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# Effect of storage conditions on storability and antioxidant potential of pears cv. 'Conference'

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**Abstract:** Late pear cultivars, such as 'Conference', can be stored for a long period, with their storability depending on storage conditions. A three-year study (2011-2013) compared the impact of half-year storage using four technologies – normal atmosphere, normal atmosphere + 1-methylcyclopropene (1-MCP), controlled atmosphere, controlled atmosphere + 1-MCP – on the quality parameters of 'Conference' pears, such as mass loss, firmness, total soluble solids, acidity, antioxidant capacity, and the incidence of diseases and disorders. Additionally, the study analysed different storage conditions in terms of profitability, based on the market prices for pears in the seasons during which the pears were stored. The storage conditions had a very strong influence on the fruit quality parameters, and was found to affect most visibly the mass loss and the incidence of postharvest diseases and disorders. The storage of 'Conference' pears for 180 days in normal atmosphere is not economically viable, even if the fruit is subjected to 1-MCP treatment.

**Keywords:** rootstock; 1-MCP; cost-effectiveness of technology, controlled atmosphere, cold storage, ORAC, TSS, acidity, firmness

## 1. Introduction

Pears are the most cultivated pome species in the world after apples [1]. Pear cv. 'Conference' is the most important cultivar in Europe with the yearly production of around 1 million tonnes [2]. It is also one of the most commonly stored cultivars. The storability of pear, which is a typical climacteric species [3], depends on various factors [4], most notably, the optimal harvest date [5], the fruit cooling rate after harvest [6], the degree of pollination [7], storage conditions [8], fertilization and health [9]. Sometimes, however, as in the case of apples, other factors may be in play, such as the rootstock used, which, by affecting the nutrition of trees can influence the properties of the stored fruit [10]. Temperature is a factor that crucially influences the rate of any reaction, in particular, of respiration-related reactions [11]. The optimal fruit storage temperature depends on the species, and sometimes on the cultivar [12]. Pears belong to the few fruits which suffer no damage if stored at a temperature below zero. The optimal temperature is between -1 and 0°C, with a clear preference towards the negative temperature [13]. As early as 1964, Porritt found out that the storage life of 'd'Anjou' and 'Bartlett' pear was, respectively, 35% and 40% greater at -1 °C than at 0 °C [14].

Controlled atmosphere (CA) storage significantly extends the storability of pears compared to the normal atmosphere (NA) storage system [4]. CA storage delays ripening and preserves fruit quality [15], but it may cause a decrease in the production of aromatic compounds [16]. The very low oxygen content (ULO) commonly used for long-term storage of apples cannot be used for pears due to their greater susceptibility to damage due to oxygen deficiency [17]. Low oxygen levels trigger anaerobic respiration resulting

in the accumulation of alcohol in pears, which is directly responsible for damage to the flesh [18]. This can be prevented by the monitoring of changes in the alcoholic respiration in the atmosphere [19]. However, in a controlled atmosphere, it is the internal disorders like internal browning, which are a major limiting factor [20]. Also, high carbon dioxide content may cause internal browning in many cultivars, and 'Conference' pears are considered to be sensitive to high levels of this gas [21].

Another method used in recent years to improve storability is to use substances that limit ethylene production in climacteric fruit [22]. One of such substances is 1-methylcyclopropene (1-MCP), which has been used for nearly two decades [23]. In both NA and CA cold storage, 1-MCP can be applied to maintain the quality attributes of fruit, especially firmness. 1-MCP, a gaseous ethylene binding inhibitor, has proven useful in preventing the formation of ethylene in fruit, thus increasing its shelf life after harvest and enabling greater flexibility in distribution and retailing [24]. However, it has been shown that, unlike in apples, low doses of 1-MCP, do not completely inhibit ethylene production in pears. 1-MCP interacts with fruit in manifold ways. It can limit the development of fungal diseases. It can also reduce the occurrence of superficial scald [25], but it may also cause an unexpected increase in the incidence of this physiological disorder [26].

The objectives of this study was to assess (1) the impact of storage conditions on monthly qualitative changes in 'Conference' pears during six months of storage, (2) the effect of the rootstock on the storability of 'Conference' pears, (3) the impact of 1-MCP applications on the storability of 'Conference' pears and how all these factors translate into revenues from the sale of pears after storage.

## 2. Materials and Methods

The experiment was conducted in the experimental orchard and laboratory of the Department of Pomology of the University of Life Sciences in Poznan (52°31' north latitude and 16°38' east longitude). 'Conference' pears were collected from trees planted in spring 2002 at spacing of 4 × 1.5 m. Pears were grafted on three different rootstocks: *Pyrus caucasica* Federov, Pyrodwarf, and Quince S1. There were 64 trees on each rootstock. The pear orchard was maintained according to the standard commercial practice for integrated fruit production.

### 2.1. Sampling

The experiment was carried out from autumn 2011 to spring 2014. The harvest occurred on dates determined as the optimum harvest dates (OHD), using the starch test [27] and the sum of active temperatures (growing degree units) method proposed by Łysiak [28]. The sum of active temperatures determined according to the latter method was 2580 degrees.

After harvest, pears intended for storage were graded to eliminate those not meeting the highest commercial quality standard applicable in OECD countries [29]. According to those standards, pears of superior quality ('extra'), have to be intact, sound, clean, and free of any damage. The experiment was carried out using 20 boxes of 15 kg of graded pears. Each box contained about 75 pears.

### 2.2. Storage conditions

After harvesting and sorting, the fruit was put in the cold chamber for 48 hours to stabilize the fruit temperature. Then half of the fruit (10 boxes) was inserted into a gas-tight chamber where 1-MCP was applied at a dose of 0.05 gm<sup>-3</sup> for 24 hours. After the application, the fruit was placed in four experimental gas-tight chambers with a capacity of 1m<sup>3</sup> each (5 boxes per each chamber). The following storage conditions were applied:

1. Normal atmosphere (NA), temp. -1°C
2. Normal atmosphere (NA), + 1-MCP, temp. -1°C
3. Controlled atmosphere (CA) 2% O<sub>2</sub> + 1% CO<sub>2</sub>, temp. -1°C
4. Controlled atmosphere (CA) 2% O<sub>2</sub> + 1% CO<sub>2</sub>, + 1-MCP, temp. -1°C

### 2.3. Quality measurements

1. Loss of fruit mass was measured in each stored box. Ten pears were numbered and weighed with an accuracy of 0.1 g before and after each month of storage. The mass loss is shown as a percentage of the initial mass.
2. Firmness was measured using a Fruit Tester 327 EFFEGI FT327 penetrometer (Facchini srl, Alfonsine (Ra), Italy), mounted on stand. The maximum penetration force of a probe of 8 mm in length and 11 mm in diameter, applied to a small area with skin removed, on two opposite sides of the fruit, was recorded.
3. Total soluble solids (TSS) were determined using an ATAGO PAL-1 digital refractometer with automatic temperature compensation (Atago, Tokyo, Japan). The results were shown as an average of nine repetitions per sample and expressed as percentage values.
4. Titrable acidity (TA): titration with 1n NaOH to 8.1 pH, mval 100 mL<sup>-1</sup>; the results were expressed as mmol of malic acid per kg of fresh mass.
5. Starch pattern during harvest was determined with Lugol's iodine (measured according to a 10-point scale where 10 means no starch on the pear cross section) [30].
6. The Streif index is a combination of firmness (F), soluble solids content (R) and starch index (S) according the formula:

$$\text{Index} = F/RS$$

### 2.4. Measurement of Antioxidant Capacity

Antioxidant capacity of methanol extracts was determined by means of spectrophotometric method using a cationic radical (ABTS+) [2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)] [31]. The ABTS+ cation was generated by mixing 7 mM ABTS and 2.45 mM K<sub>2</sub>S<sub>2</sub>O<sub>8</sub> (potassium persulfate or potassium peroxydisulfate) solutions at a ratio of 1:0.5. The ABTS+ cationic radical solution and methanol extract samples were diluted using Phosphate Buffer Solution (PBS) pH 7.4. Absorbance was measured at a wavelength of 734 nm on samples incubated for 6 min at 30°C against PBS as a reference assay. Antioxidant capacity was determined based on the percentage reduction of absorbance of the ABTS+ cationic radical solution by the sample compared to the reducing power of Trolox (6-hydroxy-2,5,7,8-tetramethylchromate-2-carboxylic acid). The measurements were conducted using a Helios Alpha spectrophotometer (Thermo Electron Corporation USA) equipped with a water bath for the thermostating of samples. The results were expressed as an average of nine repetitions per sample and expressed in μmol Trolox/g d.m.

### 2.5. Incidence of diseases and disorders

Fruit was harvested in line with commercial quality standards and was free from diseases and disorders. After 6 months of storage, the pears were assessed for the presence of physiological disorders and fungal diseases. The results were expressed as a percentage share of infected/damaged fruit in the total number of evaluated fruit.

### 2.6. Economic viability

Prices were obtained from "Fruga", a company trading on the Polish market in fruit produced in Poland and imported from other EU countries. The calculation was based on the average monthly prices received by the grower. Fruit mass losses measured each month were due to transpiration and differences in respiration of fruit undergoing the treatments. In addition, the losses identified after 6 months of storage included fruit mass loss due to fungal diseases and physiological disorders disqualifying the affected fruit as not meeting the highest commercial quality standard applicable in OECD countries [29].

### 2.7. Statistical analysis

The results were analysed by one-way and multiple-way ANOVA according to the experimental design, using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA). The assumed sources of variation included the used rootstocks, the storage atmosphere (CA, NA) and the application of 1-MCP. The mean values were compared using Duncan's test at  $P \leq 0.05\%$ . The correlation coefficient analysis was carried out using Microsoft Office 365 Excel tools.

## 3. Results

### 3.1. Rootstock effect

Fruit growers use different rootstocks to match the tree vigour to the climatic, soil and agricultural conditions [32]. In apples, the rootstock also influences the speed of fruit ripening and thus the date of harvest [33]. However, in this study, the ripening speed and the harvest date were hardly affected by the rootstock type (Table 1). The Streif index, which is considered a good indicator of harvest maturity [34,35], did not vary much in the discussed experiment. There were no index differences in 2013, and very small differences in the other two years. The starch index, which affects the Streif index most strongly, also showed only slight, although significant, differences. Differences in firmness between the fruit coming from trees grown on different rootstocks were very small as well. No firmness differences were found in two years (2011 and 2012), and a significant difference, although of only 2 N, was identified in 2013.

A study assessing the influence of six rootstocks on the TSS of 'Forelle' pears found that the differences in TSS at harvest were very small and did not exceed 0.5 °Brix within two years [10]. TSS differences were also small in our study. No differences were detected in the first year of the experiment, and even though they occurred in the two subsequent years, they were rather incidental and random. Total acidity followed a more clear pattern and was the lowest in fruit from trees growing on *Pyrus caucasica*. However, the TSS/TA ratio, which is crucial for the subjective perception of fruit taste [36], did not vary much between fruit from trees grown on different rootstocks.

As the present study did not show any significant and permanent influence of the rootstock on the basic quality features of pears, this factor was omitted in our further analyses regarding storage and storability, except for mass loss.

**Table 1.** The influence of rootstock on the quality parameters of pears at harvest in 2011-2013

Rootstock	Streif index	Starch index	Firmness (N)	TSS (%)	TSS/TA	Total acidity (% malic acid)
2011						
PG <sup>1</sup>	0.09 a <sup>1</sup>	6.6 b	63.7 a	12.9 a	62.3 a	0.21 b
GK	0.10 b	5.4 a	64.7 a	12.9 a	68.6 a	0.19 a
PD	0.10 b	5.8 ab	63.7 a	13.3 a	65.8 a	0.20 b
2012						
PG	0.08 a	6.5b	60.8 a	12.0 a	57.9 ab	0.21 a
GK	0.09 ab	6.3ab	61.8 a	12.4 b	61.6 b	0.20 a
PD	0.09 b	6.0a	62.8 a	12.2 ab	57.0 a	0.21 b
2013						
PG	0.06 a	9.2 b	66.7 b	12.4 b	69.3 b	0.18 a
GK	0.07 a	8.6 a	66.7 b	11.9 a	66.1 a	0.18 a
PD	0.06 a	8.8 a	64.7 a	12.1 a	67.1 a	0.18 a
Mean						
PG	0.07 a	7.4b	63.7 a	12.1 a	62.8 a	0.20 b
GK	0.08 a	6.8a	64.7 a	12.4 a	65.4 a	0.19 a
PD	0.08 a	6.5a	63.7 a	12.5 a	63.3 a	0.20 b

<sup>1</sup> one-way analyses of variance; data in the same column marked with the same letter, separately for each year of experiment, are not significantly different at  $\alpha = 0.05$  (Duncan's test).

### 3.2. Mass loss

Fruit mass loss during storage depends on a number of factors occurring both before and after harvest, such as the content of minerals (especially calcium) in fruit, fruit maturity at harvest, incidence of diseases and disorders, and storage conditions [11]. As all fruit analysed in the present study grew under the same conditions and was treated in the same way at the time of harvest, and its selection was entirely random in line with the experimental design, it can be assumed that the loss of fruit mass was influenced only by the experimental factors. All factors applied in this study affected the loss of fruit mass during storage (Tables 2-4). The rootstock may affect the quality parameters of fruit [37], as well as the speed and time of ripening [38]. In 2011, the effect of the rootstock type on the mass loss of NA-stored fruit was significant from the first measurement until the 120th day of storage. In the following year, no such effect was found, but in 2013 the rootstock clearly affected the loss of fruit mass throughout the storage period, regardless of treatment.

The use of 1-MCP reduces autocatalytic ethylene production and thus significantly slows down respiration [39]. The strongest impact of 1-MCP application was found in the last year of the research (

Table 3), in which the reduction of fruit mass loss as compared to untreated pears had the highest level of significance in each month of testing. In 2011 and 2012, no differences between 1-MCP treated and untreated samples were identified after the first month of storage, whereas the differences were highly significant in the subsequent months.

However, it was the gaseous composition of the storage atmosphere which had by far the greatest impact on the mass loss during storage. During respiration, in addition to burning sugars as a result of respiratory reactions, water is produced, the excess of which is transpired into the environment thus resulting in fruit mass loss [8,11]. The composition of gases in the storage atmosphere strongly influences the rate of fruit respiration [12]. Reducing the oxygen level and increasing the carbon dioxide level slow down respiration and, along with it, the consumption of respiration substrates. This study, during which the oxygen content was reduced to 2%, and the carbon dioxide content was increased to 1%, confirmed the beneficial effect of CA in each year and after each month of storage. This impact was highly significant in each year of the study.

Mass loss during storage might also have been caused by parthenocarpy, and 'Conference' pear is known for producing a large number of parthenocarpic fruit in years of adverse weather conditions. It was observed in some earlier studies that parthenocarpy and the number of seeds produced in pears affected both their quality and storability [7].

**Table 2.** Mass loss (%) of untreated (control) and of 1-MCP treated 'Conference' pears after storage in normal (NA) and controlled (CA) atmosphere in 2011

Rootstock	Storage atmosphere	1-MCP dose	Days of storage					
			30	60	90	120	150	180
Q S1	NA	Control	1.82 <sup>a</sup> (0.31)	3.72 (0.32)	5.13 (0.21)	6.14 (0.23)	7.10 (0.54)	7.50 (0.42)
		1-MCP	2.15 (0.29)	2.65 (0.44)	3.23 (0.59)	4.39 (0.97)	5.56 (1.32)	6.06 (1.47)
	KA	Control	1.49 (0.51)	1.97 (0.51)	2.52 (0.55)	3.00 (0.61)	3.48 (0.70)	4.11 (0.85)
		1-MCP	0.92 (0.19)	1.37 (0.29)	1.88 (0.42)	2.02 (0.37)	2.42 (0.38)	3.32 (0.61)
CP	NA	Control	1.52 (0.47)	2.69 (0.28)	4.74 (0.34)	5.60 (0.59)	6.24 (0.56)	6.77 (0.59)
		1-MCP	2.31 (0.79)	3.01 (1.00)	3.89 (1.43)	5.38 (1.80)	5.51 (1.58)	6.22 (1.86)
	CA	Control	1.01 (0.06)	2.02 (0.30)	3.05 (0.44)	3.46 (0.60)	4.32 (0.62)	5.18 (0.64)
		1-MCP	0.93 (0.13)	1.78 (0.15)	2.26 (0.46)	2.77 (0.41)	3.43 (0.44)	3.93 (0.47)
PD	NA	Control	1.41 (0.23)	2.82 (0.31)	4.52 (0.42)	5.41 (0.55)	6.30 (0.55)	6.64 (0.58)
		1-MCP	1.83 (0.25)	2.34 (0.28)	3.41 (0.51)	4.59 (1.01)	5.23 (1.12)	5.74 (1.29)
	CA	Control	1.07 (0.17)	1.98 (0.49)	2.56 (0.50)	3.08 (0.60)	3.59 (0.74)	4.44 (0.75)
		1-MCP	0.94 (0.19)	1.42 (0.28)	1.94 (0.39)	2.26 (0.45)	2.79 (0.56)	3.31 (0.68)
<b>Main effects<sup>b</sup></b>								
Rootstock (A)			**	**	*	*	ns	ns
Storage atmosphere (B)			***	***	***	***	***	***
1-MCP dose (C)			ns	***	***	***	***	***
<b>Interaction</b>								
A x B			ns	**	ns	ns	**	*
A x C			*	***	ns	*	ns	ns
B x C			***	ns	**	ns	ns	ns
A x B x C			ns	*	ns	ns	ns	ns

<sup>a</sup> Numbers in parentheses are the standard deviation of the mean (n = 10).

<sup>b</sup> P-value of F ratio: ns, not significantly different; \*P < 0.05; \*\*P < 0.01; \*\*\*P < 0.001.

**Table 3.** Mass loss of untreated (control) and of 1-MCP treated 'Conference' pears after storage in normal (NA) and controlled (CA) atmospheres in 2012

Rootstock	Storage atmosphere	1-MCP dose	Days of storage					
			30	60	90	120	150	180
Q S1	NA	Control	1.96 <sup>a</sup> (0.60)	4.00 (0.90)	5.47 (0.78)	6.32 (0.66)	7.17 (0.53)	7.96 (0.50)
		1-MCP	1.94 (0.28)	2.78 (0.56)	3.78 (0.57)	4.42 (0.53)	5.13 (0.69)	5.98 (0.95)
	KA	Control	1.21 (0.29)	1.92 (0.27)	2.59 (0.31)	2.93 (0.25)	3.90 (0.43)	4.70 (0.44)
		1-MCP	1.23 (0.30)	1.68 (0.30)	1.99 (0.32)	2.75 (0.57)	3.26 (0.76)	4.23 (0.93)
CP	NA	Control	2.54 (0.62)	3.90 (0.70)	5.15 (0.62)	5.92 (0.49)	6.71 (0.56)	7.88 (0.65)
		1-MCP	1.96 (0.43)	2.90 (0.76)	4.06 (0.62)	4.74 (0.58)	5.50 (0.84)	6.36 (0.89)
	CA	Control	1.15 (0.23)	1.89 (0.33)	2.49 (0.37)	3.01 (0.38)	3.79 (0.44)	4.62 (0.48)
		1-MCP	1.19 (0.13)	1.55 (0.20)	1.86 (0.24)	2.37 (0.33)	2.96 (0.45)	3.92 (0.59)
PD	NA	Control	2.18 (0.25)	4.02 (0.37)	5.39 (0.65)	6.05 (0.59)	6.70 (0.53)	7.53 (0.47)
		1-MCP	1.84 (0.57)	2.55 (0.51)	3.63 (0.59)	4.38 (0.59)	5.10 (0.51)	6.06 (0.47)
	CA	Control	1.01 (0.14)	1.88 (0.34)	2.67 (0.53)	3.03 (0.66)	3.78 (0.77)	4.73 (0.81)
		1-MCP	1.17 (0.07)	1.55 (0.14)	1.85 (0.20)	2.36 (0.37)	3.09 (0.70)	4.10 (0.93)
<b>Main effects<sup>b</sup></b>								
Rootstock (A)			ns	ns	ns	ns	ns	ns
Storage atmosphere (B)			***	***	***	***	***	***
1-MCP dose (C)			ns	***	***	***	***	***
<b>Interaction</b>								
A x B			ns	ns	ns	ns	ns	ns
A x C			ns	ns	ns	ns	ns	ns
B x C			**	***	***	***	***	***
A x B x C			ns	ns	ns	*	ns	ns

<sup>a</sup> Numbers in parentheses are the standard deviation of the mean (n = 10).

<sup>b</sup> P-value of F ratio: ns, not significantly different; \*P < 0.05; \*\*P < 0.01; \*\*\*P < 0.001.

**Table 4.** Mass loss of untreated (control) and of 1-MCP treated 'Conference' pears after storage in normal (NA) and controlled (CA) atmospheres in 2013

Rootstock	Storage atmosphere	1-MCP dose	Days of storage					
			30	60	90	120	150	180
Q S1	NA	Control	1.86 <sup>a</sup> (0.31)	3.41 (0.40)	4.48 (0.43)	5.09 (0.52)	5.93 (0.50)	6.63 (0.45)
		1-MCP	1.79 (0.52)	2.60 (0.51)	3.31 (0.50)	4.02 (0.44)	4.71 (0.43)	5.36 (0.45)
	KA	Control	1.10 (0.15)	1.61 (0.22)	2.12 (0.37)	3.02 (0.28)	3.69 (0.25)	4.09 (0.33)
		1-MCP	0.92 (0.17)	1.63 (0.60)	1.98 (0.57)	2.48 (0.71)	2.98 (0.86)	3.16 (0.60)
CP	NA	Control	2.15 (0.27)	3.66 (0.68)	5.01 (0.90)	5.86 (0.95)	6.28 (0.62)	7.13 (0.68)
		1-MCP	1.93 (0.28)	3.29 (0.38)	3.67 (0.38)	4.51 (0.37)	5.26 (0.39)	6.33 (0.48)
	CA	Control	1.02 (0.13)	1.88 (0.18)	2.73 (0.23)	3.21 (0.30)	4.07 (0.28)	4.83 (0.38)
		1-MCP	0.92 (0.08)	1.82 (0.19)	2.16 (0.41)	2.53 (0.65)	3.02 (0.49)	3.88 (0.50)
PD	NA	Control	2.27 (0.27)	3.79 (0.43)	5.27 (0.77)	5.83 (0.85)	6.13 (0.74)	6.96 (0.44)
		1-MCP	1.68 (0.61)	2.54 (0.77)	3.57 (0.45)	4.08 (0.56)	4.82 (0.58)	5.47 (0.64)
	CA	Control	0.98 (0.06)	1.67 (0.29)	2.37 (0.50)	3.07 (0.60)	3.62 (0.59)	4.03 (0.49)
		1-MCP	0.98 (0.06)	1.75 (0.54)	1.99 (0.81)	2.26 (0.72)	2.77 (0.85)	3.27 (0.99)
<b>Main effects<sup>b</sup></b>								
Rootstock (A)			ns	**	**	*	*	***
Storage atmosphere (B)			***	***	***	***	***	***
1-MCP dose (C)			***	***	***	***	***	***
<b>Interaction</b>								
A x B			ns	ns	ns	ns	ns	ns
A x C			ns	ns	ns	ns	ns	ns
B x C			ns	ns	***	**	ns	ns
A x B x C			*	ns	ns	ns	ns	ns

<sup>a</sup> Numbers in parentheses are the standard deviation of the mean (n = 10).

<sup>b</sup> P-value of F ratio: ns, not significantly different; \*P < 0.05; \*\*P < 0.01; \*\*\*P < 0.001.

### 3.3. Changes in quality parameters during storage

Firmness is one of the most important quality criteria for traders and consumers alike [12]. Fruit starts to soften when still on tree, about 4 weeks preceding the optimum harvest date [40]. After harvest, fruit continues to soften to finally reach edible firmness, and the softening rate does not depend on the harvest date and cultivar, but depends on storage conditions. The softening rate of late-maturing pear cultivars, such as 'Conference', was found to depend on the synthesis of two enzymes: acetyl-CoA synthase (ACS) and 1-aminocyclopropane carboxylic acid (ACC) [6]. In this study, both the softening rate and the total loss of firmness were clearly dependent on storage conditions (Tables 5-7). The initial firmness measured at harvest varied little between years, with the lowest value observed in 2012 and the highest in 2011. Also, there were virtually no differences between years in the final firmness after 180 days of NA storage, and the total loss of firmness ranged from 34 and 40%. No clear regularity was revealed in individual years as regards firmness loss per month, but the firmness losses did tend to decrease, as the greatest loss was noted in the last (sixth) month of NA storage in two years and in the next-to-last (fifth) month in one year of the study.

1-MCP application significantly reduces the softening rate of climacteric fruit and vegetables [24]. This study revealed that 1-MCP application visibly slows down the softening rate, particularly in the first months of storage – it reduced total firmness losses by about 1/3 compared to the untreated fruit after half year of NA storage. Also CA storage with the concentration of O<sub>2</sub> of 1.5-3% and CO<sub>2</sub> of 0.5-1.0% for 'Conference' slows down the softening rate [41]. The fruit stored in such conditions softened significantly more slowly than the NA-stored fruit, but at an approximately equal rate as the NA-stored + 1-MCP treated fruit. No differences were observed after 180 days of storage in two years, whereas there was a significant difference in one year of the study, but it did not exceed 10%.

CA-stored + 1-MCP treated pears had by far the highest firmness. Their average firmness loss within the three years of the study was only about 15% of the initial value, and such a difference does not affect consumer preferences [42]. Firmness losses during the first months of storage were considerably higher in the 1-MCP untreated fruit. 1-MCP application had a stronger influence on the softening rate than the gaseous composition of storage atmosphere during the first two months of storage, but the reverse was true (storage atmosphere more strongly reduced the softening rate than 1-MCP) at the end of the storage period. This could be explained by the way in which 1-MCP works: it slows down respiration by blocking ethylene receptors, but new non-blocked receptors are formed on the fruit skin with time [24], and the treated fruit becomes similar to untreated fruit.

#### 3.3.1. Total Soluble Solids, Total Acidity and TSS/TA ratio

A very important qualitative criterion is the content of sugars, referred to as TSS, and the content of acids, referred to as TA and assessed as the sum of acids converted into malic acid [7,12]. The TSS value usually grows in the initial storage period, which is caused by the degradation of polysaccharides into monosaccharides, but may decrease later as the fruit uses spare substances for respiration [43]. The speed of changes depends on the storage time and storage conditions [11]. The TSS value at harvest was similar and ranged between 12.1 and 12.6% in all years of the study. TSS changed the fastest in the NA-stored fruit: it increased relatively fast to reach its maximum after four or five months. After six months of storage, TSS dropped but were still significantly higher than at harvest. In NA-stored 1-MCP treated pears TSS grew more slowly and reached their peak value in the last 2-3 months of storage. CA storage considerably reduced the ripening speed expressed by TSS, regardless of whether 1-MCP was applied or not. 1-MCP application may have an inconsistent effect, both in CA and NA storage [44]. In this study, TSS in the CA-stored pears gradually grew and rose to their maximum value after the entire storage period. This suggests that after 180 days of CA storage the 'Conference' pears did not start yet the excessive consumption of sugars in the respiration process.

Total acidity in the stored fruit changed according to a more clear pattern than TSS. Monthly measurements showed a systematic decrease in TA at a rate dependent on the storage conditions and 1-MCP treatment. This corresponds with the findings by Hedges et al. [23], who additionally pointed to the harvest date as a factor affecting TA as a harvest delay resulted in a visible decrease in its initial value. What deserves mentioning as regards our study is the weather conditions prevailing during the growing season because the initial TA values measured at the optimal harvest date varied between years. The differences were not large, but are consistent with the findings from a study on apples harvested in the same year in three European countries characterized by different weather conditions [45]. In this study, TA declined during storage irrespective of storage conditions, but it reached the lowest values in the NA-stored fruit and amounted to about 1/3 of the initial value after storage in each year. The 1-MCP treated pears had a significantly higher TA, which never fell below 50% of the initial value. CA storage slowed down the degradation of acids still further and the combination of CA and 1-MCP prevented TA from dropping below 20% of the initial value after six months. Such conditions were shown to be highly effective not only for 'Conference' pears, but also for another popular European pear cultivar 'Alexander Lukas' [23].

Consumers' perception of fruit sweetness and acidity depends not only on the absolute TSS or TA values, but also on the TSS/TA ratio [46]. In our study, the TSS/TA ratio changed very fast in each of the three years and was strongly influenced by storage conditions. For example, whereas the TSS in NA-stored pears did not vary by more than 20% in any of the years, their TSS/TA ratio varied by at least 300%. This was the only quality parameters which was different virtually in every month, regardless of storage conditions and 1-MCP application.

### 3.3.2. Oxygen Radical Absorbance Capacity (ORAC)

Free radical scavenging activity is highly dependent on the species, cultivar, climatic conditions and the harvest date [11]. During storage, it can remain unchanged as was the case for 'Rocha' pears in Portugal [47], or it can grow as shown by [48] for 'Golden Smoothie' apples. In our research, ORAC varied depending on storage conditions. Antioxidant capacity dropped considerably after NA storage, whereas the decrease was significantly smaller in the 1-MCP treated sample. No changes were observed after CA storage, the ORAC value even rose after the 1-MCP application. These differences can be explained by the differences in the ripening processes induced by increased respiration. Larrigaudiere et al. [49] found out that ripening may involve a noticeable decline in the content of ascorbic acid, which is one of the substances making up the antioxidant potential of fruit.

**Table 5.** Effect of storage technology on the quality parameters of pears in 2011

Storage duration	Firmness			TSS (%)	TA (% malic acid)	TSS/TA	ORAC $\mu\text{mol}$ TE/100 g (d.m.)
	(N)	Monthly loss (%)	Total loss (%)				
NA							
0	64.2 <sup>1</sup> n	0		12.6 a	0.21 l	60.0 a	2858.8 d
30	62.2 mn	3.0 a	3.0	12.9 a-c	0.18 i	73.2 b	
60	55.9 g-i	10.1 c	12.8	13.3 b-d	0.15 ef	89.9 c-e	
90	52.2 f	6.8 b	18.7	14.6 g-i	0.11 c	134.5 g	
120	50.9 ef	2.4 a	20.7	14.9 i	0.11 c	135.5 g	
150	43.0 ab	15.5 d	32.9	14.6 g-i	0.10 b	154.0 h	
180	40.6 a	5.7 b	36.8	13.9 ef	0.06 a	231.7 i	2562.5 a
NA + 1-MCP							
0	64.2 n	0		12.6 a	0.21 l	60.0 a	2858.8 d
30	63.4 n	1.1 a	1.1	12.8 ab	0.19 i-l	67.8 ab	
60	58.1 i-k	8.4 c	9.5	12.9 a-c	0.19 i-k	69.3 ab	
90	53.5 fg	7.9 b	16.6	13.4 c-e	0.16 f-h	84.8 cd	
120	47.6 cd	11.0 e	25.8	14.3 f-i	0.16 e-h	92.1 c-e	
150	43.4 b	8.9 d	32.4	14.5 f-i	0.15 e	99.5 e	
180	42.9 ab	1.1 a	33.2	14.7 hi	0.10 bc	147.8 h	2782.5 b
CA							
0	64.2 n	0		12.6 a	0.21 l	60.0 a	2858.8 d
30	64.6 n	-0.7 a	-0.7	12.5 a	0.18 ij	69.0 ab	
60	62.3 mn	3.5 b	2.9	12.7 a	0.19 i-l	66.7 ab	
90	57.8 h-j	7.3 e	10.0	13.1 a-d	0.18 i	74.5 b	
120	54.8 g	5.1 c	14.6	14.1 fg	0.15 e-g	93.9 c-e	
150	48.6 de	11.3 f	24.2	14.5 g-i	0.15 e-h	95.1 de	
180	45.3 bc	6.7 d	29.3	14.8 i	0.12 d	123.7 f	2817.5 c
CA + 1-MCP							
0	64.2 n	0		12.6 a	0.21 l	60.0 a	2858.8 d
30	63.6 n	0.8 b	0.8	12.8 ab	0.21 m	60.6 a	
60	59.4 kl	6.7 f	7.4	12.6 a	0.20 kl	64.1 ab	
90	60.7 lm	-2.2 a	5.4	13.1 a-d	0.19 ij	71.0 ab	
120	59.1 jk	2.7 c	7.9	13.5 de	0.16 gh	84.0 c	
150	55.3 gh	6.4 e	13.8	13.9 ef	0.17 h	84.7 cd	
180	53.3 fg	3.5 d	16.9	14.3 f-i	0.16 e-h	89.4 c-e	2962.5 e

<sup>1</sup> one-way analyses of variance; data in the same column marked with the same letter are not significantly different within a year at  $\alpha = 0.05$  (Duncan's test).

**Table 6.** Effect of storage technology on the quality parameters of pears in 2012

Storage duration	Firmness			TSS (%)	TA (% malic acid)	TSS/TA (N)	ORAC $\mu$ mol TE/100 g (d.m.)
	(N)	Monthly loss (%)	Total loss (%)				
NA							
0	60.6 <sup>1</sup> l	0		12.2 a	0.23 m	53.0 a	2635.0 c
30	56.4 hi	6.9 c	6.9	12.6 a-d	0.20 j-l	64.7 a-d	
60	53.5 fg	5.1 a	11.6	13.1 e-h	0.19 h-j	70.4 c-f	
90	50.5 de	5.6 b	16.6	13.5 f-i	0.17 f	79.4 gh	
120	46.9 c	7.1 d	22.6	14.0 j-l	0.15 e	93.3 i-k	
150	43.7 b	6.9 c	27.9	14.2 l	0.11 b-e	137.4 l	
180	39.8 a	8.9 e	34.3	13.6 k	0.07 a	194.3 m	2435.0 a
NA + 1-MCP							
0	60.6 l	0		12.2 a	0.23 m	53.0 a	2635.0 c
30	58.9 jl	2.8 b	2.8	12.4 ab	0.19 i-k	66.5 b-e	
60	58.3 i-l	1.1 a	3.8	12.5 a-c	0.19 h-j	67.4 b-f	
90	56.3 hi	3.4 c	7.1	13.0 d-g	0.18 g-i	71.9 d-g	
120	52.0 ef	7.6 d	14.2	13.4 f-i	0.17 f	79.4 gh	
150	47.9 c	7.8 e	20.9	13.9 j-l	0.12 c	122.8 k	
180	44.2 b	7.8 e	27.1	14.3 l	0.11 bc	130.9 l	2537.5 b
CA							
0	64.2 m	0		12.2 a	0.23 m	53.0 a	2635.0 c
30	60.4 l	5.9 d	5.9	12.2 a	0.20 lm	60.9 a-c	
60	58.6 i-l	2.9 b	8.7	12.5 a-c	0.19 j-l	65.3 a-d	
90	57.4 h-k	2.1 a	10.6	12.8 b-e	0.18 g-i	70.7 c-f	
120	55.7 h	2.8 b	13.1	13.2 f-i	0.18 fg	75.4 f-h	
150	53.1 fg	4.7 c	17.2	13.6 i-k	0.15 de	92.6 i-k	
180	48.9 cd	8.1 e	23.9	14.2 l	0.14 d-g	100.4 j-l	2627.5 c
CA + 1-MCP							
0	60.6 l	0		12.2 a	0.23 m	53.0 a	2635.0 c
30	60.6 l	0.0 b	0.0	12.2 a	0.21 m	58.8 ab	
60	59.5 kl	1.8 c	1.8	12.3 ab	0.20 l	62.5 a-c	
90	58.3 i-l	2.0 d	3.8	12.7 b-e	0.20 j-l	65.5 a-d	
120	58.5 i-l	-0.4 a	3.3	12.9 c-f	0.18 f-h	72.7 d-g	
150	56.9 h-j	2.8 e	6.0	13.5 h-j	0.18 g-i	73.9 e-h	
180	55.2 gh	3.0 f	8.8	14.0 kl	0.17 fg	81.0 h-j	2777.5 d

<sup>1</sup> one-way analyses of variance; data in the same column marked with the same letter are not significantly different within a year at  $\alpha = 0.05$  (Duncan's test).

**Table 7.** Effect of storage technology on the quality parameters of pears in 2013

Storage duration	Firmness			TSS (%)	TA (% malic acid)	TSS/TA (N)	ORAC $\mu$ mol TE/100 g (d.m.)
	(N)	Monthly loss (%)	Total loss (%)				
NA							
0	65.9 <sup>1</sup> k	0		12.1 a	0.18 m	67.5 a	2975.0 c
30	64.4 i-k	2.2 a	2.2	12.5 a-c	0.18 m	70.7 ab	
60	62.8 hi	2.5 b	4.7	12.7 b-d	0.15 h	87.6 cd	
90	56.1 f	10.6 d	14.8	13.6 f	0.13 fg	101.7 ef	
120	49.7 cd	11.4 e	24.6	14.3 gh	0.11 c	130.0 h	
150	45.4 b	8.6 c	31.0	14.8 jk	0.07 b	208.3 i	
180	39.9 a	12.3 f	39.5	13.7 f	0.06 a	228.3 j	2750.0 a
NA + 1-MCP							
0	65.9 k	0		12.1 a	0.18 m	67.5 a	2975.0 c
30	64.4 i-k	2.2 b	2.2	12.4 ab	0.18 m	70.7 ab	
60	64.1 i-k	0.5 a	2.7	12.4 a-c	0.16 j-l	76.8 ab	
90	61.1 h	4.6 c	7.2	12.8 c-e	0.15 h	88.3 cd	
120	55.8 f	8.8 f	15.4	13.6 f	0.12 de	107.7 f	
150	51.4 de	7.9 e	22.0	14.6 ij	0.12 d	121.7 g	
180	47.6 bc	7.3 d	27.7	14.6 ij	0.11 c	132.7 h	2890.8 b
CA							
0	65.9 k	0		12.1 a	0.18 m	67.5 a	2975.0 c
30	66.2 k	-0.5 a	-0.5	12.3 ab	0.18 m	69.1 a	
60	63.3 h-j	4.4 c	4.0	12.4 ab	0.18 m	69.0 a	
90	62.0 hi	2.1 b	6.0	12.6 a-c	0.16 jk	80.4 bc	
120	57.7 fg	6.9 e	12.4	13.8 fg	0.15 h	93.4 de	
150	52.9 e	8.4 f	19.8	14.7 ij	0.14 g	107.9 f	
180	49.9 cd	5.6 d	24.2	15.1 k	0.13 ef	119.0 g	2990.0 c
CA + 1-MCP							
0	65.9 k	0		12.1 a	0.18 m	67.5 a	2975.0 c
30	66.3 k	-0.6 a	-0.6	12.2 a	0.18 m	68.9 a	
60	64.3 i-k	3.0 c	2.4	12.4 ab	0.17 l	73.9 ab	
90	63.3 h-k	1.5 b	3.9	12.5 a-c	0.16 kl	75.9 ab	
120	61.4 h	3.1 c	6.9	13.1 de	0.16 j-l	80.6 bc	
150	58.6 g	4.5 d	11.1	13.7 fg	0.16 ij	88.5 cd	
180	55.8 f	4.7 e	15.3	14.1 hi	0.15 hi	96.7 de	3107.5 d

<sup>1</sup> one-way analyses of variance; data in the same column marked with the same letter are not significantly different within a year at  $\alpha = 0.05$  (Duncan's test).

### 3.4. Revenue differences related to differences in storage technology

Pome fruits, the most popular of which are apples and pears, are characterized by high storability [12]. As apples and pears can endure long-term storage, they can be supplied on the market all year round. The price of stored fruit is often similar to, and in some years even higher than, that of freshly harvested fruit [50]. In addition to market dependencies, including mainly the supply of fruit over a given period, the most important factor affecting the price is the quality of the fruit [51]. For a grower who prepares fruit for sale it is important that it meets the parameters allowing its classification as the top-class fruit for fresh consumption [52]. Fruit discarded after grading generates either no or very low revenue. This study compared the values of fruit stored in different conditions, taking into account the losses which arose during storage. Two types of loss were considered that could be measured based on the study results. Fruit mass loss caused by transpiration depends on relative humidity and respiration [12]. Assuming that the storage humidity was equal for all fruit, fruit mass loss resulted mainly from the rate of respiration. It has been shown in section 3.2. that CA storage and 1-MCP application have a significant impact on respiration. The figures in Table 8 demonstrate that this translated directly in to the grower's revenue.

The difference between the highest and the lowest value of the yield that could be obtained per 1 ha did not exceed EUR 100 after the first month of storage (NA, NA+1MCP, CA, CA+1MCP), but it grew with each month. Even in the 2011/2012 season, in which the market prices were the most stable, this difference amounted to over EUR 350 after half-year storage. In the following season, during which the market prices rose much faster and the average yield was 2.5 t h<sup>-1</sup> lower, the difference was as much as about EUR 500. With the previous seasons's yield, the potential difference between revenues from the yield subjected to the simplest treatment (NA) and the most advanced treatment (CA+1MCP) would have exceeded EUR 1500. In the last season, the difference decreased, but only to EUR 400, due to a high average yield.

The least advanced storage technologies give low protection against increased transpiration and the incidence of physiological disorders and fungal diseases [12,50]. The total losses caused by fungal diseases varied among individual years, because many of them originate in the orchard. The biggest difference was observed in the last year of the study – the revenues from the sale of the average pear yield in the EU after CA + 1-MCP treatment were over EUR 2300 higher than those calculated for the same yield after NA storage. CA + 1MCP-treated pears will be certainly easier to sell because also their other parameters are superior to those of the NA-stored pears. Since the costs of building a controlled atmosphere storage room, if properly designed, can be only about 5% higher than the costs of building a cold storage room [53], the financial advantages that can be achieved each year will surely more than make up for higher capital expenditures.

**Table 8.** Differences in revenues from the sale of the average pear yield in the EU at market prices in each year of the study, depending on storage conditions.

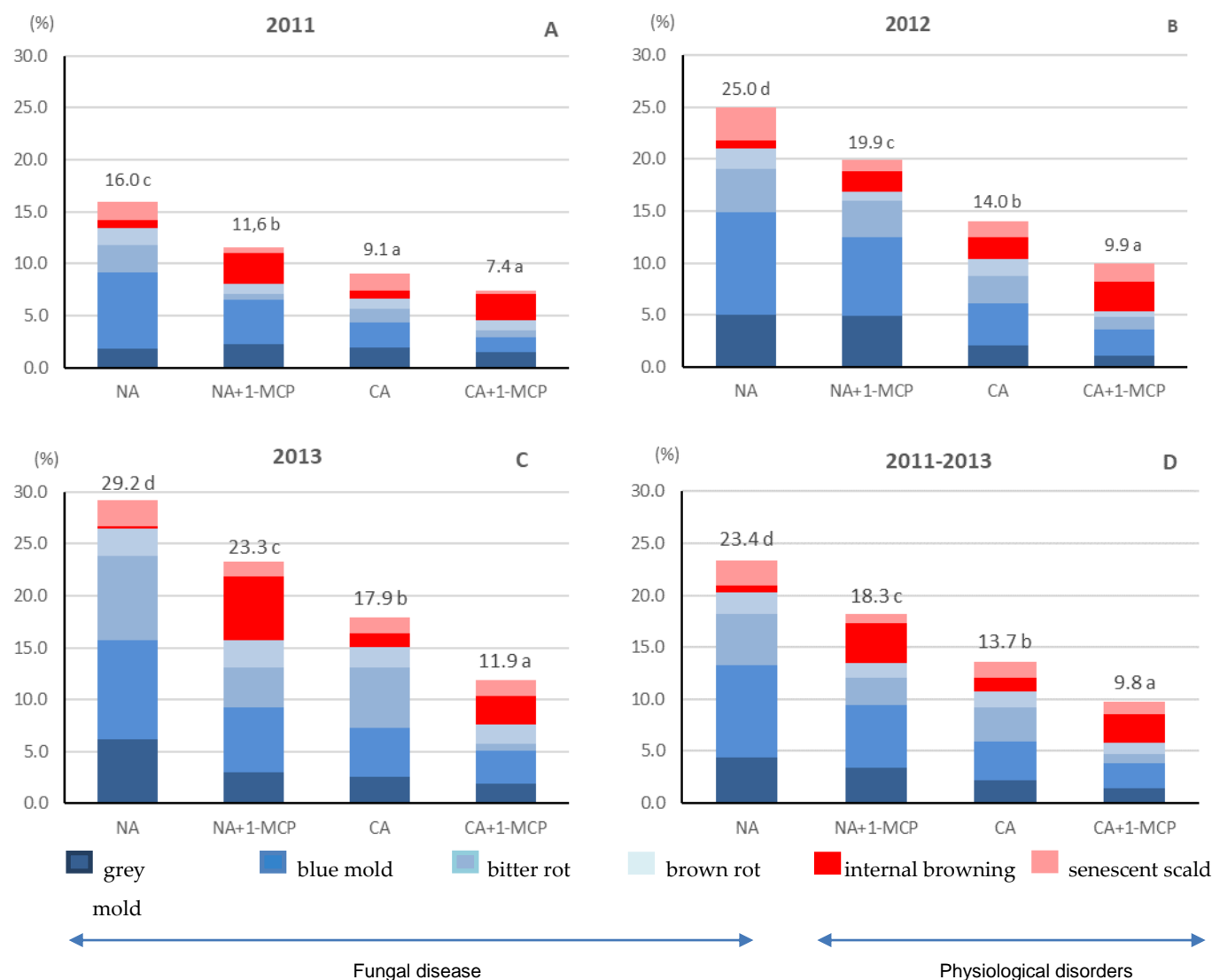
Storage days	NA	NA 1-MCP	CA	CA 1-MCP	Price kg in (EUR)	NA	NA 1-MCP	CA	CA 1-MCP
	<b>2011/2012 (Av. Yield = 14.03 t·h<sup>-1</sup>)<sup>1</sup></b>								
	<b>Transpiration (%)</b>					<b>Value after storage (EUR)</b>			
0	0.0	0.0	0.0	0.0	0.55 <sup>2</sup>	7 723 <sup>3</sup>	7 723	7 723	7 723
30	1.6	2.1	1.2	0.9	0.55	7 600	7 561	7 631	7 651
60	3.1	2.7	2.0	1.5	0.55	7 485	7 517	7 569	7 605
90	4.8	3.5	2.7	2.0	0.57	7 659	7 762	7 827	7 882
120	5.7	4.8	3.2	2.3	0.57	7 585	7 659	7 789	7 856
150	6.5	5.4	3.8	2.9	0.62	8 119	8 216	8 358	8 438
180	7.0	6.0	4.6	3.5	0.64	8 382	8 469	8 598	8 693
	<b>Storage diseases (%)</b>								
	16.0 ±3.9 <sup>4</sup>	11.6 ±3.5	9.1 ±3.3	7.4 ±3.5		6 944	7 424	7 782	8 026
	<b>Value difference after storage</b>					-779	-299	59	303
<b>2012/2013 (Av. Yield = 11.78 t·h<sup>-1</sup>)</b>									
	<b>Transpiration (%)</b>					<b>Value after storage (EUR)</b>			
0	0.0	0.0	0.0	0.0	0.58	6 846	6 846	6 846	6 846
30	2.2	1.9	1.1	1.2	0.58	6 693	6 714	6 769	6 763
60	4.0	2.7	1.9	1.6	0.65	7 395	7 490	7 555	7 579
90	5.3	3.8	2.6	1.9	0.73	8 100	8 230	8 336	8 395
120	6.1	4.5	3.0	2.5	0.82	9 106	9 260	9 408	9 456
150	6.9	5.2	3.8	3.1	0.99	10 892	11 082	11 247	11 332
180	7.8	6.1	4.7	4.1	1.14	12 361	12 583	12 778	12 858
	<b>Storage diseases (%)</b>								
	25.0 ±3.7	19.9 ±3.6	14.0 ±2.7	9.9 ±2.6		9 004	9 916	10 899	11 531
	<b>Value difference after storage</b>					3 070	4 053	4 686	3 070
<b>2013/2014 (Av. Yield = 18.85 t·h<sup>-1</sup>)</b>									
	<b>Transpiration (%)</b>					<b>Value after storage (EUR)</b>			
0	0.0	0.0	0.0	0.0	0.43	8 122	8 122	8 122	8 122
30	2.1	1.8	1.0	0.9	0.53	9 719	9 748	9 824	9 834
60	3.6	2.8	1.7	1.7	0.53	9 567	9 648	9 756	9 754
90	4.9	3.5	2.4	2.0	0.57	10 296	10 448	10 568	10 608
120	5.6	4.2	3.1	2.4	0.60	10 649	10 806	10 930	11 007
150	6.1	4.9	3.8	2.9	0.60	10 590	10 724	10 852	10 950
180	6.9	5.7	4.3	3.4	0.60	10 501	10 635	10 793	10 892
	<b>Storage diseases (%)</b>								
	29.2 ±4.4	23.3 ±3.1	17.9 ±3.9	11.9 ±1.8		7 211	8 006	8 776	9 550
	<b>Value difference after storage</b>					-911	-115	654	1 428

<sup>1</sup> average pear yield per 1 hectare in the EU countries where production exceeds 1000 ha<sup>2</sup> price of pears obtained by growers in the period<sup>3</sup> average pear yield per ha in the EU countries in which pear production exceeds 1000 ha x average pear price for growers<sup>4</sup> standard deviation

### *3.5. Incidence of diseases and disorders*

Postharvest diseases of pome fruit result in substantial economic losses during storage worldwide every year [9]. In this study, the occurrence of fungal diseases, physiological disorders and visible physical damage of fruit flesh changed every year but always depended on treatment (

Figure 1, **Figure 2**). Fungal diseases occurred more often than physiological disorders – this tendency is stronger in pears than in apples [50]. The biggest total losses – of about 30% – were observed after half-year storage in 2013 (Figure 1C). The 1-MCP treatment of NA-stored pears reduced the total losses and visibly curbed the incidence of fungal diseases despite an increased incidence of internal browning. CA storage reduced the total losses by about half and the CA+ 1-MCP combination significantly cut the incidence of diseases and disorders. The smallest losses caused by diseases and disorders were noted in the first year of the study (Figure 1A), but the 1-MCP application reduced the incidence of diseases and disorders only in the NA-stored fruit. In the second year, model results were obtained – starting from NA storage, each further treatment caused a drop in the total losses caused by diseases and disorder after half-year storage (Figure 1 B). Other studies report different outcomes, though, which certainly depended on weather conditions in the orchard [54–57].

**Figure 1.** Total fruit losses caused by fungal diseases and physiological disorders

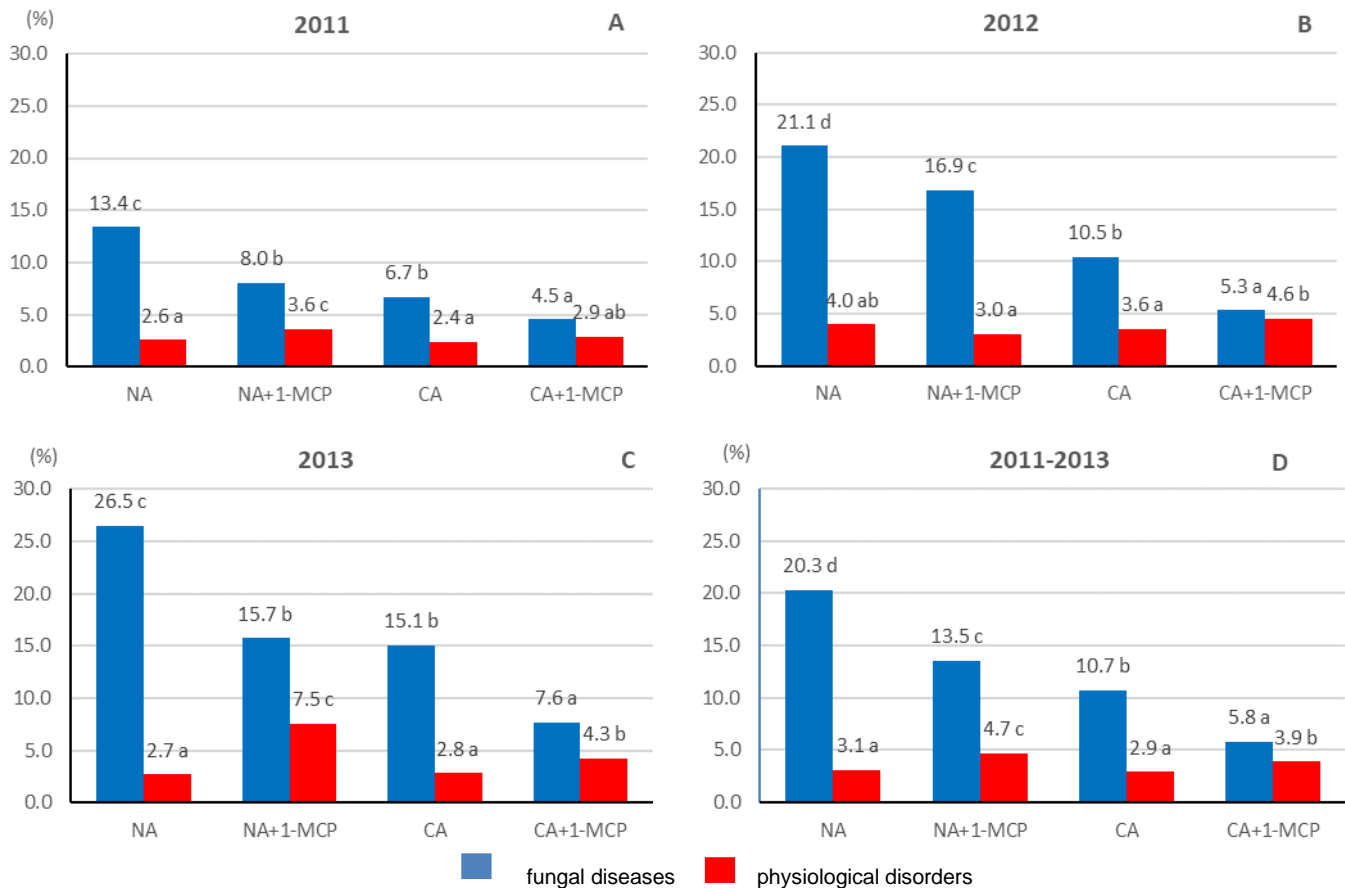
### 3.6. Incidence of diseases and disorders

Fungal pathogens are the main source of losses during the storage and sale of pears [50]. This finding is confirmed by the results of this study except the CA-stored + 1MCP-treated pears. In 2011-2012, the share of fruit with physiological disorders was similar to that of those with fungal diseases (Figure 2). It seems that it was because the treatments very strongly reduced the incidence of fungal diseases. The most important fungal pathogens causing losses due to rotting are *Penicillium expansum*, *Botrytis cinerea*, and *Mucor piriformis* [55]. Other etiological factors include *Phialophora malorum*, *Alternaria spp.*, *Cladosporium herbarum*, and *Neofabrea spp.* [58]. Their spores are ubiquitous in the orchard and infect also other tree parts. Fungal diseases were found to be the main loss factor in each year of the study. In 2013, the year of increased incidence of fungal diseases during storage, the percentage of fruit infected with fungal diseases in NA storage was about 10 times higher than the percentage of fruit showing symptoms of physiological disorders. Pears suffer from physiological disorders more rarely than apples [12], which was also clearly apparent in the two other years of the study. In 2011 and 2013, no differences in the incidence of fungal diseases were found between the NA-stored +1-MCP treated pears and the CA-stored pears, but the combination of CA and 1-MCP treatment allowed the reduction of the incidence of fungal diseases by half

(2013) or by one-third (2011). In 2012, the incidence of fungal diseases decreased gradually and significantly between samples from the level observed after NA storage to the level noted after CA +1-MCP treatment.

Even though physiological disorders occur more rarely compared to fungal diseases, they are more difficult to contain by changing the composition of the atmosphere or applying 1-MCP [59–61]. The share of fruit affected by physiological disorders varied considerably between treatments, but it did not exceed 7.5% in any of the samples, which shows that physiological disorders are a minor cause of losses during storage.

**Figure 2.** Fungal diseases and physiological disorders after storage in different conditions



The share of individual diseases and disorders causing losses during storage varied between years (

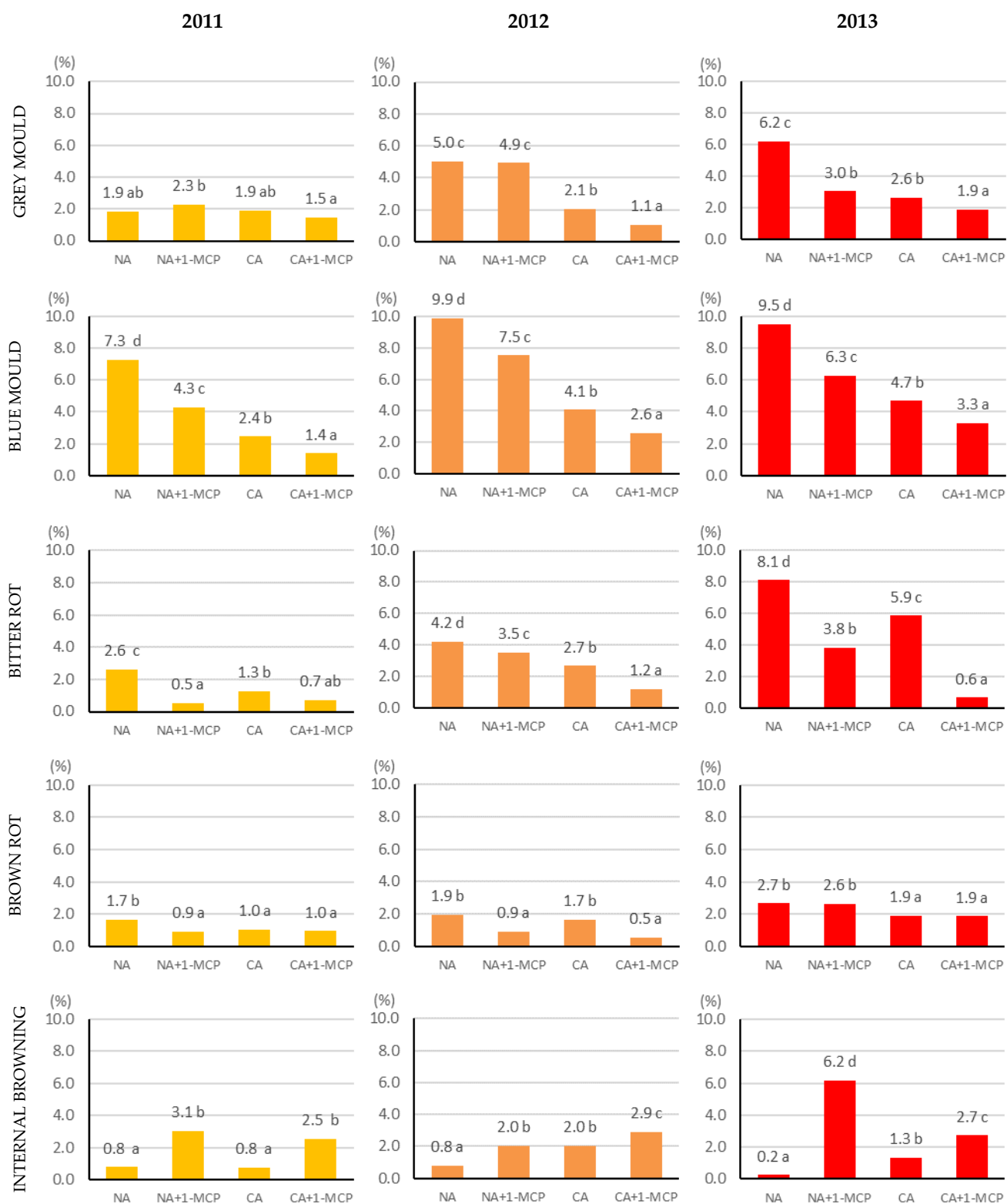
Figure 3). Blue mold led to the biggest losses in all years of the study. It is caused by *Penicillium expansum*, a fungus commonly found in orchards [62]. The study clearly shows that the best way to control the disease is to improve the storage conditions. Every method to enhance the storage conditions significantly reduced the infection rate so that the incidence of blue mold in the CA-stored + 1-MCP treated fruit constituted 20-30% of that found in the NA-stored fruit. Blue mold control has not only economic relevance for growers, but it also allows limiting the development and spread of strains that produce patulin, a mycotoxin that affects humans [62].

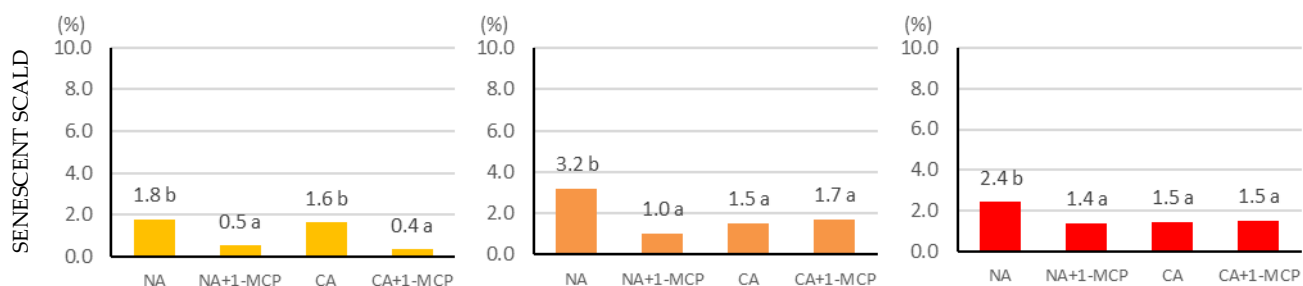
Grey mold, which is caused by *Botrytis cinerea*, was another fungal disease which was observed to infect the fruit in each year of the study. The lowest grey mold incidence rate was noted in 2011 and it is probably due to the low number of infected pears that the differences between the treatments were small and generally insignificant. In the two subsequent years the differences were bigger and CA storage had a noticeable limiting effect on the disease. Controlled atmosphere systems are recommended for the storage of grapes for fresh consumption, which are very susceptible to grey mold [63].

Postharvest pathogens with economic importance for stored fruit also include bitter rot caused by *Colletotrichum spp* [9]. In this study, the application of 1-MCP was much more effective in controlling this disease than the modification of storage atmosphere. Such a positive outcome of 1-MCP treatment was observed during the storage of apples [64]. Brown rot occurred in less fruit compared to the other fungal diseases. The differences in the incidence of bitter rot between treatments were small, although significant in some cases. In 2011, the highest number of infected pears was found in the samples stored in NA for six months. The other samples showed no differences. In 2012, 1-MCP had a beneficial effect on both NA- and CA-stored fruit, whereas in 2013 a difference was noted only between the NA- and CA-stored samples, regardless of 1-MCP treatment.

Physiological disorders caused much smaller losses than fungal diseases, which confirms the findings usually reported after the storage of pears [7,11]. The differences between individual treatments appeared to be random and there was even a growth in the number of fruit showing the symptoms of physiological diseases after the application of 1-MCP. 'Conference' pears are prone to internal browning, the incidence of which may increase during CA storage [65,66]. This study only partially supported those findings and the 1-MCP treatment seemed to more strongly promote the development of internal browning, which agreed with the observations already made by Hendges et al. [61] during and after the storage of 'Alexander Lucas' pears. The possible reason for this is the loss of the antioxidant capacity and/or energetic deficit caused by a reduction in the respiratory activity of fruit stored under CA. It has also been suggested that the inhibition of ethylene production may induce a stress response and thereby cause cell damage [67]. In our study, the significant increase in the incidence of internal browning was noted in 2011 and 2013 in both NA- and CA-stored fruit.

Senescent scald was a second physiological disorder observed in our study. It manifests itself with skin decolorization [12]. 1-MCP effectively reduces senescent scald in apples, but it not clear how successfully it helps control this disorder in pears [68]. Our study did not yield clear result either, but much more often than not 1-MCP limited the occurrence of senescent scald. In 2011, the positive impact of 1-MCP was found after both NA and CA storage. In the following years, the difference was significant for NA-stored fruit. This suggests that the period of 6 months is too long for the storage of 'Conference' pears under NA conditions. The same conclusions were presented in an Italian study assessing the influence of 1-MCP on 'Abbé Fétel' stored in normal atmosphere [54].

**Figure 3.** Impact of storage technology on the incidence of postharvest diseases and disorders in 2011-2013



#### 4. Conclusions

Most of the results obtained in this study on how half-year storage affects fruit quality and proceeds from its sale show that ‘Conference’ pears should not be stored in NA for so long. The high incidence of fungal diseases and physiological disorders after such a long storage period and the resulting losses cannot be compensated by the benefits of long-term storage. The economic analysis has revealed that it pays off much more to sell the fruit directly after harvest than after six month of NA storage. The application of 1-MCP alleviates the above-mentioned drawbacks, but does not fully make up for the expenditures. The best solution is to keep fruit under CA and to additionally apply 1-MCP. This technology is recommended as it allows preserving firmness, an appropriate proportion between sugars and acids, and a high content of antioxidant substances.

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