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Effect of Controlled Atmospheres and Environmental Conditions on the Physicochemical and Sensory Characteristics of Sweet Cherry Cultivar Satin

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Abstract: Sweet cherry is a highly appreciated seasonal fruit with a high content of bioactive compounds; however, this highly perishable fruit has a relatively short shelf-life period. Here, we evaluated the evolution of the physicochemical and sensory qualities of sweet cherries (*Prunus avium* (L.) cv. Satin) under different storage conditions, namely at a Farmers' Organization (FO) and in a Research Centre (RC) under normal and four different conditions of controlled atmosphere for 49 days. Additional parameters were monitored, such as rotten fruit incidence and stem appearance. Temperature was the factor that most influenced the fruit quality changes over the study time. In fact, fruits stored at higher mean temperatures showed higher weight loss, higher variation in CIE-Lab colour parameters, higher firmness loss, and browner and more dehydrated stems and were less appealing to the consumer. Controlled atmosphere conditions showed a smaller decrease in CIE-Lab colour parameters and lower weight loss. The incidence of rotting was very low and was always equal or lower than 2% for all conditions. Thus, RC chamber conditions were able to sustain fruit quality parameters over 28 days under normal atmosphere conditions and 49 days under controlled atmosphere conditions.

Keywords: carbon dioxide; controlled atmosphere; refrigeration; sensory evaluation; sweet cherry

1. Introduction

Sweet cherry (*Prunus avium* L.) is a non-climacteric fruit with a significant content of nutrients and bioactive compounds, such as ascorbic acid, fibre, anthocyanins and carotenoids [1,2]. However, this highly perishable fruit has a short marketing period, extending from May in Southern Europe to August in Northern Europe [2,3].

In 2019, the three main global sweet cherry producers were Turkey (664,224 t), USA (321,420 t) and Chile (233,929 t). In the same year, Portugal produced 19,130 t of sweet cherry [4], mainly from the municipalities of Fundão, Covilhã and Belmonte, which are located in the Beira Interior region [5,6].

Sweet cherries deteriorate rapidly after being harvested, especially if stored at room temperature [7]. This may include changes in skin colour, peduncle dehydration and browning, pulp softening, decrease of acidity and rotting [8–11]. Fungal spoilage, especially from the genera *Botrytis*, *Monilia*, *Penicillium* and *Rhizopus*, is the most important reason for sweet cherry post-harvest losses [11–13].

The maturity of a fruit can be defined as the stage of development that is associated with the minimum acceptable quality for the consumer [14]. Soluble solids content (SSC), titrable acidity (TA), the ratio SSC/TA, skin colour and firmness are parameters that have been suggested to be used as indices to evaluate the maturity of sweet cherries [15–19]. More particularly, Crisosto et al. [15] report that, depending on the sweet cherry cultivar, a minimum of light red colour and/or 14% to 16% SSC is required for consumer acceptance.

Refrigeration is the most common technique used to extend fruit shelf life. Combined with refrigeration, controlled atmospheres (CAs) have been shown to help delay fruit quality decay. This technique uses low oxygen (O_2) and high carbon dioxide (CO_2) concentrations to lower the respiration rate and to stop or delay mould development [7,20,21], thus enabling fruit storage for longer time periods.

Specifically, CA conditions may help maintain adequate levels of acidity, brighter skin colour and greener stems [11,22]. High amounts of CO_2 have a fungistatic action (delay of fungal growth), preserving fruit quality and contributing to the extension of fruit shelf life [12,21]. Additionally, CA conditions induce metabolic changes in volatile compounds, phenolics and pigments [23].

Optimum values for O_2 and CO_2 concentrations vary among different studies. However, intervals are usually between 3% and 10% for O_2 concentration, and between 10% and 15% for CO_2 concentration, according to the review presented in Andrade et al. [24]. Very low concentration of O_2 and/or very high concentration of CO_2 may cause anaerobic fermentation, development of fruit injuries and off-flavours, leading to fruit spoilage [23].

In fact, O_2 concentrations under 1% may result in surface pitting and increase the risk of anaerobic fermentations occurring in the fruit tissues, which leads to the development of off-flavours [25,26], and CO_2 concentrations above 30% may induce skin discoloration and off-flavour occurrence [15].

This study intended to evaluate the effect of different storage conditions and different atmosphere compositions on the quality parameters of sweet cherry cv. Satin, namely loss of weight, CIE-Lab colour, firmness, soluble solids content, titrable acidity, sensorial variables and rotting incidence during a storage period of 49 days.

2. Materials and Methods

2.1. Sweet Cherry Storage Conditions and Sampling

The study was conducted over two years, 2019 and 2020, starting on the harvest day, on 12 June 2019 and on 16 June 2020, for a period of 28 to 49 days (Table 1), and weekly sampling analysis was performed. Sweet cherries came from the same orchard (Fundão, Portugal) to minimize the variability influence of environmental conditions, with the harvest date decided by the Farmers' Organization. However, in both years, the fruits used in the study were further selected to form homogeneous samples in terms of colour and weight.

Table 1. Description of the experimental design used in the sweet cherry cv. Satin conservation study: atmosphere conditions, storage time and location of the refrigeration chambers.

Treatment	Atmosphere	O_2 (%)	CO_2 (%)	Total Storage Time (Days)	Storage Location	Chamber
1	Normal	21	0.04	28	Farmers' Organization	A
2					Research Centre	B
3	Controlled	3	10	49		
4			15			
5		10	10			C
6			15			

This experiment evaluated a total of 6 treatments (Table 1). Treatments 1 and 2 were under normal atmosphere (NA) conditions and treatments 3 to 6 were under controlled atmosphere (CA) conditions. The 6 treatments were organized in 3 refrigeration chambers, named A, B and C. Chamber A was located at FO and received treatment 1 (NA). Chambers B and C were located at RC and received treatments 2 to 6. Chamber B received treatments 2 (NA), 3 (3%O_2–10%CO_2) and 4 (3%O_2–15%CO_2), and chamber C received treatments 5 (10%O_2–10%CO_2) and 6 (10%O_2–15%CO_2). Sampling was performed once a week (every 7 days of storage), except for CA treatments where sampling was initiated after 14 days. The duration of the study was 28 days for NA (treatments 1 and 2) and 49 days for CA (treatments 3 to 6).

Temperature and relative humidity were monitored inside the refrigeration chambers using dataloggers (EL-USB-2-LCD+, Lascar Electronics). The 2 storage locations, namely FO (chamber A) and RC (chambers B and C) had different temperature conditions and similar relative humidity (Table 2).

Table 2. Temperature and relative humidity values in the three chambers of the sweet cherry cv. Satin conservation study. Chamber A was located in FO with treatment 1. Chambers B and C were located in RC with treatments 2 (NA), 3 (3%O_2–10%CO_2), 4 (3%O_2–15%CO_2), 5 (10%O_2–10%CO_2) and 6 (10%O_2–15%CO_2).

		Temperature (°C)			Relative Humidity (%)		
		A (FO)	B (RC)	C (RC)	A (FO)	B (RC)	C (RC)
2019	Mean ± Standard deviation	4.8 ± 2.7	2.0 ± 0.7	1.8 ± 0.6	91.1 ± 2.9	97.1 ± 1.2	97.0 ± 1.5
	Maximum	12.9	10.5	10.8	98.0	99.9	99.1
	Minimum	1.1	1.7	1.6	81.2	84.4	83.9
2020	Mean ± Standard deviation	6.7 ± 1.0	0.9 ± 0.4	1.6 ± 0.7	94.2 ± 3.3	98.7 ± 3.2	98.8 ± 3.3
	Maximum	12.0	6.8	10.7	100.0	100.0	100.0
	Minimum	4.5	0.3	0.6	81.4	60.2	58.8

The mean temperature in the FO (chamber A) was systematically higher than the mean temperatures in RC (chambers B and C), namely, for chamber A, 4.8 ± 2.7 °C (2019) and 6.7 ± 1.0 °C (2020), compared to chamber B, 2.0 ± 0.7 °C (2019) and 0.9 ± 0.4 °C (2020), and chamber C 1.8 ± 0.6 °C (2019) and 1.6 ± 0.7 °C (2020). In terms of relative humidity, all the chambers had an average higher than 90% during storage. According to Crisosto et al. [15], the optimum values of temperature and relative humidity for the storage of sweet cherry are, respectively, −0.5 ± 0.5 °C and 90–95%. All storage chambers were above that interval, yet the mean value of temperature from chamber A (FO) was significantly higher. The mean values found for the relative humidity were near (chamber A) or slightly above (chambers B and C) the recommended interval [15].

The sweet cherries used in the study were selected to be homogeneous both in colour and weight. For the physicochemical analysis, a total of 60 sweet cherries per treatment and sampling day were individually numbered and distributed in 3 small netted baskets (20 sweet cherries per basket). Each small basket was filled with 30 more cherries (to a total of 50 cherries), which were not used in the physicochemical analysis. The basket was then placed in the middle of a 5 kg tray with approximately 4500 cherries, simulating commercial storage conditions (Figure 1). The evaluation of stem aspects and rotting incidence was done with 50 sweet cherries per treatment and sampling day, corresponding to 1 full netted basket. These sweet cherries were not numbered and received only minimum handling to avoid unnecessary contamination.

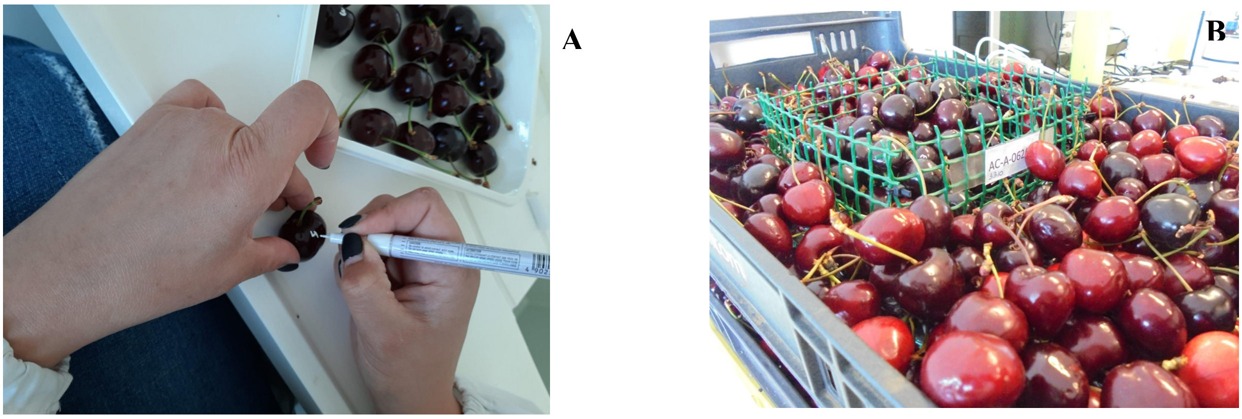

Figure 1. Sweet cherries cv. Satin numbering (**A**) and netted basket with the numbered sweet cherries placed in the centre of a 5 kg commercial tray (**B**).

Fruit trays were stored on euro-sized pallets; CA treatments were covered and sealed with an LDPE plastic bag connected to a GAC 5000 unit (Fruitcontrol Equipment S.R.L.) to monitor and add gases when necessary (Figure 2). Gases used in the study were CO_2 (Biogon® C, E290, Linde), N_2 (Nitrogen 30, Sysadvance) and O_2 (air compressor, HYAC24-2, Hyundai).

Figure 2. LDPE plastic bag cover of controlled atmosphere treatments and connection to the GAC 5000 unit for gas monitoring and control.

2.2. Fruit Quality Evaluation

2.2.1. Physicochemical Analysis

At day 0 (harvest), a sample of 60 fruits was used as a start reference based on the determination of weight, CIE-Lab colour parameters, firmness, soluble solids content (SSC) and titrable acidity. Additionally, all marked sweet cherries (60 cherries per treatment and sampling day) were individually evaluated for weight (digital scale, TE1502S, Sartorius) and colour, the 2 non-destructive parameters that can be monitored throughout the storage period.

Every sampling day, the weight, CIE-Lab colour parameters, firmness, SSC and titrable acidity were measured.

Weight loss (Δw) was expressed as a percentage of the initial weight. It was determined for each numbered sweet cherry by the ratio between the weight difference and the fruit weight on day 0. The weight difference corresponds to the difference between the weight on the sampling day and the weight on day 0.

Colour was evaluated on opposite sides of the numbered fruit with a tristimulus colorimeter (CR-400 Chroma Meter, Konica Minolta), the illuminant D65 and the software Colour DATA CM-S100w. CIE-Lab colour space was used. The differences in each colour parameter (ΔL, Δa and Δb) were determined between the sampling day and day 0.

SSC was determined using the refractometer PR-32 alpha, Atago. Results were expressed as °Brix.

Firmness was obtained by compressing the sample against a flat surface (TA-XTplus, Stable Microsystems), using a flat 75 mm diameter (P/75). The deformation rate was set to 5%, and the deformation speed to 1 mm/s. The results were expressed in newtons (N).

Titrable acidity was determined in the 3 sub-samples of 6–7 fruits (split of the 20 fruits) by potentiometric titration to pH 8.1, with a solution of NaOH 0.1 mol dm^{-3} using an automatic titrator (Titromatic 2S+3B, Crison) and the software TiCom. The results were expressed as the equivalent percentage of malic acid.

2.2.2. Rotten Fruit Evaluation

The incidence of rotten fruit was evaluated by direct observation based on the 50 fruits of the minimally handled tray. Results were expressed as a percentage.

2.2.3. Stem Visual Aspect

The visual stem aspect was determined using a scale of 1 to 5 (1—all brown and dry; 5—all green and turgid), created for this study (Figure 3).

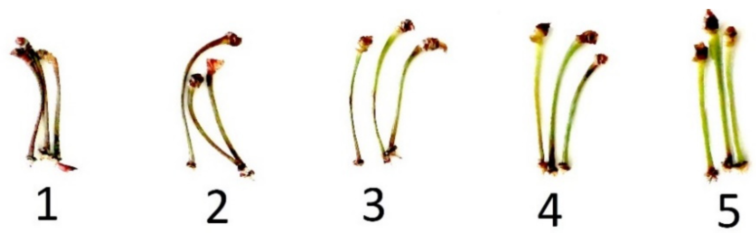

Figure 3. Scale used to classify the aspects of stems, ranging from 1 (completely brown and dehydrated) to 5 (completely green and fresh).

2.2.4. Sensory Evaluation

The sensory evaluation was conducted in a sensory laboratory designed in accordance with ISO 8589 [27]. Parameters included the visual classification of the sweet cherry (aspect), firmness, juiciness, flavour and the overall sensory classification (global score). These parameters were evaluated by 10 consumers using a 9-point scale (1—dislike extremely, 5—neither like nor dislike, 9—like extremely). A minimum classification of 5 was defined as an acceptance indicator. The samples were presented randomly in Petri dishes, coded with a three digit number. Consumers were asked to rinse their palate with water after the evaluation of each sample.

2.2.5. Statistical Analysis

Statistical analysis was performed with SPSS 23 (IBM). For the physicochemical variables, the comparisons between means were performed with an Analysis of Variance (ANOVA), and the means were ordered using the Tukey HSD post hoc test. For the sensory variables, a Kruskal-Wallis test was used [28]. Statistical differences were accepted if $p < 0.05$.

3. Results and Discussion

3.1. Fruit Quality Evaluation

3.1.1. Physicochemical Analysis—Initial Conditions

Table 3 presents the initial values of weight, CIE-Lab colour variables, firmness, soluble solids content and titrable acidity. Colour-related variables, especially *a** and *b**, showed the highest variation between the 2 years, probably because of the natural heterogeneity of sweet cherry skin colour. Nevertheless, the values found in *L** were similar to what was reported by Harb et al. [29] for cv. Regina, more precisely, 27.9 and 29.0 in their studies conducted in 2001 and 2002, respectively. Firmness values, 3.17 N in 2019 and 3.85 N in 2020, were similar or slightly higher than those found by Paulo et al. [30] for cv. Sweetheart (2.9–3.3 N).

Table 3. Initial values of the physicochemical variables evaluated in the sweet cherry cv. Satin conservation study for each of the 2 years of analysis.

	Weight (g)	*L**	*a**	*b**	Firmness (N)	SSC (°Brix)	Titrable Acidity (% Malic Acid)
2019	9.36	33.35	24.25	8.20	3.17	16.92	0.50
2020	10.37	29.66	12.26	2.51	3.85	16.76	0.42

SSC—soluble solids content.

The values found for SSC, 16.92 °Brix (2019) and 16.76 °Brix (2020), were similar to the 16.1 °Brix reported by Costa [31], which indicates a high sugar content characteristic of this production region, where SSC frequently is over 20 °Brix. Simões et al. [32], using 12 cultivars, observed a minimum of 15.5 °Brix (cv. Earlise) and a maximum SSC of 24.4 °Brix (cv. Sweetheart). Remón et al. [22] reported 14.7 °Brix found in cv. Burlat, Akbudak et al. [33] reported an SSC of 13.8 °Brix for cv. 0900, and Ziraat and Dziedzic et al. [2] reported values between 14.8 °Brix and 16.6 °Brix for cv. Regina.

The acidity was 0.50% (2019) and 0.42% (2020), which is a lower value compared to other results. The values of titrable acidity are mainly determined by the cultivar, but there is also an influence of weather conditions. Costa [31] reported 0.77% for cv. Satin in the Beira Interior region. The titrable acidity levels found in the literature were also higher, more precisely, 0.66% for cv. Burlat [22], 0.7% for cv. 0900 Ziraat [33] and between 0.57% and 0.74% for cv. Regina [2].

3.1.2. Physicochemical Analysis—Weight Losses

Weight losses were higher in treatment 1 and significantly increased throughout the storage time, both in 2019 and in 2020 (Tables 4 and 5), reaching −8.83% in 2019 and −10.50% in 2020, after 28 days of storage. For treatment 2, weight loss reached −1.36% in 2019 and a residual value of −0.30% in 2020. This low value of 2020 was related to some condensation due to the proximity of an evaporator. Under CA conditions (treatments 3 to 6), it was always below −3.0% at the end of storage period of 49 days. In 2019, there were no significant differences in weight loss over the storage period for treatment 6 in 2019 and for treatments 4 and 5 in 2020. Globally, CA conditions correspond to lower weight losses, which is in accordance with Akbudak et al. [11,33], who reported higher weight losses under normal atmosphere (NA) conditions when compared to CA. However, the influence of different CA conditions on weight loss is not consensual among the reported studies. For example, Harb et al. [29] reported small or insignificant differences between the different treatments. Nevertheless, Akbudak et al. [11] pointed out that the water vapour accumulated inside the CA containers may have influenced the lower weight losses under these conditions. Sweet cherry low skin diffusion resistance and high surface/volume ratio increases the chances of weight loss [2,13].

Table 4. Comparison of physicochemical variables between treatments and sampling days in 2019 evaluated in the sweet cherry cv. Satin conservation study. Treatment 1 was located at the FO under normal atmosphere conditions. Treatments 2 to 6 were located at the Research Centre. Treatment 2 was under normal atmosphere conditions. The atmosphere compositions of treatments 3 to 6 were 3%O_2–10%CO_2, 3%O_2–15%CO_2, 10%O_2–10%CO_2 and 10%O_2–15%CO_2, respectively.

	Treat	7 d	14 d	21 d	28 d	35 d	42 d	49 d
Δ*w* (%)	1	−2.95 $^{\text{A}}$ ± 0.60	−4.92 $^{\text{B-e}}$ ± 1.36	−7.18 $^{\text{C-d}}$ ± 1.68	−8.83 $^{\text{D-b}}$ ± 1.93			
	2	−0.66 $^{\text{A}}$ ± 0.19	−0.64 $^{\text{A-a}}$ ± 0.28	−0.92 $^{\text{B-a}}$ ± 0.28	−1.36 $^{\text{C-a}}$ ± 6.84			
	3		−1.51 $^{\text{A-bc}}$ ± 0.60	−1.51 $^{\text{A-b}}$ ± 0.47	−1.49 $^{\text{A-a}}$ ± 0.50	−1.64 $^{\text{AB-a}}$ ± 0.75	−1.92 $^{\text{B-ns}}$ ± 0.91	−1.99 $^{\text{B-b}}$ ± 0.99
	4		−1.22 $^{\text{A-b}}$ ± 0.30	−1.75 $^{\text{BC-bc}}$ ± 1.41	−1.52 $^{\text{AB-a}}$ ± 0.60	−1.79 $^{\text{BC-a}}$ ± 0.50	−2.09 $^{\text{CD}}$ ± 0.70	−2.37 $^{\text{D-b}}$ ± 0.95
	5		−1.76 $^{\text{AB-c}}$ ± 0.44	−1.77 $^{\text{ABC-bc}}$ ± 0.56	−2.28 $^{\text{C-a}}$ ± 0.62	−1.95 $^{\text{BC-a}}$ ± 0.96	−2.11 $^{\text{BC}}$ ± 1.17	−1.41 $^{\text{A-a}}$ ± 1.63
	6		−2.24 $^{\text{NS-d}}$ ± 0.51	−2.20 $^{\text{c}}$ ± 0.62	−2.32 $^{\text{a}}$ ± 1.00	−2.64 $^{\text{b}}$ ± 1.38	−2.39 ± 0.95	−2.36 $^{\text{b}}$ ± 1.01
Δ*L**	1	0.43 $^{\text{A}}$ ± 1.06	−1.21 $^{\text{B-c}}$ ± 1.28	−3.06 $^{\text{C-d}}$ ± 2.26	−1.23 $^{\text{B-c}}$ ± 1.69			
	2	−0.57 $^{\text{A}}$ ± 0.96	−1.27 $^{\text{B-c}}$ ± 1.25	−2.06 $^{\text{C-c}}$ ± 1.51	−0.26 $^{\text{A-b}}$ ± 0.95			
	3		0.14 $^{\text{D-a}}$ ± 1.44	1.68 $^{\text{B-a}}$ ± 1.60	0.88 $^{\text{C-a}}$ ± 0.65	1.32 $^{\text{BC-ns}}$ ± 0.74	2.44 $^{\text{A-ns}}$ ± 0.77	−0.17 $^{\text{D-b}}$ ± 2.31
	4		−0.04 $^{\text{D-a}}$ ± 0.98	0.08 $^{\text{D-b}}$ ± 0.85	1.32 $^{\text{BC-a}}$ ± 0.60	1.49 $^{\text{B}}$ ± 0.87	2.60 $^{\text{A}}$ ± 1.17	0.84 $^{\text{C-a}}$ ± 1.00
	5		−0.23 $^{\text{D-ab}}$ ± 0.80	−0.25 $^{\text{D-b}}$ ± 1.26	0.82 $^{\text{C-a}}$ ± 0.95	1.51 $^{\text{B}}$ ± 0.76	2.63 $^{\text{A}}$ ± 0.89	0.75 $^{\text{C-a}}$ ± 0.90
	6		−0.79 $^{\text{D-bc}}$ ± 1.47	−0.02 $^{\text{C-b}}$ ± 0.78	0.82 $^{\text{B-a}}$ ± 0.79	1.25 $^{\text{B}}$ ± 1.54	2.30 $^{\text{A}}$ ± 1.32	0.96 $^{\text{B-a}}$ ± 0.98
Δ*a**	1	−2.48 $^{\text{A}}$ ± 1.96	−4.18 $^{\text{A-c}}$ ± 3.59	−10.46 $^{\text{B-c}}$ ± 4.68	−10.66 $^{\text{B-c}}$ ± 4.15			
	2	−1.74 $^{\text{A}}$ ± 1.22	−2.70 $^{\text{B-b}}$ ± 1.39	−4.01 $^{\text{C-b}}$ ± 1.45	−6.54 $^{\text{D-b}}$ ± 1.71			
	3		−0.83 $^{\text{A-a}}$ ± 2.20	−1.20 $^{\text{AB-a}}$ ± 3.22	−2.43 $^{\text{BC-a}}$ ± 0.92	−3.39 $^{\text{CD-ab}}$ ± 1.39	−4.74 $^{\text{DE-ns}}$ ± 1.22	−5.27 $^{\text{E-b}}$ ± 5.16
	4		−1.03 $^{\text{A-a}}$ ± 1.18	−1.86 $^{\text{B-a}}$ ± 0.84	−2.33 $^{\text{C-a}}$ ± 1.14	−3.85 $^{\text{C-b}}$ ± 1.31	−4.87 $^{\text{D}}$ ± 1.55	−3.32 $^{\text{C-a}}$ ± 1.63
	5		−1.33 $^{\text{A-a}}$ ± 1.17	−1.75 $^{\text{A-a}}$ ± 1.31	−2.49 $^{\text{B-a}}$ ± 1.20	−2.87 $^{\text{B-a}}$ ± 1.12	−4.22 $^{\text{C}}$ ± 1.30	−2.49 $^{\text{B-a}}$ ± 1.11
	6		−1.55 $^{\text{A-a}}$ ± 1.25	−1.83 $^{\text{A-a}}$ ± 1.11	−2.10 $^{\text{A-a}}$ ± 0.97	−3.79 $^{\text{BC-ab}}$ ± 1.42	−4.55 $^{\text{C}}$ ± 2.30	−3.39 $^{\text{B-a}}$ ± 1.75
Δ*b**	1	−0.36 $^{\text{A}}$ ± 1.14	−1.59 $^{\text{B-b}}$ ± 1.98	−4.39 $^{\text{C-d}}$ ± 3.32	−3.31 $^{\text{C-c}}$ ± 2.77			
	2	0.63 $^{\text{A}}$ ± 0.66	−1.32 $^{\text{B-b}}$ ± 1.24	−2.30 $^{\text{C-c}}$ ± 1.52	−1.96 $^{\text{C-b}}$ ± 1.31			
	3		0.23 $^{\text{AB-a}}$ ± 1.37	0.49 $^{\text{A-a}}$ ± 1.63	−0.52 $^{\text{BC-a}}$ ± 0.75	−0.37 $^{\text{ABC-b}}$ ± 0.88	−0.69 $^{\text{C-b}}$ ± 0.99	−2.21 $^{\text{D-b}}$ ± 3.29
	4		−0.14 $^{\text{NS-a}}$ ± 0.65	−0.42 $^{\text{b}}$ ± 0.50	−0.07 $^{\text{a}}$ ± 0.64	−0.36 $^{\text{b}}$ ± 1.01	−0.44 $^{\text{ab}}$ ± 1.03	−0.41 $^{\text{a}}$ ± 1.01
	5		−0.13 $^{\text{AB-a}}$ ± 0.91	−0.44 $^{\text{B-b}}$ ± 0.92	−0.35 $^{\text{B-a}}$ ± 0.96	0.13 $^{\text{A-a}}$ ± 0.66	−0.01 $^{\text{AB-a}}$ ± 0.92	−0.08 $^{\text{AB-a}}$ ± 0.89
	6		−0.23 $^{\text{NS-a}}$ ± 0.67	−0.16 $^{\text{ab}}$ ± 0.52	0.11 $^{\text{a}}$ ± 0.69	−0.27 $^{\text{ab}}$ ± 0.89	−0.32 $^{\text{ab}}$ ± 1.56	−0.09 $^{\text{a}}$ ± 0.98
Firmness (N)	1	2.68 $^{\text{A}}$ ± 0.53	2.39 $^{\text{B-c}}$ ± 0.54	2.22 $^{\text{B-c}}$ ± 0.49	1.92 $^{\text{C-d}}$ ± 0.53			
	2	3.42 $^{\text{NS}}$ ± 0.61	3.57 $^{\text{a}}$ ± 0.84	3.72 $^{\text{a}}$ ± 0.82	3.75$^{\text{a}}$ ± 0.72			
	3		3.35 $^{\text{B-ab}}$ ± 0.76	3.94 $^{\text{A-a}}$ ± 0.87	3.72 $^{\text{AB-a}}$ ± 0.85	3.58 $^{\text{AB-b}}$ ± 0.76	3.97 $^{\text{A-ns}}$ ± 1.06	3.73 $^{\text{AB-ns}}$ ± 0.71
	4		3.58 $^{\text{NS-a}}$ ± 0.81	3.65 $^{\text{ab}}$ ± 0.87	3.59 $^{\text{ab}}$ ± 0.91	3.77 $^{\text{b}}$ ± 0.83	3.81 ± 0.91	3.91 ± 0.75
	5		3.32 $^{\text{BC-ab}}$ ± 0.80	3.66 $^{\text{AB-ab}}$ ± 0.82	3.23 $^{\text{C-bc}}$ ± 0.69	3.76 $^{\text{A-a}}$ ± 1.01	3.53 $^{\text{ABC}}$ ± 0.88	3.48 $^{\text{ABC}}$ ± 0.71
	6		3.15 $^{\text{B-b}}$ ± 0.67	3.27 $^{\text{AB-b}}$ ± 0.73	3.12 $^{\text{B-c}}$ ± 0.73	3.56 $^{\text{A-b}}$ ± 0.82	3.57 $^{\text{A}}$ ± 0.96	3.64 $^{\text{A}}$ ± 0.71
SSC (°Brix)	1	16.63 $^{\text{B}}$ ± 1.81	17.60 $^{\text{AB-a}}$ ± 2.46	17.79 $^{\text{A-a}}$ ± 2.44	18.56 $^{\text{A-a}}$ ± 2.73			
	2	16.27 $^{\text{NS}}$ ± 1.27	16.33 $^{\text{b}}$ ± 1.76	16.25 $^{\text{b}}$ ± 2.07	16.70 $^{\text{bc}}$ ± 2.16			
	3		16.70 $^{\text{AB-ab}}$ ± 1.94	16.68 $^{\text{AB-ab}}$ ± 1.67	17.33 $^{\text{A-bc}}$ ± 2.05	16.16 $^{\text{BC-b}}$ ± 2.47	15.94 $^{\text{BC-ns}}$ ± 1.59	15.64 $^{\text{C-ns}}$ ± 2.09
	4		17.06 $^{\text{AB-ab}}$ ± 2.71	17.22 $^{\text{A-ab}}$ ± 1.79	17.09 $^{\text{AB-bc}}$ ± 2.92	16.55 $^{\text{AB-b}}$ ± 2.49	16.40 $^{\text{AB}}$ ± 1.59	15.92 $^{\text{B}}$ ± 1.64
	5		16.90 $^{\text{AB-ab}}$ ± 1.82	16.57 $^{\text{B-b}}$ ± 2.07	16.16 $^{\text{B-c}}$ ± 1.78	17.72 $^{\text{A-a}}$ ± 2.37	16.43 $^{\text{B}}$ ± 1.94	16.06 $^{\text{B}}$ ± 2.07
	6		17.26 $^{\text{AB-ab}}$ ± 2.66	17.81 $^{\text{A-a}}$ ± 3.21	17.39 $^{\text{AB-ab}}$ ± 1.91	16.18 $^{\text{BC-b}}$ ± 2.27	16.45 $^{\text{BC}}$ ± 1.91	15.62 $^{\text{C}}$ ± 1.68
Titrable acidity (% malic acid)	1	0.36 $^{\text{B}}$ ± 0.04	0.44 $^{\text{AB-ns}}$ ± 0.02	0.45 $^{\text{A-ns}}$ ± 0.02	0.43 $^{\text{AB-ns}}$ ± 0.04			
	2	0.45 $^{\text{NS}}$ ± 0.07	0.47 ± 0.04	0.44 ± 0.01	0.47 ± 0.02			
	3		0.43 $^{\text{NS}}$ ± 0.06	0.45 ± 0.04	0.44 ± 0.05	0.39 $^{\text{ns}}$ ± 0.03	0.43 $^{\text{ns}}$ ± 0.03	0.41 $^{\text{ns}}$ ± 0.03
	4		0.48 $^{\text{NS}}$ ± 0.02	0.50 ± 0.08	0.44 ± 0.05	0.41 ± 0.07	0.43 ± 0.05	0.42 ± 0.04
	5		0.44 $^{\text{NS}}$ ± 0.01	0.46 ± 0.03	0.41 ± 0.06	0.43 ± 0.05	0.42 ± 0.02	0.36 ± 0.07
	6		0.47 $^{\text{NS}}$ ± 0.03	0.47 ± 0.04	0.44 ± 0.06	0.39 ± 0.03	0.43 ± 0.01	0.40 ± 0.04

Different capital letters in the same row indicate statistical differences ($p < 0.05$) between sampling days. Different small letters in the same column indicate statistical differences ($p < 0.05$) between treatments. NS—non significant ($p \geq 0.05$) differences between sampling days, ns—non significant ($p \geq 0.05$) differences between treatments.

Comparing results from 2019 and 2020 for treatments 1 and 2, the higher weight losses that occurred in treatment 1 may have been caused by constant exposure to higher storage temperature. This was also noticed and reported by Dziedzic and co-authors [2].

Table 5. Comparison of physicochemical variables between treatments and sampling days in 2020, evaluated in the sweet cherry cv. Satin conservation study. Treatment 1 was located at FO under normal atmosphere conditions. Treatments 2 to 6 were located at RC. Treatment 2 was under normal atmosphere conditions. The atmosphere composition of treatments 3 to 6 was, respectively, 3%O_2–10%CO_2, 3%O_2–15%CO_2, 10%O_2–10%CO_2 and 10%O_2–15%CO_2.

	Treat	7 d	14 d	21 d	28 d	35 d	42 d	49 d
Δ*w* (%)	1	$-3.30^{\text{A}} \pm 0.82$	$-6.06^{\text{B-c}} \pm 1.31$	$-7.22^{\text{C-d}} \pm 1.84$	$-10.50^{\text{D-d}} \pm 2.57$			
	2	$0.96^{\text{B}} \pm 1.24$	$2.12^{\text{A-a}} \pm 1.31$	$-1.08^{\text{D-a}} \pm 0.53$	$-0.30^{\text{C-a}} \pm 0.74$			
	3		$-1.48^{\text{A-b}} \pm 2.63$	$-1.44^{\text{A-ab}} \pm 1.11$	$-1.69^{\text{A-bc}} \pm 0.71$	$-1.66^{\text{A-ns}} \pm 1.15$	$-2.19^{\text{AB-ns}} \pm 1.55$	$-2.96^{\text{B-b}} \pm 2.03$
	4		$-1.41^{\text{NS-b}} \pm 0.48$	$-2.09^{\text{c}} \pm 0.90$	$-1.85^{\text{bc}} \pm 1.36$	-1.71 ± 1.26	-2.05 ± 1.90	$-2.10^{\text{ab}} \pm 1.95$
	5		$-2.05^{\text{NS-b}} \pm 1.51$	$-2.00^{\text{bc}} \pm 0.90$	$-1.58^{\text{b}} \pm 0.72$	-1.95 ± 1.84	-1.97 ± 1.35	$-1.72^{\text{a}} \pm 2.24$
	6		$-1.73^{\text{AB-b}} \pm 0.48$	$-1.71^{\text{A-bc}} \pm 1.05$	$-2.43^{\text{B-c}} \pm 1.52$	$-2.15^{\text{AB}} \pm 1.66$	$-2.33^{\text{AB}} \pm 1.46$	$-2.39^{\text{AB-ab}} \pm 1.63$
Δ*L**	1	$-0.46^{\text{A}} \pm 0.53$	$-0.70^{\text{AB-b}} \pm 0.90$	$-0.93^{\text{B-d}} \pm 0.63$	$-1.28^{\text{C-c}} \pm 0.65$			
	2	$-0.49^{\text{NS}} \pm 0.62$	$-0.41^{\text{ab}} \pm 0.75$	$-0.60^{\text{cd}} \pm 0.75$	$-0.75^{\text{b}} \pm 0.74$			
	3		$-0.25^{\text{A-a}} \pm 0.52$	$-0.61^{\text{B-cd}} \pm 0.59$	$-0.32^{\text{AB-a}} \pm 0.72$	$-0.18^{\text{A-ns}} \pm 0.72$	$-0.28^{\text{AB-ab}} \pm 0.62$	$-0.35^{\text{AB-ns}} \pm 0.65$
	4		$-0.26^{\text{AB-a}} \pm 0.78$	$-0.08^{\text{A-ab}} \pm 0.50$	$-0.34^{\text{AB-a}} \pm 0.68$	$-0.16^{\text{A}} \pm 0.91$	$-0.63^{\text{B-b}} \pm 1.07$	$-0.43^{\text{AB}} \pm 0.78$
	5		$-0.47^{\text{NS-ab}} \pm 0.65$	$-0.38^{\text{bc}} \pm 0.86$	$-0.31^{\text{a}} \pm 0.81$	-0.14 ± 0.75	$-0.37^{\text{ab}} \pm 0.74$	-0.41 ± 0.64
	6		$-0.19^{\text{AB-a}} \pm 0.72$	$0.07^{\text{A-a}} \pm 0.55$	$-0.38^{\text{BC-ab}} \pm 0.55$	$-0.25^{\text{ABC}} \pm 0.65$	$-0.24^{\text{ABC-a}} \pm 0.73$	$-0.53^{\text{C}} \pm 0.71$
Δ*a**	1	$-1.72^{\text{A}} \pm 0.80$	$-3.31^{\text{B-b}} \pm 3.67$	$-5.18^{\text{C-c}} \pm 1.87$	$-5.60^{\text{C-c}} \pm 1.77$			
	2	$-0.62^{\text{A}} \pm 0.70$	$-1.52^{\text{B-a}} \pm 0.65$	$-2.09^{\text{C-b}} \pm 0.85$	$-2.86^{\text{D-b}} \pm 1.10$			
	3		$-0.78^{\text{A-a}} \pm 0.71$	$-1.50^{\text{B-ab}} \pm 1.02$	$-1.41^{\text{B-a}} \pm 1.39$	$-1.71^{\text{BC-ns}} \pm 0.89$	$-2.32^{\text{D-ns}} \pm 0.97$	$-2.17^{\text{C D-ab}} \pm 1.14$
	4		$-1.30^{\text{A-a}} \pm 0.80$	$-1.40^{\text{A-a}} \pm 1.03$	$-1.64^{\text{AB-a}} \pm 0.94$	$-2.21^{\text{BC}} \pm 1.45$	$-2.34^{\text{C}} \pm 1.32$	$-2.70^{\text{C-bc}} \pm 1.37$
	5		$-1.18^{\text{A-a}} \pm 0.98$	$-1.50^{\text{AB-ab}} \pm 1.14$	$-1.81^{\text{BC-a}} \pm 0.94$	$-1.99^{\text{BC}} \pm 1.16$	$-2.32^{\text{C}} \pm 1.06$	$-2.01^{\text{BC-a}} \pm 1.07$
	6		$-1.28^{\text{A-a}} \pm 0.93$	$-1.77^{\text{AB-ab}} \pm 0.90$	$-1.99^{\text{B-a}} \pm 1.21$	$-2.07^{\text{B}} \pm 0.88$	$-2.09^{\text{B}} \pm 1.23$	$-2.76^{\text{C-c}} \pm 1.22$
Δ*b**	1	$-0.24^{\text{A}} \pm 0.32$	$-0.53^{\text{AB-b}} \pm 0.96$	$-0.94^{\text{C-b}} \pm 0.76$	$-0.84^{\text{BC-c}} \pm 0.62$			
	2	$-0.10^{\text{A}} \pm 0.27$	$-0.06^{\text{A-a}} \pm 0.38$	$-0.10^{\text{A-a}} \pm 0.33$	$-0.30^{\text{B-b}} \pm 0.60$			
	3		$0.10^{\text{A-a}} \pm 0.21$	$0.03^{\text{AB-a}} \pm 0.27$	$-0.04^{\text{B-a}} \pm 0.31$	$0.06^{\text{AB-ab}} \pm 0.24$	$-0.07^{\text{B-b}} \pm 0.27$	$0.02^{\text{AB-ns}} \pm 0.29$
	4		$0.04^{\text{NS-a}} \pm 0.19$	$0.08^{\text{a}} \pm 0.28$	$0.09^{\text{a}} \pm 0.24$	$0.16^{\text{ab}} \pm 0.29$	$0.15^{\text{a}} \pm 0.37$	0.07 ± 0.26
	5		$0.00^{\text{NS-a}} \pm 0.28$	$0.03^{\text{a}} \pm 0.32$	$0.04^{\text{a}} \pm 0.38$	$0.03^{\text{b}} \pm 0.41$	$0.05^{\text{ab}} \pm 0.29$	0.15 ± 0.32
	6		$-0.04^{\text{B-a}} \pm 0.30$	$0.05^{\text{AB-a}} \pm 0.28$	$0.09^{\text{AB-a}} \pm 0.32$	$0.17^{\text{A-a}} \pm 0.23$	$0.14^{\text{A-a}} \pm 0.35$	$0.13^{\text{A}} \pm 0.34$
Firmness (N)	1	$3.01^{\text{NS}} \pm 0.75$	$3.02^{\text{d}} \pm 0.61$	$2.72^{\text{d}} \pm 0.68$	$2.91^{\text{b}} \pm 0.91$			
	2	$4.65^{\text{NS}} \pm 1.33$	$4.94^{\text{a}} \pm 0.92$	$4.63^{\text{ab}} \pm 1.12$	$4.94^{\text{a}} \pm 1.04$			
	3		$3.90^{\text{C-bc}} \pm 0.82$	$4.23^{\text{BC-bc}} \pm 0.83$	$4.41^{\text{ABC-a}} \pm 1.16$	$4.77^{\text{A-ns}} \pm 1.07$	$4.38^{\text{ABC-b}} \pm 1.08$	$4.66^{\text{AB-ns}} \pm 0.93$
	4		$4.28^{\text{B-b}} \pm 1.03$	$4.73^{\text{AB-a}} \pm 1.08$	$4.64^{\text{AB-a}} \pm 0.93$	$4.80^{\text{AB}} \pm 1.07$	$5.02^{\text{A-a}} \pm 1.38$	$4.62^{\text{AB}} \pm 0.90$
	5		$4.19^{\text{A-b}} \pm 1.21$	$4.42^{\text{A-ab}} \pm 0.95$	$4.43^{\text{A-a}} \pm 1.03$	$4.62^{\text{A}} \pm 1.18$	$4.25^{\text{A-b}} \pm 0.92$	$4.37^{\text{A}} \pm 0.90$
	6		$3.58^{\text{C-c}} \pm 0.81$	$3.85^{\text{BC-c}} \pm 0.80$	$4.71^{\text{A-a}} \pm 0.98$	$4.53^{\text{A}} \pm 1.03$	$4.24^{\text{AB-b}} \pm 0.91$	$4.38^{\text{A}} \pm 1.13$
SSC (°Brix)	1	$17.11^{\text{NS}} \pm 2.47$	$17.66^{\text{a}} \pm 2.01$	$17.30^{\text{a}} \pm 1.89$	$17.81^{\text{a}} \pm 2.13$			
	2	$16.23^{\text{A}} \pm 1.40$	$15.44^{\text{B-c}} \pm 1.67$	$16.75^{\text{A-abc}} \pm 1.86$	$16.00^{\text{AB-b}} \pm 1.61$			
	3		$16.78^{\text{NS-ab}} \pm 1.94$	$16.61^{\text{abc}} \pm 1.70$	$16.50^{\text{b}} \pm 2.24$	$16.55^{\text{ns}} \pm 1.81$	$16.37^{\text{ns}} \pm 2.01$	$16.97^{\text{a}} \pm 2.48$
	4		$16.06^{\text{NS-bc}} \pm 2.21$	$16.02^{\text{c}} \pm 1.65$	$16.30^{\text{b}} \pm 1.94$	16.61 ± 2.37	16.46 ± 1.74	$15.95^{\text{ab}} \pm 1.75$
	5		$16.67^{\text{NS-ab}} \pm 2.09$	$16.32^{\text{bc}} \pm 2.02$	$16.00^{\text{b}} \pm 1.91$	16.37 ± 1.79	16.38 ± 1.94	$16.36^{\text{ab}} \pm 2.09$
	6		$17.12^{\text{A-ab}} \pm 2.52$	$17.06^{\text{A-ab}} \pm 2.05$	$16.64^{\text{AB-b}} \pm 2.29$	$16.71^{\text{AB}} \pm 1.94$	$16.76^{\text{AB}} \pm 1.86$	$15.66^{\text{B-b}} \pm 2.42$
Titrable acidity (% malic acid)	1	$0.48^{\text{A}} \pm 0.04$	$0.40^{\text{B-ab}} \pm 0.02$	$0.41^{\text{B-ab}} \pm 0.04$	$0.38^{\text{B-ab}} \pm 0.04$			
	2	$0.37^{\text{AB}} \pm 0.03$	$0.38^{\text{AB-b}} \pm 0.03$	$0.40^{\text{A-b}} \pm 0.02$	$0.36^{\text{B-b}} \pm 0.03$			
	3		$0.42^{\text{A-ab}} \pm 0.04$	$0.41^{\text{A-ab}} \pm 0.03$	$0.38^{\text{AB-ab}} \pm 0.02$	$0.36^{\text{B-ns}} \pm 0.04$	$0.35^{\text{B-ns}} \pm 0.03$	$0.34^{\text{B-ns}} \pm 0.03$
	4		$0.44^{\text{A-a}} \pm 0.04$	$0.39^{\text{AB-b}} \pm 0.01$	$0.39^{\text{AB-ab}} \pm 0.04$	$0.36^{\text{BC}} \pm 0.05$	$0.32^{\text{C}} \pm 0.03$	$0.31^{\text{C}} \pm 0.03$
	5		$0.44^{\text{A-a}} \pm 0.04$	$0.41^{\text{AB-ab}} \pm 0.03$	$0.37^{\text{BC-ab}} \pm 0.02$	$0.35^{\text{C D}} \pm 0.03$	$0.33^{\text{C D}} \pm 0.04$	$0.32^{\text{D}} \pm 0.03$
	6		$0.44^{\text{A-a}} \pm 0.04$	$0.44^{\text{A-a}} \pm 0.04$	$0.40^{\text{AB-a}} \pm 0.03$	$0.37^{\text{BC}} \pm 0.03$	$0.36^{\text{BC}} \pm 0.03$	$0.34^{\text{C}} \pm 0.03$

Different capital letters in the same row indicate statistical differences ($p < 0.05$) between sampling days. Different small letters in the same column indicate statistical differences ($p < 0.05$) between treatments. NS—non-significant ($p \geq 0.05$) differences between sampling days, ns—non-significant ($p \geq 0.05$) differences between treatments.

3.1.3. Physicochemical Analysis—CIE-Lab Colour Parameters

The range of Δ*L** values was higher in 2019 than in 2020 (Tables 4 and 5). In the first year, Δ*L** values were between −3.06 (treatment 1, 21 days) and 2.63 (treatment 5, 42 days). However, in 2020 the values were spread between −1.28 (treatment 1, 28 days) and 0.07 (treatment 6, 21 days).

CA conditions resulted mostly in positive values for Δ*L** in 2019 and negative values in 2020. Apart from a global decrease in the values of this variable found in 2019 and 2020 for treatment 1, the other treatments did not show any consistent evolution pattern either in 2019 or in 2020 (Tables 4 and 5), which was contrary to the more prevailing decrease pattern reported in other studies [7,22,33].

The treatments under CA conditions showed lower differences in the *L** value than the treatments under NA between 14 and 28 days of storage (in 2019, Table 4) or at 28 days of storage (in 2020, Table 5), indicating lower differences in the brightness of the fruits. Akbudak et al. [33], working with cv. 0900 Ziraat, also reported lower colour variation in sweet cherries stored under CA conditions. In a similar way, Yang et al. [7] reported that the sweet cherries cv. Lapins under CA conditions which, in their case, included argon (Ar) instead of nitrogen (N_2) as the inert gas (5%O_2–10%CO_2–85%Ar) had higher *L** values than the cherries under NA conditions.

A decreasing tendency was found in Δ*a** for all treatments, pointing to *a** as the main affected colour parameter under storage (Tables 4 and 5), reaching −10.66 (in 2019) and −5.60 (in 2020) in treatment 1. Higher variation of *a** was observed in NA compared to CA, which is consistent with the results of Akbudak et al. [33].

In 2019 (Table 4) and 2020 (Table 5), *b** values showed a decreasing pattern throughout time for NA treatments (treatments 1 and 2) and showed a higher decrease in the *b** value (higher Δ*b** in modulus) than the CA treatments, similar to what was reported by Akbudak et al. [33]. Δ*b** values for CA conditions were always <1 for all treatments and remained stable through time for treatment 4 (2019 and 2020), treatment 6 (2019) and treatment 5 (2020), which means that CA conditions were better at preserving the colour characteristic than NA conditions.

The temperature difference between treatments 1 and 2 may have influenced the CIE-Lab colour parameter evolution, since treatment 1 showed a higher decrease in values than treatment 2 (Tables 4 and 5).

3.1.4. Physicochemical Analysis—Firmness

The fruit firmness from treatment 1 was lower than other treatments after 14 days (Tables 4 and 5), reaching 1.92 N (2019) and 2.91 N (2020). This might have been influenced by different temperature conditions since (a) treatment 2 fruit firmness did not statistically differ (in most cases) from CA fruit firmness treatments (3 to 6) and (b) the fruit firmness of treatment 1 was systematically lower than treatment 2, both under NA conditions. Dziedzic et al. [2] also found lower firmness values for 'Regina' sweet cherries stored under NA at 8 °C than at 2 °C in both years presented (12.2 N vs. 14.1 N in 2011 and 17.1 N vs. 18.9 N in 2012). However, since these authors used a different probe (8 mm) for the firmness determination, the absolute values cannot be directly compared with ours. Nevertheless, the trends between treatments remain valid.

In this study, no differences in fruit firmness between atmosphere compositions were found. However, in most studies, CA treatments showed similar or higher firmness than NA treatments. For example, Dziedzic et al. [2], using cv. Regina, reported mean values of 21.2 N when stored at 2 °C under 3%O_2–5%CO_2 and 18.9 N for NA conditions in their study performed in 2012. However, in the study performed the year before, also presented in the same article, Dziedzic et al. [2] reported similar mean values between CA (14.2 N) and NA (14.1 N) treatments.

Yang et al. [7] also reported a sharper decrease in fruit firmness from 'Lapins' sweet cherries stored under NA when compared to the fruits stored under CA conditions (5%O_2–10%CO_2–85%Ar). After 63 days of storage, the firmness of the fruits under NA was approximately 4 N, while the firmness was 5.5 N under CA treatment.

Treatment 6 (2019) showed an increase of firmness (reaching 3.64 N at 49 days). Similar evolution was also reported by Tian et al. [9] for 'Lapins' sweet cherries stored under CA (5%O_2–10%CO_2).

Globally fruit firmness was higher in 2020. At harvest, fruit firmness was 3.85 N in 2020 compared to 3.17 N in 2019 and remained very stable under CA conditions, inside the interval of 3.58 to 5.02 N in 2019 and 3.15 to 3.97 N in 2020 (Tables 4 and 5).

3.1.5. Physicochemical Analysis—Soluble Solids Content

SSC mean values at day 0 were 16.92 °Brix and 16.76 °Brix (Table 3), higher than the minimum indicated by Crisosto et al. (1996) for acceptable quality (14–16 °Brix).

Neither clear nor systematic evolution patterns throughout time were found (Tables 4 and 5). Treatment 1 showed, at the end of storage period (28 days), the highest values for SSC: 18.56 °Brix in 2019 and 17.81 °Brix in 2020. Our results did not show any relationship between SSC and CA conditions. The results found in the literature regarding the sweet cherry SSC evolution are not consensual. Dziedzic et al. [2] reported an increase of SSC for 'Regina' sweet cherries, higher at 8 °C than at 2 °C, which may be explained by the sugar concentration due to water loss [2] or by the conversion of cell wall polysaccharides into sugar, since sweet cherry starch amount is low [33]. On the other side, Yang et al. [7] reported a decrease in SSC of 'Lapins' sweet cherries, which was lower under CA conditions (5%O_2–10%CO_2).

3.1.6. Physicochemical Analysis—Titrable Acidity

Titrable acidity (TA) is very important for sweet cherry sensorial properties [12]. Starting from a low value of 0.50% (2019) and 0.40% (2020), no significant differences were found for titrable acidity evolution in 2019 (Table 4). In 2020, a decreasing tendency was found for all treatments through storage time (Table 5), which is similar to what was reported by other authors [2,7,12,22,29,33,34]. The use of organic acids as substrates for physiological processes may be one reason for TA decrease [2,33]. However, no differences were found in TA content between CA conditions for >35 d (Table 4). Akbudak et al. [11,33], working with cv. 0900 Ziraat, found higher values for TA in the CA treatments (5%O_2–5% to 25%CO_2) compared to NA conditions, which was not observed in our results.

3.1.7. Visual Observation—Rotten Fruits

Sweet cherries are highly perishable and susceptible to fungal fruit decay. The observation of rotten fruits was low in all results and was equal to or lower than 3% (Table 6). In both years, the first observed rotten fruits occurred after 21 days of storage, sooner than the 30 days reported by Akbudak et al. [11]. Due to a low percentage of rotten fruits, no relationship between the percentage of rotten fruits and atmosphere composition was found, contrary to what was reported by Akbudak et al. [33], who found a lower percentage of rotten fruits in the higher CO_2 treatments (20% CO_2 and 25% CO_2).

Table 6. Percentage of rotten sweet cherries cv. Satin for each year, treatment and storage time. Before 21 days of conservation, no rotten fruits were found. Treatment 1 was located at FO under normal atmosphere conditions. Treatments 2 to 6 were located at RC. Treatment 2 was under normal atmosphere conditions. The atmosphere composition of treatments 3 to 6 was, respectively, 3%O_2–10%CO_2, 3%O_2–15%CO_2, 10%O_2–10%CO_2 and 10%O_2–15%CO_2. Treatments 1 and 2 were evaluated until the 28th day. Treatments 3 to 6 were evaluated until the 49th day. The absence of values indicates 0% rotten sweet cherries.

	Treatment	21 d	28 d	35 d	42 d	49 d
2019	1	3%	2%			
	2		3%			
	3					2%
	4	2%	2%			
	5					
	6					
2020	1	3%	2%			
	2					
	3		2%			
	4					
	5					3%
	6			2%		

N = 50 fruits per treatment and sampling day.

3.1.8. Stem Aspect

Green and non-shrivelling stems are considered a freshness characteristic by consumers [2] and are very important in retail. Stem browning is related to the fact that water evaporates more easily from stems than from fruits [11].

All treatments showed a generic decrease in the mean classification values through the storage time (Figure 4). Treatment 1 had the lowest mean values: one scale point lower on average. This indicates a more severe stem dehydration and browning related to higher storage temperatures.

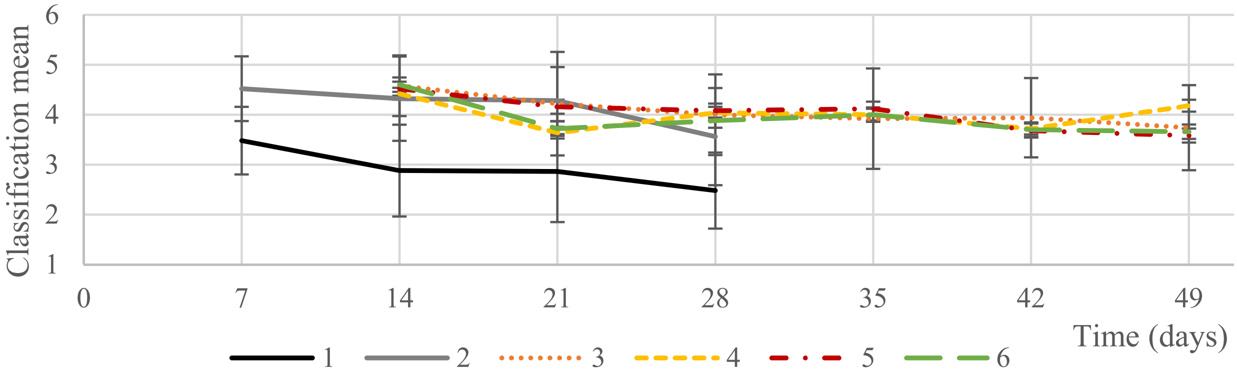

Figure 4. Stem aspect evolution (N = 50) expressed as mean values of the visual classification. Classification (Figure 3, Materials and methods) ranged from 1 (completely brown and dehydrated stem) to 5 (completely green and fresh stem). Treatment 1 was located at FO under normal atmosphere conditions. Treatments 2 to 6 were located at RC. Treatment 2 was under normal atmosphere conditions. The atmosphere compositions of treatments 3 to 6 were, respectively, 3%O_2–10%CO_2, 3%O_2–15%CO_2, 10%O_2–10%CO_2 and 10%O_2–15%CO_2.

CA conditions clearly maintained stems in the same classification throughout storage time. Thus, the browning and shrivelling of stems were kept at a minimum.

Differences were not observed between treatment 2 and CA treatments until 21 days (Figure 2). This indicates that, in our study, NA conditions preserved stem freshness until 21 days and did not differ considerably from CA conditions in the stem aspects. This observation differs from other authors [2,11,23,34]. Nevertheless, Stow et al. [35], working with sweet cherry cultivars Lapins and Colney, reported that, though the percentage of green stems was higher in the treatments with lower O_2 content (0.5% and 1%), it was similar for the control, NA conditions and the treatment with higher CO_2 content (10%), which, in their study, was conjugated with atmosphere O_2 content (21%).

3.1.9. Sensory Evaluation

In 2019, no differences between treatments were found in any sensory variable. In 2020, differences were found only at 28 days of storage for aspect, flavour and global score, and treatment 1 showed the lowest classification (Figure 5). Moreover, at 28 days of storage, the median of aspect scores in treatment 1 was below the minimum defined for sensory acceptance (5 points), which represents the negative influence of a higher storage temperature and not atmosphere composition, since no significant differences were found between treatment 2 (NA) and treatments 3 to 6 (CA).

In 2019, no differences were found between sampling days in any sensory variable, with the exception of aspect and flavour. The medians of the scores given to these two variables were lower at 28 days than at the other sampling days. Nevertheless, all medians of scores were equal or higher than the minimum defined for sensory acceptance (5).

In 2020 there was a global decrease in medians from all CA treatments in the variables of juiciness, flavour and global score. This decrease also occurred for firmness, except for treatment 3. Despite this, and similar to what was found in 2019, the medians of the scores at the end of the study (49 days) were all equal to or higher than the minimum established for sensory acceptance (5).

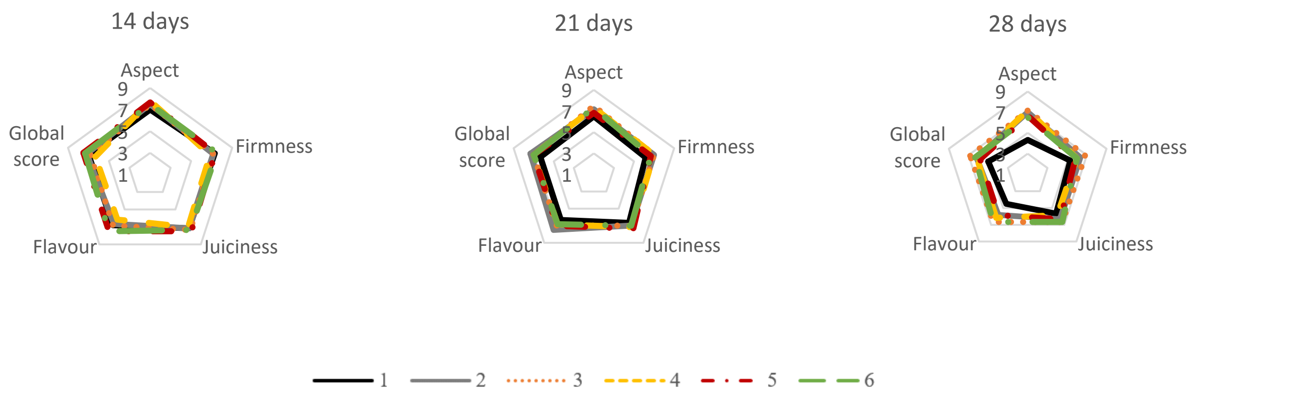

Figure 5. Results from the sensory evaluation of sweet cherries cv. Satin in 2020 after 14 days, 21 days and 28 days. The evaluation followed a 9-point scale ranging from 1 (dislike extremely) to 9 (like extremely). Treatment 1 was located at FO under normal atmosphere conditions. Treatments 2 to 6 were located at RC. Treatment 2 was under normal atmosphere conditions. The atmosphere compositions of treatments 3 to 6 were 3%O_2–10%CO_2, 3%O_2–15%CO_2, 10%O_2–10%CO_2 and 10%O_2–15%CO_2, respectively.

The influence of atmosphere composition in sweet cherry sensory characteristics, more precisely, in flavour, appear to be variable across different cultivars. Wang and Vestrheim [34] reported that atmosphere composition did not significantly influence the flavour of cv. Van, Sam and Stella. Nevertheless, according to the same authors, cv. Kristin, Huldra and Emperor Francis showed higher flavour scores under CA conditions.

4. Conclusions

The mean chamber temperature of the Farmers' Organization was higher than the chambers of the Research Centre, allowing differential treatment conditions. Higher mean storage temperature was correlated to higher weight loss, higher variation in colour parameters, especially *a** parameter, lower firmness, and more dehydrated and browner stems, resulting in lower sensorial fruit classifications, particularly concerning aspect, flavour and global score. Controlled atmosphere treatments maintain fruit quality, namely the colour parameters, fruit firmness, and sensorial elements. Additionally, at the end of our study (49 days), the classifications of all sensory parameters were above the limit defined for sensory acceptance. In CA conditions, fruit weight loss was 2% to 3% after 49 days of storage. Few rotten fruits, less than 2%, were observed throughout the storage period. No clear distinction could be found between CA treatments using sweet cherry cv. Satin.

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