

Effect of different modified atmosphere packaging and storage time on bioactive compounds in fresh-cut Tropic Beauty peaches

Efeito de diferentes embalagens em atmosfera modificada e tempo de armazenamento sobre os compostos bioativos em pêssegos Tropic Beauty minimamente processados

Efecto de diferentes empaques em atmosferas modificadas y tiempo de almacenamiento sobre compuestos bioactivos en duraznos Tropic Beauty recién cortados

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Abstract

Modified atmosphere packaging (MAP) was evaluated for respiration rate, color, total phenolic content (TPC), antioxidant activity DPPH, flavonoids and pigments of fresh-cut Tropic Beauty peach. Modified atmospheres (21% O₂ [Control], 5% CO₂ [MAP₁], 8% CO₂ [MAP₂] and 0% O₂ [MAP₃]) were evaluated for storing fresh-cut peaches for up to 10 days in temperatures of 5°C. MAP significantly ($p < 0.05$) affected the properties investigated as compared to control. Peaches with MAP₃ have higher respiration ($p < 0.05$) respiration rate than the peaches with the other treatments. Fresh-cut peaches in MAP₂ showed more stable ($p < 0.05$) carotenoid and anthocyanin contents, better attributes in the bioactive compounds. MAP₁ and MAP₂ exhibited better antioxidant properties at low storage temperature (5°C) for up to 10 days storage and similar result was verified by principal component analysis used where modified atmosphere was observed as major factor.

Keywords: (*Prunus persica* (L.) Batsch); Fresh-cut; Modified atmosphere packaging; Respiration rate; Bioactive compounds; Shelf-life.

Resumo

Embalagens em atmosferas modificadas (MAP) foi avaliado quanto a taxa respiratória, cor, conteúdo fenólico total (TPC), atividade antioxidante DPPH, flavonoides e pigmentos de pêssego Tropic Beauty minimamente processado. Atmosferas modificadas (21% O₂ [Control], 5% CO₂ [MAP₁], 8% CO₂ [MAP₂] e 0% O₂ [MAP₃]) foram avaliados para armazenar pêssego minimamente processado por até 10 dias em temperatura de 5°C. MAP afetou significativamente ($p < 0.05$) as propriedades pesquisadas em comparação com o controle. Os pêssegos com MAP₃ tem taxa respiratória mais alta ($p < 0.05$) do que os pêssegos com os outros tratamentos. Os pêssegos embalados em MAP₂ exibiram teores de carotenoides e antocianina mais estáveis ($p < 0.05$), melhores atributos nos compostos bioativos. AS MAP₁ e MAP₂ exibiram melhores propriedades antioxidantes em temperaturas de refrigeração (5°C) por até 10 dias

de armazenamento e similar foi verificado por análise de componente principal usado onde atmosfera modificada foi observado como fator principal.

Palavras-chave: (*Prunus persica* (L.) Batsch); Corte fresco; Embalagem de atmosfera modificada; Taxa respiratoria; Compostos bioativos; Vida de prateleira.

Resumen

Se evaluó el envasado en atmósfera modificada (MAP) para determinar la tasa de respiración, color, contenido fenólico total (TPC), actividad antioxidante DPPH, flavonoides y pigmentos del durazno Tropic Beauty recién cortado. Se evaluaron atmósferas modificadas (21% O₂ [Control], 5% CO₂ [MAP₁], 8% CO₂ [MAP₂] y 0% O₂ [MAP₃]) para almacenar duraznos recién cortados hasta por 10 días a temperaturas de 5°C. MAP afectó significativamente ($p < 0,05$) a las propiedades investigadas en comparación con el control. Los duraznos con MAP₃ tienen una tasa de respiración más alta ($p < 0,05$) que los duraznos con los otros tratamientos. Duraznos recién cortados en MAP₂ mostraron contenidos de carotenoides y antocianinas más estables ($p < 0,05$), mejores atributos en los compuestos bioactivos. MAP₁ y MAP₂ exhibieron mejores propiedades antioxidantes a baja temperatura de almacenamiento (5°C) por hasta 10 días de almacenamiento y se verificó un resultado similar mediante el análisis de componentes principales utilizado donde se observó la atmósfera modificada como factor principal.

Palabras clave: (*Prunus persica* (L.) Batsch); Envasado en atmósfera modificada; Recién cortado; Tasa de respiración; Compuestos bioactivos; Vida útil.

1. Introduction

Peach (*Prunus persica* (L.) Batsch) is an appreciated fruit among consumers in the global market for its pleasant organoleptic properties, such as color and flavor; also being highlighted for its high nutritional value and antioxidants, such as vitamins (A, C and E), carotenoids and phenolic compounds (Bassi et al., 2016). Peach has a wide variety of phenolic compounds, such as chlorogenic acid, neochlorogenic acid, catechin, epicatechin and cyanide and quercetin derivatives (Liu et al., 2014).

In plants, bioactive compounds protect the vegetable cells against diseases, filter ultraviolet rays and protect the fragile seeds in the process of germination, eliminating free radicals (Ding et al., 2020). Life style and new demands of modern consumers for healthy, flavorful and easy to prepare vegetable food were responsible for the current increase in the production and consumption of minimally processed fruits and vegetables (Baselice et al., 2017; Ma et al., 2017; Plazzotta et al., 2017). Minimal processing or fresh-cut describes non-thermal technologies to process food in a way to guarantee safety and preserve the quality of the food, as well as keeping, as much as possible, the fresh characteristics of fruits and vegetables (Vivek et al., 2019).

Ripening of the fruits is a genetically programmed and highly coordinated process of transformation of the organs from the immature stage to mature, to produce an attractive edible fruit with an ideal combination of color, flavor, taste and texture (Perotti et al., 2014). Peach is a highly perishable fruit, due to its high metabolic activity, especially for presenting a high respiration rate (climacteric fruit), causing biochemical, physiological and structural changes, reducing shelf life post-harvest (Xi et al., 2017).

One of the main challenges faced during the production and commercialization process of fresh and minimally processed products is the fast quality deterioration (Yousuf et al., 2018), reducing shelf life, causing physiological and biochemical disorders due to mechanical damage (Velderrain-Rodríguez et al., 2019). The loss of nutrients can be accelerated when the plants' tissues are harmed, however, in comparison with the physiological and microbial changes that occur with time, little information is available about the retention of vitamins, minerals, bioactive compounds in minimally processed products during handling, storage and senescence (Brecht et al., 2010). Modified atmosphere packaging, used for a perishable product, has an atmospheric composition that is different from the air composition, usually reducing O₂ concentration and increasing CO₂ concentration to increase the shelf life of fruits and vegetables (Dey & Neogi, 2019; Mahajan et al., 2017).

The use of modified atmospheres have successfully prolonged post-harvest shelf life of *in natura* and minimally processed products, reducing their respiration rate, minimizing metabolic activity, delaying enzymatic browning and maintaining visual appearance (Martínez-Hernández et al., 2019; Opara et al., 2019). The effect of the O₂ atmosphere with low or high phenolic concentration can change depending on the biological material and O₂ concentration. This accumulation of phenolic compounds might be a physiological response to stress or lesions, the wound stimulates phenylalanine ammonia lyase (PAL) during minimal processing with the consequent additional production of phenolic compounds (Belay et al., 2019).

However, there is limited information about the effect of modified atmosphere in phenolic compounds and in the antioxidant activity of minimally processed climacteric fruit during storage. The aim of the present research was to investigate the effect of four modified atmosphere packaging on the biochemical parameters of minimally processed peach cv Tropic Beauty during 10 days of storage and shelf-life conditions.

2. Methodology

2.1 Plant Material

Peaches cv. Tropic Beauty acquired from the Holambra Company, located in Paranapanema-SP, 23°23'19" S, 48°43'22" W and 610 m altitude, were used. The fruits were selected by uniform size and ripening, free of diseases and visual damage, aiming for a homogenization of the lot.

2.2 Processing and Packaging

After being selected, the fruits were washed in running water, immersed for 10 minutes in sodium hypochlorite (NaClO) diluted at 1000 µL L⁻¹. To remove the excess of NaClO, the fruits were immersed in running potable water (Chen et al., 2016). After disinfection, the fruits were manually cut in slices with a stainless-steel knife. The slices were 1,5 cm ± 0,2 cm thick and 3,0 ± 0,5 cm wide. Then, fresh-cut peaches were immersed in citric acid (2% p/v) for 10 minutes (Denoya et al., 2015). Peach slices were placed on absorbent paper to remove excess moisture.

The peach slices were packaged in low-density polyethylene film, provided by Plastifilme®, São Paulo, Brazil. The polyethylene bags were 14 µm thick, 27 cm wide and 18 cm long. The polyethylene bags' transmission rates for oxygen and carbon dioxide were 4,9 x 10⁻⁹ and 1,3 x 10⁻⁷ ml m⁻² s⁻¹ Pa⁻¹, respectively. The AP500 Tecmaq® vacuum sealer was used.

2.3 Experimental Design

For each packaging, an average of 120 g of sliced peach was used. The experimental outline was completely randomized in factorial scheme (6 x 6) with 3 repetitions. The treatments consisted of six different levels of gas composition, 21% O₂ + 0.03 CO₂ + 79 N₂ (Control), 4% O₂ + 5% CO₂ + 91% N₂ (MAP₁), 4% O₂ + 8% CO₂ + 88% N₂ (MAP₂) and 0% O₂ + 0% CO₂ + 0% N₂ (MAP₃), associated with six sample dates (0, 2, 4, 6, 8, 10 days). Packaged fresh-cut were stored at 5 ± 0,5°C and 85 ± 5% relative humidity for 10 days.

2.4 Determination of respiration rate

The determination of the respiration rate was performed indirectly, it was carried out in respirometer, through the measure of CO₂ kg⁻¹ h⁻¹ released, according to the methodology adapted from (Bleinroth, 1986).

2.5 Color determination

The color parameters of the peach slices were measured with Minolta CR-400 colorimeter (Konica Minolta, Inc. Osaka, Japan), using the CIEL*a*b* scale, where L^* represents lightness, a^* represents color saturation or intensity and b^* represents color matrix or angle (0° =red and 90° =yellow). The equipment was configured for illuminant D65 and observer angle 2° and calibrated using standard white board. The surface of three peach slices were evaluated for each treatment.

2.6 Extraction of phenolic compounds.

The peach slices were frozen and macerated in liquid nitrogen for biochemical analysis. 500 mg of peach and 10 ml of acetone solvent 60% (v/v) were used. The mixture was centrifuged at 6000 rpm for 15 minutes (Zentrifugen MIKRO 220R) and then filtered through paper filter Quanty JP41. The extraction process was performed in triplicate. The obtained extracts were used to determine the total phenolic compounds (TPC), total flavonoid compounds (TFC) and antioxidant activity of DPPH radicals elimination (Mokrani & Madani, 2016).

2.7 Determination of total phenolic compounds (TPC)

The total phenolic compounds were determined by the spectrophotometric method (Singleton & Rossi, 1965). In summary, 200 μ L of extract were mixed with 0.5 Na₂CO₃ at 7,5% (p/v) and left at rest for 2 minutes at room temperature. For each sample, 1.0 ml of Folin-Ciocalteu reagent at 50% (v/v) was added with mixing and left at rest for 30 minutes. The absorbance was carried out at 765 nm in spectrophotometer (Shimadzu, Uvmini-1240), and the total phenolic content of the samples was expressed in mg of gallic acid equivalent to 100 g⁻¹ of fresh peach.

2.8 Determination of total flavonoid content (TFC)

The total flavonoids were determined using a colorimetry assay according to the procedure by (Zhishen et al., 1999). 7575 μ L of NaNO₂ (5%) were added to 1 ml of peach extracts. After 5 minutes, 1 ml of AlCl₃ at 2% (p/v) was added. The mixture was left at rest for 6 minutes at room temperature. Then, 0.5 ml of NaOH 1 mol L⁻¹ were added to this mixture. The final volume was adjusted to 2.5 ml with distilled water. The absorbance was measured against white at 410 nm. The total flavonoids of the samples were expressed in mg of quercetin equivalent to 100 g of dry peach (mg QE / 100 g). All measures were performed in triplicate.

2.9 Determination of free radical scavenging activity (DPPH-RSA)

The free radical activity by DPPH assay of peach extract was carried out according to the procedure described by Blois (1958) with some modifications. The peach extracts (0.1 ml) were used to react with 0.9 ml of DPPH radical solution (0.1 mM in methanol) for 20 minutes, in the dark, covered with aluminum foil. The reduction of absorbance in the resulting solution (RS) was monitored at 517 nm in a spectrophotometer. The absorbance of the blank DPPH solution (2 ml) was used as experimental control (EC). The radical elimination activity (%ER) of the extracts was expressed with the percentage of DPPH radical inhibition.

2.10 Determination of pigments

To quantify the pigments, the method recommended by Sims & Gamon (2002) was used, in an environment protected from light, with results expressed in mg 100 g⁻¹ of pulp. The spectrophotometer absorbance reading was performed in four wavelengths, 663, 645, 537, 470 nm for chlorophyll a, chlorophyll b, anthocyanin and carotenoids, respectively.

2.11 Statistical Analysis

The obtained data were subjected an analysis of variance (ANOVA), using the statistical software Minitab (version 15.3.1). The main effects and the interactions were analyzed and the measures were compared using the Tukey test ($p < 0.05$). Lastly, the results were subjected to principal component analysis (PCA) to observe the possible relations present among the variables through the software (JMP 10).

3. Results

ANOVA results for the treatments with modified atmosphere packaging and cold storage time and their interactions in the parameters of minimally processed peaches are expressed on Table 1.

Tabela 1: Results of significant differences for bioactive compounds, color and respiratory rate of minimally processed peach according to different treatments and storage days

Variáveis	Effects	df	F-value	p value
Total Phenolic content (TPC)	MAP	3	13.58**	<0.0001
	Storage Time (ST)	5	24.73**	<0.0001
	MAP x ST	15	17.88**	<0.0001
DPPH-RSA	MAP	3	25.71**	<0.0001
	Storage Time	5	26.73**	<0.0001
	MAP x ST	15	14.07**	<0.0001
Total Flavonoids contente (TFC)	MAP	3	9.15**	<0.0001
	Storage Time	5	62.34**	<0.0001
	MAP x ST	15	2.22*	0.0185
Chlorophyll a	MAP	3	0.6 ns	0.6157
	Storage Time	5	40.12**	<0.0001
	MAP x ST	15	0.58	0.8770
Chlorophyll b	MAP	3	15.50**	<0.0001
	Storage Time	5	150.06**	<0.0001
	MAP x ST	15	1.66 ns	<0.0929
Anthocyanin	MAP	3	117.92**	<0.0001
	Storage Time	5	337.14**	<0.0001
	MAP x ST	15	39.43**	<0.0001
Carotenoids	MAP	3	30.95**	<0.0001
	Storage Time	5	146.83**	<0.0001
	MAP x ST	15	70.33**	<0.0001
Lightness (L*)	MAP	3	1.83 ns	0.1541

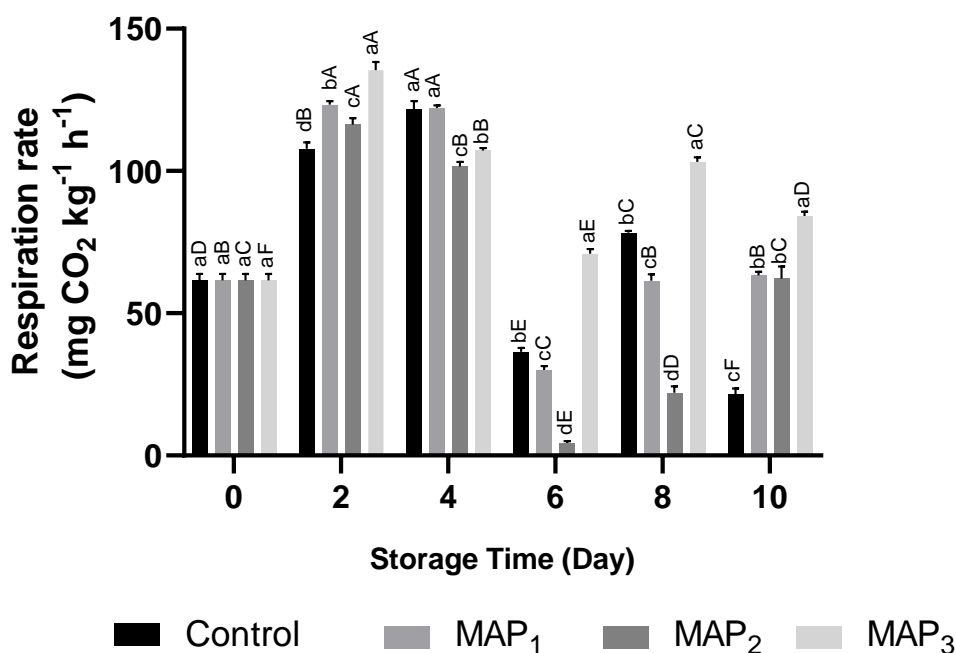
	Storage Time	5	3.92 **	0.0046
	MAP x ST	15	0.53 ns	0.9086
Chroma (C*)	MAP	3	1.35 ns	0.2688
	Storage Time	5	6.25**	0.0002
	MAP x ST	15	1.10 ns	0.3794
Hue angle (°h)	MAP	3	2.16 ns	0.1054
	Storage Time	5	5.40**	0.0005
	MAP x ST	15	1.47ns	0.1567
Respiration rate (RR)	MAP	3	5089.74**	<0.0001
	Storage Time	5	20875.00**	<0.0001
	MAP x ST	15	1601.55**	<0.0001

Source: Authors.

3.1 Respiration Rate.

The data are presented in Figure 1. The treatment groups, storage time and their respective interaction present significant difference ($p \leq 0.05$). CO₂ respiration rate exhibited a standard climacteric respiration characteristic in the ripening process of peach in modified atmosphere. The peaks in the respiration rate of minimally processed peach appeared approximately in the 2nd day of storage at 5% CO₂ (MAP₁), 8% CO₂ (MAP₂) and 0% O₂ (MAP₃), and the respiration peak in the fruit stored in 21% O₂ (Control) was after 4 days. The respiration rate of fresh-cut peaches packaged in 5% CO₂ and 8% CO₂ on the 10th day of storage were 63.23 and 62.16 mg CO₂ kg⁻¹ h⁻¹.

Figure 1: Effect of MAP treatment on respiration rate, during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

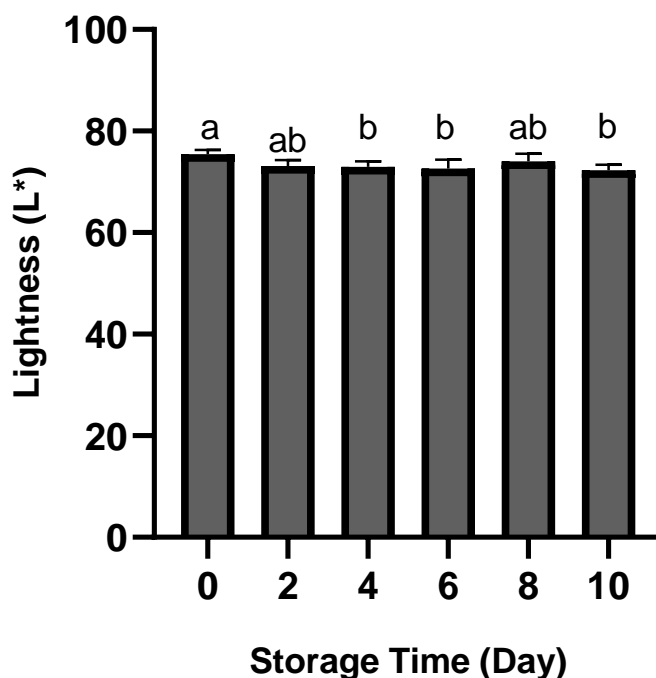
3.2 Color attributes

Influence of the modified atmospheres on the color of minimally processed peach was evaluated by monitoring the changes in Lightness (L^*), Chroma (C^*) and hue Angle of the peach stored at 5°C for 10 days (Figures 2, 3, 4).

The characteristics of the color were not affected by the modified atmosphere packaging used in this study but showed significant difference ($p < 0.05$) during storage time.

L^* values decreased significantly with storage time. Initially, all samples presented lightness of 75.49, after 10 days of storage, the samples decreased 4.27% of the initial value. The minimally processed peach in atmosphere with 8% CO_2 (MAP_3) presented higher values of 74.07, not having a significant difference with the atmosphere with 0% O_2 (Control) (72.56). The higher the L^* value of the minimally processed peach, the brighter is the cutting surface.

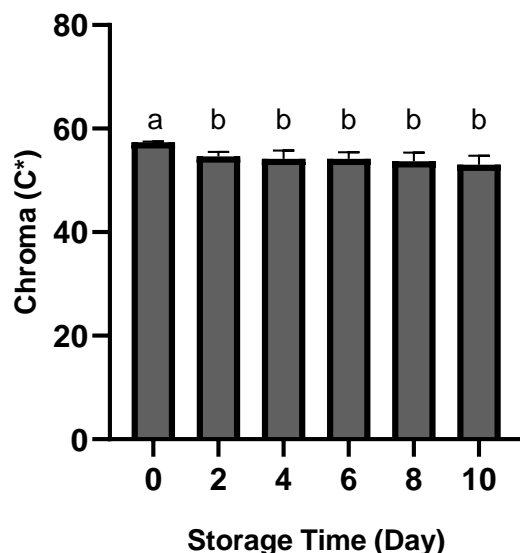
Figure 2: Effect of MAP treatment on Lightness (L^*) during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test



Source: Authors.

In the study, there was no significant difference among the modified atmosphere packaging. Chromaticity decreased significantly with storage time in the MAP_1 and MAP_2 treatments, after 10 days, the samples presented values of 51.40 and 52.53 (Figure 3).

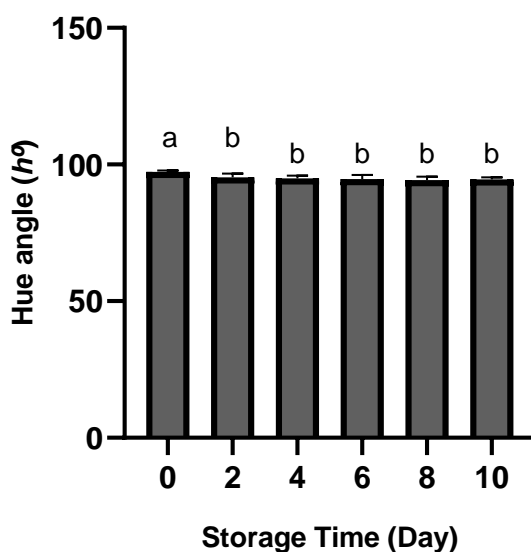
Figure 3: Effect of MAP treatment on Chroma value during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

The hue angle of the minimally processed peach with 5% CO₂ (MAP₂) decreased from 97.33 to 93.41 after 10 days of storage in cold conditions, this being the treatment with the highest decrease, but not presenting significant difference with other treatments (Figure 4). However, the decrease in hue angle was not significant in the fruit samples treated with modified atmospheres.

Figure 4: Effect of MAP treatment on Hue angle (h°) during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test.



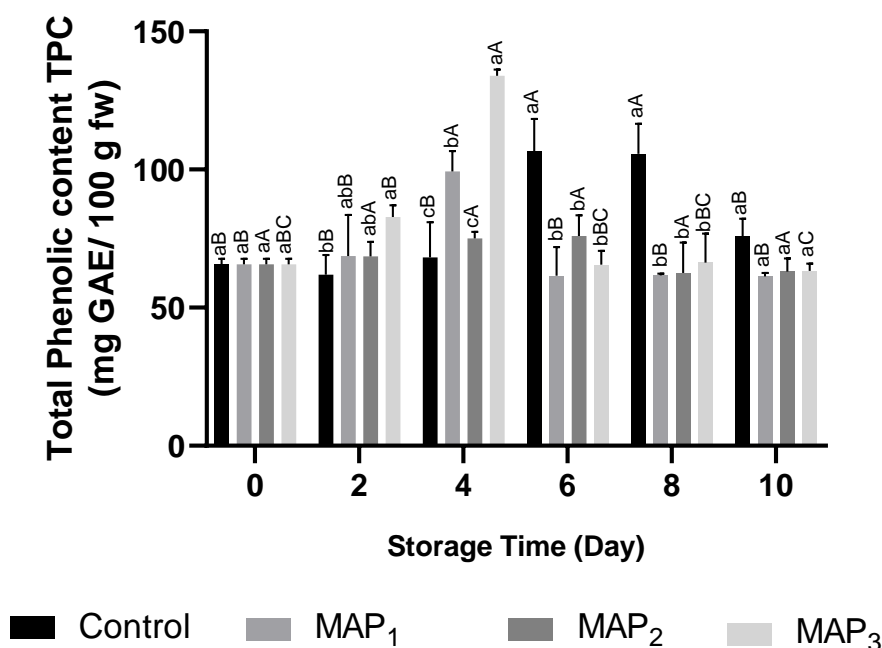
Source: Authors.

3.3 Total phenolic content (TPC), total flavonoid content (TFC) and DDPH antioxidant activity (DPPH-RSA)

Modified atmosphere packaging, storage time and their interaction significantly affected phenolic compound content, flavonoids content and antioxidant activity during cold storage ($p < 0.05$). Figures 5, 6 and 7 show the changes in TPC, TFC and antioxidant activity in minimally processed peach with modified atmosphere during cold storage.

The phenolic compound content in the control treatment (21% O₂) presented a tendency to increase until day 6 and then decrease. A similar behavior was observed in the MAP₁ (5% CO₂) and MAP₃ (0% O₂) treatments, increasing phenolic compound content until day 4, then all treatments presented a significant decrease in phenolic compound content in relation to the beginning of storage time. The modified atmosphere with 8% CO₂ (MAP₂) evidenced stability in the synthesis of total phenolic compounds during all storage time, not showing significant change.

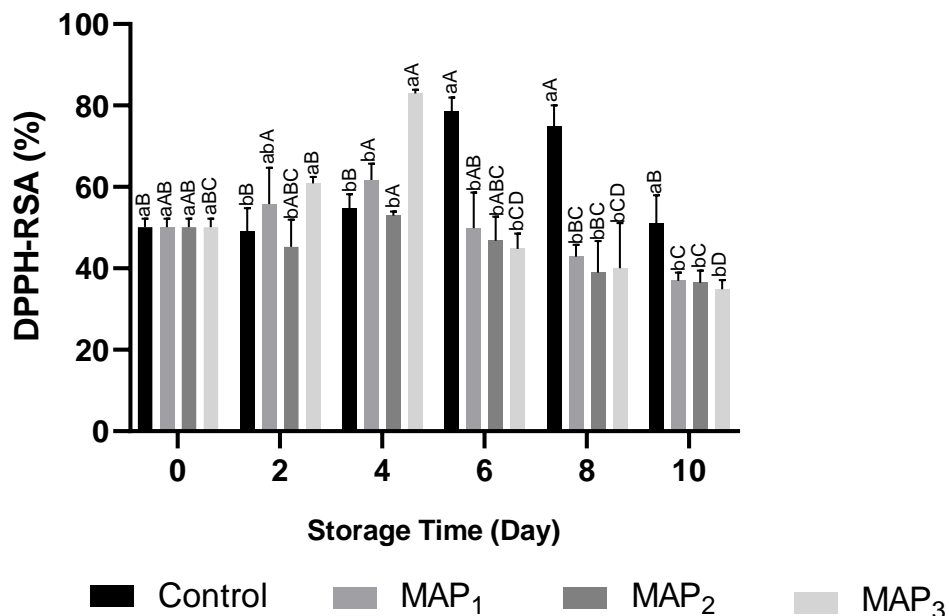
Figure 5: Effect of MAP treatment on total phenolic compounds (TPC), during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

Control treatment presented a peak in antioxidant activity of 78.51% on day 6 of storage (Figure 6). Minimally processed peach exposed to 0% O₂ showed the highest DPPH radical-scavenging activity after 4 days of storage with 82.93%. Fruit kept in MAP₁ (5% CO₂) presented antioxidant activity of 61.72% after 4 days of storage. However, in MAP₂ (8% CO₂), it presents a stability in antioxidant activity during the whole storage time, the peak of antioxidant activity being on day 4, with 52.98%, but not presenting significant difference during the other days of storage. A relatively long shelf life was discovered in the peach slices under the MAP₁ (5% CO₂) and MAP₂ (8% CO₂) treatments at 5°C, with 36.98% and 36.48%, respectively, of antioxidant activity after 10 days.

Figure 6: Effect of MAP treatment on DPPH-RSA, during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $p < 0.05$ by Tukey's multiple range test.

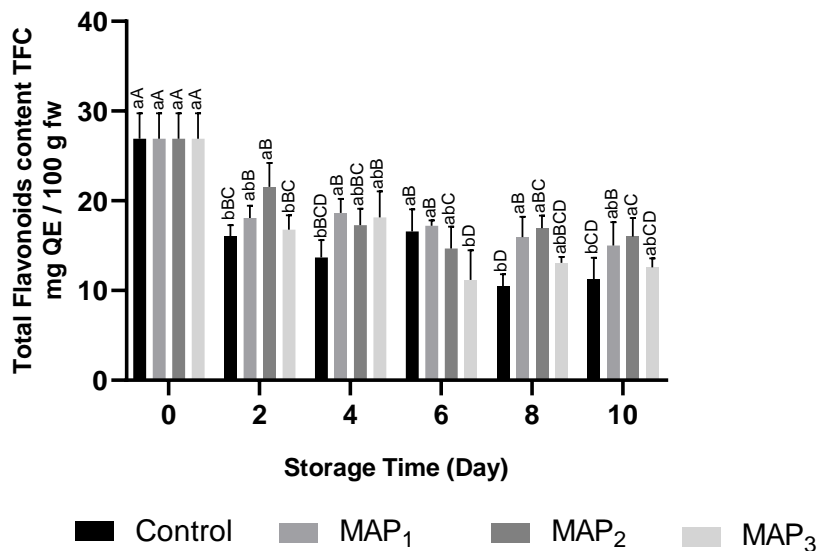


Source: Authors.

Total flavonoids content decreased during storage for all treatments. The initial flavonoid content in minimally processed Tropic Beauty peach was 26.92 mg QE 100 g⁻¹ fresh mass (Figure 7). The flavonoid contents were significantly affected by the modified atmospheres during storage ($p < 0.05$). In our study, the highest decrease in flavonoid content was detected in fresh-cut peaches stored in packaging with 21% O₂ (Control). We observed that the packaging with the highest O₂ content had the highest loss of flavonoids by accelerating the oxidative processes. The fruit stored in atmosphere with 8% CO₂ (MAP₂) presented flavonoids content (16 mgQE/100 g fresh mass) for 10 days.

Our results showed that the 5% CO₂ (MAP₁) and 8% CO₂ (MAP₂) levels in all packagings had the lowest decrease in flavonoids content during the 10 days of storage, reaching 15 and 16.02 mg QE 100 g⁻¹ of fresh weight, respectively.

Figure 7: Effect of MAP treatment on total flavonoids content (TFC), during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $p < 0.05$ by Tukey's multiple range test.

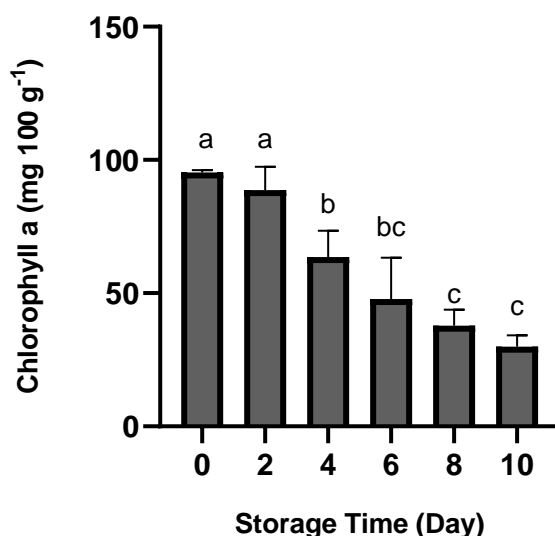


Source: Authors.

3.4 Pigments

The total chlorophyll a, chlorophyll b, anthocyanin and carotenoid contents by the treatments with modified atmospheres and storage time were also analyzed to reveal the color changing mechanism (Figures 8, 9, 10 and 11). Figure 8 shows that storage time presents significant change, reaching values of 29.99 mg 100 g⁻¹ of chlorophyll a on day 10. However, the chlorophyll a content did not change significantly in relation to the applied modified atmospheres.

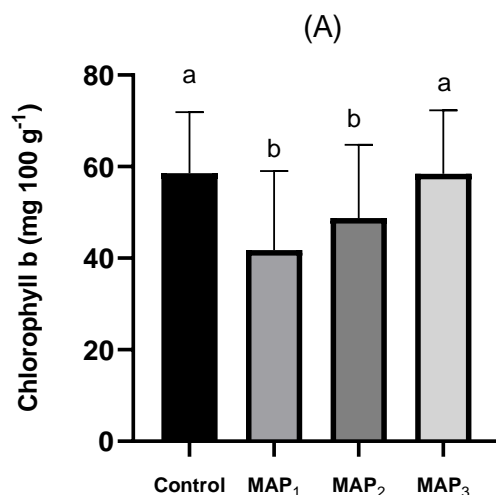
Figure 8: Effect of chlorophyll a in fresh-cut peaches storage time. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

Figure 9a shows the changes in chlorophyll b content between control and modified atmospheres of minimally processed peach. The chlorophyll b content was significantly higher than in MAP₁ and MAP₂ treatments, but it did not present significant difference with MAP₃.

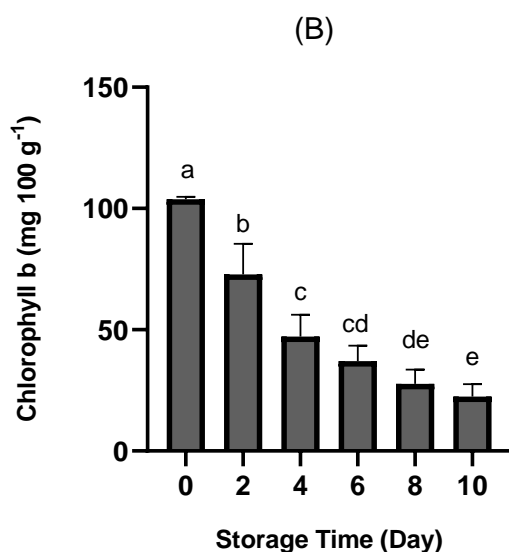
Figure 9a: Effect of MAP treatment on chlorophyll b in fresh-cut peaches. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test



Source: Authors.

However, the chlorophyll b content changed significantly from day zero until the end of shelf life (10 days), presenting the lowest chlorophyll b levels (22.49 mg 100 g⁻¹ chlorophyll b) (Figure 9b).

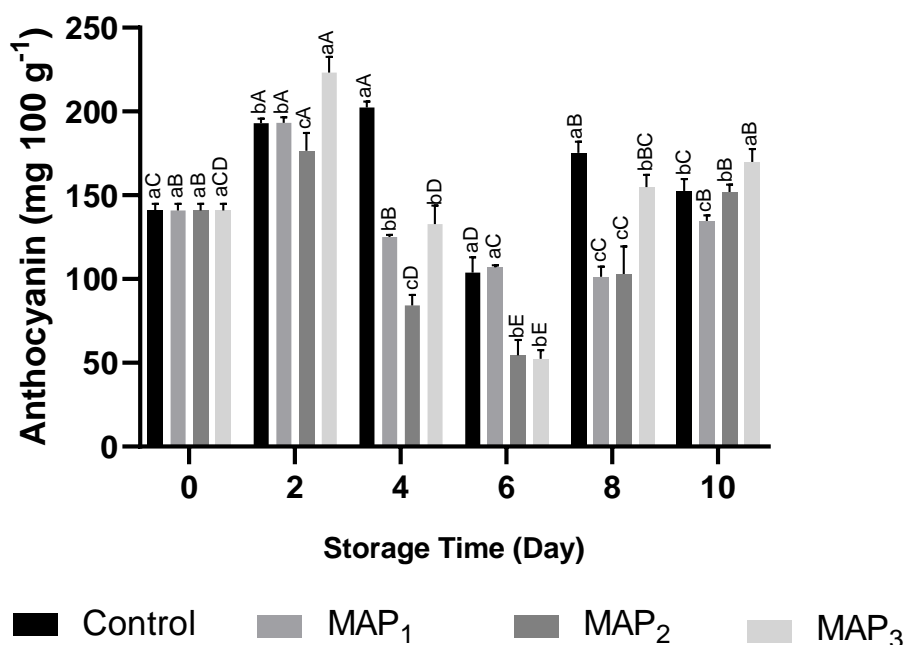
Figure 10: Effect of chlorophyll b during fresh-cut peaches storage time. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

Total anthocyanin value showed a change pattern similar to the total phenolic value during storage time as a response to the use of modified atmosphere. Significantly higher levels of anthocyanin were detected in fruit packaged with 0% O₂ (MAP₃) in comparison with slices treated with 8% CO₂ (MAP₂) on day 2 of storage. However, no significant difference was found in the anthocyanin content among the 0% O₂ (MAP₃), 8% CO₂ (MAP₂) and 21% O₂ (Control) treatments at the end of storage time (Figure 10).

Figure 10: Effect of MAP treatment on anthocyanin, (d) carotenoids during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $\rho < 0.05$ by Tukey's multiple range test

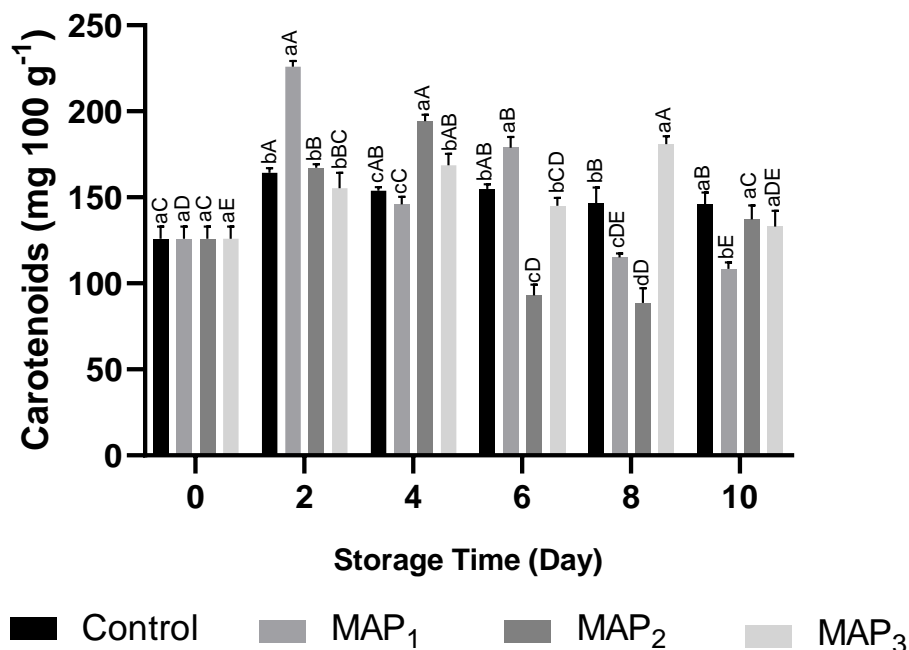


Source: Authors.

The treatments with modified atmosphere and storage time promoted the significant increase in the total amount of carotenoids, which can be illustrated by the fact that modified atmospheres can promote carotenoid synthesis during post-harvest storage. In the treatments with 5% CO₂ (MAP₁) and 8% CO₂ (MAP₂), the increase in carotenoids was more evident, with 225.94 and 194.35 mg 100 g⁻¹, respectively (Figure 11).

It was possible to observe that, up to day 10, the amount of carotenoids synthesized in the treatment with 8% CO₂ and 21% O₂ were the highest.

Figure 111: Effect of MAP treatment on carotenoids during fresh-cut peaches storage. Each value is the mean for three replicates, with vertical bars indicating standard errors. Different lower case letters indicate significant different within the MAP treatment. Different uppercase letters indicate within the storage day at $p < 0.05$ by Tukey's multiple range test.



Source: Authors.

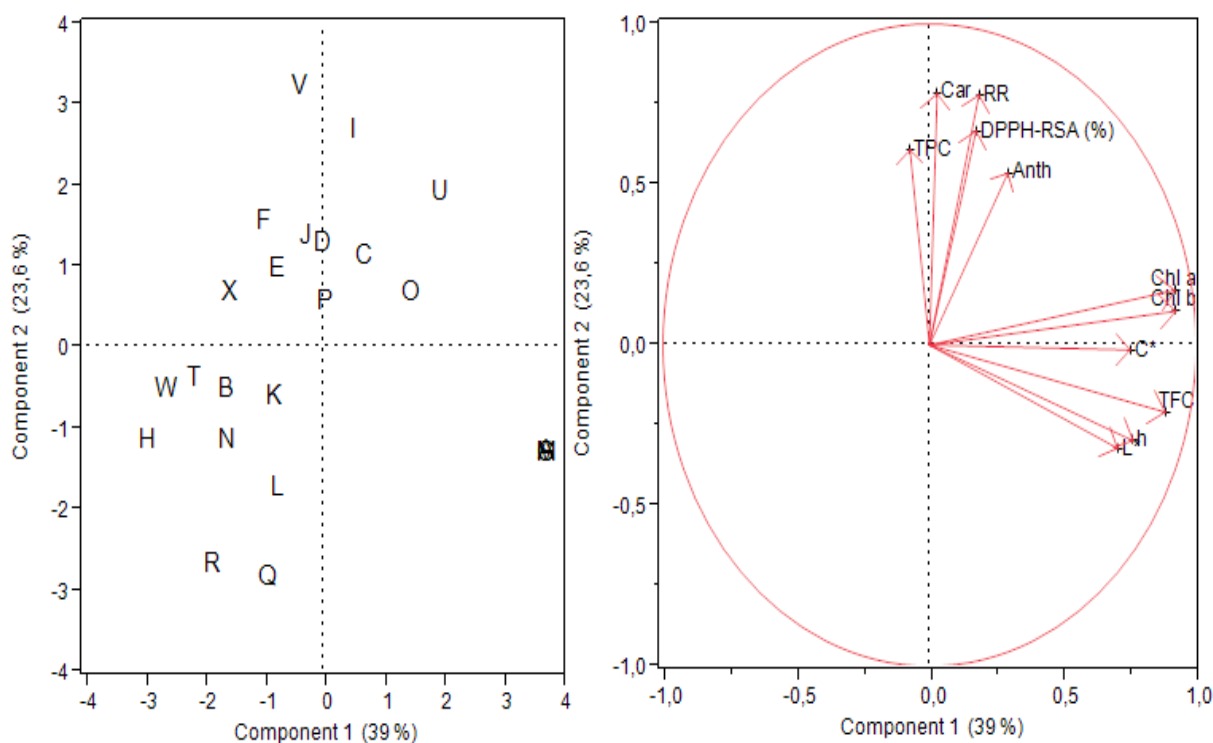
3.5 Principal component analysis.

Principal component analysis (PCA) was performed on the dataset of the results for the four modified atmosphere treatments, using storage time, for the 11 evaluated characteristics (physical and biochemical parameters, color attributes, total phenolic compounds and antioxidant capacity).

The total variability was explained by 11 principal components (PCs). The first three presented eigenvalues > 1 , however, PC1 and PC2 were responsible for 62.6% of the total variation (Figure 12). PC1, which explained 39% of the total variation, was efficient in separating the control, MAP₁, MAP₂ and MAP₃ treatments on day zero of storage. The examination of the PC1 loads suggests that this separation is due to chlorophyll a, chlorophyll b, total flavonoids, lightness, chroma and hue angle. The PC1 scores and loads suggest that the concentrations or values of these compounds were higher for all treatments on the second day of storage.

The PC2 accounted for 23.6% of variability, MAP₃ being efficient on the fourth day of storage and MAP₁ on the second day storage. The examination of the PC2 loads indicates that this separation is, especially, because of anthocyanin, carotenoids and phenolic compounds contents, DPPH antioxidant activity and respiration rate. The PC2 scores and loads suggest that the control and MAP₃ treatments, on day six and eight of storage, present high values of DPPH antioxidant activity and phenolic compounds. Therefore, the principal component analysis was efficient in confirming the results presented here.

Figure 122: Plots of the principal component analysis of bioactive compounds data for four treatments MAP with storage time. PC1/PC2 scores (A) and loadings plot (B) accounted for 62.6% of the total variation. Samples: Control- day 0 [A], Control- day 2 [C], Control- day 4 [D], Control- day 6 [E], Control- day 8 [F], Control- day 10 [B], MAP1-day 0 [G], MAP1-day 2 [I], MAP1-day 4 [J], MAP1-day 6 [K], MAP1-day 8 [L], MAP1-day 10 [H], MAP2-day 0 [M], MAP2-day 2 [O], MAP2-day 4 [P], MAP2-day 6 [Q], MAP2-day 8 [R], MAP2-day 10 [N], MAP3-day 0 [S], MAP3-day 2 [U], MAP3-day 4 [V], MAP3-day 6 [W], MAP3-day 8 [X], MAP3-day 10 [T]. Trait abbreviations: carotenoids [Car], anthocyanin [anth], chlorophyll a [chl a], chlorophyll b [chl b], total flavonoids content [TFC], total phenolic content [TPC], DPPH antioxidant capacity [DPPH-RSA], respiration rate [RR], Chroma [C*], Lightness [L*], Angle hue [°h].



Source: Authors.

4. Discussion

The respiration rate changes throughout the product's life. The metabolic activity is especially high during the initial growth of the product, during the ripening of the climacteric fruit and during injury healing periods (Saltveit, 2019). The respiration metabolism can be reduced, restricting oxygen availability for the tissue. Pérez-López et al. (2014) evaluated the kinetic of the peach respiration rate during storage in different stages of maturation, obtaining maximum readings of 87 CO₂ kg⁻¹ h⁻¹. The suppression of the respiration rate in minimally processed peach stored in modified atmospheres could, thus, increase storage time and maintain quality. MAP depends on a delicate balance between the respiration frequency of the included product and the diffusion properties of the packaging. Each one must be within a narrow range for the desired atmosphere to be created and maintained inside the package (Yahia et al., 2019).

The color of the fruit is one of the most important factors in determining the quality and commercialization of the fruit by the consumer. The acceptance by the consumer is also strongly influenced by the color of the fruit. Change of the color attributes is due to, especially, the degradation of chlorophyll caused by high metabolic activity, leading to loss of green color and accumulation of carotene and anthocyanin in the fruit (Solovchenko et al., 2019). The use of refrigeration can reduce chlorophyll degradation in the thylakoid membrane, stabilizing the biochemical reactions of the photosystem during the

storage period. Junior et al. (2010) reported similar values in peach cv. Aurora-1 with a value of 70 on day 0 and 69.85 on day 7. The development of enzymatic browning is usually reflected by a decrease in lightness value, which can be associated to the browning of the fruit, influenced especially by enzymatic browning.

Chroma expresses the saturation (color intensity) of the pigments, the decrease of these values proves the depigmentation (browning) of the peach pulp during storage. Rocculi et al. (2004) researched modified atmosphere packaging for prolonging the shelf life of minimally processed apples, observing the common tendency of decrease in color intensity during 12 days of storage.

The decrease in hue angle, during the storage period, indicates the yellowing of the pulp. This metabolic behavior suggests changes in the coloration of fruit, which involves chlorophyll loss due to chlorophyllase activity, and later synthesis of new pigments, such as carotenoids and anthocyanins. A similar tendency of decrease in the hue angle of nectarine subjected to -MCP and modified atmosphere were reported by Özkaya et al. (2016), where the control treatment decreased from 88° to 66° after 40 days of storage, both in cold storage and in shelf life conditions.

Fruits and vegetables with more bioactive compounds content are nutritionally valuable for human health (Bursać Kovačević et al., 2020). The increase in phenolic compounds during storage might be related to the stimulus to the activity of some enzymes involved in phenolic biosynthesis as a tissue response to the stress suffered during processing (De la Rosa et al., 2019). It was also verified that the low O₂ content in the packages might restrict the synthesis of phenolic compounds in minimally processed fruit, which are considered a biochemical response to mechanical damage by cutting (Artes et al., 2007). Mota et al. (2012) reported similar results in several peach cultivars, cv. Douradão with 53.38 mg gallic acid 100 g⁻¹, cultivar Granada with 72,38 mg gallic acid 100 g⁻¹ and cultivar Marli with 78,09 mg gallic acid 100 g⁻¹.

Cortellino et al. (2015) reported that, in apple slices exposed to atmospheres with low O₂ content, lead to the preservation of phenolic compounds in comparison with the air (21% O₂). Therefore, the decrease in phenolic compounds in minimally processed products can depend on the O₂ and CO₂ levels inside the packaging as well as the variety of fruit. For “Tropic Beauty” peach, low O₂ was the most efficient in maintaining phenolic concentration in comparison with high O₂ packaging.

Antioxidant activity tendency was almost similar to the total phenolic compounds. This metabolic behavior was similar to that reported by Li et al. (2012), who evidenced similar tendency in minimally processed pear, stored in modified atmospheres with high and low O₂ content, concluding that the packaging with high O₂ content in the modified atmosphere was efficient in maintaining free radical reduction capacity, according to the DPPH method. This study shows the existence of a correlation between the phenolic compound level and DPPH radical elimination activity. A low DPPH radical scavenging activity resulted in a decrease in phenolic content, which, in turn, possibly accelerated the oxidation of the phenolic compounds and tissue browning. The fruit antioxidant activity might be a valuable indicator for the general quality of the peach slices. Oxidative stress generated by mechanical damage (cutting) exceeds the capacity of the natural antioxidant system, it results in disorders, such as browning and deterioration of the sensory quality of the fruit. The results are consistent with those obtained with pomegranate (Selcuk & Erkan, 2014), orange (Alasalvar et al., 2005) nectarine (Cefola et al., 2014), and the low O₂ content could maintain antioxidant activity by restricting respiration, as well as delaying senescence.

Carbon dioxide in modified atmosphere packaging can regulate the PPO and PAL enzymes activity and, consequently, the synthesis of phenolic compounds, oxidation and browning of the tissue in a pattern, depending on the dosage. PAL is activated in the samples with low phenolic compounds, in an environment with high carbon dioxide, resulting in an increase in biosynthesis of phenolic compounds, especially phenolic acids, such as camphoric and chicoric acids (Mathooko, 1996).

It might suggest that the metabolic stage (maturity level) of the product has an important role in activating these enzymes. Carbon dioxide can also activate antioxidant enzymes (POD and CAT), which can accelerate the synthesis of phenolic compounds.

Flavonoids are the most abundant phenolic compounds in fruits and vegetables, they are responsible for almost two thirds of the diet's phenolic compounds and, as a group, are the most bio-active (Birt & Jeffery, 2013; De la Rosa et al., 2019).

According to Naheed et al. (2017), the higher the O₂ levels inside the packaging, the higher the flavonoid loss. The flavonoids degradation might be widely related to the O₂ concentrations inside the packaging. However, some studies reported that high CO₂ showed positive effects in the maintenance of flavonoids in garlic (Pérez-Gregorio et al., 2011). The high CO₂ levels in the packaging are probably responsible for the preservation of total flavonoids.

The chlorophyll degradation is fundamental for the process of reducing the green color that occurs during the ripening of most fruits. This degradation causes color changes in fruits, which, in turn, unveils the previously synthesized pigments (Choo, 2018).

Red color in peaches is usually associated to the anthocyanin content present, especially, in the cell vesicle of peach peel, or spread throughout the pulp (Denoya et al., 2015). The increase in anthocyanin concentration can be related to the physiological response to oxidative stress during storage, while the depletion and increase in phenolic compounds might be due to the fact that the phenolics are involved in the lignin synthesis in the fruits' damaged tissue (Belay et al., 2019).

Minas et al. (2018) reported that the characteristic color of peach depends on the accumulation of pigments, such as chlorophyll, carotenoids and anthocyanin, but the red color is caused by anthocyanins, especially cyanidin-3-galactoside. The biosynthesis of anthocyanins is controlled by a high-energy photoreaction and protects against excess of light and it has been used as a model system to study the mechanisms of photoregulation in vegetable tissues.

Oliveira et al. (2015) evaluated the effect of modified atmosphere on the phytochemical profile of pasteurized peach puree, observing a similar behavior in the synthesis of carotenoids, with an increase on the initial days of storage and later decrease in synthesis. The authors reference that the carotenoid degradation is due to β -carotene oxidation that occurs through a synthesis of free radicals and the water content had shown to have a protective effect on carotene stability, presumably through its interaction with free radicals.

5. Conclusion

The study was carried out to evaluate the effects of modified atmospheres and storage time on different physical and biochemical quality attributes of minimally processed peach cv. Tropic Beauty. All factors showed significant effects on phenolic compounds, antioxidant activity, pigments and color. MAP₂ (8% CO₂) can be considered as a relatively better modified atmosphere packaging. A storage time of 10 days is ideal to preserve the quality of fresh-cut peaches. More research involving several gas concentrations in the modified atmospheres of peach in relation to other quality attributes can be carried out to guarantee the ideal use of this technique to obtain more economic benefits and benefits related to the health of this fruit. Effects on biochemical activity, especially on antioxidant activity, of minimally processed fruit in modified atmosphere packaging need to be studied.

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