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The Effect of Harvest Date and Storage Conditions on the Quality of Remontant Strawberry Cultivars Grown in a Gutter System under Covers

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Abstract: The storage characteristics of three remontant strawberry cultivars San Andreas®, Albion® and Murano® were studied in 2018–2020. The short-term storage conditions (7 days) of strawberries used in the study significantly affected fruit quality indicators. The highest quality of stored strawberries was provided by controlled atmosphere (CA) conditions, as evidenced by the typically highest fruit firmness and the lowest natural loss of strawberry weight. The modified atmosphere packaging (MAP) conditions obtained in the Xtend® bags provided a similar good storage effect for strawberries. Strawberries stored in MAP bags had the lowest respiratory intensity, and their firmness and the percentage of rotten fruit were the same as those stored in a controlled atmosphere. In addition, MAP bags were effective in reducing the weight loss of stored strawberries. The quality of strawberries stored in a conventional air storage (AA) was slightly lower compared to the fruit stored in a controlled and modified atmosphere. This was due to their lower firmness and significantly higher respiration intensity and higher weight loss. In addition, the percentage of rotten fruit, although low, has always been the highest among AA strawberries. The quality of the strawberries also depended on the date of fruit harvest. Strawberries harvested later, compared to those collected earlier, were generally characterized by higher firmness, lower acidity and lower respiration intensity.

Keywords: strawberry; harvest date; controlled atmosphere; modified atmosphere; fruit quality

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1. Introduction

From recent scientific research we have discovered that berries and less known fruits are a source of many bioactive substances, positively influencing human health. The most valuable fruit species in this respect include strawberry, raspberry, highbush blueberry, haskap berry, quince, dogwood and kiwifruit [1–8]. One of the most important factors that affect the quality of dessert fruit is flower pollination. For stone trees, the percentage of fruit set that guarantees a good quality yield is 25–40, while in plants of blueberries and strawberries, fruit set are in the range of 80–100percent [9–11]. The content of bioactive compounds and fruit quality depend on agriculture practices and environmental factors. Fruit quality and shelf life are strongly influenced by the application of calcium at the fruit growth stage and the maintenance of a good biological condition of the soil, including the presence of mycorrhizal fungi [12–19]. Strawberry (*Fragaria ananasa* Duch.) is a popular and attractive fruit thanks to its taste and visual qualities [20–22]. It is included in the group of 'soft fruits', which rank high among fresh fruits due to their antioxidant content and their attributed role in preventing chronic diseases, such as cancer and heart disease, related to oxidative damage [23]. It is the richest source of bioactive compounds with antioxidant properties that provide protection against harmful free radicals [24]. The physical, sensory and nutritional properties of strawberry fruit are related to characteristics such as size, firmness, color, taste and aroma, and vitamin C and phenol content [25]. The ratio of soluble solids content to total acidity (SSC/TA) is considered a good indicator of the taste quality of strawberry fruit [26]. The storage properties of the fruit depend largely on their physiological maturity at harvest [27,28].Strawberry fruits require appropriate storage technology to maintain post-harvest quality [16,29]. Strawberry is a non-climacteric fruit and it must be harvested at full maturity to achieve the maximum quality in relation to flavor and color [30]. The fruits have short shelf life and are highly perishable, with a high rate of respiration and suffer relatively high post-harvest losses due to fungal development, mechanical damage, physiological deterioration and water loss [31]. Strawberry fruits have a short postharvest life, often estimated at less than 5 days [32]. Strawberries are highly susceptible to microbial contamination due to the fact that their skin is soft and easily ruptured, has numerous indentations and hair-like protuberances, which allow most organisms to attach and proliferate [33]. Strawberries are highly active metabolically. The rate of evolution of ethylene is low, but due to its characteristic high respiration rate (50–100 mL CO_2 per kg of fruit per hour at 20 °C), it is a highly perishable fruit and can be stored for a very short period [34]. The main post-harvest pathogen of strawberry is *Botrytis cinerea*—the causal agent of grey mold. The disease manifests itself only during the post-harvest phase, when the fruit ripens, during transit and marketing [35]. Optimum storage conditions for strawberries are 0 °C and 90–95% relative humidity. In such conditions, strawberries can have a 7–10-day storage life. However, storage life largely depends on the handling of berries during and after harvest [16]. Storage temperature greatly affects the physiological and biological changes that occur in the strawberry fruit [36]. The storage of the fruit in a temperature range of 0–1 °C (32 and a 34 °F) and relative humidity of 90–95% increases its shelf life, minimizes physiological deterioration and suppresses the incidence of pathogenic decay [37]. Low-temperature storage also influences increased fruit firmness, titratable acidity, total soluble solids, ascorbic acid content and total terpenes in strawberry fruit; furthermore, stress from dehydration is more severe in strawberry fruits stored at room temperature [38]. A modified atmosphere, which can be produced by increasing $CO_2$and reducing O_2levels, produced good results in the preservation of the strawberry [29]. Packing in polyethylene bags decreases respiration, preserves quality and prolongs shelf life [39]. The benefits of decreased oxygen and elevated carbon dioxide levels in MAP include reduced respiration, delayed softening and compositional changes, and reduced decay [20]. MAP composition recommended for strawberries is 5–10% O_2, 15–20% CO_2 and 70–80% N_2 [40]. In addition to low temperature, the long-term storage of strawberries also requires the use of film packaging, which prevents drying [41]. The storage of strawberries in CA conditions slows the respiration rate and the fruit softening process [42]. It is effective in reducing fruit rot caused by *Botritis* and *Penicillium* [43]. Strawberries stored in CA in 2% O_2 and 12% CO_2, compared to the fruits stored in AA, were characterized by higher firmness, titratable acidity and soluble solid and ascorbic acid contents. They also contained higher concentrations of volatile substances [38]. A controlled atmosphere of 15–20% CO_2 and 5–10% O_2has been suggested for strawberry storage [44]. Strawberries can be stored for 10–14 days at 1 °C with a CA composition of 3–5% O_2 and 15–20% CO_2. Too high a concentration of CO_2 or too low O_2levels can cause unpleasant taste and skin discoloration [45].

The aim of this study is to assess the impact of harvest date and air, modified and controlled atmosphere on the quality of remontant strawberry cultivars after short-term storage.

2. Materials and Methods

The research was conducted in three consecutive seasons of 2018–2020. The subject of the study was the fruit of remontant strawberry cultivars: San Andreas®, Albion® and Murano®. Strawberries were grown in a gutter system under covers in coconut substrate (Figure 1A,B). In 2018 and 2020, strawberries for storage were harvested three times at approximately 30-day intervals, i.e., that is, in July, August and September, and four times in 2019 (in July, August, September and additionally in October). The average temperature was recorded in July, August, September and October. In 2018, the average temperature was 19.0 °C, 19.6 °C, 14.6 °C and 9.7 °C, respectively, and 18.6 °C, 20.1 °C, 14.8 °C and 10.6 °C in 2019, respectively, and 20.0 °C, 20.4 °C, 14.9 °C and 11.2 °C in 2020, respectively. The harvest date was determined on the basis of the coloring of the fruit surface, and it fell at a stage close to full maturity, where the fruit surface was colored red. The representative fruit samples for the tested cultivar and harvest date were divided into 4 replicates, each representing approximately 0.5 kg of fruit. The strawberries were stored for 7 days in air atmosphere (AA) (RH 90%, 2 ± 0.5 °C), modified atmosphere (MAP) in Xtend® bags made of polyethylene film (2 ± 0.5 °C) and in a controlled atmosphere (CA) (15% CO_2 and 5% O_2, RH 90%, 2 ± 0.5 °C).

Figure 1. Strawberries cv. 'San Andreas'. (**A**,**B**)—Strawberry grown in technology in the described experiment, (**C**)—Storing strawberries in MAP bags, (**D**)—cv. 'San Andreas' after one week of storage in MAP bags, (**E**)—cv. 'San Andreas' after one week of storage in an air atmosphere, (**F**)—cv. 'San Andreas' after one week of controlled atmosphere storage.

Fruit measurements and chemical analyses were performed on a random sample for each combination of 40 fruits. Strawberry fruit firmness [N] was measured with a TA 500 Lloyd Texture Analyzer using a 6.35 mm diameter tip. Soluble solids content SSC (%) and total acidity TA (% citric acid) were determined in the juice of strawberries, whose firmness was previously measured using an Atago Pal-BX/Acid 4 instrument. The soluble solids content to total acidity ratio (SSC/TA) was calculated. The fruit respiration rate (mg CO_2 kg^{-1} h^{-1}) was measured (on a sample of 9 strawberries from the combination) with an Air Tech 2500-P CO_2 analyzer. Moreover, after storing strawberries, on the basis of the difference in fruit weight before and after storage, natural weight losses [%] and the occurrence of fungal storage diseases [%] were determined.

Data were analyzed using two-way analysis of variance (ANOVA) implemented in the Statistica software v. 13.3 (Tibco Software Inc., Palo Alto, CA, USA); calculations were conducted for each season separately. The values expressed as a percentage were transformed according to the Bliss function ($y = \arcsin \sqrt{x}$). A Fisher's LSD test was used to determine the significance of differences between mean values at the significance level of $p \leq 0.05$.

3. Results and Discussion

In each year of the study, the harvesting date of all remontant strawberry cultivars studied had a significant effect on the indicators characterizing fruit quality determined directly after harvest (Tables 1–3). Nunes et al. [46] showed the significant variability in strawberry quality parameters in relation to harvest date. According to Zhang et al. [47], the harvest date was the main factor affecting the appearance, color, SSC, TA and SSC/TA of strawberries. These authors also showed that, in addition to genotype, harvest date affected strawberry firmness. The harvest date did not affect the SSC/TA ratio and respiration intensity of strawberries of the cv. Albion only in 2000 (Table 2). According to Kader [48], ripe strawberries contain about 7% SSC. In the present study, SSC content in all strawberry cultivars was higher in each harvest.

Table 1. Fruit quality of 'San Andreas' strawberry directly after harvest.

Year	Harvest	Fruit Firmness [N]	Soluble Solids Content [%]	Total acidity [% Citric Acid]	Ratio SSC/TA	Respiration rate [mg $CO_2 kg^{-1} h^{-1}$]
2018	1	3.2 ± 0.24 a *	7.5 ± 0.34 a	0.96 ± 0.07 b	7.9 ± 0.64 a	67.9 ± 11.46 ab
	2	3.3 ± 0.18 a	7.6 ± 0.28 a	0.76 ± 0.03 a	10.0 ± 0.56 b	73.9 ± 12.08 b
	3	5.7 ± 0.38 b	9.4 ± 0.38 b	0.77 ± 0.04 a	12.2 ± 0.75 c	61.6 ± 11.44 a
2019	1	3.1 ± 0.32 a	8.7 ± 0.57 c	1.12 ± 0.06 c	7.8 ± 0.25 a	106.4 ± 24.66 c
	2	3.2 ± 0.22 a	8.0 ± 0.27 b	0.93 ± 0.06 b	8.6 ± 0.48 b	56.7 ± 16.87 b
	3	3.8 ± 0.23 b	7.6 ± 0.27 a	0.84 ± 0.09 a	9.1 ± 1.06 b	51.7 ± 13.39 b
	4	4.9 ± 0.54 c	10.5 ± 0.61 d	0.82 ± 0.03 a	12.8 ± 0.56 c	36.1 ± 7.70 a
2020	1	3.2 ± 0.11 a	8.7 ± 0.76 b	1.03 ± 0.09 c	8.5 ± 0.85 a	55.5 ± 9.40 b
	2	3.4 ± 0.17 b	7.9 ± 0.56 a	0.89 ± 0.03 b	8.9 ± 0.79 b	61.8 ± 10.85 b
	3	4.3 ± 0.35 c	8.3 ± 0.40 ab	0.78 ± 0.05 a	10.7 ± 0.61 c	47.1 ± 31.35 a

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Strawberries harvested at the latest dates (3rd or 4th harvest) were characterized by greater firmness and a higher SSC/TA ratio, as well as a lower respiration intensity compared to fruit from the earlier harvest. According to Zhang et al. [47], late strawberry harvest resulted in a higher SSC/TA ratio. On the other hand, the results of a study by Dominguez et al. [26] indicated a higher value of SSC/TA in strawberries harvested at an earlier date.

The acid content determined in the fruit from the last harvest was lower compared to the value of this trait determined in the strawberries harvested on the first date. Ariza et al. [49] presented different results, showing an increase in TA content in strawberries in successive harvests. Dominguez et al. [26] also showed a higher TA value in strawberries harvested later. A significant influence of the harvest date on the SSC content was also demonstrated in the fruits of all strawberry cultivars; however, changes in the value of this index varied depending on the cultivar and the year of the study. Zhang et al. [47] showed a higher SSC content in strawberries from earlier harvests. On the contrary, Dominguez et al. [26] reported a trend of higher SSC values for late-harvest strawberries. According to Wang and Camp [50], the higher growth temperature of strawberries causes a decrease in the SSC and TA content in the fruit. MacKenzie et al. [51] reported that temperature was positively correlated with SSC and vitamin C content; however, the late season fruit harvest showed an inverse relationship between SSC and temperature.

Table 2. Fruit quality of 'Albion' strawberry directly after harvest.

Year	Harvest	Fruit Firmness [N]	Soluble Solids Content [%]	Total Acidity [% Citric Acid]	Ratio SSC/TA	Respiration Rate [mg $CO_2kg^{-1}h^{-1}$]
2018	1	3.0 ± 0.14 a *	9.7 ± 0.26 a	1.19 ± 0.08 b	8.2 ± 0.78 a	77.5 ± 17.70 c
	2	3.0 ± 0.20 a	8.7 ± 0.51 a	0.77 ± 0.03 a	11.4 ± 0.62 b	65.0 ± 13.45 b
	3	4.7 ± 0.36 b	10.3 ± 0.44 c	0.72 ± 0.05 a	14.3 ± 0.94 c	29.0 ± 8.27 a
2019	1	3.5 ± 0.11 a	11.0 ± 0.67 b	1.21 ± 0.05 c	9.1 ± 0.78 a	112.0 ± 26.11 d
	2	3.6 ± 0.21 a	8.3 ± 0.22 a	0.93 ± 0.07 b	8.7 ± 0.80 a	64.0 ± 20.55 c
	3	3.4 ± 0.18 a	8.4 ± 0.20 a	0.74 ± 0.04 a	11.5 ± 0.42 b	40.1 ± 18.37 b
	4	5.3 ± 0.32 b	11.0 ± 0.48 b	0.79 ± 0.03 a	13.9 ± 0.66 c	24.0 ± 9.02 a
2020	1	3.1 ± 0.53 a	9.3 ± 0.33 b	0.89 ± 0.10 b	10.9 ± 0.71 a	44.9 ± 9.85 a
	2	4.1 ± 0.30 b	9.1 ± 0.29 ab	0.84 ± 0.03 a	10.8 ± 0.36 a	47.5 ± 11.83 a
	3	4.9 ± 0.44 c	8.9 ± 0.58 a	0.86 ± 0.02 ab	10.4 ± 0.92 a	47.1 ± 20.13 a

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Table 3. Fruit quality of 'Murano' strawberries directly after harvest.

Year	Harvest	Fruit Firmness [N]	Soluble Solids Content [%]	Total Acidity [% Citric Acid]	Ratio SSC/TA	Respiration Rate [mg $CO_2kg^{-1}h^{-1}$]
2018	1	3.3 ± 0.16 a *	9.1 ± 0.34 b	0.79 ± 0.05 b	11.6 ± 0.74 a	84.0 ± 16.76 c
	2	3.3 ± 0.22 a	8.4 ± 0.62 a	0.68 ± 0.04 a	12.5 ± 1.08 a	50.5 ± 10.59 b
	3	5.5 ± 0.50 b	10.9 ± 0.58 c	0.67 ± 0.02 a	16.6 ± 0.80 b	37.4 ± 9.45 a
2019	1	3.0 ± 0.27 a	11.0 ± 0.46 d	1.22 ± 0.09 c	9.5 ± 1.20 a	128.0 ± 15.08 d
	2	3.0 ± 0.19 a	8.2 ± 0.35 a	0.94 ± 0.08 b	8.8 ± 0.90 a	66.8 ± 10.38 c
	3	3.6 ± 0.67 b	8.5 ± 0.54 b	0.73 ± 0.07 a	11.8 ± 1.68 b	45.3 ± 5.73 b
	4	4.5 ± 0.80 c	10.4 ± 0.36 c	0.74 ± 0.06 a	14.4 ± 1.29 c	28.4 ± 9.26 a
2020	1	4.3 ± 0.17 b	11.3 ± 0.46 c	0.88 ± 0.12 b	12.9 ± 1.70 b	49.2 ± 14.78 c
	2	3.9 ± 0.23 a	8.2 ± 0.70 a	0.69 ± 0.06 a	11.8 ± 0.66 a	39.9 ± 14.15 b
	3	5.1 ± 0.49 c	10.7 ± 0.72 b	0.72 ± 0.07 a	14.8 ± 1.21 c	34.3 ± 7.10 a

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Short-term storage conditions of 7 days, as well as the harvest date, usually had a significant impact on the value of most parameters that determine the quality and storage life of the fruit of the studied strawberry cultivars (Tables 4–6, Figures 1C–F and 2–4).

The strawberries of all cultivars stored in CA were firmer than those stored under AA conditions. The only exception was the firmness of strawberries of the cultivar Murano measured in 2018 (Table 6). According to Chandra et al. [52], strawberries hardened as the concentration of CO_2 increased, even for a short time. The beneficial effect of CA conditions on strawberry firmness was demonstrated by Alamar et al. [53]. In addition, storing strawberries in MAP bags usually ensures a higher firmness compared to the fruit from AA, which has been confirmed in previous research [54]. On the other hand, Ozkaya et al. [55] found no significant effect of storage conditions on strawberry firmness. It is worth mentioning that the relatively high firmness after storing of all tested strawberries should ensure their good shelf life in the trade.

Table 4. Effect of storage conditions on the quality of 'San Andreas' strawberries and average for harvest dates.

Year	Storage Conditions	Fruit Firmness [N]	Soluble Solids Content [%]	Total Acidity [% Citric Acid]	Ratio SSC/TA	Respiration Rate [mg $CO_2 kg^{-1} h^{-1}$]
2018	AA	3.6 ± 0.40 a *	8.7 ± 0.72 b	0.90 ± 0.05 b	9.7 ± 1.28 a	63.6 ± 22.86 c
	MAP	4.0 ± 0.56 b	8.4 ± 0.68 a	0.87 ± 0.04 ab	9.8 ± 1.16 a	35.0 ± 9.98 a
	CA	4.1 ± 0.80 b	8.4 ± 0.76 a	0.85 ± 0.06 a	9.9 ± 1.40 a	48.4 ± 12.04 b
2019	AA	3.5 ± 0.69 a	8.8 ± 1.34 b	0.89 ± 0.09 a	9.6 ± 1.70 a	80.2 ± 24.44 c
	MAP	3.6 ± 0.79 a	9.0 ± 1.47 c	0.90 ± 0.12 ab	9.9 ± 1.79 b	64.3 ± 23.46 a
	CA	4.0 ± 1.03 b	8.6 ± 1.31 a	0.92 ± 0.11 b	9.7 ± 1.59 ab	69.9 ± 14.75 b
2020	AA	3.7 ± 0.41 a	8.4 ± 0.67 b	0.86 ± 0.07 b	9.8 ± 0.98 a	69.8 ± 26.64 c
	MAP	3.9 ± 0.52 b	8.3 ± 0.69 b	0.83 ± 0.07 a	10.1 ± 1.13 a	53.6 ± 23.78 a
	CA	4.1 ± 0.42 c	8.1 ± 0.70 a	0.82 ± 0.05 a	10.0 ± 1.22 a	64.7 ± 25.76 b

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Table 5. Effect of storage conditions on the quality of 'Albion' strawberries and average for harvest dates.

Year	Storage conditions	Fruit Firmness [N]	Soluble Solids Content [%]	Total Acidity [% Citric Acid]	Ratio SSC/TA	Respiration Rate [mg $CO_2 kg^{-1} h^{-1}$]
2018	AA	3.6 ± 0.74 a *	9.9 ± 1.16 a	0.97 ± 0.12 a	10.2 ± 1.88 a	69.5 ± 30.14 b
	MAP	3.7 ± 0.68 ab	10.1 ± 1.24 a	0.94 ± 0.10 a	10.7 ± 1.64 a	52.7 ± 21.34 a
	CA	4.0 ± 0.70 b	10.1 ± 1.22 a	0.95 ± 0.13 a	10.6 ± 1.79 a	58.4 ± 20.96 a
2019	AA	3.2 ± 0.66 a	9.9 ± 1.91 a	0.93 ± 0.11 a	10.9 ± 2.25 a	82.3 ± 23.54 c
	MAP	3.5 ± 0.77 b	9.9 ± 1.95 a	0.94 ± 0.14 a	10.7 ± 2.36 a	54.5 ± 18.91 a
	CA	3.8 ± 0.87 c	9.8 ± 1.82 a	0.93 ± 0.12 a	10.8 ± 2.11 a	61.1 ± 34.69 b
2020	AA	3.5 ± 0.60 a	9.1 ± 1.18 ab	0.87 ± 0.10 b	10.5 ± 1.65 a	91.5 ± 34.75 c
	MAP	3.7 ± 0.63 b	8.9 ± 1.10 a	0.81 ± 0.10 a	11.1 ± 1.87 b	54.8 ± 23.63 a
	CA	4.3 ± 0.78 c	9.2 ± 1.07 b	0.80 ± 0.09 a	11.6 ± 1.52 c	61.1 ± 14.94 b

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Table 6. Effect of storage conditions on the quality of 'Murano' strawberries and average for harvest dates.

Year	Storage Conditions	Fruit Firmness [N]	Soluble Solids Content [%]	Total Acidity [% Citric Acid]	Ratio SSC/TA	Respiration Rate [mg $CO_2 kg^{-1} h^{-1}$]
2018	AA	4.1 ± 0.84 a *	10.5 ± 1.46 b	0.89 ± 0.10 b	11.8 ± 1.18 a	77.3 ± 30.78 c
	MAP	4.0 ± 0.76 a	10.3 ± 1.22 ab	0.80 ± 0.08 a	12.9 ± 1.48 b	28.9 ± 18.88 a
	CA	4.2 ± 0.92 a	10.0 ± 1.40 a	0.80 ± 0.09 a	12.5 ± 1.42 b	53.5 ± 24.06 b
2019	AA	3.0 ± 0.78 a	7.9 ± 1.27 a	0.59 ± 0.11 a	13.4 ± 1.93 c	56.4 ± 30.82 c
	MAP	4.0 ± 0.37 c	8.6 ± 1.20 b	0.70 ± 0.12 b	12.4 ± 1.65 b	32.5 ± 21.69 a
	CA	3.8 ± 0.30 b	8.1 ± 1.20 a	0.71 ± 0.11 b	11.4 ± 1.64 a	39.9 ± 14.14 b
2020	AA	4.5 ± 0.89 a	10.2 ± 1.55 b	0.76 ± 0.08 b	13.6 ± 1.35 a	64.2 ± 23.96 c
	MAP	5.4 ± 0.88 b	9.8 ± 1.48 a	0.70 ± 0.07 a	14.0 ± 1.63 b	45.0 ± 20.26 a
	CA	6.1 ± 1.05 c	10.0 ± 1.63 ab	0.71 ± 0.10 a	14.0 ± 1.59 b	60.4 ± 20.37 b

* Means followed by the same letter within a column, for each year, do not differ significantly at $p \leq 0.05$.

Strawberries of the cultivar 'San Andreas' stored in the AA combination always contained more extracts than the fruit stored under CA (Table 4). The same relationship was found only in 2018 for the cultivar 'Murano' (Table 6).

The effect of storage conditions on the total acidity of strawberries was generally significant, but the value of the discussed characteristic varied depending on the cultivar, storage conditions and study year (Tables 4–6). Strawberry varieties of all tested cultivars in 2020 and strawberries of cultivar 'Murano' in 2018 stored in AA conditions had a higher total acidity than the fruit from MAP and CA. Holcroft and Kader [56] recorded lower titratable acidity in the fruit stored in a high CO_2 atmosphere.

Ozkaya et al. [55] did not prove a significant effect of storage conditions on either SSC or TA values. On the other hand, Abu Zahra [20] showed a higher SSC content and lower

TA in strawberries stored in MAP compared to AA-derived fruit. The results of Ebstam et al. [54] demonstrated a higher TA and lower SSC content in strawberries from MAP compared to the control fruit.

The storage conditions of the strawberries of the cultivars 'San Andreas' and 'Albion' significantly influenced the value of the SSC/TA ratio, but only in one of the three years of the study (Tables 4 and 5), while this effect was recorded for the cultivar 'Murano' every year (Table 6). The strawberries of the cultivars 'Albion' and 'Murano' from the combination of AA were characterized by a lower SSC/TA ratio compared to the fruit from the MAP and CA conditions, with the exception of the highest value of the described trait observed in 2019 in the 'Murano' strawberries stored under the AA conditions (Table 6).

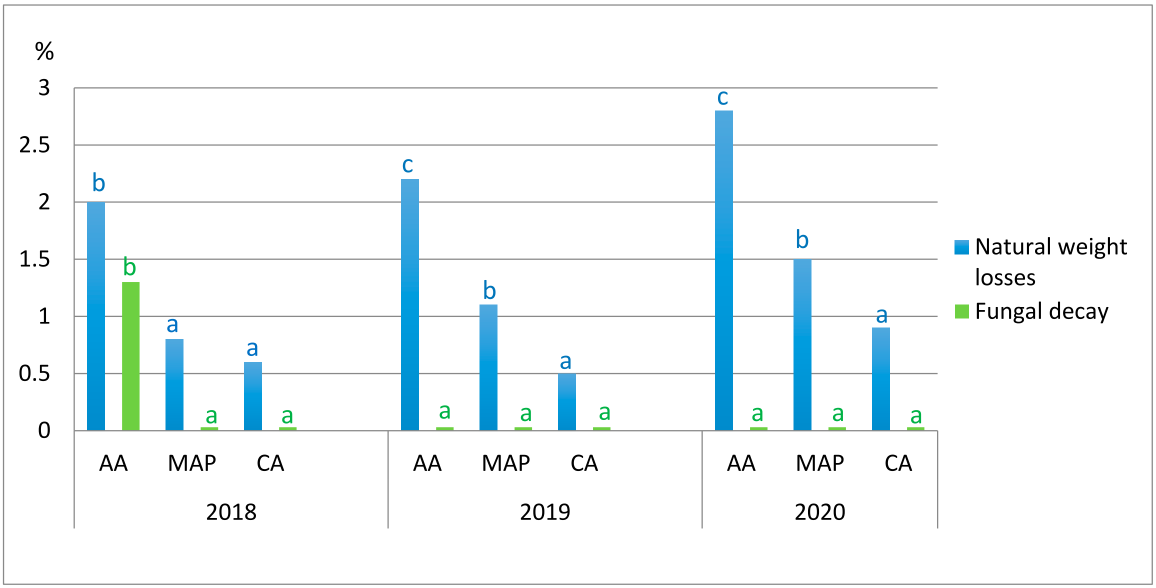

Figure 2. Natural weight losses (%) and fungal decay (%) of 'San Andreas' strawberries as affected by storage conditions. Bars characterizing fungal decay should be green (like the letters) blue letters and bars refer to weight mass losses.

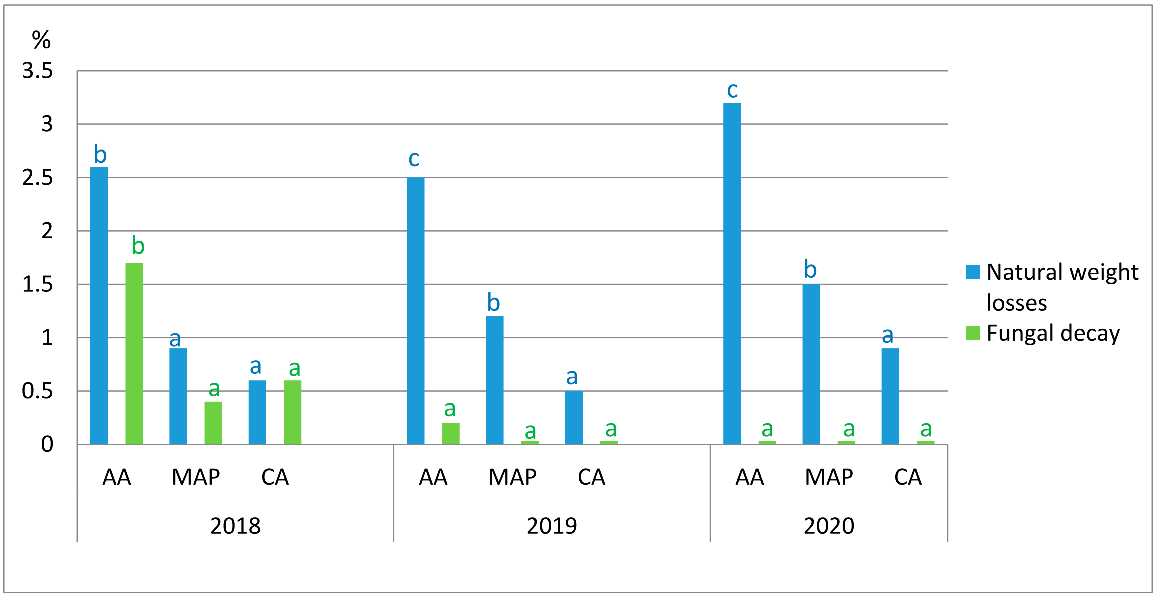

Figure 3. Natural weight losses (%) and fungal decay (%) of 'Albion' strawberries as affected by storage conditions. Bars characterizing fungal decay should be green (like the letters) blue letters and bars refer to weight mass losses.

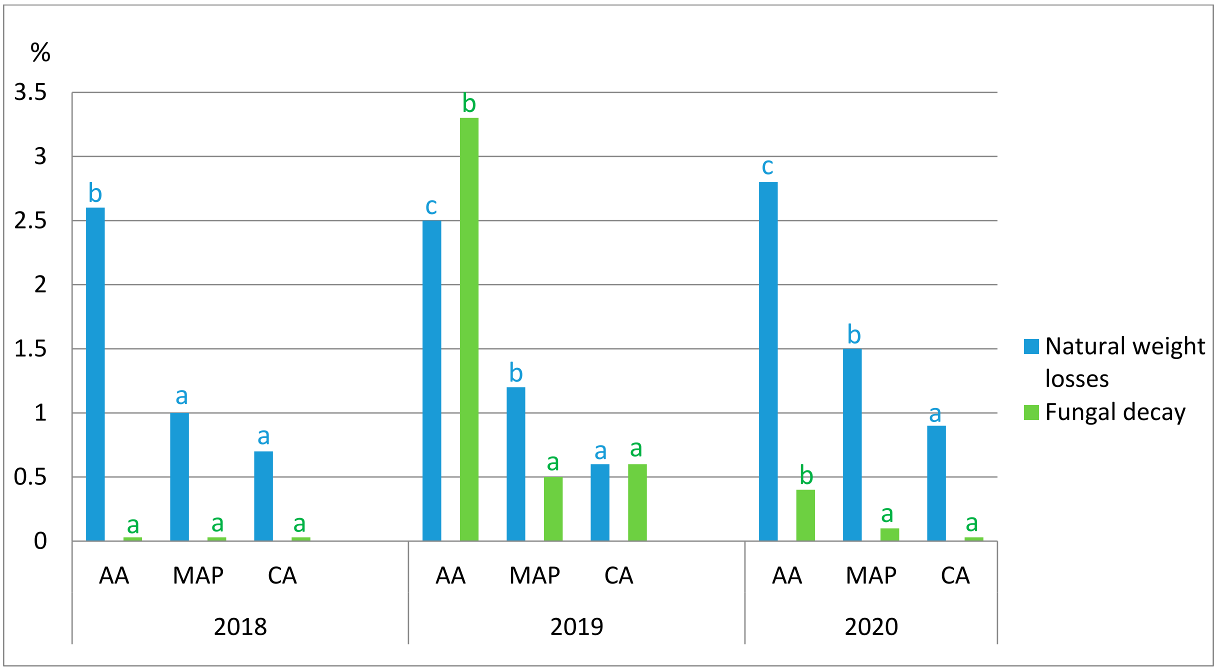

Figure 4. Natural weight losses (%) and fungal decay (%) of 'Murano' strawberries as affected by storage conditions. Bars characterizing fungal decay should be green (like the letters) blue letters and bars refer to weight mass losses.

In each study year, all strawberries stored in MAP bags were characterized by the lowest respiratory intensity, and the fruit from the AA combination showed the highest value of this characteristic (Tables 4–6). The results of the current study did not support the suggestion that high CO_2 levels reduced the respiration rate of strawberries [57,58].

The natural weight loss caused by transpiration and respiration depended on the storage conditions of the strawberries (Figures 2–4). Strawberries stored under AA conditions always showed the highest weight loss. This observation was confirmed by the results of the studies by Panda et al. [59], Choi et al. [60] and Abu Zahra [20]. Fruits from MAP bags tended to have lower weight losses, while the lowest losses were recorded for strawberries stored in CA.

Ozkaya et al. [55] reported that the storage of cv. Camarosa strawberries in MAP bags resulted in a lower fruit weight loss compared to the AA conditions. Peano et al. [29] showed that the weight loss of Envie2 strawberries stored for 96 hours in foil packaging did not exceed 1%. Robinson et al. [61] reported that a 6% loss in initial fresh weight of soft fruit should be considered the limit of marketability. According to Shiina [62], the commercial value of berries would be lost if their water content was reduced by 5% or more. In our research, the weight losses of the stored strawberries were significantly lower.

The strawberries of the studied cultivars were distinguished by low susceptibility to fungal storage diseases, as evidenced by the small percentage of rotten fruit recorded during the study (Figures 2–4). The only disease whose symptoms were observed on the fruit was grey mold caused by *Botritis cinerea* Pers. The impact of the storage conditions of 'San Andreas' strawberries on the incidence of storage diseases was visible only in the first year of the study, where 1.3% of the fruit of the AA combination was rotten, while the remaining strawberries were healthy (Figure 2). Symptoms of grey mold were observed on strawberries from the cultivar 'Albion' in two study years (Figure 3). In 2018, the percentage of rotten strawberries of AA (1.7%) was significantly higher compared to the fruit stored in MAP bags (0.4%) and in CA (0.6%). The following year, only 0.2% of strawberries in the AA combination were affected by grey mold. Symptoms of the disease on the fruit of the cultivar 'Murano' were observed in the last two years of the study (Figure 4). In 2019, the percentage of rotten strawberries stored in AA (3.3%) was higher than that of the MAP

(0.5%) and CA (0.6%). The results were similar in the following year, when significantly more rotten fruit came from AA (0.4%) compared to MAP (0.1%) and CA (0.0%).

Ozkaya et al. [55] found that MAP bags were more effective than AA conditions in reducing strawberry rot caused by fungal storage diseases. According to Ebtsam et al. [54], MAP significantly prevented strawberry rot and improved their shelf life. In contrast, Abu-Zahra [20] reported different findings, but they resulted from a much longer storage period of strawberries in MAP packages.

4. Conclusions

Remontant strawberry cultivars San Andreas®, Albion® and Murano® grown in gutters under canopies are characterized by good storability, thanks to which they retain high quality and shelf life after 7-day storage.

The harvest date had a significant impact on the value of the analyzed strawberry quality indicators. Fruits harvested on the latest date (September or October) tended to have a higher firmness and extract-to-acid ratio, as well as lower respiration intensity compared to strawberries from earlier harvests (July and August).

Controlled (CA) and modified (MAP) atmosphere conditions ensured better quality of stored strawberries compared to air atmosphere (AA). This was evidenced by the lower respiration rate of strawberries, lower weight loss and typically higher firmness, acidity and health of the fruit. The values of the quality indicators for strawberries stored in a controlled atmosphere and in MAP bags were often comparable. For this reason, MAP packaging can be recommended as a similar effective and significantly cheaper method of short-term strawberry storage than controlled atmosphere.

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