

Processing, storage and light exposure: impacts on murici jelly stability and volatile profile

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ABSTRACT: This study aimed to evaluate how processing, packaging type, and storage time influence the functional and volatile attributes of jelly. A factorial experimental design was used, with two types of packaging (with and without light exposure) and five storage periods (0, 3, 6, 9, and 12 months). Processing increased the levels of phenolic compounds and antioxidants, organic acids and aldehydes, while it reduced vitamin C, alcohols and volatile esters. Gallic acid was the majority phenolic compound in both pulp and jelly. Regarding the volatile compounds, esters group was predominant in murici pulp, while the short-chain organic acids were predominant in jelly. The jelly storage was marked by the reduction of phenolic compounds, antioxidant activity and volatile esters. However, no significant changes were found regarding the packaging factor.

Keywords: antioxidant activity; *Byrsonima crassifolia*; phenolic compounds; volatiles

Processamento, armazenamento e exposição à luz: impactos na estabilidade e no perfil volátil da geleia de murici

RESUMO: Este estudo teve como objetivo avaliar como o processamento, o tipo de embalagem e o tempo de armazenamento influenciam os atributos funcionais e voláteis da geleia. Um delineamento experimental fatorial foi usado, com dois tipos de embalagem (com e sem exposição à luz) e cinco períodos de armazenamento (0, 3, 6, 9 e 12 meses). O processamento aumentou os níveis de compostos fenólicos e antioxidantes, ácidos orgânicos e aldeídos, enquanto reduziu a vitamina C, álcoois e ésteres voláteis. O ácido gálico foi o composto fenólico predominante tanto na polpa quanto na geleia. Em relação aos compostos voláteis, o grupo dos ésteres foi predominante na polpa de murici, enquanto os ácidos orgânicos de cadeia curta foram predominantes na geleia. O armazenamento da geleia foi caracterizado pela redução de compostos fenólicos, atividade antioxidante e ésteres voláteis. No entanto, não foram encontradas alterações significativas em relação ao fator embalagem.

Palavras-chave: atividade antioxidante; *Byrsonima crassifolia*; compostos fenólicos; compostos voláteis

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INTRODUCTION

The Brazilian Cerrado is considered the largest savanna formation in the Americas and the second largest biome in Brazil, currently comprising about two million square kilometers (25% of the surface area of the country) and encompassing a wide variety of fauna and flora ([Batlle-Bayer et al., 2010](#); [Cardoso et al., 2011](#); [Arruda & Almeida, 2015](#)). In recent decades, agricultural expansion in Brazil has threatened the original coverage of the Cerrado, resulting in significant environmental impacts ([Cardoso et al., 2011](#); [Melo et al., 2014](#)).

Many fruits of Brazilian native species have peculiar sensory characteristics, high nutritional value and functional appeal. Among them is noteworthy the murici, *Byrsonima crassifolia* (L.) Rich, an important species of the Cerrado and Amazon biomes, belonging to the Malpighiaceae family ([Sannomiya et al., 2007](#); [Neves et al., 2015](#); [Uekane et al., 2017](#)). The fruit is considered a small drupe, rounded or elongated, having about 1-2 cm in diameter and when ripe it presents a yellowish color. The pulp is soft, pasty, sweet tasting, with a fruity aroma similar to rancid cheese ([Alves & Franco, 2003](#); [Ferreira, 2005](#); [Uekane et al., 2017](#); [Silva et al., 2019L](#)).

Several studies have shown that the murici has high antioxidant capacity ([Rufino et al., 2010](#); [Almeida et al., 2011](#); [Souza et al., 2012](#); [Malta et al., 2013](#)), mainly due to its high content of phenolic compounds, such as quercetin and gallic acid derivatives, catechins and protocyanidins ([Gordon et al., 2011](#)), vitamin C ([Almeida et al., 2011](#); [Souza et al., 2012](#); [Neves et al., 2015](#)) and carotenoids content, especially as lutein and zeaxanthin ([Mariutti et al., 2013](#)).

According to [Alves & Jennings \(1979\)](#), the volatile constituents present in murici from the Amazon region and identified were: terpenoids, alcohols, carbonyls and esters, predominantly 2-butanone, ethyl acetate, ethyl butyrate, ethyl hexanoate. According to [Alves & Franco \(2003\)](#) and [Rezende & Fraga \(2003\)](#), the most abundant chemical class of volatiles from murici from the north and northeast of Brazil was the esters (55%), like ethyl butanoate (fruity and sweet), ethyl hexanoate (fruity), followed by alcohols (31.5%) and 1-octen-3-ol (odor similar to that of mushroom), 2-phenylethanol (floral) and some organic acids, such as butanoic acid (rancid cheese) and hexanoic acid (pungent). More recently, [Silva et al. \(2019a\)](#) found that both murici da praia and murici do campo exhibit high levels of volatile fatty acids and esters, which significantly contribute to their characteristic aroma. Similarly, [Uekane et al. \(2017\)](#) confirmed that the volatile profile of murici (*Byrsonima crassifolia* (L.) Rich) is mainly composed of esters, with carboxylic acids as the second most prevalent group.

The processing of murici fruit, in the form of jelly for example, is considered a viable alternative that allows the fruit consumption as a co-product throughout the year. However, for the characteristics of the fruit to be preserved in the jelly, at least partially, adequate care must be taken during processing and storage. According to [Cunha et al.](#)

[\(2019\)](#), the effect of processing and storage on the quality of murici jelly affects the nutritional, microbiological content and promotes better sensory acceptance. However, to prevent loss of bioactive compound with functional potential, there is a need for packages that block the incident light.

The native Cerrado fruit, such as murici (*Byrsonima crassifolia* (L.) Rich), are appreciated for their pleasant peculiarities such as color, aroma and taste, however, is underutilized as food due to the lack of information and studies. Although that fruit does not have widespread use as food, it is necessary to make the population aware of its importance, not only as a source of nutrients, but also regarding its sensory potential. Therefore, the production of murici jelly can increase the consumption of this fruit, besides being a way to add value and extend the shelf life and sensory acceptance of the product prepared.

Therefore, given the need to increase availability and value native Brazilian fruits, several recent published studies have shown that fruit processing in the form of jellies is perfectly viable, in addition to promoting better sensory acceptance, such as mangaba jelly (*Hancornia speciosa* Gomes) ([Zitha et al., 2020](#)), curriola jelly (*Pouteria ramiflora* (Mart) Radlk) ([Cunha et al., 2020 ab](#)) and murici jelly (*Byrsonima crassifolia* (L.) Rich) ([Cunha et al., 2019](#)).

The proposal of this study was to prepare a jelly from reconstituted murici pulp and determine, through antioxidant activity, phenolic and volatile compounds, the impact of the processing and the effect of glass package (transparent and amber) along one year of storage, on the quality of the product prepared.

MATERIALS AND METHODS

Obtaining the raw material

Murici pulp, used in the jelly manufacturing, was acquired from the *Frutos do Cerrado* company located in Uberlândia, Minas Gerais – Brazil (latitude: 18.9180° S, longitude: 48.2750 °W), and stored in plastic bags at -18°C until processing.

Jelly preparation

For the jelly processing, the murici pulp was thawed and filtered through a fine mesh sieve, separating the juice from the solid residue. The sieve used had a mesh size of 1 mm, aiming to separate the juice from the pulp to ensure a smoother texture in the jelly. The pulp was then reconstituted in the following proportion: for every liter of juice obtained, 500 g of pulp residue were added. A sample of the reconstituted pulp was reserved for the characterization analysis. The reconstituted sample was stored at a temperature of 4°C to preserve its biochemical characteristics before processing. Subsequently, conventional jelly formulations were prepared, considering the proportion for extra-type jellies, a 1:1 ratio of reconstituted pulp and commercial sugar, using a 1% pectin concentration (Brazil, 1978). For the preparation of the jelly 1.5 kg of reconstituted pulp, 15 g of commercial pectin and 1.5 kg of crystal sugar

were used. The jellies were made in eight batches in the same proportions, on the same day. The flowchart of murici jelly processing is illustrated in [Figure 1](#). The yield of jelly corresponded to 56%, producing 1.68 kg of product. The

murici jelly was packed in glass containers (amber and transparent) and stored at $20.9^{\circ}\text{C} \pm 2.93$ and $69.3\% \text{ RH} \pm 13.28$ for twelve months.

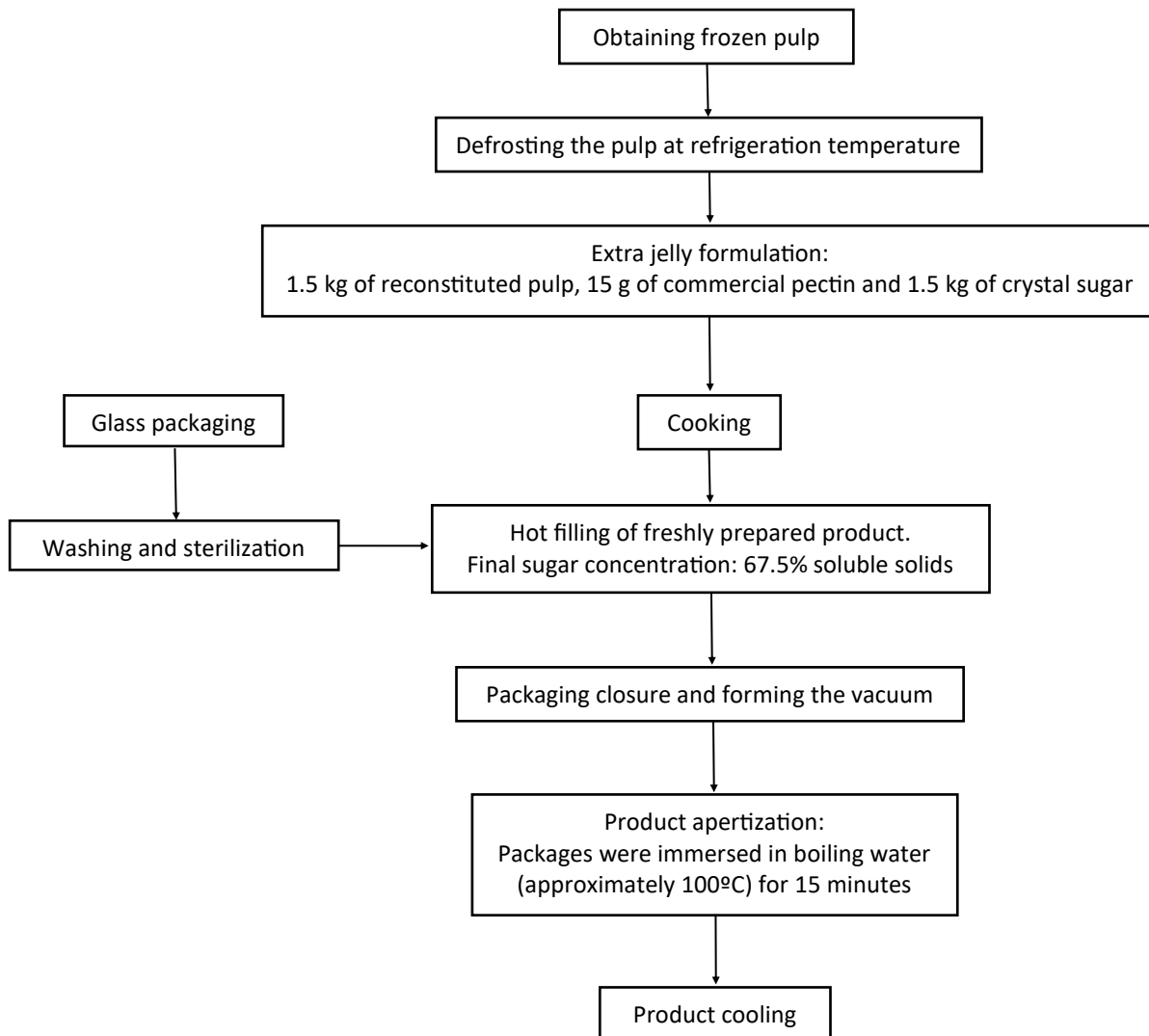


Figure 1. Flowchart of murici jelly processing.

Experimental design

Two experiments were carried out. In the first one, murici fresh jelly was compared to the murici reconstituted pulp, before processing. In the second experiment, a completely randomized design (CRD) was used, with a double factorial scheme, including two types of packages (transparent and amber glass packages) and five storage periods (0, 3, 6, 9 and 12 months). Four replicates were used for the total phenolics, vitamin C and antioxidant activity analyses and two replicates were used for analysis of phenolic profile and volatile compounds and the experimental parcel consisted of 80 g of jelly (two bottles of 40 g).

Preparation of extracts for determination of antioxidant activity

To obtain the antioxidant extracts, the methodology described by [Larrauri et al. \(1997\)](#) was used. 2.5 g portions of

each sample, together with 20 mL of 50% (v/v) methyl alcohol, were homogenized and left to rest for 1 hour at room temperature and protected from light. After that period, the homogenate was centrifuged at $8.832 \times g$, for 10 minutes and the supernatant transferred to a 50 mL flask. To the residue were added 20 mL of 70% acetone (v/v), repeating the extraction procedure. The second supernatant was added to the first, in the volumetric flask, making up the volume with distilled water. The extracts obtained were used to determine the antioxidant activity and total phenolics, despite the methods used.

Determination of total phenolics, vitamin C and antioxidant activity

The total phenolic contents were determined according to the Folin-Ciocalteu method, adapted by [Waterhouse \(2002\)](#). For the determination, the extracts were diluted at a 1:5 ratio

(v/v), in triplicate. An aliquot (0.5 mL) of the extract dilution was taken and added to 2.5 mL of 10% (v/v) Folin-Ciocalteu reagent and 2.0 mL of 4% (v/v) sodium carbonate solution. The mixture was then homogenized and left to stand for 2 hours, protected from light. The absorbance was measured using a spectrophotometer at a wavelength of 750 nm. For the standard curve, a 2000 $\mu\text{g mL}^{-1}$ gallic acid solution was prepared (0.1 g of gallic acid in 50 mL of ethanol), and standard solutions were prepared with concentrations ranging from 5 $\mu\text{g mL}^{-1}$ to 40 $\mu\text{g mL}^{-1}$. The results were expressed in mg of gallic acid 100g⁻¹ sample.

The vitamin C analysis was carried out through the colorimetric method using 2,4-dinitrophenylhydrazine as proposed by [Strohecker & Henning \(1967\)](#). The results were expressed in mg of ascorbic acid 100g⁻¹.

The following methods were used to determine the antioxidant activity: i) ABTS^{•+} method: performed according to the methodology described by [Re et al. \(1999\)](#). A 7 mM ABTS stock solution was prepared by dissolving 192 mg of ABTS reagent in 50 mL of deionized water, and a 140 mM potassium persulfate solution was prepared by dissolving 378.4 mg of potassium persulfate in 10 mL of deionized water. The ABTS^{•+} radical was generated by mixing 5 mL of the ABTS stock solution with 88 μL of the potassium persulfate solution. This mixture was kept in an amber bottle, protected from light, at room temperature for 16 hours. Subsequently, 1 mL of this solution was diluted in 100 mL of ethanol to obtain an absorbance of 0.70 ± 0.05 at a wavelength of 734 nm. For the assay, the extracts were diluted to concentrations of 750, 500, and 250 mg L⁻¹, in duplicate. Determinations were performed by adding a 30 μL aliquot of each extract dilution to 3 mL of the ABTS^{•+} solution. After 6 minutes of reaction, absorbance was measured in a spectrophotometer at 734 nm. For the standard curve, a 2000 μM trolox stock solution was prepared (25 mg of trolox in 50 mL of ethanol), and standard solutions were prepared from this stock by diluting to concentrations ranging from 100 μM to 1500 μM . The results expressed in μmol of trolox g⁻¹; ii) DPPH method: performed according to the methodology described by [Brand-Williams et al. \(1995\)](#). For the determination, the extracts were diluted to the following concentrations: 1,000, 500, and 250 mg L⁻¹, in duplicate. The determinations were performed by adding a 0.1 mL aliquot of each extract dilution and of the control solution (prepared with 40 mL of 50% methanol, 40 mL of 70% acetone, and completed to 100 mL with deionized water) to 3.9 mL of 60 μM methanolic DPPH solution (2.4 mg of DPPH in 100 mL of methanol). After 60 minutes of reaction, the absorbance was measured using a spectrophotometer at 517 nm. From the 60 μM DPPH stock solution (10 mL), standard solutions ranging from 100 μM to 1500 μM were prepared to generate the calibration curve. The results expressed as IC₅₀ in mg mL⁻¹ of DPPH; iii) β -carotene/linoleic acid method: performed according to the methodology described by [Miller \(1971\)](#). For the preparation of the β -carotene/linoleic acid system solution, 40 μL of linoleic acid, 530 μL of Tween 40, and 50 μL

of a 20 mg mL⁻¹ β -carotene solution (20 mg of β -carotene in 1 mL of chloroform) were added. To solubilize the mixture, 1 mL of chloroform was added, followed by evaporation under heating. Subsequently, oxygenated water was added until an absorbance of 0.7 at 470 nm was reached. For the determination, 0.4 mL of the extract (in duplicate) was mixed with 5 mL of the system solution. The first absorbance reading was taken at 470 nm using a spectrophotometer. Afterward, the reaction mixture was incubated in a water bath at 40°C for 2 hours. A second absorbance reading was then performed at 470 nm. The results being expressed as a percentage of oxidation.

Extract preparation for determining the phenolic compounds profile

The extracts for the identification of phenolic compounds by the chromatographic method were prepared following the methodology described by [Ramaiya et al. \(2013\)](#). For the extraction, 2.5 g of sample were used, homogenized in 20 mL of 70% HPLC grade methanol (v/v), for 1 hour in an ultrasonic bath at room temperature. The obtained extract was centrifuged at 8.832xg for 15 min at 4°C and filtered through filter paper with 14 μm porosity. For sample injection, the extracts were filtered again using 0.45 μm porous membrane filters.

Phenolic compounds profile determination

The quantitation and identification of phenolic compounds were performed by High Performance Liquid Chromatograph using a Shimadzu chromatograph (Shimadzu Corporation, Kyoto, Japan) equipped with four high-pressure pumps (Model LC-20AT), with a diode array detector (Model SPD-M20A), degasser (Model DGU-20A5), CBM-20A interface, CTO-20AC oven and autosampler (Model SIL-20A). Separations were performed using a Shimadzu Shim-pack ODS GVP-C18 (4.6 x 250 mm, 5 mm) column attached to a pre-column (Shimadzu-pack ODS GVP-C18, 4.6 x 10 mm, 5 μm). The mobile phase consisted of 2% (v/v) acetic acid in deionized water (Mobile Phase A) and 70:28:2 (v/v) methanol/water/acetic acid (Mobile Phase B) at a flow rate of 1.0 mL min⁻¹ with a gradient elution program and execution time of 65 minutes. The injection volume was 20 μL . Phenolic compounds were detected at 280 nm. The standard solutions were diluted in methanol and calibration curves were obtained from injections of ten different concentrations, in duplicate. The phenolic compounds were identified by comparing retention times with the authentic standards (gallic acid, catechin, chlorogenic acid, caffeic acid, ferulic acid, *trans*-cinnamic acid, vanillin, rutin, quercetin, *m*-coumaric acid, *p*-coumaric acid, *o*-coumaric acid). The results were expressed in mg of the phenolic compound 100g⁻¹ fresh sample. For all phenolic compound analytical curves, the R² was > 0.99, the limit of detection (LOD) was 0.009 to 0.1713 mg L⁻¹, and the limit of quantification (LOQ) was 0.005 to 0.50 mg L⁻¹, calculated using the parameters of the analytical curves, according to [Ribani et al. \(2004\)](#) as shown in [Table 1](#).

Table 1. Chromatographic parameters used for the detection and quantification of phenolic compounds present in reconstituted murici pulp and jelly.

Phenolic compounds	Limit of detection (LOD) (mg L ⁻¹)	Limit of quantification (LOQ) (mg L ⁻¹)	Linearity*	Determination Coefficient (R ²)	Retention time (minutes)
1. Gallic acid	0.036	0.112	$y = 7 \times 10^9 x + 739.34$	0.9969	6.82
2. Catechin	0.083	0.251	$y = 3 \times 10^9 x - 233.23$	0.9968	10.80
3. Chlorogenic acid	0.171	0.519	$y = 7 \times 10^9 x - 1844.4$	0.9944	12.56
4. Caffeic acid	0.015	0.047	$y = 1 \times 10^{10} x - 2181.2$	0.9918	15.05
5. Vanillin	0.001	0.005	$y = 1 \times 10^{10} x - 23.522$	0.9989	17.65
6. <i>p</i> -coumaric acid	0.018	0.055	$y = 2 \times 10^{10} x - 2350.7$	0.9934	21.81
7. Ferulic acid	0.012	0.036	$y = 6 \times 10^9 x - 1192.4$	0.9970	24.79
8. <i>m</i> -coumaric acid	0.009	0.027	$y = 2 \times 10^{10} x - 243.76$	0.9969	27.62
9. <i>o</i> -coumaric acid	0.043	0.130	$y = 2 \times 10^{10} x - 1691.8$	0.9930	34.62
10. Quercetin	0.072	0.218	$y = 9 \times 10^9 x + 729.72$	0.9957	37.59
11. <i>trans</i> -cinnamic acid	0.004	0.013	$y = 3 \times 10^{10} x + 7304.5$	0.9975	51.66
12. Rutine	0.166	0.504	$y = 1 \times 10^{10} x - 8136.7$	0.9976	53.49

Notes: * x represents the concentration in mol L⁻¹ and y represents the peak area.

Extraction and identification of volatiles compounds

For the extraction and identification of volatiles the parameters described by [Silva et al. \(2019\)](#) were used with adaptations. The volatile compounds were extracted by the solid phase microextraction technique (SPME) and tentatively identified by Gas Chromatography Mass Spectrometry.

The samples were transferred to a 20 mL vial (suitable for volatile retention). The volatile compounds present in the samples were extracted for 30 minutes at 40°C, using a 50/30 µm (1 cm) fiber of polydimethylsiloxane/divinylbenzene/carboxene (PDMS/DVB/CAR). The fiber was conditioned at a temperature of 270°C for 30 minutes before use. The fiber was exposed to 1 cm of the headspace of the glass vial containing the sample. After 30 minutes of exposure to the fiber at 40°C, the syringe was immediately taken to the GC-MS injector, in which the volatile compounds were desorbed at 220°C and in split (1:5) mode for 2 minutes.

A gas chromatograph coupled to mass spectrophotometry (Shimadzu GCMS QP2010), equipped with a fused silica capillary column (Supelco SLBtm – 5MS column of dimensions 30 m x 0.25 mm, 0.25 µm film thickness) with a stationary phase of 5% diphenyl and 95% polydimethyl siloxane (DB5), was used to separate and identify the extracted compounds. The injector temperature was 220°C, and the column was programmed to have an initial temperature of 40°C, increasing 4°C every minute until reaching 200°C. The carrier gas (helium) flow rate was 1.0 mL min⁻¹ split (1:5). The mass spectrometer (MS) conditions were: mass selective detector operating by electronic impact

and impact energy of 70 eV; scan speed 1000 m z⁻¹ s⁻¹; scanning interval 0.5 fragments/s and fragments detected of 45 Da and 600 Da. The compounds were tentatively identified by comparing the retention times of C₅ – C₂₀ alkane standards from the literature retention index. Mass fragments were compared using Willey 8 libraries and specific literature of [Adams \(2007\)](#). The aroma descriptions of most compounds were compared to those reported in the Flavornet ([Acree & Arn, 2004](#)).

Statistical analysis

Statistical analysis was performed using the SISVAR software version 5.6 ([Ferreira, 2011](#)). The multifactorial analysis was performed considering the storage time and the type of glass package and their interaction as main factors of variation. After analysis of variance, the polynomial regression models and the coefficients of determination (R²) were selected based on the significance of the F test of each model tested. The t-test Student was used to evaluate differences between the reconstituted pulp and freshly prepared jelly for antioxidant and profile of phenolic compounds analysis. All tests were carried out at 5% of probability.

RESULTS AND DISCUSSION

Data of bioactive compounds contents and antioxidant activity of the reconstituted murici pulp and fresh jelly are presented in [Table 2](#).

Table 2. Bioactive compounds and antioxidant activity of reconstituted murici pulp and fresh jelly

Bioactive compounds and activity antioxidant	Reconstituted murici pulp	Murici jelly	t-value	p-value
Total phenolic [mg (GAE) 100 g ⁻¹]	325.99 ± 6.30 ^b	1013.81 ± 14.41 ^a	-89.93	0.00
Vitamin C (mg ascorbic acid 100 g ⁻¹)	37.84 ± 3.08 ^a	19.33 ± 1.03 ^b	9.88	0.00
ABTS (μmol of trolox g ⁻¹)	362.50 ± 11.90 ^b	2685.76 ± 479.09 ^a	-9.70	0.00
DPPH IC ₅₀ (g of sample g ⁻¹ DPPH)	397.98 ± 36.75 ^a	119.00 ± 30.94 ^b	12.47	0.00
β-carotene/linoleic acid (% oxidation)	38.58 ± 7.58 ^a	35.12 ± 11.93 ^a	0.55	0.61

Notes: Data presented as mean ± standard deviation of four repetitions. Significance level at 5% probability.

It was found that the processing of the reconstituted pulp and its consequent conversion into jelly, in general, increased phenolic and antioxidant activity levels, except for β-carotene/linoleic acid method; however, processing reduced vitamin C levels (Table 2). The results are associated with the heat treatment (cooking) that concentrate the phenolic compounds, due to evaporation of part of the water during the jelly processing, and consequently increase the antioxidant activity. These results are similar to those reported by Kim et al. (2006) and Raupp et al. (2011). On the other hand, according to Bertin et al. (2016) and Cunha et al. (2020a) the use of high temperatures in the cooking process promoted decrease in vitamin C, an unstable and thermolabile compound that can be easily degraded during processing. This degradation process occurs via oxidation, particularly in the presence of oxygen and heat, leading to the conversion of ascorbic acid to dehydroascorbic acid and, subsequently, to diketogulonic acid, resulting in the loss of biological activity (Verbeyst et al., 2013).

The processing positively impacted total phenolics, which increased from 325.99 mg (GAE) 100 g⁻¹ to 1013.81 mg (GAE) 100 g⁻¹ fresh mass, comparing the reconstituted pulp and freshly prepared jelly, respectively (Table 2). In fact, the evaporation of water, during processing, contributes to the concentration of phenolic compounds and reducing the water volume in the pulp. This behavior may also occur, according to Raupp et al. (2011), due to the application of heat treatment using temperatures above 90°C and the presence of slight acidity in the preparation of the jelly, which may cause disruption of the plant cell wall and thus liberate and increase the insoluble phenolic compounds during extraction process. The increase in phenolic compounds during heating can be associated with the breakdown of fruit cell walls, releasing more phenolic compounds (Ghafoor et al., 2019). Similar results were reported by Kim et al. (2006), in which the effect of grape seed heating favored the release of phenolics and therefore increased their quantification. The same observation is reported by Cunha et al. (2020a) due to the effect of processing the curriola pulp in jelly.

After preparation of the jelly, ascorbic acid reduction from 37.84 mg 100 g⁻¹ to 19.33 mg 100 g⁻¹ fresh mass was observed at the initial time (Table 2). This result is due to the oxidation of vitamin C, a biologically active compound, unstable and reversibly oxidized to L-dehydroascorbic acid. Vitamin C, being thermolabile, is oxidized during storage due

to exposure to oxygen and light, leading to the degradation of ascorbic acid (Basak et al., 2023). It is decomposed to 2,3-dicetoglulonic acid what leads to the formation of hydroxymethylfurfural (HMF) (Shinwari & Rao, 2018), responsible for browning after the preparation of the jelly. According to Cunha et al. (2019), the effect of processing and storage on the quality of murici jelly affected the color of the product, specifically with the reduction in L* value, due to processes involving oxidation of vitamin C and non-enzymatic darkening reactions. Such browning reactions are enhanced by increased temperature and oxygen permeability, especially in transparent packaging, further justifying the use of protective packaging in long-term storage (Putnik et al., 2017).

The DPPH method showed that the amount of reconstituted pulp required to reduce DPPH radicle by 50% (from 397.98 g of sample g⁻¹ DPPH) is relatively higher when compared with the jelly results (119.0 g of sample g⁻¹), what shows the higher antioxidant activity of the jelly. The jelly also presented higher antioxidant activity, measured by ABTS method, increasing from 362.50 μmol of trolox g⁻¹ (reconstituted pulp) to 2685.76 μmol of trolox g⁻¹ (jelly) (Table 2).

The increase in the antioxidant activity may associated to the concentration of bioactive compounds, as reported to phenolic, due the evaporation of water by heat treatment. This increase in activity could also be influenced by the type of bioactive compound detected by each method. The ABTS method may be more sensitive to water-soluble phenolic compounds, while DPPH may be more efficient in detecting lipophilic compounds (Floegel et al., 2011). It also be attributed to the formation of Maillard reaction products, such as hydroxymethylfurfural (HMF), as well as the release of reducing sugars which may interfere with antioxidant activity and thus contribute to the increase the radical sequestering activity by the DPPH and the ABTS methods (Dueñas et al., 2005; Siddhuraju & Manian, 2007).

Flavonoids (catechin) and non-flavonoids (gallic acid, vanillin, *p*-coumaric acid, ferulic acid, caffeic acid and *trans*-cinnamic acid) were identified and quantified in the murici pulp and jelly and chlorogenic acid only in the jelly (Table 3). The levels of all phenolic compounds increased, numerically, with the processing, although statistical differences ($p < 0.05$) have been proved only for gallic and ferulic acids, besides of chlorogenic acid only in the jelly.

Table 3. Quantification and identification by HPLC-DAD/UV-Vis of phenolic compounds of murici reconstituted pulp and fresh jelly

Phenolic compounds	Retention time (min)	Reconstituted pulp of murici (mg 100 g ⁻¹)	Murici jelly (mg 100 g ⁻¹)	t-value	p-value
1. Gallic acid	6.82	15.93 ± 0.14 ^b	18.58 ± 0.26 ^a	-12.694	0.0500
2. Catechin	10.80	0.33 ± 0.08 ^a	2.40 ± 2.12 ^a	-6.1288	0.1029
3. Chlorogenic acid	12.56	-	2.05 ± 0.47 ^a	-6.3636	0.0496
4. Caffeic acid	15.05	0.31 ± 0.03 ^a	0.79 ± 0.16 ^a	-4.2933	0.1456
5. Vanillin	17.65	0.08 ± 0.00 ^a	0.13 ± 0.07 ^a	-0.9288	0.5324
6. <i>p</i> -coumaric acid	21.81	0.28 ± 0.01 ^a	0.49 ± 0.08 ^a	-3.4049	0.1818
7. Ferulic acid	24.79	0.13 ± 0.00 ^b	0.23 ± 0.01 ^a	-13.251	0.0056
8. <i>m</i> -coumaric acid	27.62	-	-		
9. <i>o</i> -coumaric acid	34.62	-	-		
10. Quercetin	37.59	-	-		
11. <i>trans</i> -cinnamic acid	51.66	0.12 ± 0.02 ^a	1.25 ± 0.69 ^a	-2.2948	0.2616
12. Rutine	53.49	-	-		

Notes: Data presented as mean ± standard deviation of two replicates. Significance level at 5% probability.

Gallic acid was the majority phenolic compound such in the reconstituted pulp as in the jelly (Table 3). Fifteen point ninety-three milligrams of gallic acid was found in 100 g of reconstituted pulp, while the levels of the others phenolic compounds ranged from 0.08 to 0.33 mg 100 g⁻¹. The level of gallic acid found in 100 g of murici jelly was 18.58 mg, while the other compounds ranged from 0.13 to 2.40. According to Mariutti et al. (2013), the major phenolic compound identified and quantified in murici (*Byrsonima crassifolia*), by HPLC-DAD/MS, was gallic acid (4.20 ± 0.01 µg mL⁻¹), as

observed in this study, although at different concentrations. In fact, fruit of species of *Byrsonima* are reported to be rich in gallic acid derivatives, such as galloyl quinic acid (Maldini et al., 2011; Sannomiya et al., 2007).

Twenty-nine volatile compounds were tentatively identified in reconstituted murici pulp, the highest proportion being esters (58.20%), highlighting the ethyl hexanoate as the major compound, followed by carboxylic acids, notably hexanoic acid, hexanoic acid (2-methyl) and octanoic acid (Table 4).

Table 4. Volatile compounds, retention rate, relative concentration and related odor of reconstituted murici pulp and fresh jelly

Volatile compounds	Retention index	Murici pulp	Murici jelly	Odor ¹
Alcohols				
Ethanol	-	x	x	sweet, candy
2-butanol	602	x		
Hexan-1-ol	863	x	x	flower green
4-Ciclohexanol-1-methyl	1025	x		
1-butanol-2-ethyl	1213	x		malt
Aldehydes				
2-methylbutanal	664		x	almond, malt
2E-Heptenal	954		x	
2,3-Dihidroxypropanal	1025		x	
2E-Octen-1-al	1049		x	
Nonanal	1100	x	x	fat, citrus, green
2E-Decenal	1263		x	green
Carboxylic acids				
Acetic acid	563		x	
Butanoic acid	772	x	xx	cheese, rancid
Hexanoic acid	967	xxxx	xxxxx	pungent

continued...

Table 4. Continuation

Volatile compounds	Retention index	Murici pulp	Murici jelly	Odor ¹
Carboxylic acids				
2-methylhexanoic acid	1027	xx	x	
Heptanoic acid	998		xxxx	
2-methylpropylhexanoic acid	1129	x		
Octanoic acid	1167	xx	xx	sweet, cheese
Nonanoic acid	1267		x	green, fat
9-Decenoic acid	1359		x	
Decanoic acid	1364	x	x	rancid, fat
1,2-benzene dicarboxylic acid	1586		xx	
Ketones				
2-propanone	-	xx	x	
2-butanone-3-hidroxy	652	x	x	
Esters				
Ethyl acetate	605	x		pineapple
Methyl butanoate	659	x		fruity, sweet
Ethyl butanoate	801	x	x	
2-ethyl butanoate	843	x		
Methyl hexanoate	965	x		fruity, fresh, sweet
Ethyl hexanoate	999	xxxx		
2-ethyl hexanoate	1035	x		apple peel, fruity
Ethyl hexenoate	1044	x		
Tertbutyl pentanoate	1053		x	
Propyl hexanoate	1094	x	x	fruity
Methyl octanoate	1123	xx	x	fruity, fat
Butyl hexanoate	1190	xx	x	fruity
Ethyl octanoate	1195	xx	x	
Hexyl hexanoate	1385	x	x	apple peel, peach
Ether				
Metoxy ethane	602		x	
Ethanol 2-butoxy acetate	1088	x		
2-metoxy-2-methylpropane	1135		x	
Others				
E<beta>-ocimene	1044	X		citrus, herbal, flowers

Notes: Relative concentrations are indicated by xxxxx = very large (> 60% area); xxxx = large (50-30% area); xxx = medium (30-10% area); xx = small (>10% area); x = trace (>1.0% area). ¹ Flavor and human odor description from Acree & Arn (2004).

Figure 2 illustrates the comparative analysis of volatile compound concentrations in murici pulp and jelly. Notably, hexanoic acid exhibits a significant increase in concentration from 0.8 in pulp to 1.0 in jelly, contributing to a pungent odor. Certain compounds, such as 2-butanol, are detected in pulp but absent in jelly, suggesting that processing alters the

volatile profile and potentially influences flavor characteristics. Furthermore, butanoic acid, characterized by a "cheese, rancid" odor, doubles in concentration from 0.2 in pulp to 0.4 in jelly, likely enhancing the sensory intensity of the jelly.

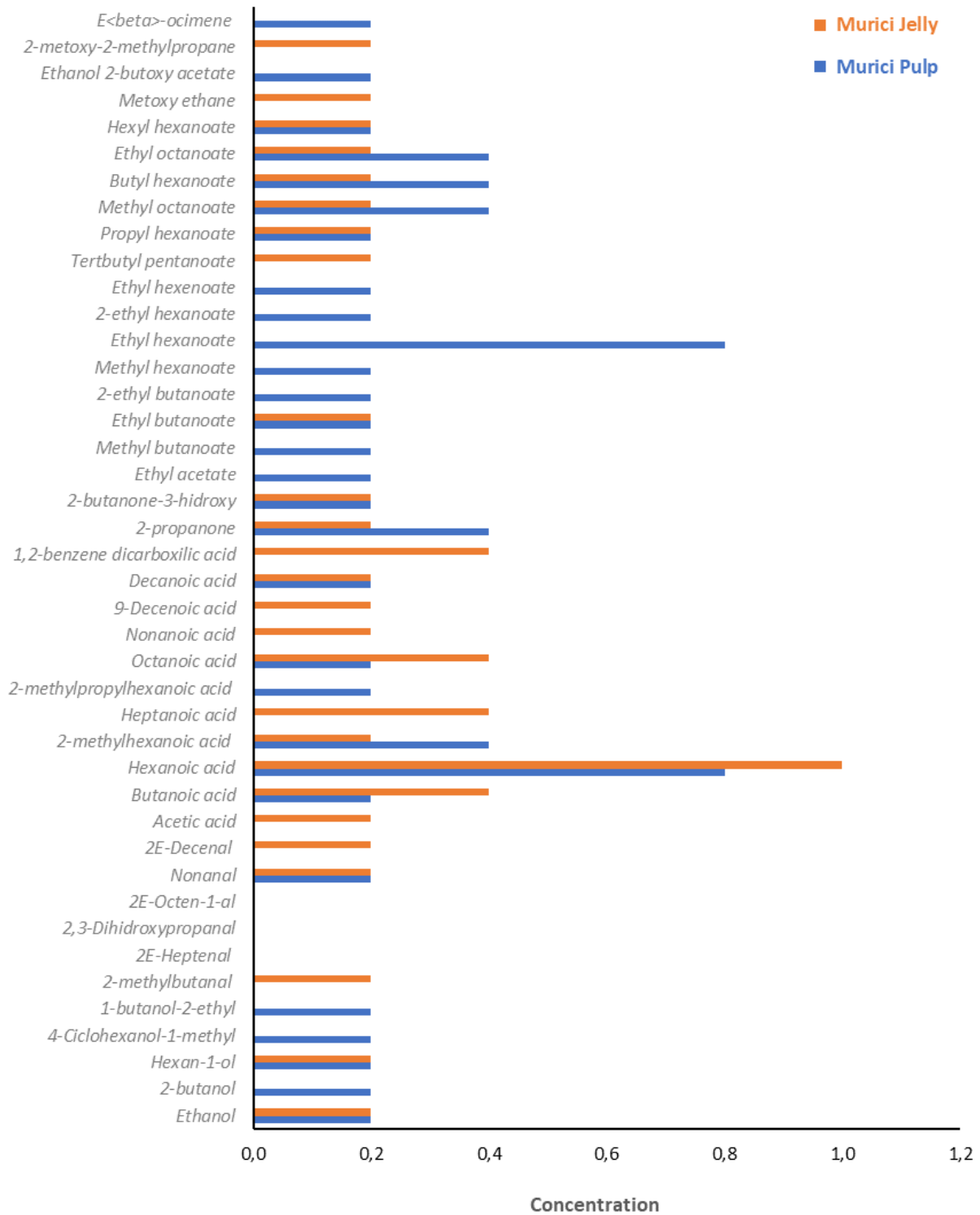


Figure 2. Volatile compounds in murici pulp and jelly.

In general, the processing promoted reduction or disappearance of compounds such as alcohols (2-butanol, 4-ciclohexanol-1-methyl and 1-butanol-2-ethyl) and esters (ethyl acetate, methyl acetate, 2-ethyl butanoate, methyl hexanoate, ethyl hexanoate, 2-ethyl hexanoate and ethyl hexenoate). It also promoted, in general, increase and appearance of carboxylic acids, such as acetic, butanoic, hexanoic, hexanoic (2-methyl) and heptanoic acids and the

aldehydes butanal (2-mehtyl), heptanal, 2,3-dihidroxypropanal, octen-1-al and decenal. In fact, the heat and shaking of the processing contribute to volatilization of a number of compounds, depleting their levels partially or even totally. The increase in the amount of carboxylic acids may have originated from the breaking of esters present in the reconstituted murici pulp due to the effect of processing conditions (high temperatures, low pH and cooking time).

Part of carboxylic acids may have been converted to aldehydes from the action of Acyl CoA reductases.

Alves & Jennings (1979), using the simultaneous distillation-extraction technique, identified 23 compounds in murici pulp. The major compounds were esters, as observed in this study, especially butanoate, hexanoate and ethyl octanoate. Alves & Franco (2003) extracted murici volatile compounds by SPME, the same technique used in this study, and identified a wide variety of alcohols, sulfur compounds, aromatic compounds, organic acids, and a wide range of esters. Compounds with the same functional groups, with the

exception of the sulfurs, were also identified in this study. The presence of butanoic and hexanoic acids is notable in murici, also observed by Alves & Franco (2003), who describe them as having a cheese, rancid and butter aroma.

The murici jelly, packed in transparent and amber glasses, was stored for 12 months. The storage time significantly influenced ($p < 0.05$) all variables studied, except catechin and caffeic and *trans*-cinnamic acids (Figures 3, 4 and 5). No variable studied was affected differently by the packages ($p < 0.05$).

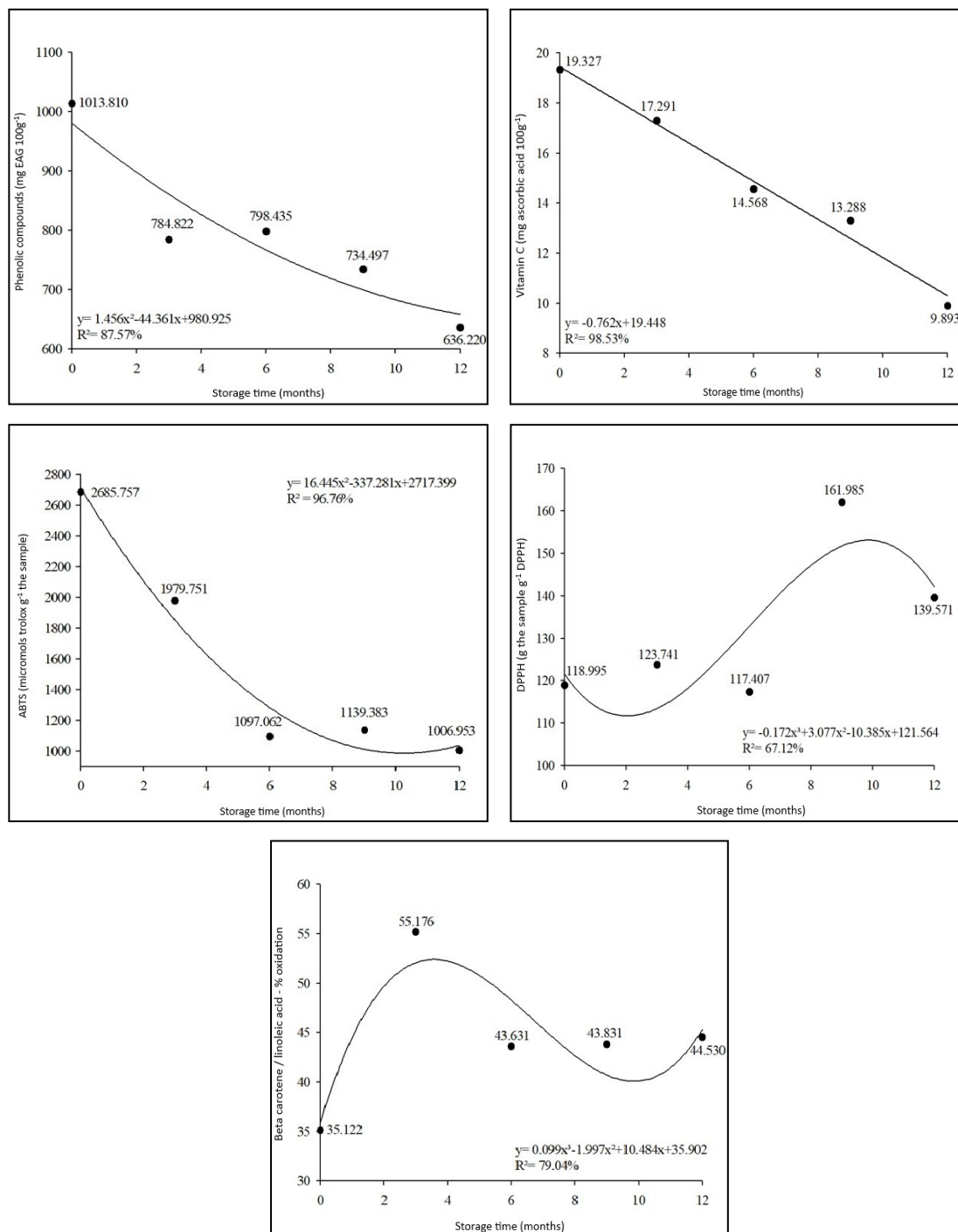


Figure 3. Total phenolics, vitamin C and antioxidant activity (ABTS, DPPH and β - carotene/linoleic acid) of murici jelly stored at $20.9^\circ\text{C} \pm 2.93$ and $69.3\% \text{ UR} \pm 13.28$ for twelve months ($p < 0.05$). The numbers presented in the graphs refer to the data observed in the experiment.

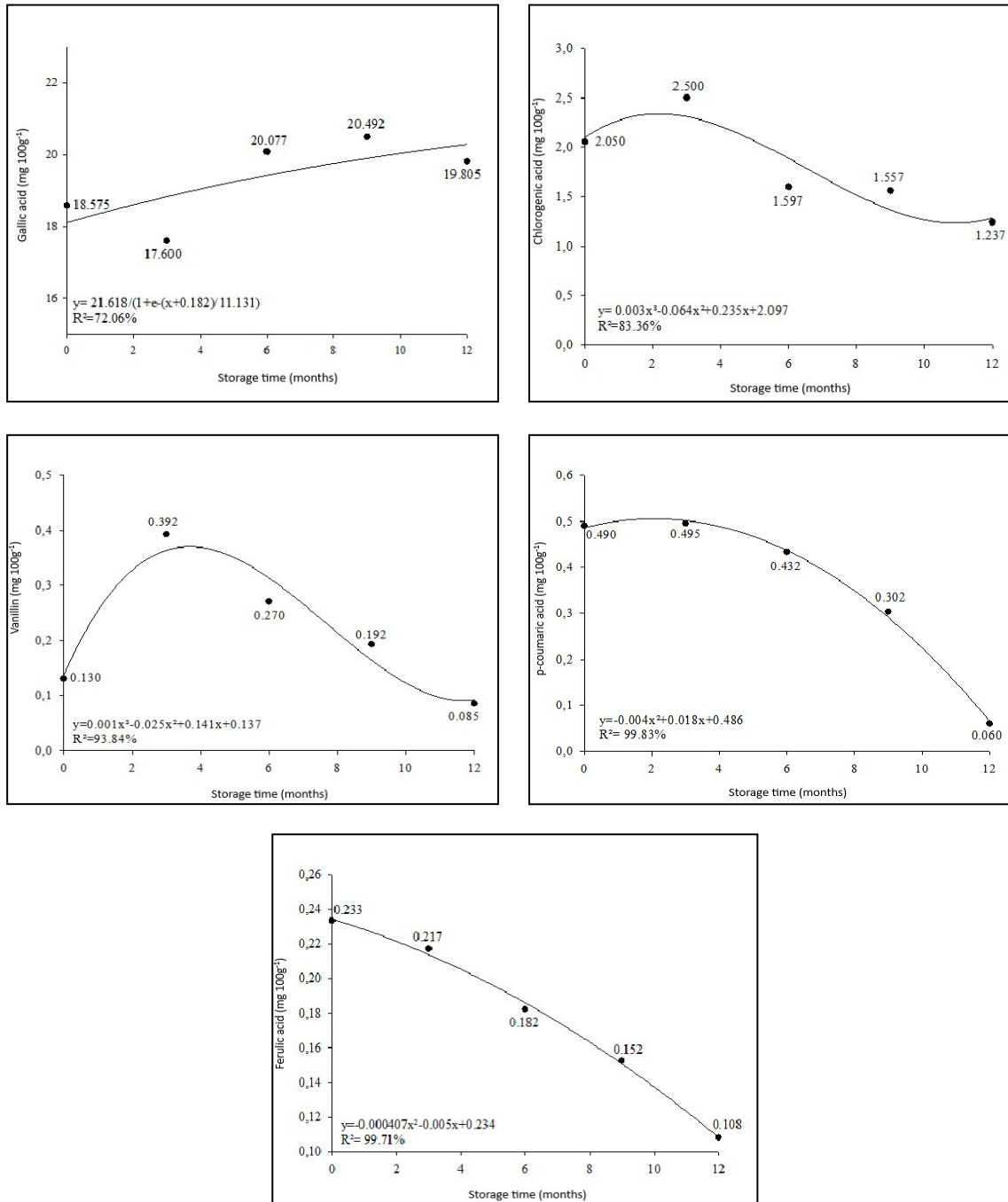


Figure 4. Phenolic compounds identified by HPLC-DAD/UV-Vis of murici jelly stored at 20.9°C ± 2.93 and 69.3% UR ± 13.28 for twelve months ($p < 0.05$). The numbers presented in the graphs refer to the data observed in the experiment.

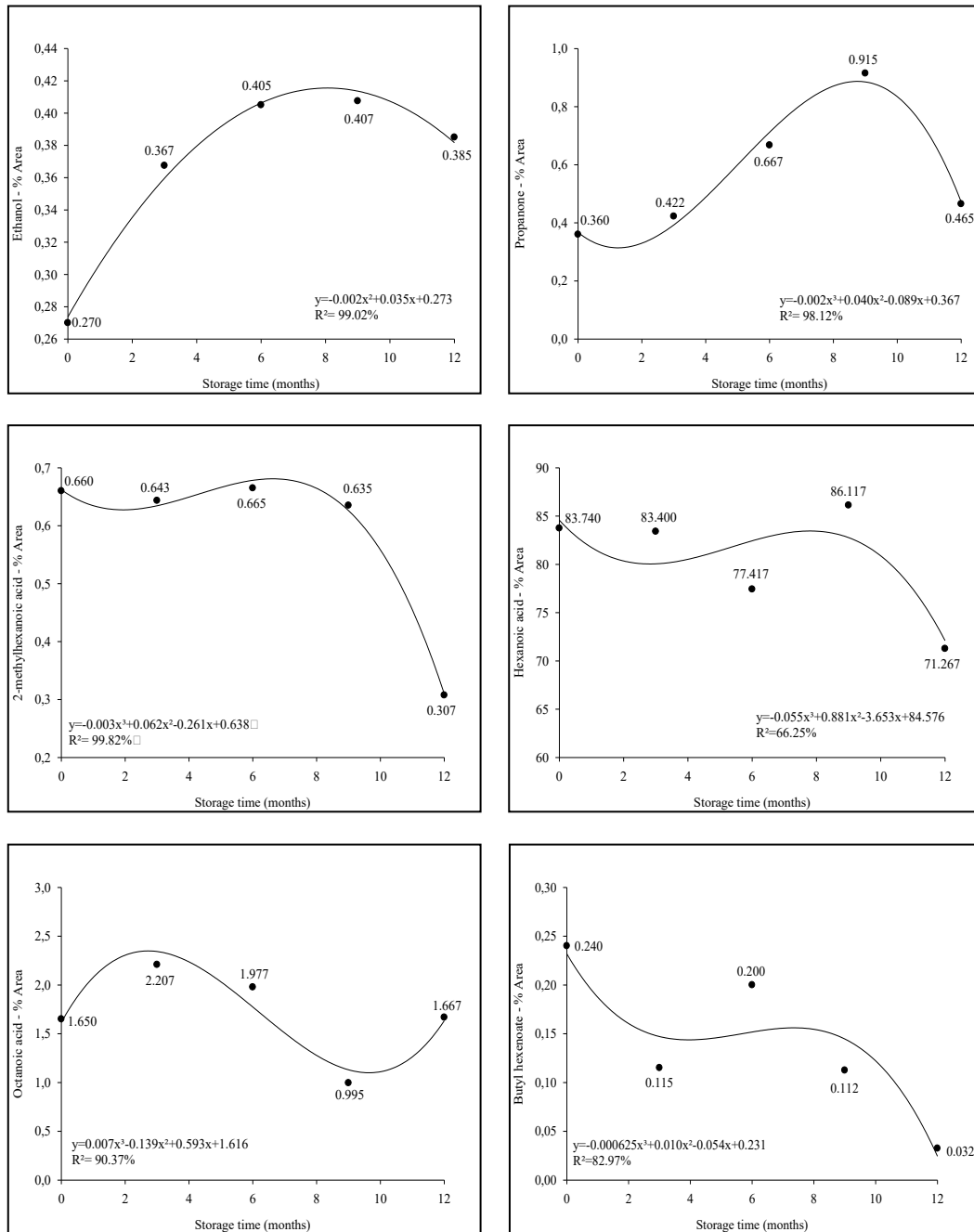


Figure 5. Volatile compounds identified by GC-MS of murici jelly stored at $20.9^\circ\text{C} \pm 2.93$ and $69.3\% \text{ UR} \pm 13.28$ for twelve months ($p < 0.05$). The numbers presented in the graphs refer to the data observed in the experiment.

There was reduction of 62.36% of phenolic compounds over the storage period ($p < 0.05$; [Figure 3](#)). That is due to the storage conditions (exposed to room temperature) and/or oxidative decomposition of products from the non-enzymatic browning reactions, which contributes to the reduction of phenolic compounds. The quadratic behavior of phenolic compounds observed ([Figure 3](#)) is similar to that reported by [Damiani et al. \(2012\)](#), during storage of mixed araçá and marolo jam.

There was a linear decrease of ascorbic acid ($p = 0.000$) detectable over 12 months of storage ([Figure 3](#)). According to the results obtained by [Damiani et al. \(2012\)](#), the vitamin C content significantly decline ($p < 0.05$) during the storage of mixed araçá and marolo jam, being detectable only up to the

4th month of storage. According to Dietary Reference Intakes ([USDA, 2011](#)), a daily vitamin C requirement is estimated at $75\text{--}90 \text{ mg day}^{-1}$ for adults aged 31 to 50 years which should be obtained through intake of food of fresh plant origin. As such, the murici jelly has a low content of the component, however, one serving (20 g) corresponds to 4.30% of the daily intake recommendation.

There was a decline of 37.49% in the antioxidant activity (ABTS) of murici jelly after 12 months of storage, while the antioxidant activity, measured by the DPPH IC_{50} method, increased in the first nine months of storage, then decreasing in the last 3 months ($p < 0.05$; [Figure 3](#)). It is noteworthy that the lower DPPH IC_{50} values the higher antioxidant activity. This decline in antioxidant activity throughout the storage

time, observed for the ABTS and DPPH methods, may be related to the decrease in total phenolic and vitamin C contents (Figure 3). In effect, one of the main causes of total phenolic and vitamin C losses are non-enzymatic oxidation reactions, which contribute to the reduction of antioxidant potential (Patras et al., 2011). The antioxidant activity measured by β -carotene/linoleic acid method increased in the first 3 months of storage, then decreasing and keeping relatively stable from 6 to 12 months (Figure 3). Based to Duarte-Almeida et al. (2006), the murici jelly stored from 3 to 12 months may be classified as of intermediate efficiency (40 -70% of β -carotene/linoleic acid antioxidant activity).

The was a trend of increase in gallic acid and reduction in vanillin and chlorogenic, *p*-coumaric acid and ferulic acids over the storage period ($p < 0.05$; Figure 4). The phenolic compounds catechin ($2.41 \pm 0.52 \text{ mg } 100 \text{ g}^{-1}$), caffeic acid ($0.77 \pm 0.40 \text{ mg } 100 \text{ g}^{-1}$) and *trans*-cinnamic acid ($1.90 \pm 0.68 \text{ mg } 100 \text{ g}^{-1}$) did not changed significantly ($p < 0.05$) during storage, in spite of packages (transparent and amber). Although packaging did not show statistically significant effects, it is relevant to consider that the type of packaging could theoretically influence the stability of bioactive compounds, particularly those sensitive to light. Amber glass packaging, due to its light-filtering properties, is known to offer better protection against photodegradation when compared to transparent packaging. Light exposure may catalyse oxidative and photolytic reactions, leading to degradation of phenolic compounds and vitamins such as ascorbic acid (Basak et al., 2023). Thus, while no significant difference was found, the use of amber packaging may still contribute to improved preservation of sensitive compounds under real storage conditions. Moreover, temperature control during storage is also essential, since elevated temperatures accelerate degradation kinetics of phenolic compounds and vitamins.

According to Correa (1984), the genus *Byrsonima* presents an exocarp rich in hydrolysable tannins. Therefore, those compounds widely distributed in the plant kingdom, are made up of a mixture of simple phenols such as gallic acid esters, readily soluble under acidic conditions (Battestin et al., 2004). Consequently, due to processing conditions and storage time, there may have been hydrolysis of the ester bond and an increase ($p < 0.05$) in the gallic acid concentration during the storage period. The decrease of vanillin and chlorogenic, *p*-coumaric acid and ferulic acids may be associated to degradation reactions promoted by processing conditions.

A review published recently by Pires et al. (2020), recognize *Vaccinium myrtillus* fruit as a rich natural source of polyphenols and other bioactive compounds, with health-protective action. In this review, the phenolic compounds are potentially associated to health benefits, such as antioxidant and anti-proliferative properties, with promising anti-carcinogenic, besides the effects cardioprotective, hypoglycemic, anti-obesity, anti-inflammatory and antimicrobial.

Based to the presented data, murici jelly may be

considered a rich source of phenolic compounds since it has higher levels of galic acid, caffeic acid and catechin and similar levels of chlorogenic acid, compared to *Vaccinium myrtillus* fruit, a recognized source of these compounds ($1.9 - 6.2$, $0.3 - 0.546$, $0.2 - 0.27$ and $0.12 - 23.1 \text{ mg } 100 \text{ g}^{-1} \text{ fw}$, respectively) (Može et al., 2011; Değirmenciöglu et al., 2017). Besides, *p*-coumaric acid, vanillin and *trans* cinnamic acid, found in murici jelly, was not found in *Vaccinium myrtillus* fruit. The levels of ferulic acid found in murici jelly was lower than that reported for *Vaccinium myrtillus* fruit ($0.4 - 1.06 \text{ mg } 100 \text{ g}^{-1} \text{ fw}$), by Može et al. (2011) and Değirmenciöglu et al. (2017).

The phenolic profile, as well as the total phenolic and vitamin C contents and antioxidant activity suggest the functional appeal of the murici jelly, even at 12th month of storage (Figure 3 and 4). The same condition observed by Cunha et al. (2020a), during the 12th month storage of curriola jelly, where even the significant reduction ($p < 0.05$) observed in the contents of phenolic compounds, vitamin C and antioxidant activity, the functional appeal can be observed throughout its useful life.

Ethanol, propanone and butanoic and hexanoic acids levels increased in the first nine months of storage followed by decrease until the 12th month (Figure 5). The level of hexanoic acid (2-methyl) stay relatively constant in the first nine months and then dropped, while the levels of octanoic acid fluctuated and of butyl hexanoate decreased during storage, according to the polynomial adjustments (Figure 5).

According to studies by Gonçalves et al. (2018), where possible changes in volatile compounds in mangaba pulp submitted to different pasteurization processes, freezing methods and prolonged storage were evaluated, which observed that pasteurization favors the yield of aromatic compounds present in mangaba pulp, regardless of the freezing method used, in addition, from the 9th month of storage, there is a development of compounds responsible for aroma degradation, such as ethanol, ethyl acetate and acetic acid. The same condition can be observed in this study.

CONCLUSION

The processing of murici pulp results in increased levels of phenolics and antioxidant activity and of the amount of aldehydes and short-chain organic acids originated from the hydrolysis of volatile esters, as well as reduced amounts of volatile ester and alcohols. The storage of murici jelly is marked by the reduction of phenolic compounds, antioxidant activity and volatile esters, while no significant effect of glass packaging factor (with and without exposure to light) is noted.

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COMPLIANCE WITH ETHICAL STANDARDS

Authors' contributions: Conceptualization: MCC; Data curation: MCC; Formal analysis: MCC, PSM, AGDPM, LMZL; Methodology: MCC, AGDPM, LMZL; Project administration: EENC, EVBVB; Supervision: EENC, EVBVB; Validation: AGDPM, LMZL; Visualization: MCC, EVBVB; Writing – original draft: MCC, PSM, EENC, EVBVB; Writing – review & editing: MCC, EVBVB.

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