MCP. This relationship was not confirmed after twelve weeks of storage at ULO and CA. Evaluation of the effect of 1-MCP showed that it was more pronounced in fruit stored in NA. 'Geneva' fruit treated with 1-MCP and stored in NA at all evaluation dates had a lower SSC value than fruit not treated with 1-MCP. Similarly, the 'Ananasnaya' fruit was evaluated only from the first harvest. Statistical analysis showed that only in a few cases of storage in ULO and CA was it possible to confirm the effect of 1-MCP in inhibiting the increase in SSC value in fruit.

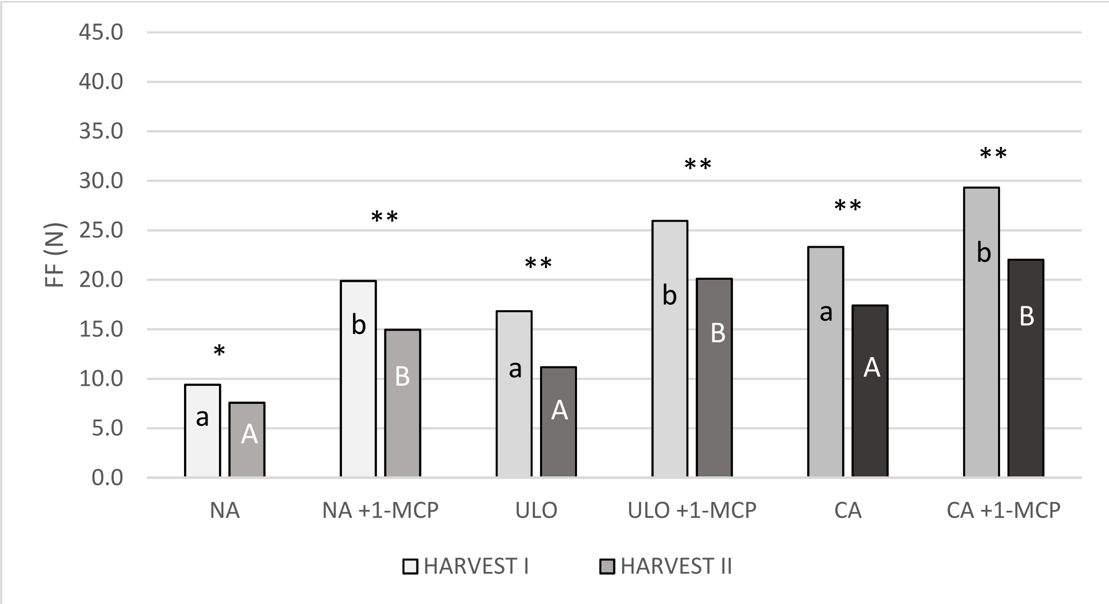

Figure 1. 'Geneva' fruit firmness (FF) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): *—for 5%. **—for 1%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

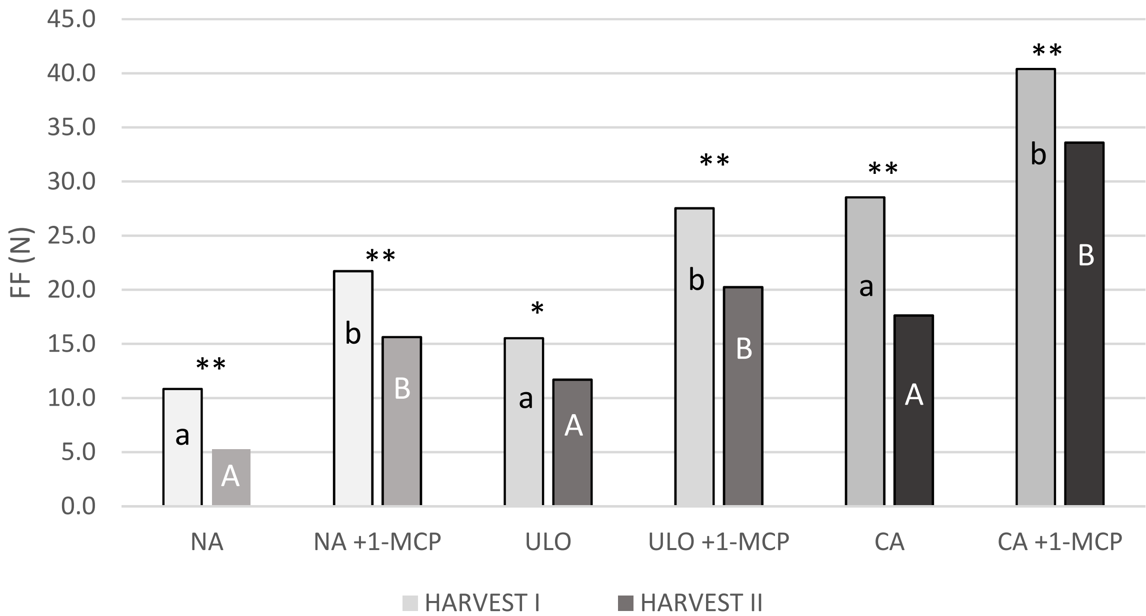

Figure 2. 'Anansnaya' fruit firmness (FF) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): *—for 5%. **—for 1%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

Table 2. Changes of firmness [N] measured in 'Geneva' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						*p*-Value
		2	4	6	8	10	12	
NA								
Harvest I	+1-MCP	29.3 ± 0.18 ^{aA}	25.1 ± 1.13 ^{aB}	16.2 ±.0.99 ^{aB}	8.8 ± 0.79 ^{aB}	-	-	<0.01
	−1-MCP	16.8 ± 0.86 ^{aA}	12.0 ± 0.54 ^{aA}	6.0 ± 0.37 ^{aA}	2.6 ± 0.24 ^{aA}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
Harvest II	+1-MCP	25.9 ± 0.95 ^{aA}	20.1 ± 1.45 ^{aA}	8.6 ± 1.32 ^{aA}	5.1.± 0.18 ^{aA}	-	-	<0.01
	−1-MCP	15.2 ± 1.03 ^{aA}	9.1 ± 0.21 ^{aA}	3.8 ± 0.55 ^{aA}	2.1 ± 0.56 ^{aA}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
ULO								
Harvest I	+1-MCP	36.1 ± 1.73 ^{bA}	33.8 ± 2.49 ^{bA}	34.1 ± 2.00 ^{bB}	22 5 ±.1.80 ^{bB}	16.3 ± 0.99 ^{aB}	12.6 ± 1.35 ^{aB}	<0.01
	−1-MCP	33.5 ± 1.73 ^{bA}	26.4 ± 0.81 ^{bB}	19.0 ± 1.08 ^{bB}	9.7 ± 1.05 ^{bB}	5.8 ± 0.57 ^{aA}	6.3 ± 1.02 ^{aA}	<0.01
	p-value	0.127	<0.01	<0.01	<0.01	<0.01	<0.01	
Harvest II	+1-MCP	35.1 ± 0.77 ^{bA}	33.3 ± 0.79 ^{bA}	21.7 ± 1.05 ^{bA}	16.3 ± 0.79 ^{bA}	8.5 ± 1.02 ^{aA}	5.6 ± 0.81 ^{aA}	<0.01
	−1-MCP	30.5 ± 2.06 ^{bA}	18.2 ± 0.42 ^{bA}	7.6 ± 1.10 ^{aA}	4.2 ± 1.12 ^{aA}	3.0 ± 0.13 ^{aA}	3.3 ± 0.48 ^{aA}	<0.01
	p-value	0.023	<0.01	<0.01	<0.01	<0.01	0.014	
CA								
Harvest I	+1-MCP	34.8 ± 2.20 ^{bA}	34.6 ± 1.65 ^{bA}	35.6 ± 2.44 ^{bB}	27.6 ± 1.65 ^{cB}	24.4 ± 0.36 ^{bB}	18.6 ± 1.31 ^{bB}	<0.01
	−1-MCP	36.8 ± 1.47 ^{bB}	33.8 ± 1.98 ^{cA}	29.6 ± 2.20 ^{cB}	16.7 ± 1.36 ^{cB}	13.6 ± 1.61 ^{bB}	9.2 ± 0.74 ^{aA}	<0.01
	p-value	0.269	0.638	0.034	<0.01	<0.01	<0.01	
Harvest II	+1-MCP	35.0 ± 1.03 ^{bA}	33.5 ± 1.00 ^{bA}	20.9 ± 0.83 ^{bA}	18.1 ± 1.61 ^{bA}	15.2 ± 1.01 ^{bA}	9.2 ± 0.64 ^{bA}	<0.01
	−1-MCP	31.6 ± 4.35 ^{bA}	30.0 ± 3.20 ^{cA}	18.2 ± 3.42 ^{cA}	11.3 ± 0.71 ^{cA}	7.6 ± 1.32 ^{bA}	5.6 ± 0.59 ^{aA}	<0.01
	p-value	0.26	0.14	0.25	<0.01	<0.01	<0.01	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation; different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

Table 3. Changes of firmness [N] measured in 'Ananasnaya' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						*p*-Value
		2	4	6	8	10	12	
NA								
Harvest I	+1-MCP	36.4 ± 1.72 ^{aB}	24.6 ± 0.85 ^{aB}	14.7 ± 0.32 ^{aB}	11.0 ± 0.44 ^{aB}	-	-	<0.01
	−1-MCP	19.1 ± 0.93 ^{aB}	12.9 ± 0.41 ^{aB}	8.1 ± 0.30 ^{aB}	3.0 ± 0.21 ^{aA}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
Harvest II	+1-MCP	32.6 ± 1.54 ^{aA}	15.7 ± 0.46 ^{aA}	7.7 ± 0.96 ^{aA}	6.3 ± 0.69 ^{aA}	-	-	<0.01
	−1-MCP	11.6 ± 0.88 ^{aA}	4.1 ± 0.07 ^{aA}	2.8 ± 0.27 ^{aA}	2.3 ± 0.19 ^{aA}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
ULO								
Harvest I	+1-MCP	47.9 ± 1.60 ^{bA}	35.6 ± 1.03 ^{bA}	30.3 ± 0.42 ^{bB}	25.1 ± 1.47 ^{bB}	16.6 ± 0.96 ^{aB}	9.3 ± 0.10 ^{aB}	<0.01
	−1-MCP	38.3 ± 1.85 ^{bB}	25.9 ± 0.81 ^{bB}	16.3 ± 0.61 ^{bB}	6.0 ± 0.42 ^{bA}	4.0 ± 0.31 ^{aA}	2.3 ± 0.16 ^{aA}	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	
Harvest II	+1-MCP	45.4 ± 2.78 ^{bA}	33.6 ± 3.66 ^{bA}	18.5 ± 1.69 ^{bA}	14.0 ± 1.19 ^{bA}	6.2 ± 0.61 ^{aA}	3.5 ± 0.86 ^{aA}	<0.01
	−1-MCP	35.0 ± 2.65 ^{bA}	12.4 ± 0.22 ^{bA}	8.5 ± 0.80 ^{bA}	7.1 ± 0.58 ^{bA}	4.4 ± 0.35 ^{aA}	2.5 ± 0.93 ^{aA}	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01	0.011	0.059	
CA								
Harvest I	+1-MCP	52.9 ± 4.56 ^{cB}	47.3 ± 2.00 ^{cB}	42.6 ± 2.23 ^{cB}	38.3 ± 2.31 ^{cB}	34.7 ± 1.16 ^{bB}	26.3 ± 0.94 ^{bB}	<0.01
	−1-MCP	49.0 ± 3.51 ^{cB}	33.1 ± 2.81 ^{cB}	27.9 ± 0.75 ^{cB}	27.1 ± 0.93 ^{cB}	19.6 ± 1.22 ^{bB}	14.2 ± 1.06 ^{bB}	<0.01
	p-value	0.082	<0.01	<0.01	<0.01	<0.01	<0.01	
Harvest II	+1-MCP	47.0 ± 5.65 ^{bA}	43.2 ± 5.05 ^{cA}	40.0 ± 3.39 ^{cA}	35.0 ± 4.30 ^{cA}	21.6 ± 3.05 ^{bA}	14.5 ± 1.67 ^{bA}	<0.01
	−1-MCP	43.3 ± 4.97 ^{cA}	25.2 ± 3.20 ^{cA}	14.7 ± 2.29 ^{cA}	11.8 ± 1.61 ^{cA}	6.6 ± 0.52 ^{bA}	3.8 ± 0.88 ^{aA}	<0.01
	p-value	0.125	<0.01	<0.01	<0.01	<0.01	<0.01	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation; different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

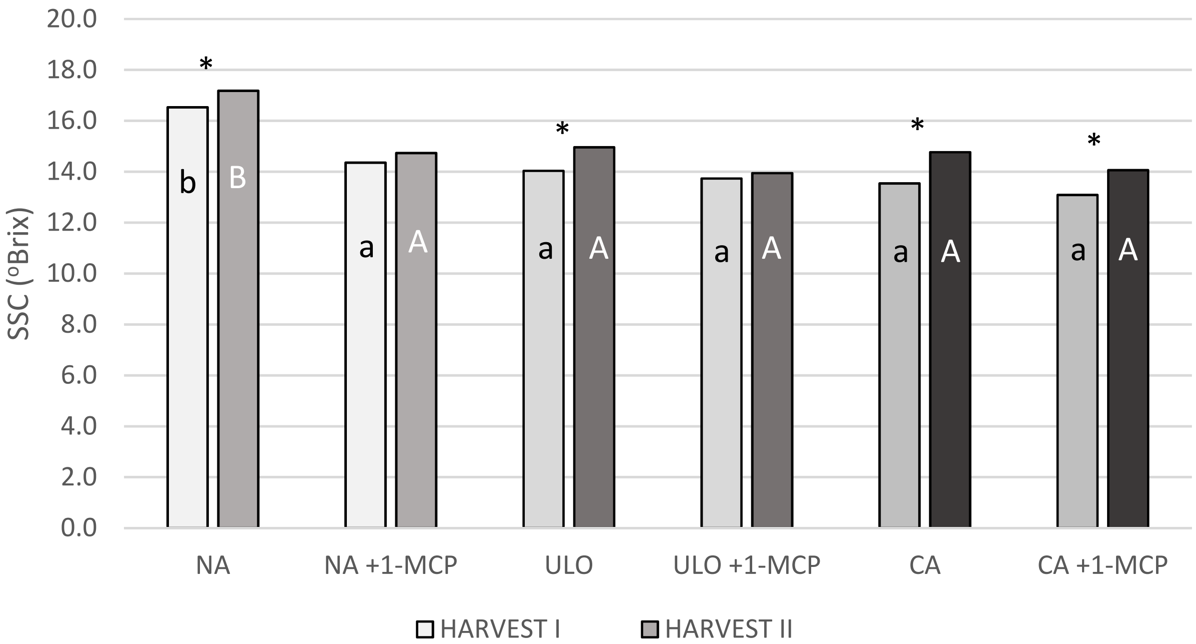

Figure 3. Soluble solids content of 'Geneva' fruit (°Brix) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): *—for 5%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

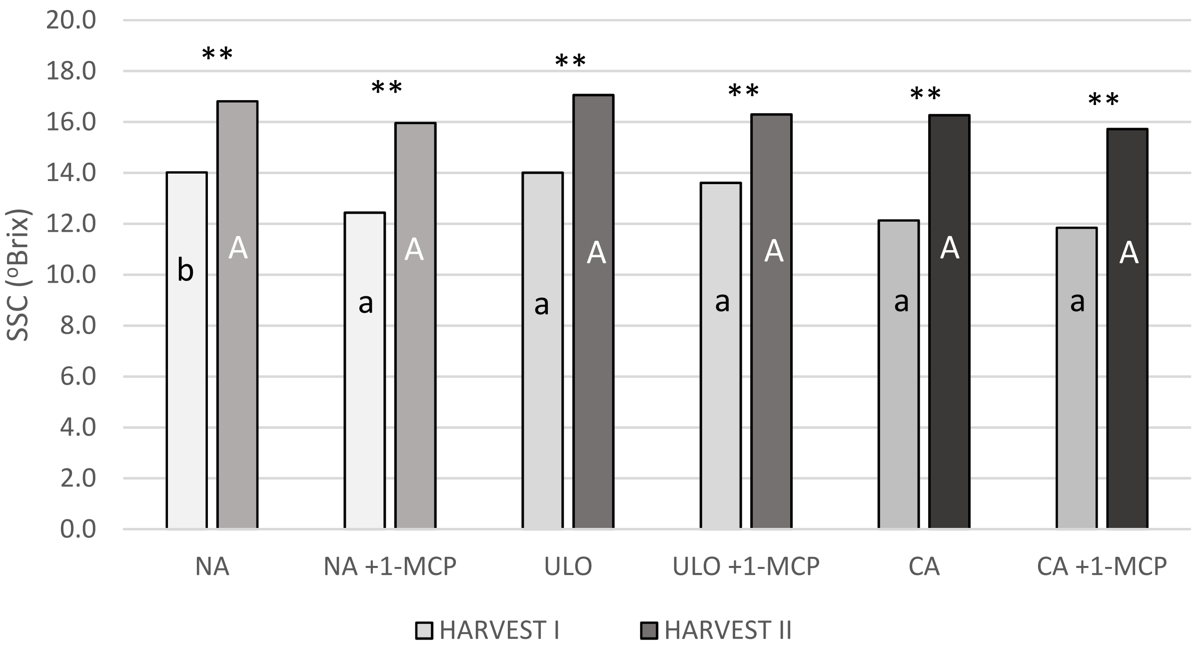

Figure 4. Soluble solids content of 'Ananasnaya' fruit (°Brix) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): **—for 1%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

Table 4. Changes of solids soluble content (°Brix) measured in 'Geneva' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						p-Value
		2	4	6	8	10	12	
NA								
Harvest I	+1-MCP	12.3 ± 0.2 ^{bB}	13.3 ± 0.2 ^{bA}	15.6 ± 0.2 ^{bA}	16.2 ± 0.4 ^{bA}	-	-	<0.01
	−1-MCP	13.9 ± 0.3 ^{bA}	15.5 ± 0.2 ^{bA}	17.9 ± 0.2 ^{bA}	18.7 ± 0.2 ^{bA}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
Harvest II	+1-MCP	11,1 ± 0.5 ^{aA}	13.9 ± 0.2 ^{bA}	16.3 ± 0.1 ^{bA}	17.6 ± 0.4 ^{bB}	-	-	<0.01
	−1-MCP	13.8 ± 0.2 ^{bA}	16.5 ± 0.2 ^{bB}	18.3 ± 0.2 ^{cA}	20.1 ± 0.4 ^{cB}	-	-	<0.01
	p-value	<0.01	<0.01	<0.01	<0.01			
ULO								
Harvest I	+1-MCP	10.9 ± 0.3 ^{aA}	12.8 ± 0.1 ^{bA}	13.9 ± 0.2 ^{aA}	14.3 ± 0.3 ^{aA}	15.0 ± 0.3 ^{aA}	15.7 ± 0.5 ^{bA}	<0.01
	−1-MCP	11.6 ± 0.2 ^{bA}	12.5 ± 0.4 ^{aA}	14.2 ± 0.4 ^{aA}	14.8 ± 0.6 ^{aA}	15.8 ± 0.2 ^{bA}	15.3 ± 0.5 ^{aA}	<0.01
	p-value	0.028	0.232	0.238	0.372	0.01	0.363	
Harvest II	+1-MCP	11.2 ± 0.2 ^{aA}	12.6 ± 0.1 ^{aA}	13.9 ± 0.1 ^{aA}	15.9 ± 0.7 ^{aB}	14.8 ± 0.4 ^{aA}	15.2 ± 0.7 ^{aA}	<0.01
	−1-MCP	11.5 ± 0.1 ^{aA}	12.5 ± 0.2 ^{aA}	15.2 ± 0.1 ^{bB}	16.6 ± 0.4 ^{bB}	17.2 ± 0.6 ^{aB}	16.8 ± 0.2 ^{aB}	<0.01
	p-value	0.057	0.274	<0.01	0.18	<0.01	0.024	
CA								
Harvest I	+1-MCP	10.5 ± 0.4 ^{aA}	11.3 ±.0.4 ^{aA}	13.3 ± 0.3 ^{aA}	14.4 ± 0.2 ^{aA}	14.4 ± 0.5 ^{aA}	14.6 ± 0.4 ^{aA}	<0.01
	−1-MCP	10.7 ± 0.2 ^{aA}	11.8 ± 0.1 ^{aA}	14.2 ± 0.2 ^{aA}	14.6 ± 0.2 ^{aA}	14.4 ± 0.3 ^{aA}	15.5 ± 0.5 ^{aA}	<0.01
	p-value	0.431	0.104	0.016	0.315	0.917	0.087	
Harvest II	+1-MCP	12.0 ± 0.2 ^{bB}	12.6 ± 0.7 ^{aB}	13.9 ± 0.4 ^{aA}	15.1 ± 0.3 ^{aA}	15.2 ± 0.5 ^{aA}	15.6 ± 0.4 ^{aB}	<0.01
	−1-MCP	12.1 ± 1.0 ^{aB}	12.9 ± 0.4 ^{aB}	14.4 ± 0.2 ^{aA}	15.3 ± 0.3 ^{aA}	17.7 ± 0.8 ^{aB}	16.2 ± 0.2 ^{aA}	<0.01
	p-value	0.83	0.53	0.086	0.56	<0.01	0.102	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation; different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

This study showed a significant interaction between titratable acidity and investigated factors (Supplementary Tables S1 and S2). The titratable acidity of both mini kiwi cultivars depended on the time of fruit harvest. Definitely, more TA acidity was contained in fruits harvested at the harvest maturity stage, especially 'Geneva' (Figure 5). 'Ananasnaya' mini kiwi were characterized by lower acidity and, at the same time, the effect of the harvest time of the fruit of this cultivar on the indicator in question was smaller (Figure 6). After storage in NA, 'Ananasnaya' fruits from the first harvest were characterized by higher acidity than those from the second harvest. However, after storage in CA and additional treatment of fruit with 1-MCP, there was no effect of harvest date on fruit acidity. The experiment showed that the application of 1-MCP to mini kiwi fruit after harvest reduces the loss of acidity, but this process depends on the storage technology (Tables 6 and 7). Fruits treated with 1-MCP, from both harvests and cultivars, stored in NA were characterized by higher acidity than untreated 1-MCP, which was observed in 'Geneva' fruit after six and eight weeks of storage, and in 'Ananasnaya' fruit at almost every evaluation date. There was no effect of 1-MCP on the titratable acidity of mini kiwi stored in ULO and CA. Only a higher acidity of 'Geneva' fruit from the first harvest after ten and twelve weeks of storage in CA was noted, and a similar effect of 1-MCP on 'Ananasnaya' fruit from the second harvest also after ten and twelve weeks of storage in CA.

Table 5. Changes of solids soluble content (°Brix) measured in 'Ananasnaya' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						*p*-Value
		2	4	6	8	10	12	
				NA				
Harvest I	+1-MCP	10.3 ± 0.3 ^{bA}	11.6 ± 0.3 ^{bA}	13.3 ± 0.6 ^{bA}	14.5 ± 0.3 ^{bA}	-	-	<0.01
	−1-MCP	12.1 ± 0.2 ^{bA}	13.0 ± 0.1 ^{bA}	14.8 ± 0.2 ^{cA}	16.2 ± 0.3 ^{cA}	-	-	<0.01
	p-value	<0.01	<0.01	0.014	<0.01			
Harvest II	+1-MCP	13.3 ± 0.3 ^{bB}	15.2 ± 0.3 ^{bB}	17.4 ± 0.1 ^{bB}	18.0 ± 1.3 ^{bB}	-	-	<0.01
	−1-MCP	13.6 ± 0.3 ^{bB}	16.4 ± 0.4 ^{bB}	17.9 ± 0.2 ^{bB}	19.4 ± 0.3 ^{bB}	-	-	<0.01
	p-value	0.207	0.014	0.013	0.156			
				ULO				
Harvest I	+1-MCP	9.6 ± 0.2 ^{abA}	10.9 ± 0.1 ^{bA}	12.7 ± 0.1 ^{bA}	14.1 ± 0.3 ^{bA}	17.1 ± 0.3 ^{bA}	17.3 ± 0.3 ^{bA}	<0.01
	−1-MCP	9.6 ± 0.1 ^{aA}	11.8 ± 0.6 ^{bA}	13.4 ± 0.8 ^{bA}	14.7 ± 0.2 ^{bA}	16.9 ± 0.4 ^{bA}	17.7 ± 0.3 ^{bA}	<0.01
	p-value	0.815	0.07	0.207	0.048	0.414	0.163	
Harvest II	+1-MCP	12.8 ± 0.4 ^{abB}	14.6 ± 0.6 ^{abB}	17.0 ± 0.1 ^{bB}	16.5 ± 1.5 ^{aB}	18.4 ± 0.2 ^{aB}	18.5 ± 0.1 ^{aB}	<0.01
	−1-MCP	13.5 ± 0.5 ^{bB}	16.5 ± 0.3 ^{bB}	17.3 ± 0.1 ^{bB}	18.4 ± 0.3 ^{aB}	18.5 ± 0.1 ^{aB}	18.2 ± 0.3 ^{aA}	<0.01
	p-value	0.123	<0.01	<0.01	0.276	0.374	0.07	
				CA				
Harvest I	+1-MCP	9.3 ± 0.4 ^{aA}	9.6 ± 0.2 ^{aA}	10.6 ±0.3 ^{aA}	11.6 ± 0.1 ^{aA}	15.1 ± 0.4 ^{aA}	14.8 ± 1.3 ^{aA}	<0.01
	−1-MCP	9.1 ± 0.4 ^{aA}	9.4 ± 0.1 ^{aA}	10.8 ± 0.3 ^{aA}	11.7 ± 0.6 ^{aA}	15.7 ± 0.6 ^{aA}	16.2 ± 0.6 ^{aA}	<0.01
	p-value	0.573	0.148	0.547	0.802	0.225	0.187	
Harvest II	+1-MCP	12.1 ± 0.2 ^{aB}	13.8 ± 0.4 ^{aB}	15.5 ± 0.1 ^{aB}	17.2 ± 0.1 ^{abB}	17.5 ± 0.6 ^{aB}	18.3 ± 0.1 ^{aB}	<0.01
	−1-MCP	11.9 ± 0.1 ^{aB}	14.1 ± 0.5 ^{aB}	16.1 ± 0.3 ^{aB}	17.8 ± 0.5 ^{aB}	18.7 ± 0.6 ^{aB}	18.9 ± 0.4 ^{aB}	<0.01
	p-value	0.345	0.370	0.045	0.076	0.065	0.069	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation; different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

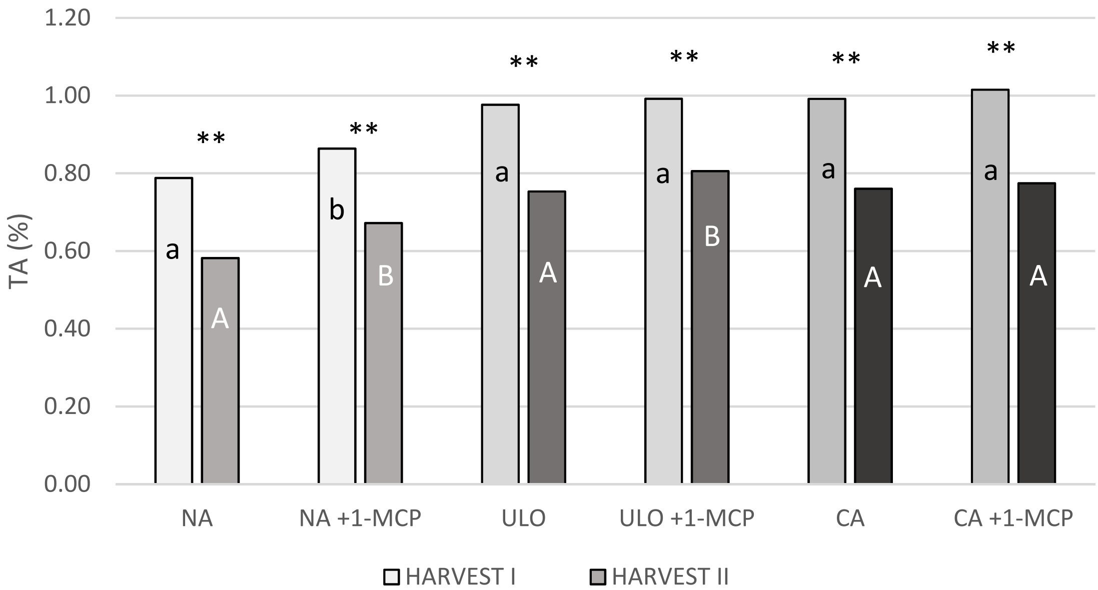

Figure 5. Titratable acidity of 'Geneva' fruit (%) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): **—for 1%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

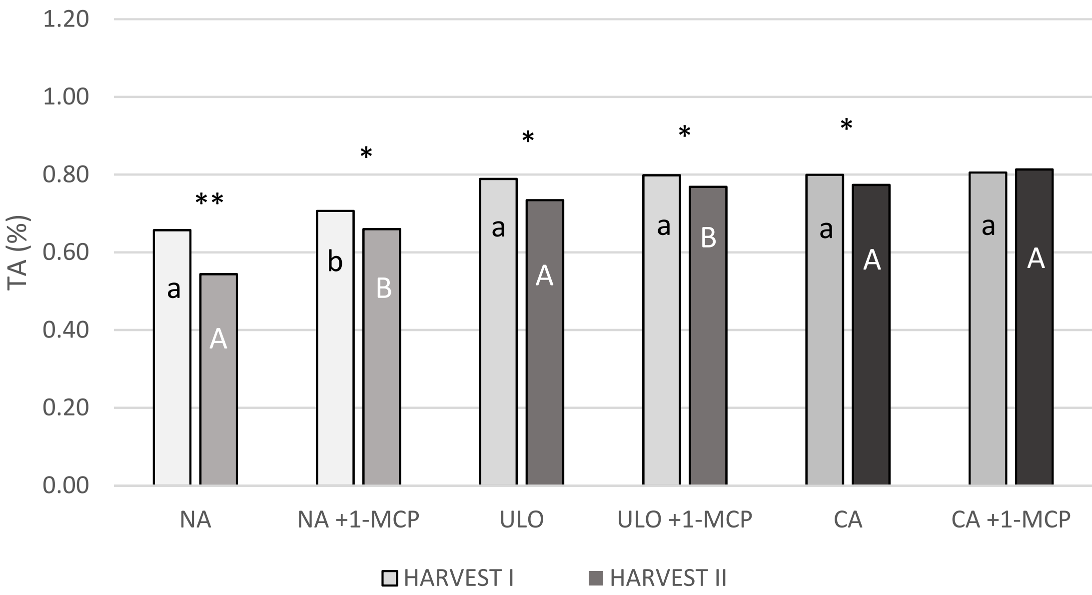

Figure 6. Titratable acidity of 'Ananasnaya' fruit (%) depending on harvest time and 1-MCP treatment under three storage technologies. Statistically significant difference between first and second harvest fruit (Newman–Keuls range test): *—for 5%. **—for 1%. Different letters were assigned to statistically significant differences when comparing the effect of 1-MCP, separately for storage conditions.

Table 6. Changes of titratable acidity (%) measured in 'Geneva' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						*p*-Value
		2	4	6	8	10	12	
NA								
Harvest I	+1-MCP	0.966 ± 0.02 ^{aB}	0.858 ± 0,01 ^{aB}	0.852 ± 0.01 ^{aB}	0.781 ± 0.01 ^{aB}	-	-	<0.01
	−1-MCP	0.949 ± 0.01 ^{aB}	0.877 ± 0.02 ^{aB}	0.714 ± 0.02 ^{aB}	0.611 ± 0.02 ^{aB}	-	-	<0.01
	p-value	0.187	0.242	<0.01	<0.01			
Harvest II	+1-MCP	0.761 ± 0.02 ^{aA}	0.720 ± 0.02 ^{aA}	0.611 ± 0.01 ^{aA}	0.596 ± 0.01 ^{aA}	-	-	<0.01
	−1-MCP	0.741 ± 0.01 ^{aA}	0.659 ± 0.05 ^{aA}	0.491 ± 0.03 ^{aA}	0.435 ± 0.03 ^{aA}	-	-	<0.01
	p-value	0.207	0.11	<0.01	<0.01			
ULO								
Harvest I	+1-MCP	1.167 ± 0.03 ^{bB}	1.087 ± 0.01 ^{bB}	1.041 ± 0.03 ^{bB}	0.917 ± 0.03 ^{bA}	0.919 ± 0.01 ^{aB}	0.820 ± 0.01 ^{aB}	<0.01
	−1-MCP	1.241 ± 0.01 ^{bB}	1.066 ± 0.04 ^{bB}	1.008 ± 0.01 ^{bB}	0.881 ± 0.02 ^{bB}	0.867 ± 0.02 ^{aB}	0.796 ± 0.04 ^{aB}	<0.01
	p-value	<0.01	0.393	0.108	0.154	0.029	0.331	
Harvest II	+1-MCP	0.929 ± 0.01 ^{bA}	0.934 ± 0.03 ^{bA}	0.817 ± 0.02 ^{bA}	0.812 ±0.02 ^{bA}	0.657 ± 0.06 ^{aA}	0.685 ± 0.03 ^{bA}	<0.01
	−1-MCP	0.947 ± 0.01 ^{bA}	0.924 ± 0.03 ^{bA}	0.782 ± 0.01 ^{bA}	0.713 ± 0.07 ^{bA}	0.582 ± 0.08 ^{aA}	0.573 ± 0.03 ^{aA}	<0.01
	p-value	0.029	0.67	0.038	0.088	0.26	0.013	
CA								
Harvest I	+1-MCP	1.205 ± 0.03 ^{bB}	1.120 ± 0.01 ^{bB}	1.045 ± 0.01 ^{bB}	0.936 ± 0.01 ^{bB}	0.921 ± 0.01 ^{aB}	0.866 ± 0.02 ^{aB}	<0.01
	−1-MCP	1.184 ± 0.02 ^{bB}	1.069 ± 0.03 ^{bB}	1.042 ± 0.03 ^{bB}	1.013 ± 0.04 ^{bB}	0.847 ± 0.04 ^{aB}	0.793 ± 0.01 ^{aB}	<0.01
	p-value	0.428	0,07	0.807	0.026	0.032	<0.01	
Harvest II	+1-MCP	0.915 ± 0.04 ^{bA}	0.897 ± 0.02 ^{bA}	0.827 ± 0.02 ^{bA}	0.742 ± 0.03 ^{bA}	0.663 ± 0.04 ^{aA}	0.602 ± 0.01 ^{aA}	<0.01
	−1-MCP	0.943 ± 0.03 ^{bA}	0.933 ± 0.01 ^{bA}	0.820 ± 0.02 ^{bA}	0.711 ± 0.05 ^{bA}	0.596 ± 0.02 ^{aA}	0.560 ± 0.07 ^{aA}	<0.01
	p-value	0.39	0.054	0.706	0.396	0.062	0.377	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation; different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

Table 7. Changes of titratable acidity (%) measured in 'Ananasnaya' mini kiwi fruit in the post-harvest period.

Harvest Time	Post-Harvest Treatment	Time of Storage (Weeks)						*p*-Value
		2	4	6	8	10	12	
NA								
Harvest I	+1-MCP	0.785 ± 0.01 ^{aA}	0.726 ± 0.02 ^{aA}	0.671 ± 0.02 ^{aA}	0.644 ± 0.02 ^{aB}	-	-	<0.01
	−1-MCP	0.743 ± 0.02 ^{aA}	0.697 ± 0.03 ^{aB}	0.618 ± 0.02 ^{aB}	0.569 ± 0.03 ^{aB}	-	-	<0.01
	p-value	0.017	0.261	0.021	0.023			
Harvest II	+1-MCP	0.751 ± 0.01 ^{aA}	0.726 ± 0.02 ^{aA}	0.617 ± 0.03 ^{aA}	0.545 ± 0.01 ^{aA}	-	-	<0.01
	−1-MCP	0.756 ± 0.02 ^{aA}	0.564 ± 0.03 ^{aA}	0.441 ± 0.02 ^{aA}	0.415 ± 0.01 ^{aA}	-	-	<0.01
	p-value	0.609	<0.01	<0.01	<0.01			
ULO								
Harvest I	+1-MCP	0.903 ± 0.03 ^{bA}	0.889 ± 0.03 ^{bA}	0.842 ± 0.05 ^{bA}	0.807 ± 0.04 ^{bA}	0.695 ± 0.03 ^{aA}	0.654 ± 0.05 ^{aA}	<0.01
	−1-MCP	0.878 ± 0.03 ^{bA}	0.856 ± 0.05 ^{bA}	0.794 ± 0.04 ^{bA}	0.757 ± 0.05 ^{bA}	0.718 ± 0.01 ^{aA}	0.730 ± 0.02 ^{aB}	<0.,01
	p-value	0.373	0.418	0.273	0.230	0.069	<0.01	
Harvest II	+1-MCP	0.870 ± 0.06 ^{bA}	0.829 ± 0.01 ^{bA}	0.826 ± 0.01 ^{bA}	0.754 ± 0.02 ^{bA}	0.695 ± 0.02 ^{aA}	0.636 ± 0.02 ^{aA}	<0.01
	−1-MCP	0.881 ± 0.03 ^{bA}	0.794 ± 0.02 ^{bA}	0.819 ± 0.02 ^{bA}	0.694 ± 0.06 ^{bA}	0.651 ± 0.05 ^{aA}	0.568 ± 0.01 ^{aA}	<0.01
	p-value	0.794	0.036	0.637	0.185	0.209	0.012	
CA								
Harvest I	+1-MCP	0.873 ± 0.01 ^{aA}	0.852 ± 0.06 ^{bA}	0.854 ± 0.06 ^{bA}	0.762 ± 0.03 ^{bA}	0.755 ± 0.02 ^{aA}	0.736 ± 0.06 ^{aA}	<0.01
	−1-MCP	0.879 ± 0.05 ^{bA}	0.842 ± 0.09 ^{bA}	0.812 ± 0.05 ^{bA}	0.749 ± 0.04 ^{bA}	0.765 ± 0.02 ^{aB}	0.750 ± 0.01 ^{aA}	0.05
	p-value	0.85	0.879	0.303	0.594	0.729	0.786	
Harvest II	+1-MCP	0.864 ± 0.01 ^{bA}	0.840 ± 0.05 ^{bA}	0.795 ± 0.02 ^{bA}	0.814 ± 0.03 ^{bA}	0.785 ± 0.04 ^{bA}	0.782 ± 0.04 ^{bA}	0.08
	−1-MCP	0.865 ± 0.02 ^{bA}	0.841 ± 0.04 ^{bA}	0.814 ± 0.03 ^{bA}	0.773 ± 0.01 ^{bA}	0.671 ± 0.02 ^{aA}	0.676 ± 0.02 ^{bA}	<0.01
	p-value	0.915	0.97	0.465	0.099	0.013	0.015	

Harvest I—first harvest of fruit; Harvest II—second harvest of fruit; NA—normal atmosphere cold store; ULO—ultra low oxygen (1.5% CO_2:1.5% O_2); CA—controlled atmosphere (5% CO_2:1.5% O_2); +1-MCP—with 1-methylcyclopropene; −1-MCP—without 1-methylcyclopropene; ±—standard deviation, different superscript letters are assigned to statistically significant differences when comparing (lower case): storage conditions with or without 1-MCP treatment, (upper case) harvest time with or without 1-MCP treatment (separately for storage conditions).

4. Discussion

The mini kiwi fruit is harvested at harvest maturity and is not suitable for consumption, and the ripening process takes place in cold storage. The main reason for the loss of consumer acceptability is that the fruit softens too quickly [24]. Activation of the enzymes exo-polygalacturonase, endo-polygalacturonase, pectin esterase, and endo-1,4β-D-glucanase by ethylene is activated even at very low concentrations of this gas [25]. Inhibition of ethylene synthesis from ACC (1-aminocyclopropane-1-carboxylic acid) is possible under refrigerated conditions by reducing air temperature [13], oxygen concentration, or increasing carbon dioxide levels [20]. Previous studies [23] indicate that low-temperature storage (0–1 °C) is not sufficiently effective in maintaining the high quality of mini kiwi fruit, and new technologies are still being sought to efficiently inhibit respiration processes in the fruit and loss of quality during the post-harvest life of the fruit. However, the methods used to date, such as post-harvest of oxalic acid, salicylic acid and acetylsalicylic acid, calcium chloride treatment [42], the use of atmosphere-modifying packaging technologies [27,28], ozone [22] or dynamically controlled atmosphere technologies [26] are not as effective. An interesting ethylene inhibitor is 1-methylcyclopropene. This synthetic homolog of ethylene binds to ethylene receptors. The effect of this binding is to deactivate the enzymes responsible for the ripening of fruit and vegetables. The effect is to extend the shelf life of the products with almost unchanged quality parameters. This product is commonly used in the distribution of apples, pears, kiwis, avocados, and other fruits [34–36]. The use of 1-MCP in mini kiwi storage has been the subject of research in recent years, and the results so far are promising [28–30]. Our experiment focused on the effectiveness of using 1-MCP in combination with different storage technologies to determine the effectiveness of such treatments in reducing softening and loss of quality of hardy kiwi fruit. The effect of the application of 1-MCP on the fruit of both cultivars evaluated was as expected. It turned out that fruit stored in NA had the lowest firmness, while mini kiwi treated with 1-MCP and stored in CA had the highest firmness. The use of different storage technologies in the experiment showed the variable effect of the interaction between 1-MCP and the composition of the cold store atmosphere. Fruit not treated with 1-MCP and stored in ULO were characterized by lower firmness than fruit after storage in NA but treated with 1-MCP. A similar relationship of the effect of 1-MCP was observed between fruit stored in ULO +1-MCP and fruit stored in CA but not treated with 1-MCP.

It was also shown that differences in the firmness of fruit stored in CA determined by the application of 1-MCP were only proven after six weeks for fruit from the first harvest and after eight weeks for fruit from the second harvest. This was due to a faster softening of fruit from the second harvest, irrespective of the post-harvest treatment with 1-MCP. This thesis is supported by the data obtained after storage in NA and ULO, in which the fruit softened much faster and the effect of 1-MCP became apparent after only two weeks of storage. This means that high CO_2 concentrations also have a strong effect on reducing the loss of firmness of the fruit, as previously reported by Paulauskienė et al. [21], and Krupa et al. [20]. The results indicate that the inhibitory effect of CO_2 on firmness is limited to about 8–10 weeks; longer storage of fruit requires the use of 1-MCP. The results of our own research indicate that fruit treated post-harvest with 1-MCP and stored under higher CO_2 conditions can be successfully stored for a period of twelve weeks, and if harvested at harvest maturity (6–7 °Brix), this period can probably be extended. On a positive note, mini kiwi harvested even at a late time retained high firmness for 12 weeks of storage in CA (5% CO_2).

Soluble solids content and titratable acidity, and the ratio between the parameters are often referred to as distinguishing instrumental factors of fruit quality. There is a lack of information in the literature on the effect of post-harvest treatment with 1-MCP on SSC content or TA of mini kiwi fruit. Many authors emphasize that the SSC increases in the fruit of different species independently of the application of 1-MCP [26,34,35]. In our study, the effect of 1-MCP on the extract content of fruit stored under conventional cold storage conditions was reported. Statistical analysis showed that only in a few cases of storage in ULO and CA was it possible to confirm the effect of 1-MCP in inhibiting the increase in SSC value in fruit. On the other hand, higher fruit 'sweetness' was favored by delaying fruit harvest. When evaluating the effect of storage technology, it was noted that fruit stored in NA had a higher SSC content and that even after twelve weeks of mini kiwi storage under ULO or CA conditions, fruit may not reach as high a soluble solids content as after storage in NA. The results of this study confirm previous information that lower SSC will be observed in fruit stored in cold storage with reduced O_2 concentration and increased CO_2 levels [10,14,24]. The main determinant of fruit acidity in our study was the time of fruit harvest. Fruit harvested at harvest maturity, especially of the cultivar 'Geneva', contained significantly more acid. Assessing the overall effect of 1-MCP on the parameter, it was found that fruit treated with this inhibitor were characterized by higher titratable acidity than untreated fruit. This relationship was more pronounced after storing the fruit in NA than in ULO or CA. In addition, in studies conducted on other species, fruit treated after harvest with 1-MCP were found to have a higher acid content [35,36]. As with SSC, the rate of TA reduction in the fruit depended on the conditions in the cold store. After eight weeks of storage in NA, fruit contained less acidity than after 12 weeks of storage under ULO or CA conditions, which is consistent with previous studies on the effect of storage conditions on the physicochemical quality of mini kiwi fruit [10,14,24].

5. Conclusions

Post-harvest treatments, the date of harvest, as well as the conditions under which the fruit is stored determine its quality after storage. Initiated ethylene production in fruit from a delayed harvest (harvest II) is a determinant of the rapid ripening of mini kiwi. Lowering the temperature in cold storage is ineffective in slowing this process. The application of 1-MCP decisively inhibits the softening of mini kiwi, but its effectiveness depends on the maturity of the fruit at the time of application. The effectiveness of the 1-MCP application is lower for fruit with more advanced ripening processes—from a delayed harvest. An effective inhibitor of fruit softening is CO_2, which in high concentrations, inhibits ethylene synthesis. The synergistic effect of 1-MCP and controlled atmosphere conditions (CA) has a positive effect on maintaining the high firmness of mini kiwi fruit. Storage of fruit post-harvest treated with 1-MCP under controlled atmosphere conditions with higher CO_2 content gives satisfactory results even for storing fruit from a delayed harvest. The effect of 1-MCP on the soluble solids content and acidity of mini kiwi fruit is insignificant and noted mainly under normal atmospheric conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture12122062/s1, Table S1. The multifactor analysis of variance (ANOVA) of firmness, soluble solids content (SSC), and titratable acidity (TA) of Ananasnaya fruit; Table S2. The multifactor analysis of variance (ANOVA) of firmness, soluble solids content (SSC), and titratable acidity (TA) of Geneva fruit.

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