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Preservation of cv. Jubileu peaches in a conventional cold storage system under a dynamic controlled atmosphere

Conservação de pêssegos cv. Jubileu em sistema refrigerado convencional, atmosfera controlada e dinâmica

Carolina Goulart[1]; Rufino Fernando Flores Cantillano[2]; Gabriel Almeida Aguiar[3]; Marines Batalha Moreno Kirinus[1]*; Paulo Celso Mello-Farias[4]; Marcelo Barbosa Malgarim[4]

Highlights

Adapting different dynamic controlled systems for cv. Jubileu.
Postharvest peach storage viable up to 50 days.
The controlled system was more efficient than ultralow temperature storage.
Three physical, chemical and phytochemical parameters.

Abstract

The peach tree (*Prunus persica*) has a considerable global economic impact because its fruits are consumed worldwide. As climacteric fruits, peaches ripen after harvest and are also highly perishable postharvest. The aim of this study was to investigate alternatives for extending storage time and preventing a decline in quality in peaches using conventional cold storage (CS) compared with controlled atmosphere (CA) and ultralow oxygen (ULO) systems. A completely randomized design was used, with a 3 x 6 factorial scheme (3 storage systems x 6 storage times), thirteen parameters assessed by analysis of variances and significance by Tukey's test and regression. Total soluble solids (TSS) varied from 12.72 to 16.07°Brix, titratable acidity (TA) declined during storage and pH varied significantly among the systems used from 40 days of storage onwards. The best TSS/TA ratio was obtained under ULO after 40 days, while firmness and weight loss declined in CA and ULO, contrasting with the brightly colored pulp. Reducing and non-reducing sugars

[1] Dras in Agronomic Department of Phytotechnics at Universidade Federal de Pelotas, UFPel, Pelotas, RS, Brazil. E-mail: carolina.goulart@yahoo.com.br; marinesfaem@gmail.com
[2] Researcher at Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA, Pelotas, RS, Brazil. E-mail: fernando.cantillano@embrapa.br
[3] Prof. Dr. at the Department of Phytotechnics at Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul, IFRS, Sertão, RS, Brazil. E-mail: gabriel.aguiar@sertao.ifrs.edu.br
[4] Profs. at the Department of Phytotechnics at UFPel, Pelotas, RS, Brazil. E-mail: mellofarias@yahoo.com.br; malgarim@yahoo.com.br
* Author for correspondence

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decreased under CA and ULO at 30 and 40 days of storage, whereas phenolic compounds and antioxidant activity remained similar in these systems at 30, 40 and 50 days. Carotenoids remained stable for up to 40 days in ULO.CA and ULO maintained the best physical and chemical quality parameters, both systems being the most recommended. The phytochemical compounds analyzed in this study changed little during storage in the systems analyzed.
Key words: Oxygen control. Carbon dioxide control. Cooling chamber. *Prunus persica.*

Resumo

O pessegueiro (*Prunus persica*) apresenta grande impacto econômico global, por produzirem frutos apreciados em todo o mundo. Seus frutos climatérios amadurecem após a colheita, além disso, possuem alta perecibilidade pós-colheita. O objetivo deste trabalho foi buscar alternativas que ampliem ainda mais o tempo de armazenamento evitando-se o decaimento da qualidade dos pêssegos, utilizando o sistema refrigerado convencional (SAR) em contraponto com a atmosfera controlada (SAC) e dinâmica com ultrabaixo oxigênio (SAUO). O delineamento experimental foi inteiramente casualizado em um esquema fatorial 3 x 6 (3 sistemas x 6 períodos) de armazenamento, e treze parâmetros analisados pelo teste análise de variância, significância pelo teste Tukey e regressão. Os valores de sólidos solúveis variaram de 12,72ºBrix a 16,07ºBrix, a acidez titulável reduziu ao longo do armazenamento, já o pH apresentou variação significativa a partir de 40 dias entre os sistemas utilizados. A relação SS/AT alcançou os melhores índices no SAUO até 40 dias, já a firmeza de polpa e a perda de massa apresentaram redução nos SAC e SAUO, contrastando com elevada coloração da polpa. Açúcares redutores e não redutores apresentaram redução no SAC e SAUO aos 30 e 40 dias de armazenamento, já para os compostos fenólicos e atividade antioxidante, nestes sistemas, com 30, 40 e 50 dias os valores mantiveram-se semelhantes. Os carotenóides foram mantidos até 40 dias no SAUO. O SAC manteve os melhores parâmetros de qualidade físico-químicos analisados, juntamente com SAUO, sendo ambos os mais indicados. Os compostos fitoquímicos analisados neste estudo apresentaram poucas alterações durante os dias de armazenamento nos sistemas analisados.
Palavras-chave: Controle de oxigênio. Controle gás carbônico. Câmara fria. *Prunus pérsica.*

Introduction

Brazil produced 219,598 metric tons of peaches in 2019, with the South responsible for 80% of domestic production and Rio Grande do Sul state the leading producer at 143,431 metric tons, corresponding to 66.68% of total production and demonstrating the importance of the crop to the state (Instituto Brasileiro de Geografia e Estatística [IBGE],2019).

The peach (*Prunus persica* L. Batsch) is highly valued for its flavor and appearance (Assumpção et al., 2015) and has considerable global economic importance, but is characterized by a short shelf life, with a climacteric increase in ethylene production and equivalent rise in the ripening rate (Manganaris & Crisosto, 2020).Peaches remain alive after harvest, with physiological functions such as respiration and transpiration continuing normally after harvest, meaning that postharvest metabolic changes cannot be prevented, only delayed through good postharvest management practices (Cantillano, 2014).

Fruits undergo changes during ripening that include color development, starch hydrolysis, sugar accumulation, aroma compound production, organic acid modifications and softening (Taiz et al., 2017).These can cause postharvest quality losses during peach storage, largely due to metabolic changes, mechanical damage, reduced firmness, rotting and physiological disorders. These losses are influenced by genetic factors, ripeness stage at harvesting, handling, harvesting conditions and the storage system used (Rombaldi et al., 2002; Crisosto et al., 2006). Storage technologies are widely used to delay metabolic changes, reduce loss and increase the postharvest shelf life of fruits.

Cold storage is the most common preservation method for fruit (Pinto et al., 2012; Pegoraro et al., 2015) due to the lower costs involved (Barreto et al., 2019).However, long cold storage periods can compromise fruit quality (Infante et al., 2008), affecting firmness and causing physiological disturbances and rot (Giné-Bordonaba et al., 2016).

Cold storage is being replaced by controlled atmosphere systems, which are more efficient at lowering respiration and ethylene production and, consequently, delaying ripening (Echeverría et al., 2004; Gwanpua et al., 2012; Both et al., 2014a).

Controlled atmosphere (CA) and ultralow oxygen (ULO) storage are closed systems where gases are regulated to levels that differ from normal atmospheric concentrations (Wright et al., 2015).

The low O_2 and high CO_2 pressures used in CA storage slow polyethylene production and respiration, thereby preserving physical and chemical characteristics and inhibiting and/or reducing the occurrence of physiological disturbances (Weber et al., 2013; Both et al., 2014a; Thewes et al., 2021; Both et al., 2014b).

Ultralow oxygen is an auxiliary technique in CA storage that can considerably extend the storage time and shelf life of fruits by reducing respiration, since oxygen is essential as the final electron acceptor in the electron transport chain (Steffens et al., 2005; Wright et al 2015, Thewes et al., 2020). ULO storage is an alternative technique to minimize postharvest losses. In order to maintain postharvest fruit quality under ULO, oxygen concentrations must be kept just above the anaerobic compensation point, when anaerobic respiration begins. This reduces acid or sugar loss during respiration, lowering fruit metabolism (Wendt et al., 2022). Determining the lower oxygen limit tolerated by fruit requires a series of calculations and evaluations, with different methodologies based on ethanol determination, chlorophyll fluorescence, respiratory quotient and CO_2 production (Wendt et al., 2022), as well as variations between the genotype and phenotype of the materials. However, this technique must be thoroughly studied before its use, since tolerance of ULO and high CO_2 varies according to cultivar, storage temperature and storage time (Ceretta et al., 2010).

In Brazil, storage under a ULO dynamic controlled atmosphere is currently undergoing protocol adjustments for the apple production chain through studies conducted at Embrapa Clima Temperado. The present study is justified by the fact that Pelotas is a hub in the peach production chain and the search for alternatives to increase the shelf life of fruits. The aim was to assess the physical and chemical aspects and phytochemical compounds of cv. Jubileu peaches submitted to conventional cold storage, controlled atmosphere and ultralow oxygen dynamic controlled atmosphere systems.

Material and Methods

The study was conducted in the laboratory and cooling chambers of the Postharvest Physiology Department at the Food Center of Embrapa Clima Temperado, in Pelotas, Rio Grande do Sul state (RS), Brazil. Peaches of the Jubileu cultivar were collected from a commercial orchard in the municipality of Morro Redondo, RS (31º32'40,9''S and 52º34'42,42''W, altitude of 150 m).Climate in the region is classified as humid subtropical (*Cfa*), with average annual rainfall, temperature and relative humidity of 1582 mm, 18.4ºC and 78%, respectively, and an average of 550 chill hours (CH) below 7.2ºC during winter (Instituto Nacional de Meteorologia [INMET], 2019).

The fruits were harvested at the ideal time, while still immature, in order to facilitate transport. The treatments consisted of three storage systems that differed in terms of atmospheric conditions, that is, oxygen (O_2) and carbon dioxide (CO_2) concentrations and different storage times. Concentrations under cold storage (CS) were 20-21% O_2 + 0.03-1% CO_2, 2% O_2 +10-11% CO_2 for the controlled atmosphere (CA) system and0.5-0.6% O_2 + 4-5% CO_2 in ultralow oxygen (ULO) storage. Temperature and relative humidity remained homogeneous under all conditions, at 1ºC and 90-95%, respectively. For the CA and ULO systems, special microchambers were used for gas tightness.

The storage periods analyzed were day 0 (characterization); 10; 20; 30; 40 and 50 days. After removal from the cooling chambers, the fruits were stored at 20ºC for 24h to simulate shelf life and the following evaluations subsequently performed:

Total soluble solids (TSS): obtained with an ATAGO PAL-1 digital refractometer and expressed in ºBrix (Instituto Adolfo Lutz [IAL], 2008).

Potential of hydrogen (pH): determined by the electrometric method, using a Metrohm 780/781 digital pH meter directly in the peach juice, obtained with a centrifuge (IAL, 2008).

Titratable acidity (TA): using 10mL of pulp juice added with 90mL of distilled water. Titration of the sample was performed with a Brand® digital burette containing 0.1N sodium hydroxide solution until reaching the turning point at pH 8.1. Titratable acidity was expressed in grams (g) of citric acid per 100g-1 of pulp (IAL, 2008).

Ratio of total soluble solids to titratable acidity (TSS/TA): determined by dividing the total soluble solids content by titratable acidity.

Weight loss (WL): calculated based on the difference between fruit weight at the start of the study (iW) and on the day of assessment (fW), using the following formula = [(initial weight – final weight)/ (initial weight*100)] and expressed in percentage.

Skin (HueS) and pulp color (HueP): The equatorial areas of the fruits (skin) were measured using a MinoltaCR-400 colorimeter and for the pulp, pieces of skin were removed and analyses performed at these sites. The hue angle was determined with the formula Hue= arcotan (b*/a*), and the result in radians was converted into degrees.

Reducing (RS) and non-reducing sugars (NRS): measured by spectrophotometry using a method adapted from Maldonade et al. (2013). To that end, 3g of pulp was added with 150mL of distilled water and homogenized in a mixer for 3 minutes. The final sample was then filtered using cotton wool and 0.5mL of supernatant was removed for the 3,5-dinitrosalicylic acid (DNS) test. For NRS quantification the sample was hydrolyzed byremoving 2mL of the supernatant, adding 2mL of HCl 2mol.L^{-1} and heating the mixture in a boiling water bath for 10 minutes. The sample was cooled in an ice bath, added with 2mL of NaOH 2mol.L^{-1}, agitated, and0.5mL of the supernatant was removed for the DNS test. The 0.5mL sample was pipetted into a test tube, added with 0.5mL of DNS reagent and heated in a water bath at 100°C for 5 minutes. The tube was cooled in an ice bath for 5 minutes and added with 8mL of double sodium potassium tart rate solution ($KNaC_4H_4O_6$+$4H_2O$). Absorbance was read at a wavelength of 540nm and the results expressed as% glucose

Total phenolic compounds (TFC): Phenols were quantified using a method adapted from Swain & Hillis (1959).To that end, 2.5g of pulp was weighed and homogenized with 10mL of methanol (CH_3OH) in an Ultra-Turraxhomogenizer until reaching an even consistency. The samples were centrifuged at 4000 RPM for 20 minutes at 0°C,and 90μL of the supernatant was pipetted into a tube added with 160μL of methanol, 4mL of distilled water and 250μL of Folin-Ciocalteureagent (0.25 N).After agitation, the sample was left to rest for three minutes. Next, 0.5mL of 1N Na_2CO_3 was added and the tubes were agitated and allowed to rest for two hours. Absorbance was measured in a quartz cuvette at 725nm and the results expressed in mg of gallic acid equivalent (GAE).100^{-1} g of sample

Antioxidant activity (AA): determined by DPPH via spectrophotometry, in line with methodology adapted from Brand-Williams et al. (1995). This method is based on scavenging of the DPPH (2,2-diphenyl-1-picrylhydrazil) free radical by antioxidants, resulting in decreased absorbance at 515nm. Extraction was the same as that used for TFC, with 60μL of the supernatant and 1900μL of diluted DPPH. After 2 hours and 30 minutes, reading was carried out in a Molecular Devices SpectraMax 190 spectrophotometer at a wavelength of 515nm.The results were expressed in mg Trolox.100 g^{-1} of sample.

Total carotenoids (TC): Carotenoids were quantified using a method adapted from Talcott; Howard (1999). Protected from direct light, 2.5g of pulp was weighed and homogenized in an Ultra-Turraxhomogenizer with an ethanol/acetone/BHT solution until reaching an even consistency. The sample was centrifuged for 20 minutes at 4000 RPM and 0°C, after which the supernatant was poured into plastic pots. These procedures were repeated, if necessary, until complete sample discoloration. Hexane ($CH_3(CH_2)_4CH_3$) was added (50ml), followed by 30 minutes of rest, an additional 25mL of distilled water and another30 minutes' rest. Absorbance was read in a quartz cuvette at 470nm and the results were expressed in mg β-carotene.100g^{-1} sample.

Rot percentage (RP): determined using a digital pachymeter by counting the fruits exhibiting lesionslarger than 0.5 cm in diameter, a sign of attack by fungi and bacteria, with results expressed in percentage.

A completely randomized design was used, in a 3 x 6 factorial scheme (3 storage system x 6 storage times). The experimental unit consisted of 4 repetitions of 10 fruits. The data were submitted to analysis of variance (ANOVA) and means compared by Tukey's test ($p< 0.05$) and regression analysis.

Results and Discussion

The present study aimed to assess physical, chemical and phytochemical parameters based on the variation of interaction between the storage system and storage times. The parameters assessed were total soluble solids, pH, TSS/TA ratio, firmness, weight loss, pulp and skin color, reducing and non-reducing sugars, total phenolic compounds, antioxidant activity and total carotenoids. However, analysis of variance (Table 1) showed that interaction was not significant for titratable acidity and skin color, which also occurred for storage time, with no significant difference for pulp color and total carotenoids. The remaining variables studied were significant in maintaining the postharvest quality of 'Jubileu' peaches in cold storage.

Table 1
Analysis of variance for physical and chemical (TSS, pH, TA, TSS/TA, PF, WL, HueS and HueP) and phytochemical parameters (RS, NRS, TFC, AA and TC) of 'Jubileu' peaches under different storage systems and times. Embrapa Clima Temperado, Pelotas - RS, 2020

Source of variation	DF	Meansquare						
		TSS	pH	TA	TSS/TA	PF	WL	HueS
Storage System (SS)	2	10.7*	0.03*	0.01*	17.82*	15.54*	563.21*	22.67*
Storage Times (ST)	5	1.04*	0.45*	0.39*	233.3*	2.47*	130.24*	26.04*
SSxST	10	1.8*	0.04*	0.005^{ns}	17.13*	1.18*	61.56*	5.12^{ns}
Residual	54	0.27	0.002	0.003	2.63	0.01	0.51	3.08
Total	71							
CV(%)		3.77	1.31	7.45	8.52	13.78	13.03	2.08
Mean		13.72	3.81	0.76	19.03	2.36	5.52	84.53

Source of variation	DF	Meansquare					
		HueP	RS	NRS	TFC	AA	TC
Storage System (SS)	2	8.94*	1.38*	2.22*	702.66*	3794.08*	29.87*
Storage Times (ST)	5	1.48^{ns}	3.58*	0.94*	362.52*	4092.9*	4.41ns
SSxST	10	4.34*	0.37*	0.27*	547.32*	3554.9*	12.12*
Residual	54	1.51	0.03	0.08	80.55	690.24	4.08
Total	71						
CV(%)		1.56	5.84	5.67	12.16	22.4	17.48
Mean		79.05	3.15	5.39	73.82	117.3	11.55

Variables: TSS = total soluble solids; pH: potential of hydrogen; TA = titratable acidity; TSS/TA = total soluble solid to titratable acidity ratio; PF = pulp firmness; WL = weight loss; °HueS = skin color; °HueP = pulp color; RS = reducing sugars; NRS = nonreducing sugars, TFC = total phenolic compounds; AA = antioxidant activity; and TC = total carotenoids.DF = degrees of freedom; CV = coefficient of variation; ns = not significant and * = significant according to the F test at 5% probability.

The average TSS values (Table 2) remained stable in the CA and ULO systems, but increased during storage under CS, differing statistically from the remaining ystems. This behavior corroborates that of climacteric fruits.

Table 2
Total soluble solids (TSS), potential of hydrogen (pH), titratable acidity (TA) and TSS/TA values in 'Jubileu' peaches under cold storage (CS), controlled atmosphere (CA) and ultralow oxygen (ULO) systems for0, 10, 20, 30, 40 and 50 days. Embrapa Clima Temperado, Pelotas - RS, 2020

	Storage System	Storage Period-Days						
		0	10	20	30	40	50	Means
TSS	CS	13.15a	13.97a	14.70a	14.42a	14.62a	16.07a	14.49a
	CA	13.00a	13.67a	13.70b	13.6b	13.05b	12.92b	13.32b
	ULO	13.20a	13.4a	13.42b	13.6b	13.62b	12.72b	13.33b
pH	CS	3.57a	3.64a	3.71a	3.85a	4.0a	4.37a	3.85a
	CA	3.56a	3.7a	3.76a	3.84a	3.88b	3.95b	3.78b
	ULO	3.56a	3.71a	3.69a	3.87a	3.92ab	3.99b	3.79b
TA	CS	1.09	0.9	0.73	0.69	0.7	0.54	0.78a
	CA	1.07	0.79	0.72	0.69	0.67	0.60	0.76ab
	ULO	1.06	0.82	0.75	0.67	0.57	0.53	0.73b
TSS/TA	CS	12.03a	15.59a	20.08a	20.64a	20.8b	29.93a	19.85a
	CA	12.21a	17.3a	18.79a	19.51a	19.49b	21.47b	18.12b
	ULO	12.43a	16.48a	17.68a	20.34a	23.67a	24.1b	19.12ab

Means followed by the same lowercase letters in the columns and uppercase letters in the rows do not differ according to Tukey's test at 5% significance.

In climacteric behavior, such as that observed in peaches, TSS content tends to increase during storage because respiration continues and accumulated starch is converted into sugars, causing fruit dehydration and sugar concentration (Chitarra & Chitarra, 2005).

Analysis of TSS regression (Figure 1A) indicated that the CA and ULO systems exhibited similar behavior throughout storage, with quadratic adjustment, whereby the lowest TSS values recorded were 12.92and 12.72 Brix at 50 days, respectively. The CS system displayed a linear increase in TSS during storage, with the lowest value (13.15 Brix) obtained on day 0 and the highest (16.07 Brix) at 50 days, with a coefficient of determination of 0.81.

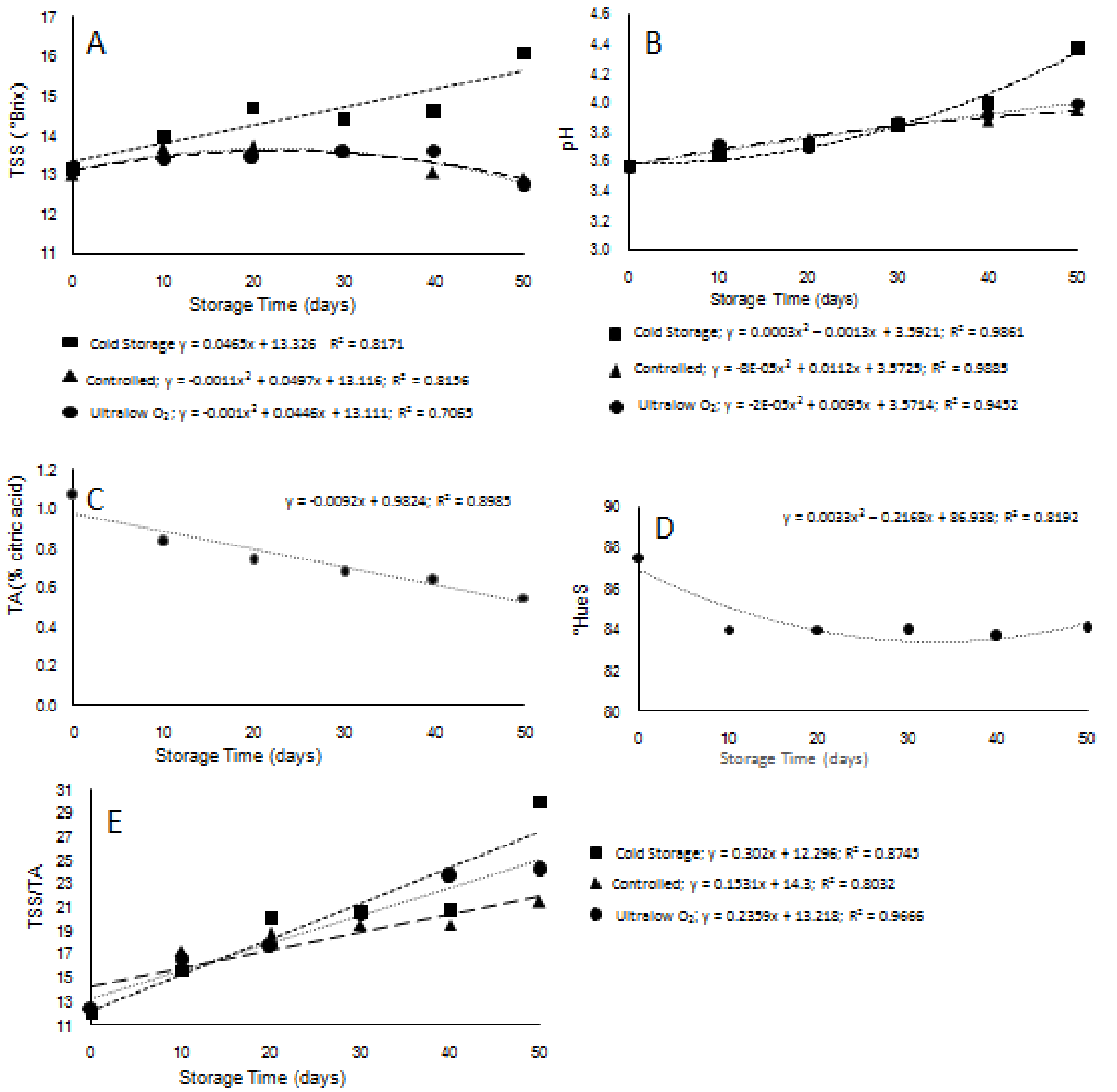

Figure 1. Regression for total soluble solids (°Brix) (A), potential of hydrogen (pH)(B), titratable acidity (TA)(C), skin color (D) and TSS/TA ratio (E) of 'Jubileu' peaches as a function of different storage systems (cold storage, controlled atmosphere and ultralow oxygen) and storage times (0, 10, 20, 30, 40 and 50 days). Embrapa Clima Temperado, Pelotas-RS, 2020.

The linear increase in TSS during cold storage was diagnosed based on this regression. According to Kirinus et al. (2018), there is a possibility of TSS increasing due to the rise in weight loss and, consequently, greater palatability because of this TSS concentration. This demonstrates the maintenance and even slight decline in these values under CA and ULO storage, related to the stability of the physical and chemical characteristics of peaches. There is a known tendency for TSS values to increase as peaches ripen, varying as a function of genotype and environmental conditions. According to Nava and Brackmann (2002), Brackmann et al. (2007) and Brackmann et al. (2009), the sugar parameters of peaches between the 'Chiripá', 'Eldorado' and 'Eragil' cultivars vary, but a controlled atmosphere has little to no influence on soluble solids.

Comparison of the storage systems showed that CS differed statistically from the remaining systems, with the highest average pH (3.8), particularly after 40 days, whereas CA and ULO were equal. However, from 40 days of storage onwards, CA and CS differed (Table 2). The behavior of pH was similar in the three systems, with a linear increase for CA and ULO and an exponential increase for CS (Figure 1 B).The change in pH occurs in the senescence process of stored fruits, when acid is consumed during respiration (Silva et al., 2013).

Titratable acidity behaved differently from TSS and pH, with a decline during storage and no significant difference between systems except for the final average value, which showed a greater reduction under CA and ULO (Table 2). The highest average value of 1.07% citric acid was obtained on day 0 and the lowest (0.55%) at 50 days, thus corroborating a linear decrease (Figure 1 C).

These physical and chemical changes are part of natural physiological behavior during fruit ripening, when sugar content and pH increase and fruit acidity declines (Chitarra & Chitarra, 2005).Given their different behavior, it is important to diagnose each cultivar, as observed in research by Sestari et al. (2008), who found higher TA values in 'Maciel' peaches under different controlled atmospheres (2% O_2 + 4% CO_2; 1% O_2 + 3% CO_2 and 2% O_2 + 6% CO_2) and by Brackmann et al. (2009) in 'Eragil' peaches. However, Rombaldi et al. (2002) reported lower TA values in 'Chiripá' peaches under CA storage with 1.5% O_2 + 5.0% CO_2 when compared to control fruits.

As shown in Figure 1 E, this relationship exhibited a linear increase during storage for all the systems studied, with a minimum value of 12.03 on day 0 and maximum of 29.93 after 50 days of CS. The overall means indicated that CS differed from CA, while ULO obtained intermediate values between the other two systems (Table 2). Kirinus et al. (2018) also observed increasing TSS/TA ratios in minimally processed 'Jubileu' peaches in cold storage.

This ratio is an important indicator fruit quality, particularly at values greater than or equal to 15.1 (Sainz & Ferri, 2015). Several studies have demonstrated the good quality of Brazilian peach varieties in terms of flavor, texture and sugar-acid ratio (Sainz & Vendruscolo, 2015; Toralles et al., 2014; Silva et al. 2013).

In the present study, pulp firmness was most affected by the storage systems, especially under CS, exhibiting higher values after 10 days of storage when compared to the remaining systems. In general, firmness is expected to decline when fruits are stored over extended periods, which did not occur here; however, this was attributed to greater pulp resistance because of moisture and weight loss under CS. By contrast, CA and ULO were effective at maintaining firmness across 50 days of storage, since there was no significant variation between storage times, as observed in linear regression (Table 3 and Figure 2 A).

Table 3
Pulp firmness (N), weight loss (%), skin color (°HueS) and pulp color (°HueP) in 'Jubileu' peaches under cold storage (CS), controlled atmosphere (CA) and ultralow oxygen (ULO) systems for 0, 10, 20, 30, 40 and 50 days. Embrapa Clima Temperado, Pelotas - RS, 2020

	Storage System	Storage Period-Days						
		0	10	20	30	40	50	Means
Pulp Firmness (N)	CS	1.68a	2.82a	3.28a	3.13a	4.03a	4.83a	3.295a
	CA	1.67a	1.80b	1.86b	2.20b	2.01b	2.19b	1.96b
	ULO	1.68a	1.73b	1.9b	1.85b	1.89b	2.03b	1.85b
Weight Loss (%)	CS	0.0a	6.74a	8.41a	13.94a	15.43a	22.13a	11.1a
	CA	0.0a	3.51b	2.74b	2.99b	2.68b	3.30b	2.54b
	ULO	0.0a	3.45b	3.15b	3.81b	3.27b	3.77b	2.91b
Skin Color (HueS)	CS	87.50	83.94	81.38	83.10	82.60	82.15	83.44b
	CA	87.50	83.83	84.55	85.47	84.71	85.88	85.32a
	ULO	87.56	84.22	86.05	83.27	83.67	84.08	84.81a
Pulp Color (HueP)	CS	79.48aA	78.65aAB	76.55bB	78.26aAB	77.95aAB	79.28aA	78.36b
	CA	79.49aA	78.48aA	78.59bA	80.1aA	78.81aA	80.27aA	79.29a
	ULO	79.48aA	79.34aA	81.25aA	78.75aA	79.34aA	78.92aA	79.51a

Means followed by the same lowercase letters in the columns and uppercase letters in the rows do not differ according to Tukey's test at 5% significance.

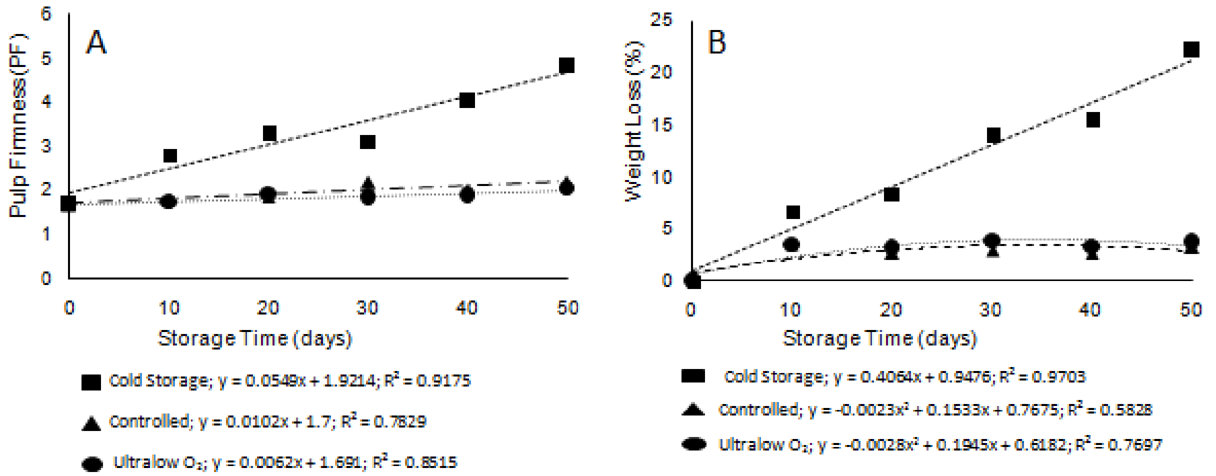

Figure 2. Regression for pulp firmness (Brix) (A) and weight loss (B), of 'Jubileu' peaches as a function of different storage systems (cold storage, controlled atmosphere and ultralow oxygen) and storage times (0, 10, 20, 30, 40 and 50 days). Pelotas-RS, 2020.

Fruits with greater weight loss were more resistant to penetration by the texture analyzer probe, exhibiting higher pulp firmness values (Table 3). Kirinus et al. (2018) reported that increased weight loss in 'Jubileu' peaches correlated with reduced firmness during cold storage. Girardi et al. (2005) observed better firmness preservation in 'Chiripá' peaches under a CA of 1.5% O_2 and 5% CO_2 at 3ºC and 0ºC for 35 and 40 days, respectively. Sestari et al. (2008) also reported greater firmness in 'Maciel' peaches in a 2% CO_2 + 4% CO_2 CA at 0.5ºC for 60 days, with an additional two days for commercialization.

Corroborating pulp firmness, weight loss percentage was significantly affected by CS (Figure 2), particularly from the tenth day of storage to the end of analyses for CA and ULO, which exhibited similar behavior, differing from CS. The greatest weight loss (22.13%) was recorded under CS at 50 days, while CA and ULO obtained 3.3 and 3.77%, respectively, in this same period (Table 3).

Figure 2 B shows regression for weight loss, with linear regression for CS as weight loss increased during storage. However, CA and ULO displayed quadratic regression with low weight loss percentages, which remained unchanged during storage, making these systems more effective for fruit storage when compared to CS.

Weight loss under CS was considered very high, reaching 6.7% in 10 days of storage. Kluge and Jacomino (2002) found that fresh weight loss greater than 5% caused shriveling and loss of consistency in peaches, compromising their quality and marketability. Nava and Brackmann (2002) observed that a controlled atmosphere reduced weight loss and maintained quality in 'Chiripá' peached for four weeks, and in the present study, storage was extended beyond this point for 'Jubileu' peaches the with no significant variations under CA and ULO.

Color change is one of the most widely used attributes to evaluate the ripeness of fruits, especially for consumers, who assess this trait visually. For skin color under CS, the average hue angle over 50 days of storage was 83.44º, differing statistically from CA and ULO, with 85.88 and 84.81º, respectively. In relation to storage time, skin color declined over the periods analyzed, with an average of 87.5°Hue on day 0 and 84°Hue at 50 days (Table 3 and Figure 1).

This is due to ripening, when fruits lose their green skin color (Figure 1 D), because chlorophyll content declines during storage and carotenoid content increases (Ferrer et al., 2005). Toralles et al. (2008) characterized cultivars from the Pelotas region and obtained hue angles of 83.44° for 'Jubileu' peaches, corroborating those obtained here. According to Brackmann et al. (2013), a hue angle of 90° indicates yellow coloring, and the further this value moves from zero, the redder the background color, that is, the riper the peach. As such, it can be inferred that CA and ULO caused less skin color change.

There was a significant difference in pulp color (HueP) at 20 days, with a higher value for ULO in relation to CA and CS. Comparison of the overall means showed that CS differed statistically from the other two systems, with values close to those obtained on the first day of the experiment. In regard to storage times, HueP varied significantly during storage only under CS (Table 3). In general, analysis of this variable indicated no skin color variation under CA and ULO. Further evidence of this fact is that no pulp darkening was observed in the 'Jubileu' peaches under any of the storage systems analyzed (Table 3).

Total sugar content can change considerably in climacteric fruits such as peaches, increasing not only during maturation, but also during harvesting and consumption. Analysis of reducing sugars demonstrated that the highest percentages were recorded in CS, particularly from 30 days onwards, differing from CA and ULO, with average values of 3.41, 2.96 and 3.06% glucose, respectively. However, a linear increase was observed throughout storage for all the systems, with a maximum of 4.3% glucose at 50 days under CS (Table 4 and Figure 3 A). Martins et al. (2013) reported a progressive increase in sugar content in Aurora-1 peaches under CS, which they attributed to the conversion of accumulated reserves, especially starch, during fruit development, or to the increase in metabolism triggered by injury.

Table 4

Reducing(% glucose) and nonreducing sugars (% sucrose) in 'Jubileu' peaches under cold storage (CS), controlled atmosphere (CA) and ultralow oxygen (ULO) systems for 0, 10, 20, 30, 40 and 50 days. Embrapa Clima Temperado, Pelotas - RS, 2020

	Storage System	Storage Period-Days						
		0	10	20	30	40	50	Means
Reducing Sugars (%)	CS	2.61a	2.51a	2.94a	3.87a	4.28a	4.30a	3.41a
	CA	2.58a	2.71a	2.68a	3.24b	2.88c	3.66b	2.96b
	ULO	2.49a	2.52a	2.99a	3.34b	3.42b	3.58b	3.06b
Nonreducing Sugars (%)	CS	4.72a	5.31a	5.19a	5.54a	6.03a	5.53a	5.39a
	CA	4.45a	4.69ab	5.03a	5.23a	5.00b	4.93b	4.89b
	ULO	4.61a	4.85ab	5.00a	5.33a	4.87b	4.36c	4.84b

Means followed by the same lowercase letters in the columns do not differ according to Tukey's test at 5% significance.

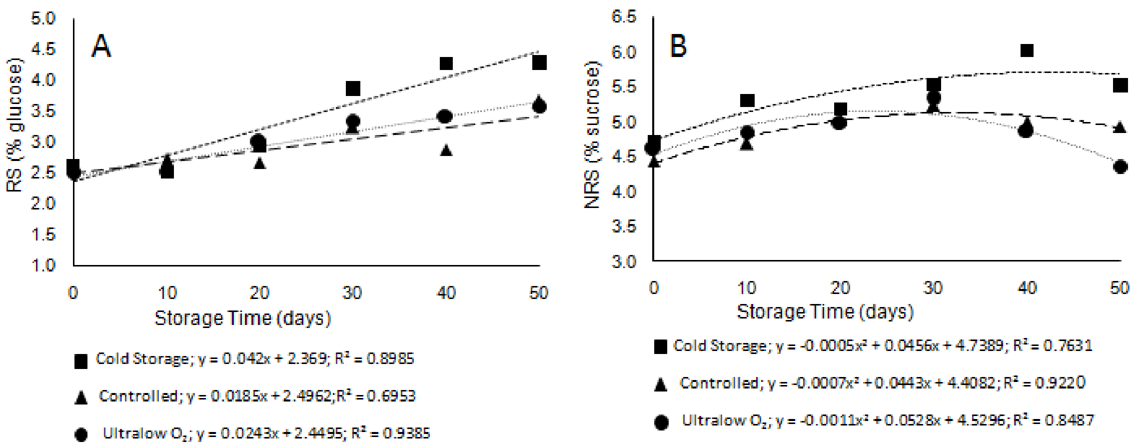

Figure 3. Regression for reducing sugars (A) and nonreducing sugars (B) in 'Jubileu' peaches as a function of different storage systems (cold storage, controlled atmosphere and ultralow oxygen) and storage times (0, 10, 20, 30, 40 and 50 days). Embrapa Clima Temperado, Pelotas-RS, 2020.

High NRS percentages were also observed in CS, particularly from 40 days of storage onwards, while CA and ULO were statistically equal, with mean values of 5.39, 4.89 and 4.84% sucrose, respectively (Table 4). Regression behavior showed quadratic adjustment (Figure 3 B), with a maximum NRS value of 6.03% sucrose at 40 days of CS and minimum of 4.36% sucrose after 50 days under ULO storage. Cultivars with a high NRS content can be considered sweeter (Leonel et al., 2011), and in the present study, RS contents were lower than those of NRS (Table 4). According to Chitarra and Chitarra (2005), sugar content in climacteric fruits typically increases by around 10% with ripening through biosynthesis or polysaccharide degradation.

Under CS, TFC varied between storage times, with the highest value of 99.91 mg GAE 100 g^{-1} fruit recorded at 20 days and the lowest (51.08 mg GAE 100 g^{-1} fruit) at 30 days. Under CA, the largest TFC increase was obtained at 30 days and the lowest at 50 days, with 81.7 and 59.14 mg GAE 100 g^{-1} fruit, respectively. With respect to ULO, the highest (88.48 mg GAE 100 g^{-1} fruit) and lowest (71.69 mg GAE 100 g^{-1} fruit) TFC values were observed at40 and 0 days, respectively. Analysis of the overall means showed that ULO differed statistically from the remaining systems, obtaining a higher average value (Table 5).

Table 5
Total phenolic compounds (mg GAE 100g-1), antioxidant activity (mg Trolox.100 g-1) and total carotenoid (mg β-carotene 100 g-1) in'Jubileu' peaches under cold storage (CS), controlled atmosphere (CA) and ultralow oxygen (ULO) systems for 0, 10, 20, 30, 40 and 50 days. Embrapa Clima Temperado, Pelotas - RS, 2020

	Storage System	Storage Period-Days						
		0	10	20	30	40	50	Médias
Total Phenolic Compounds (mgGAE.100g^{-1})	CS	71.62aB	67.05aBC	99.91aA	51.08bC	69.3bBC	63.28abBC	70.37b
	CA	70.26aAB	71.5aAB	69.58bAB	81.70aA	73.99abAB	59.14bB	71.03b
	ULO	71.69aA	80.83aA	76.46bA	88.05aA	88.48aA	74.81aA	80.05a
Antioxidant Activity (mg Trolox.100g^{-1})	CS	88.62aBC	116.58aAB	157.18aA	58.4bC	111.37bAC	93.14aBC	104.22b
	CA	93.7aB	140.31aAB	97.18bB	161.4aA	129.25abAB	88.67aB	118.4ab
	ULO	90.3aB	140.97aAB	112.64abB	142.19aAB	172.81aA	116.84aB	129.29a
Total Carotenoids (mgβ-carotene 100g^{-1})	CS	11.39aA	11.74aA	12.01aA	14.55aA	12.73aA	14.62aA	12.84a
	CA	12.09aAB	12.49aA	12.29aA	10.49bAB	8.02bB	10.32bAB	10.95b
	ULO	11.99aA	11.12aA	10.2aA	12.27abA	11.43abA	8.22bA	10.87b

Means followed by the same lowercase letters in the columns do not differ according to Tukey's test at 5% significance.

Phenolic compounds are produced as a plant defense mechanism against abiotic and biotic stress and are not directly correlated with growth and development functions (Dias et al., 2016). Phenolic compound contents in peaches can vary as a function of variety, growth conditions, ripeness and storage conditions (Gonçalves, et al., 2003). Comparison of initial TFC and AA values at 0 days of storage against the remaining storage times for each system studied indicated substantial variation despite the decline in these compounds under CS and CA. However, values remained stable under ULO when day zero and the other storage times were compared (Table 5).

Among the storage systems studied, ULO maintained higher TFC and AA values in 'Jubileu' peaches, demonstrating increased production of these compounds. According to Dias et al. (2016), this increase is due to elicitation processes involved in a complex biosynthetic pathway.

Antioxidant activity displayed similar behavior to that of TFC. The highest and lowest AA values were recordedat 20 and 30 days, with 156.18 and 58.4mg trolox 100 g^{-1} fruit, respectively, in the CS system and 161.4 and 88.67mg trolox $100g^{-1}$ fruit at 30 and 50 days under CA. However, under ULO, the lowest AA value (90.87mg trolox $100g^{-1}$ fruit) was obtained at 0 days of storage and the highest (172,81mg trolox $100g^{-1}$ fruit) at 40 days. Analysis of this behavior throughout storage showed that CA and ULO did not differ statistically, while the overall means indicated a statistical difference between CS and ULO and that CA was similar to the other two systems (Table 5).

Segantini et al. (2012) reported AA values between 35.81 and 65.39mg $100g^{-1}$ in peaches, lower than those recorded here. The genotype (cultivar) directly influences the determination of total antioxidant capacity in peaches (Tavarini et al., 2008). Other factors that should be considered are the different types of free radicals and their varying roles in living organisms, precluding a simple universal method to measure antioxidant activity accurately and quantitatively. The analytical extraction method, climate conditions, geographic origin and chemical constituents are the primary factors responsible for the differences found in the literature regarding the antioxidant activity of foods and should be taken into account when comparing results for validation purposes (Alves et al., 2010).

While storage had little influence on carotenoids, there was a statistical difference between the systems, with CS exhibiting the highest mean of 12.84mg β-carotene $100g^{-1}$ sample, and CA and ULO remaining statistically equal at 10.95 and10.87 mg β-carotene $100g^{-1}$ sample, respectively (Table 5). Across the storage times analyzed, CS maintained the highest carotenoid content, whereas from 30 days onwards CA and ULO differed. A possible explanation for the variation observed in the present study is that the qualitative and quantitative composition of carotenoids is influenced by several factors, including gentotype, stage of maturation, climate conditions, part of the fruit, and handling procedures postharvest, during storage and in processing (Rodriguez-Amaya, 1993; Remorini et al., 2008).

In regard to rot percentage (Figure 4), an increase was observed from day ten onwards in the CS system, while the first signs of rot occurred at 20 days under CA and percentages remained low until 50 days. This same initial behavior was observed under ULO storage, with maximum rot observed at 50 days.

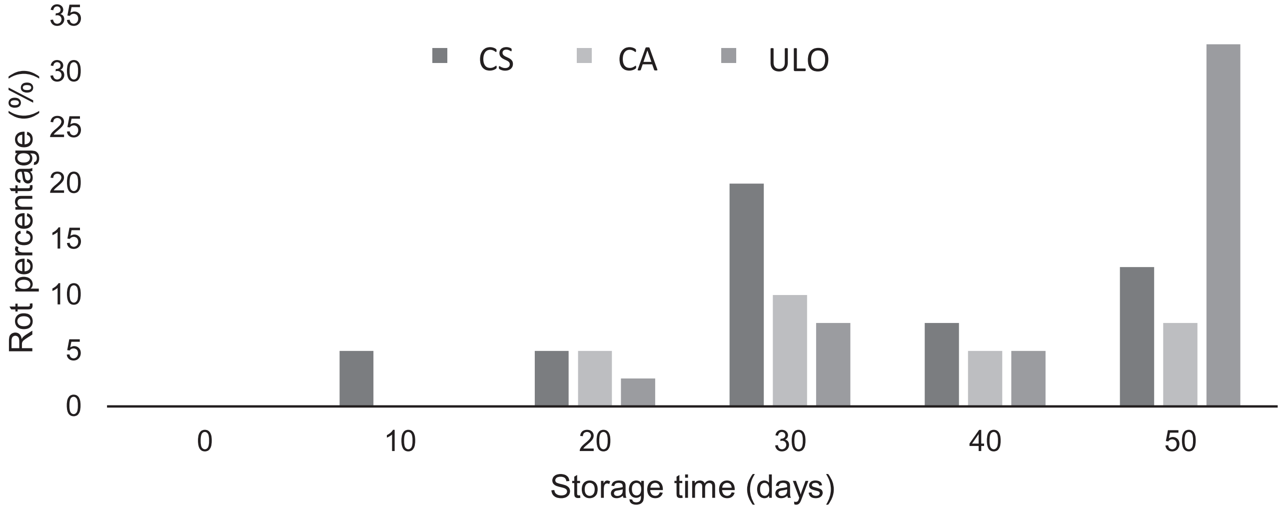

Figure 4. Rot percentage in 'Jubileu' peaches under cold storage (CS), controlled atmosphere (CA) and ultralow oxygen (ULO) systems for 0, 10, 20, 30, 40 and 50 days. Embrapa Clima Temperado, Pelotas-RS, 2020.

Unlike CA, the increased rot under ULO may be due to the different CO_2 concentrations of 10% CO_2 in the former and 5% CO_2 in the latter, since high CO_2 levels are more effective at controlling the emergence of rot. Brackmann et al. (2013) studied 'Eragil' peaches under CA with 1.0% O_2 and 8.0% CO_2 and obtained a lower rot percentage when compared with CS. Sestari et al. (2008) reported a low rot percentage in 'Maciel' peaches stored in a CA system with low O2 concentrations. The stress caused by reduced oxygen may intensify the emergence of physiological disturbances and rot (Both et al., 2014b), demonstrating the need for further research on the amount of gas in the storage unit and the gas mixture for each plant species.

Conclusions

Controlled atmosphere storage performed best in maintaining the physical and chemical quality-related parameters analyzed, including firmness, pulp and skin color, sugar content and rot percentage in 'Jubileu' peaches up to 50 days. Analysis of phytochemical parameters such as total phenolic compounds, antioxidant activity and total carotenoids showed few changes during storage for the systems analyzed. Among the systems studied, conventional cold storage was less suitable due to the high weight loss percentage observed, while controlled atmosphere and ultralow oxygen storage are more recommended. It should be noted that cold storage is more widely used; however, the present study demonstrated that in addition to temperature control, the gas mixture must also be altered to ensure more efficient storage.

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