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Evaluation of the chemical, sensory and volatile composition of sapota-do-Solimões pulp at different ripening stages

Sabrina Sauthier Monteiro[a,d,*], Stephanie Reis Ribeiro[b], Marcela Bromberger Soquetta[b], Felipe Jacob Pires[c], Roger Wagner[b], Claudia Severo da Rosa[b]

[a] Nutrition Course, Institute of Health and Biotechnology, Federal University of Amazonas (UFAM), Coari, AM, Brazil
[b] Department of Science and Food Technology, Center of Rural Sciences, Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil
[c] Mamirauá Institute for Sustainable Development, Tefé, AM, Brazil
[d] Graduate Program in Science and Food Technology, Center of Rural Sciences, Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil

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ABSTRACT

The aim of this study was to evaluate sapota-do-Solimões (*Quararibea cordata* Vischer) during ripening, verifying physical, chemical and sensory parameters, bioactive and volatile compounds. The pulps were obtained from fruits from the city of Tefé, AM, Brazil and collected at three different ripening stages: unripe (U); ripe collected from the tree (R); and ripe collected from the ground (RG). The biometric and quality parameters, total carotenoids, total phenolic compounds, chemical composition, fatty acids and volatile profiles were analyzed. The sapota-do-Solimões fruits showed positive correlation with evolution of ripened stage of the variables water activity (0.977–0.996), pH (6.53–7.04), soluble solids (8.53–12.65%), total sugars (4.26–7.98%), reducing sugars (0.99–3.14%), non-reducing sugars (3.11–4.60%) and total carotenoids (0.67–1.24 μg/g). Longitudinal and transversal diameters and fruit mass were higher in RG compared with the other ripening stages. The lipids contents increased from 0.16% for U to 0.30% for RG. The palmitic (47.1–86.4), stearic (3.1–5.9), oleic (44.4–131.1) and vaccenic (25.3–37.7) increased while palmitoleic (16.4–10.0) and linoleic (6.6–3.5) decreased. A total of 86 volatile compounds were identified, of which 57 were found in U fruits, 54 in R fruits and 68 in RG fruits. The classes most relevant found were alcohols, aldehydes, esters, ketones, furans and terpenes. An increase in the terpenes (0.4–5.6%) from U fruit to RG fruit showed potentials odoriferous characteristics, as well the increased furans (2.3–20.9%) from U fruit to RG fruit that characterized a sweet and fruity aroma. Consumers didn't detect differences in sensory attributes of the analyzed R and RG fruits. The data showed that the chemical and volatile composition of the fruit was influenced by the ripening stage of the pulp. This is the first time that a study about ripening in sapota-do-Solimões has been reported.

1. Introduction

The sapota-do-Solimões (*Quararibea cordata* Vischer) fruit is marketed *in natura* on the Amazon region during the harvest season from March to June at fairs and supermarkets. It is a bacaceous, globose or ovoid fruit, 7–15 cm in length, and has an average weight of around 418 g. Under normal conditions an adult tree can produce up to 6000 fruits per year. The pulp is the only edible part of the fruit and before consumption it is necessary to remove the thick peel (Rabelo, 2012; Yuyama et al., 2013). It is harvested when the color of the peel of the fruit under the calyx becomes yellow (Villachica, 1996). The sapota-do-Solimões pulp has been arousing interest and other works have already been published recently (Berto, Ribeiro, Evelazio de Souza, Fernandes, & Chiste, 2015; Carvalho, Damiani, Asquieri, Orsi, & Nishi, 2012; Monteiro et al., 2018; Murillo et al., 2013).

The ripening stage, during which the fruits are harvested, determines the quality of the fruit that can be offered to consumers. When the fruit is harvested at the unripe stage, in addition to being of poor quality, it has a high rate of water loss and is very susceptible to physiological disorders. On the other hand, when the fruit is harvested at a very ripe stage it rapidly becomes senescent (Manica et al., 2000). The correct determination of the ripening stage of the fruit is essential for the harvest to occur at the right time and so-called ripening indices are used for this. These indices include physicochemical aspects that undergo changes during the ripening of the fruit, which greatly influences the post-harvest condition of the fruit (Kluge, Nachtigal, & Bilhalva, 2002).

The volatile compounds in fruits have been extensively studied in

* Corresponding author at: Av. Roraima No. 1000, Prédio 42, Cidade Universitária, Camobi, CEP 97105-900 Santa Maria, RS, Brazil.
E-mail addresses: nutr.sabrinasm@hotmail.com (S.S. Monteiro), felipe.pires@mamiraua.org.br (F.J. Pires).

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recent years in order to characterize the volatile profile of a fruit and its different genotypes, as well as to investigate the behavior of these chemical compounds during the ripening, processing or storage of fruits and their by-products (Damiani, Vilas Boas, Ferri, Pinto, & Rodrigues, 2009; Galvão, Narain, Santos, & Nunes, 2011; Wang et al., 2009; Weldegergis et al., 2011). Knowledge about the composition of the volatile fraction of a food is essential in order to characterize and identity it. The flavor of a particular product, which is one of the main sensory attributes of consumer analysis and acceptance, is generally provided by a combination of several volatile molecules (Bicas et al., 2011). The volatile compounds present in fresh and processed fruits affect significantly the flavor and quality of the aroma, which is formed by a complex mixture of aldehydes, alcohols, ketones, esters, terpenes and other compounds (Riu-Aumatell, Castellari, López-Tamames, Galassi, & Buxaderas, 2004).

Thus, it is known that ripening influences the softening of the pulp, pigment development, changes in the metabolism of carbohydrates, lipids and volatile compounds due to the biochemical and physiological changes. This is the first time that a study about ripening in sapota-do-Solimões is being presented. In this way, the aim of this study was to evaluate sapota-do-Solimões pulp at three different ripening stages in order to verify the physical, chemical and sensorial parameters, as well as the bioactive (total carotenoids and total phenolic compounds) and volatile compounds.

2. Materials and methods

2.1. Raw materials

The fruits were collected from a private area in the community of Vila Vale, around Tefé, Amazonas (AM), Brazil, which is located near the experimental area of the Mamirauá Sustainable Development Institute. The geographical coordinates of the city of Tefé, where the samples were collected, are latitude 03°21′15″S and longitude 64°42′41″W, with an altitude of approximately 75 m above sea level. According to the Köppen-Geiger classification the climate is type Af, i.e. humid and equatorial tropical with an annual average temperature of 26.85 °C and average rainfall of 211.54 mm. The soil is classified as Plinthosol with reddish colors. The fruits were collected in an area that had 15 plants (individuals) of about 30 m in height, which were approximately 50 years old. The fruits were collected in March 2015. A total of sixty fruits were collected, twenty fruits for each ripening stage, forty being collected from the tree and 20 collected from the ground, and initially transported in styrofoam boxes via river and then by air, totaling 36 h of travel, to the Federal University of Santa Maria where the experiments were conducted. For the analytical determinations ten fruits were taken from each ripening stage and these were homogenized after three parts were taken for the replicates and the analyzes were performed in triplicate, i.e. the means resulted from nine values for each analysis. The remaining ten fruits from each ripening stage were used in the sensorial analysis, carried out in the city of Tefé-AM, where the fruits were collected.

The fruits were carefully collected at the following three different ripening stages: unripe (U); ripe fruit collected from the tree when the color of the peel of the fruit under the calyx turns yellow (R); and ripe fruit collected from the ground when they naturally detach from the tree (RG). The peel of the unripe fruit as well as the ripe fruits is green, the pulp of the unripe fruit was more whitish and ripe orange. When they were received, the fruits were selected for the absence of defects, pests and diseases, and then had their surfaces washed with mild detergent to remove dirt. They were then rinsed in running water. Sanitization was subsequently performed with 50 mg/Kg chlorine and an immersion time of 30 min.

2.2. Methods

2.2.1. Biometry

Thirty fresh fruits were analyzed individually in terms of the following features: longitudinal and transversal diameters (mm) were measuring using Eccofer® digital callipers, and the total fruit mass (g) was weigh using a Toledo® digital scale (Exata 2 SC model, São Paulo, Brazil).

2.2.2. Water activity, pH, titratable acidity and soluble solids

AquaLab® (Series 4 TEV, Decagon Device Inc., Pullman, USA) equipment was used to measure the water activity as recommend the manufacturer. The pH was measured using a Digimed® (DM-23 model, São Paulo, Brazil) digital potentiometer (Association of Official Analytical Chemists, 1998). The titratable acidity was determined by diluting the pulp in distilled water using 0.1 M NaOH, using phenolphthalein as ending point (AOAC, 1998). The soluble solids were measured directly in a digital refractometer (Atago®, Pocket PAL-3 model, Tokyo, Japan) according to AOAC (1998).

2.2.3. Total, reducing and non-reducing sugars

In order to determine the levels of total and reducing sugars in glucose the Lane Eynon method was employed using Fehling's reagent (Lane & Eynon, 1934). The non-reducing sugars in sucrose were calculated from the difference of the values found for the total and reducing sugars and then multiplied by 0.95. The results were expressed as a percentage (%).

2.2.4. Ascorbic acid and total carotenoids

The ascorbic acid content was determined by the spectrophotometric method at a wavelength equal to 540 nm (Biospectro, SP-220 model, São Paulo, Brazil), as described by Cox and Pearson (1976). The results were expressed as mg/100 g of pulp. The total carotenoids were determined by the Higby method (Higby, 1962). The readings were taken using a spectrophotometer (Biospectro, SP-220 model, São Paulo, Brazil) at a wavelength equal to 450 nm and the results were expressed as μg/g of pulp.

2.2.5. Sample preparation to total phenolics and antioxidant activity

The extracts for the determination of total phenolics and antioxidant activity were obtained according to Larrauri, Rupérez, and Saura-Calixto (1997) method, with modifications. The extraction was performed at room temperature (24 °C) by taking 5.0 g of each pulp; then 20 mL of 50% ethanol solution was added (first extraction solution) and the mixture that was obtained was homogenized and allowed to stand for one hour for extraction. After this period, the mixture was centrifuged at 3000 rpm for 10 min and the supernatant that was obtained was filtered and placed in a 50 mL flask protected from light. The precipitate obtained by centrifugation was dissolved in 20 mL of 70% acetone (second extraction solution). This mixture was left to stand for 1 h and then centrifuged at 3000 rpm for 10 min. The second supernatant that was obtained was mixed with the first, in the same flask, which was completed with distilled water.

2.2.6. Total phenolic compounds

The total phenolics were determined following the method described by Larrauri et al. (1997). The absorbance was read with a spectrophotometer (Biospectro, SP-220 model, São Paulo, Brazil) at 700 nm, using as reference the standard curve of gallic acid ($y = 0.0101x - 0.0266$, $R^2 = 0.9963$), which was constructed with concentrations ranging from 5 to 70 mg/L. The results were expressed as mg gallic acid equivalent (GAE)/100 g of extract.

2.2.7. Antioxidant activity by DPPH method

The method described by Brand-Willians, Cuvelier, and Berset (1995) was used to determine antioxidant activity. The technique

consisted in the incubation for 30 min of 5 mL of a solution of DPPH with 5 mL of solutions containing increasing concentrations of each extract in mg/mL (0.2; 0.4; 0.8; 1.6; 3.1; 6.2; 12.5; 25; 50 and 100), and were analyzed in a spectrophotometer (Biospectro, SP-220 model, São Paulo, Brazil) at 517 nm. The percentage of antioxidant activity (AA%) was calculated by the percentage of uptake of the DPPH radical. After evaluating the range of optimal concentration, the concentration required to capture 50% of the DPPH free radical was calculated (IC_{50}).

2.2.8. Chemical composition

The fruits were dried in an oven with forced air circulation at a temperature of 60 °C for 36 h. The samples were crushed in a micro mill that was cooled to 4 °C (Quimis, Q 298A21 model, Brazil). The chemical composition of the sapota-do-Solimões was determined by following the AOAC (1998) methods. The moisture determination was performed by drying in an oven at 105 °C to constant weight. The fixed mineral waste was assessed by incineration in a muffle furnace at 550 °C. The protein content was determined by the Kjeldahl method. The fraction of total dietary fiber was determined by the enzymatic gravimetric method. The total lipids were obtained by extraction using the Bligh and Dyer (1959) method. The carbohydrates were obtained by difference.

2.2.9. Fatty acids composition

The lipids were extracted with chloroform:methanol:water, as described by Bligh and Dyer (1959). The triglycerides were transesterified/esterified to fatty acid methyl esters (FAME) using methanolic solutions of KOH and H_2SO_4 according to Hartman and Lago (1973) method. The FAME were determined using a Varian Star 3400CX (CA, USA) gas chromatograph equipped with a flame ionization detector (GC-FID). The FAME were injected manually (1 μL) and separated in a capillary column SP™-2560 (Bellefonte, USA) (100 m × 0.25 mm i.d. × 0.20 μm film thickness). Hydrogen was used as carrier gas at a constant pressure of 25 psi. The injector remained in the splitless mode at 250 °C. The heating program of the column began at 120 °C with 1 min of standing, and then increased to 240 °C with a heating rate of 3 °C/min, maintained at isothermal conditions for 15 min. The identification of the fatty acids was performed by a comparison of the retention times of the analytes with the standard (FAME Mix-37, Sigma-Aldrich, USA). The quantification was performed by the normalization of the area of the fatty acid. Fatty acids were expressed in mg/100 g of pulp, considering the concentration of lipid content and composition for each ripening stage.

2.2.10. Volatile compounds

The volatile composition was analyzed using the headspace of the solid sample (HS-SPME). About 5.0 ± 0.1 g of *in natura* sample, with 30% of salt (NaCl), was weighed in 4 mL vials and immediately sealed with a septum with an internal surface of polytetrafluoroethylene (PTFE). The solid phase microextraction (SPME) technique was used to extract the volatile compounds. Divinylbenzene/carboxen/polydimethylsiloxane fiber (DVB/Car/PDMS) 50/30 μm × 20 mm was used as a manual holder for the extractions. The extraction of the volatile compounds was performed at 35 °C using a water bath for 45 min. Before the exposure of the fiber to the headspace, the flask containing the samples was maintained at the same temperature as the extraction for 10 min to equilibrate. The volatile compounds were thermally desorbed by inserting the fiber into the injection port of a gas chromatograph. The samples were analyzed in triplicate.

The volatile fraction was analyzed in a gas chromatograph coupled to a mass spectrometer (GC/MS), GC/MS QP-2010 *Plus* model (Shimadzu Corporation, Kyoto, Japan). The thermal desorption of the SPME fiber was carried out at 250 °C in splitless mode using a liner of 0.75 mm internal diameter. The separation of the volatiles was performed using a polar capillary column phase of polyethyleneglycol (PEG), Chrompack-WAX 52 CB (Chrompack Middelburg, Netherlands) of 60 m × 0.25 mm of i.d. × 0.25 μm of stationary phase thickness. Helium was employed as carrier gas, at a constant pressure of 30 psi. The oven temperature was held at 35 °C for 5 min, raised to 80 °C at 2 °C/min, then increased to 250 °C at 4 °C/min, and held at this temperature for 5 min. The GC/MS interface and ionization source were maintained at 250 °C. The instrument was run in the electron ionization mode with the ion source at +70 eV. The mass spectra were collected using a range of 35–350 *m/z*. The identification of the volatile compounds was carried out by matching the unknown mass spectra with those provided by the library mass spectra (National Institute of Standards & Technology library – NIST 05), by a comparison of the experimental and retention indices (RI) from the literature, and by the elution order of the compounds. A series of n-alkanes (C6–C18) was analyzed under the same conditions to obtain the RI values. The volatiles compounds were expressed in total ion count area.

2.2.11. Sensory analysis

An affective acceptability test was conducted with 50 consumers using a seven-point hedonic scale (1 = extremely dislike and 7 = extremely like) according to Dutcosky (2011) method. The panel of 50 consumers was composed of 68% female and 32% male. The predominant age group (54%) was 18–30 and 46% were aged 31–60. These individuals resided in the city of Tefé, AM, Brazil and they were invited to participate in the analysis for being considered consumers of the fruit. The evaluation was conducted in the Mamirauá Sustainable Development Institute, in the morning between 9 and 11 am and in the afternoon between 14 and 16 pm. The samples of sapota-do-Solimões at two distinct ripening stages (R and RG) were chopped and each participant tasted the two samples, which were served sequentially in completely balanced blocks with respect to the order of presentation. Each treatment was served in a plastic cup, properly identified with three-digit random numbers and presented in a monodic form to the consumers. Each consumer was also given a glass of water to clean the taste buds.

The attributes that were evaluated were color, odor, taste, texture and appearance. For the calculation of the product acceptability index the following expression was adopted: IA (%) = A × 100/B, where A = the average grade obtained for the product and B = the maximum grade given to the product. A good IA is considered to be ≥70% (Dutcosky, 2011).

The project was sent to the Ethics and Research Committee (CEP-CONEP) of the Federal University of Santa Maria and it was approved (protocol No. 50521715.1.0000.5346). The volunteers who participated in the sensorial analysis signed an informed consent form.

2.2.12. Statistical analysis

The analyses were performed in triplicate. The results were expressed as mean ± standard deviation. The data were statistically analyzed by analysis of variance (ANOVA or *t*-Student) and Tukey's test ($p < .05$), was used Statistica 7.0 software (Tulsa, USA, 2004). Furthermore, an exploratory analysis of the data using principal component analysis (PCA) was performed to visualize the correlation between the variables and the possible groupings among the samples. The Pirouette 3.11 (Woodinville, USA, 2003) statistical program was used. The data matrix consisted of nine samples and 47 independent variables, which contained statistical significance from results of the parameters regarding quality, bioactive compounds, chemical composition, fatty acids profile, and volatile compounds of samples. The data for each variable were autoscaled in order to assume the same weight during analysis.

3. Results and discussion

3.1. Biometric parameters of quality and bioactive compounds

The biometric parameters of quality and bioactive compounds of the

Table 1
Biometric parameters, of quality and bioactive compounds of sapota-do-Solimões (*Quararibea cordata* Vischer) at different ripening stages.

Analyses	Ripening stages		
	U	R	RG
Longitudinal diameter* (mm)	101.3^{b} ± 5.94	101.9^{b} ± 6.40	111.7^{a} ± 6.86
Transverse diameter** (mm)	81.6^{c} ± 8.24	89.6^{b} ± 3.66	106.5^{a} ± 4.15
Total fruit mass (g)	352^{c} ± 80.76	405^{b} ± 34.31	645^{a} ± 61.74
Water activity	0.977^{c} ± 0.002	0.992^{b} ± 0.001	0.996^{a} ± 0.003
pH	6.53^{c} ± 0.05	6.82^{b} ± 0.03	7.04^{a} ± 0.12
Titratable acidity (%)	0.18^{a} ± 0.03	0.12^{b} ± 0.03	0.09^{b} ± 0.02
Soluble solids (%)	8.53^{c} ± 0.12	12.27^{b} ± 0.26	12.65^{a} ± 0.09
Total sugars (%)	4.26^{c} ± 0.04	7.25^{b} ± 0.23	7.98^{a} ± 0.11
Reducing sugars (%)	0.99^{c} ± 0.04	2.48^{b} ± 0.03	3.14^{a} ± 0.05
Non-reducing sugars (%)	3.11^{b} ± 0.07	4.53^{a} ± 0.20	4.60^{a} ± 0.11
Ascorbic acid (mg/100 g)	12.48^{a} ± 0.12	10.93^{b} ± 0.45	10.21^{b} ± 0.37
Total carotenoids (μg/g)	0.67^{b} ± 0.06	1.27^{a} ± 0.02	1.24^{a} ± 0.18
Total phenolics (mg GAE/100 g)	11.07^{a} ± 0.23	9.22^{b} ± 0.24	8.48^{c} ± 0.14
IC_{50}*** (mg/mL)	3.33^{b} ± 0.02	3.44^{a} ± 0.03	3.47^{a} ± 0.04

U = unripe. R = ripe and collected from the tree. RG = ripe and collected from the ground. Values expressed as mean ± standard deviation. Different lowercase letters in the same line indicate 5% significance by Tukey's test.

* Longitudinal diameter = length.

** Transverse diameter = width.

*** IC_{50} = concentration necessary to capture 50% of the free radical DPPH.

sapota-do-Solimões pulp at different ripening stages are shown in Table 1. The longitudinal and transverse diameters were larger in the RG fruit. This was also true for the total fruit mass, showing that at this ripening stage the fruits were larger than the others. The total fruit mass, longitudinal diameter (length) and transverse diameter (width) varied significantly, from 352 to 645 g, from 101.3 to 111.7 mm and from 81.6 to 106.5 mm for the U and the RG fruit, respectively.

As the fruit ripened, there was a significant increase in water activity (0.977–0.996), pH (6.53–7.04), soluble solids (8.53–12.65%), total sugars (4.26–7.98%), reducing sugars (0.99–3.14%), non-reducing sugars (3.11–4.60%) and total carotenoids (0.67–1.24 μg/g of pulp).

Many important reactions occur during ripening, including a series of complex biochemical reactions, such as the hydrolysis of starch, the conversion of chloroplasts into chromoplasts with chlorophylls degradation, carotenoid production, and the formation of volatile compounds (Speirs & Brady, 1991; Vendramini & Trugo, 2000); however, this has not previously been reported for sapota-do-Solimões fruit. An increase in pH and soluble solids and a decrease in titratable acidity are common, due to the consumption of organic acids as a substrate for respiration (Cantillo, Sinuco, Solarte, & Melgarejo, 2011). High levels of soluble solids are important for the commercialization of fresh fruit and for processing. In some fruits, the soluble solids content is used to indicate the point of ripening, i.e. it can be useful to determine the harvesting point (Lopes, Bruckner, Cruz, & Freitas, 2001; Nascimento, Martins, & Hojo, 2008) and for the sapota-do-Solimões it was found that these levels increased with ripening. Sugar content varies depending on the ripening stage of the fruit because the sugar content in fruit pulp is directly related to the total soluble solids content (de Sousa, de Figueirêdo, Queiroz, Silva, & de Sousa, 2012).

Water-soluble vitamins, especially ascorbic acid, are very susceptible to post-harvest degradation when fruits are exposed to adverse handling and storage conditions. Other research regarding the stability of ascorbic acid in fruits has produced diverse results. Cardello and Cardello (1998) observed a considerable reduction of this vitamin during fourteen days of ripening of Haden mango. However, Lee and Kader (2000) reported an increase in ascorbic acid content in peach and papaya and a reduction in apple and mango, as ripening continued.

Table 2
Chemical composition of sapota-do-Solimões (*Quararibea cordata* Vischer) pulp in 100 g of fresh sample at different ripening stages.

Constituents g%	Ripening stages		
	U	R	RG
Moisture	79.23^{c} ± 0.03	86.83^{b} ± 0.01	87.05^{a} ± 0.02
Ash	0.95^{a} ± 0.01	0.68^{b} ± 0.01	0.62^{c} ± 0.01
Protein	1.25^{a} ± 0.05	0.63^{b} ± 0.04	0.68^{b} ± 0.00
Lipids	0.16^{b} ± 0.05	0.22^{ab} ± 0.05	0.30^{a} ± 0.03
Dietary fiber	10.45^{a} ± 0.81	4.64^{b} ± 0.01	3.52^{b} ± 0.06
Soluble fiber	0.22^{c} ± 0.08	0.57^{b} ± 0.20	0.93^{a} ± 0.03
Insoluble fiber	10.23^{a} ± 0.90	4.07^{b} ± 0.21	2.59^{c} ± 0.09
Carbohydrates	7.95^{a} ± 0.83	6.99^{b} ± 0.08	7.83^{a} ± 0.07
Calories (Kcal)	38.26^{a} ± 3.08	32.48^{b} ± 0.29	36.73^{a} ± 0.23

U = unripe. R = ripe and collected from the tree. RG = ripe and collected from the ground. Values expressed as mean ± standard deviation. Different letters in the same line indicate 5% significance by Tukey's test.

Several factors contribute to the degradation of ascorbic acid as light, heat, alkalinity, catalysts, physical damages and humidity can lead to aerobic oxidation or anaerobic with formation of dark pigments.

Carotenoids are very stable compounds that remain intact even when senescence is well advanced and their synthesis is important during the development of fruit (Rodriguez-Amaya & Kimura, 2004). Phenolic content is usually higher in unripe fruits than in ripe; therefore, fruits show a decrease in phenolic compounds during ripening (Ozawa, Lilley, & Haslam, 1987).

3.2. Chemical composition and analysis of fatty acids

The chemical composition of the pulps varied depending on the ripening stage (Table 2). Moisture increased significantly (79.23–87.05%) and ash decreased significantly (0.95–0.62%) throughout the period of ripening. The level of crude protein was higher in the U fruit (1.25%) and presented a significant difference when compared to the R and the RG fruit (0.63–0.68%).

The lipids increased significantly in relation to the U (0.16%) and the RG fruit (0.30%). It is known that with the growth and the ripening of the fruits they lead to changes in the composition and with that the increase of the lipids. The level of total dietary fiber reduced during ripening and there was an increase in the soluble fiber content (0.22–0.93%) and a decrease in the insoluble fiber content (10.23–2.59%). During ripening, there was a reduction with no statistical difference in the level of carbohydrates (7.95–7.83%) and calories (38.26–36.73%).

Eleven fatty acids were detected in the pulp of sapota-do-Solimões samples from different ripening stages, nine of which were identified and two of which were unidentified (Table 3). Some fatty acids present a significant difference among the ripening stages. The palmitic (16:0), stearic (18:0), oleic (18:1 n9) and vaccenic (18:1 n7) increased with ripening. The major saturated fatty acid that was found was palmitic acid, which presented a significant increase from U (47.10 mg/100 g) to the RG (86.39 mg/100 g). The unsaturated fatty acids presented higher concentrations and the major unsaturated fatty acid was oleic acid, which presented a significant increase from U (44.38 mg/100 g) to the RG (131.13 mg/100 g). The palmitoleic (16:1 n7) and linoleic (18:2 n6) presented a significant reduction during ripening, possibly due to the formation of compounds during the secondary metabolism of the fruit. The total amount of saturated and unsaturated fatty acids was as follows: U 52.16 and 104.7 mg/100 g; R 78.19 and 134.46 mg/100 g; and RG 95.27 and 193.10 mg/100 g, respectively.

The widest variety of flavor compounds formed from lipids arises via lipoxygenase activity. Many of the esters and alcohols, for example, found in fruits are derived from the oxidative degradation of linoleic and linolenic acids (Reineccius, 2006).

Table 3
Profile of fatty acids from sapota-do-Solimões (*Quararibea cordata* Vischer) pulp in mg/100 g of fresh sample at different ripening stages.

Fatty acids (mg/100 g)	Ripening stages		
	U	R	RG
Lauric (12:0)	nd	1.76^{a} ± 0.77	0.78^{a} ± 0.90
Myristic (14:0)	1.93^{a} ± 0.48	3.51^{a} ± 1.08	2.25^{a} ± 0.31
Palmitic (16:0)	47.10^{c} ± 7.15	68.64^{b} ± 2.50	86.39^{a} ± 7.48
Palmitoleic (16:1 n7)	16.44^{a} ± 2.79	12.89^{ab} ± 1.93	9.96^{b} ± 1.51
Unidentified	nd	2.91^{a} ± 0.67	5.60^{a} ± 1.25
Stearic (18:0)	3.13^{b} ± 0.37	4.28^{b} ± 0.19	5.85^{a} ± 0.64
Oleic (18:1 n9)	44.38^{c} ± 5.08	66.49^{b} ± 2.71	131.13^{a} ± 11.13
Vaccenic (18:1 n7)	25.25^{c} ± 3.31	30.55^{b} ± 0.96	37.74^{a} ± 1.24
Linoleic (18:2 n6)	6.55^{a} ± 0.91	6.42^{a} ± 1.62	3.45^{b} ± 0.74
Unidentified	3.11^{b} ± 0.37	4.43^{b} ± 0.71	6.05^{a} ± 1.19
Linolenic (18:3 n3)	12.11^{b} ± 3.79	18.11^{a} ± 1.76	10.82^{b} ± 0.68
Total saturated fatty acids	52.16	78.19	95.27
Total unsaturated fatty acids	104.73	134.46	193.10
Total unidentified fatty acids	3.11	7.34	11.65
Ratio n-6/n-3	0.54	0.35	0.32

U = unripe. R = ripe and collected from the tree. RG = ripe and collected from the ground. nd = not detected. Values expressed as mean ± standard deviation. Different letters in the same line indicate 5% significance by Tukey's test or different by *t*-Student test.

3.3. Analysis of volatile compounds

The chromatographic analysis of the volatile fraction extracted by HS-SPME in relation to the three ripening stages of the sapota-do-Solimões pulp resulted in the identification of 86 compounds; 57 components in U stage, 54 in R and 68 in RG. The identified components, their respective retention indices and mean areas at each ripening stage is shown in Table 4.

The volatile compounds found in the sapota-do-Solimões pulp belong to different classes, and most relevant were alcohols, aldehydes, esters, furans, ketones and terpenes. Although the total percentage of alcohols did not change during ripening (33.59%, 32.60% and 32.30%, respectively for U, R and RG), there was increase in the levels of ethanol during the ripening of fruits. On the other hand, hexanol, (Z)-3-hexen-1-ol and 3-methyl-1-butanol, which was present in the greatest concentration in the U. The hexanol and (Z)-3-hexen-1-ol are formed from metabolism of fatty acids, also providing green or herbaceous aromas (Romeo, Ziino, Giuffrida, Condurso, & Verzera, 2007).

The aldehydes decreased about 20% in the R and RG ripening stages in relation to U fruit. There was a reduction in the ethanol, as well as a reduction in the hexanal and (E)-2-hexenal, which are related to herbaceous odors (Cantillo et al., 2011). Hexenal and (E)-2-hexenal are formed by action of lipoxygenase pathway (Mattheis, Buchanan, & Fellman, 1997). The 2-methyl and 3-methyl-1-butanal (apple-like odor) (Lewis, 2007) compounds were found at all ripening stages of sapota-do-Solimões pulp and possibly formed from the interaction of amino acids and sugars (Hui, 2010).

Ketones result from biosynthesis and/or degradation of fatty acids by β-oxidation (Schwab, Davidovich-Rikanati, & Lewinsohn, 2008). In the ketones class, was observed that the 3-hydroxy-2-butanone compound decreased with ripening of the fruits and was not detected in the ripe fruits harvested from the ground. This compound is known an odor of acetoin that resembles butter and cream (Smogrovicová & Dömény, 1999). The 4-methoxy-3-octen-2-one areas increased with ripening, as well as 3-methyl-4-octanone and 6-methyl-5-hepten-2-one. The latter compound is citrus and known to be an oxidative byproduct or derived from carotenoids degradation (Furia, 1980; Goff & Klee, 2006).

The esters are described compounds which have fruity sensorial odors. The effect of different ripening stages on the volatile sapota-do-Solimões composition was the development of aromas evidenced by an increase in the number of volatile compounds from 4 in the green fruit to 11 in the ripe fruit harvested from the tree. In the present study, the RG presented the benzoate esters of methyl and ethyl, which are sensory described as plum, sweet and floral odors. Ethyl 3-hydroxybutanoate and ethyl benzenepropanoate appeared in the ripe samples (R and RG). The values found for this class of compounds correspond to the sum of the endogenous content and the formation by enzymatic action, which act to degrade linolenic and linoleic acids (Cantillo et al., 2011).

There was also an increase in the terpene compounds in conjunction with ripening; from 0.4% in U fruit to 5.6% in the RG fruit. These volatile compounds can be formed by the metabolism of the fruit or by the enzymatic or chemical degradation of precursors such as carotenoids or their glycosides forms. The last stage of ripening the fruit pulp is characterized by an intense orange color providing of carotenoids compounds and it degradation can occur in postharvest, as mentioned above for ketones, being the bond compounds strongly responsible of the aroma changes from unripe to over-ripened fruit. The terpenes have potential odoriferous characteristics such as α-terpineol (floral), eucalyptol (freshness, mint), linalool (flowers, lavender) and o-cymene (citrus) (Ceva-Antunes, Bizzo, Alves, & Antunes, 2003; Jirovetz, Buchbauer, & Ngassoum, 1998). Santos, Andrade, Zoghbil, and Maia (1998) showed the terpenoids compounds varied according to the different ripening stages.

The terpenes α-pinene and β-pinene appeared in the ripe fruits and in the ripe fruit collected from the ground (RG) the concentration was higher than in the ripe fruit collected from the tree (R). Both of these compounds are referred to as having a pine odor (Andrade, Zoghbi, Maia, Fabricius, & Marx, 2001; Oliveira, Lopes, Cabral, & Eberlin, 2006). In relation to (E)-β-ocimene and limonene, there was an increase during ripening and both compounds have a citric odor (Santos et al., 1998; Vendramini & Trugo, 2000). These terpenoids are primarily oxidation - degraded products of the carotenoids (Hui, 2010).

In the group miscellaneous, stand out the furans that increased from 2.4% U fruit to 20.7% from RG. The increased formation of furans compounds is characterized by a sweet and fruity aroma (Cantillo et al., 2011). The 2,5-dimethyl-2,4-dihydroxy-3 (2H) furanone and furaneol compounds increased with the ripening of the fruit, enhancing an odor that resembles caramel (Mosciano et al., 1996).

3.4. Sensory analysis

The attributes of color, odor, flavor, texture and appearance of the ripe samples R and RG were evaluated. The sensory characteristics and acceptability index are presented in Table 5.

The scores attributed to the analyzed attributes ranged from 5 to 6, which were classified as “moderately liked” and “liked a lot” in the structured seven-point hedonic scale. There were no significant difference ($p > .05$) between the ripe samples collected from the tree and the ground in terms of the analyzed attributes. Regarding the acceptability index of the samples, the values for all the attributes were higher than 70%.

The consumers reported that the sapota-do-Solimões reminded them of papaya and mango fruits, as has already been described in the literature (Cavalcante, 1991), and they also mentioned that sapota-do-Solimões reminded them of fruits such as abiu (*Pouteria caimito*), jerimum (*Curcubita noschata*), pupunha (*Bactris gasipaes*) and kaki (*Diospyrus kaki*).

The fact that there were no significant differences for the attributes analyzed could indicate that there was a short post-harvest period between fruits R and RG, and consequently there was no differentiation in acceptance of consumption. In addition, in relation to odor, at the moment of the sensorial analysis, the fruits probably had a similar level of aromatic compounds, not being noticeable the distinction of the terpene compounds, in spite of the increase or appearance from fruit R

Table 4
Volatile chemical composition (area × 10^5) of sapota-do-Solimões (*Quararibea cordata* Vischer) pulps at different ripening stages.

Component	RI[1]	RI_{lit}[2]	U[3]	R[3]	RG[3]
Alcohols					
Ethanol	940	936	485.71[a] ± 60.44	933.94[a] ± 948.85	770.96[a] ± 113.90
1-Propanol	1043	1040	10.41[a] ± 6.37	2.12[a] ± 1.42**	3.97[a] ± 0.32
3-Penten-2-ol	1099	1100	42.38[a] ± 15.25	24.37[a] ± 7.87	nd
2-Methyl-1-propanol	1101	1095	nd	nd	41.11 ± 8.82
2-Pentanol	1131	1124	2.12 ± 1.57	nd	nd
2-Methyl-2-propanol	1155	1150	15.61[ab] ± 0.21**	24.54[a] ± 6.87**	1.93[b] ± 0.07**
1-Penten-3-ol	1166	1164	14.65[a] ± 4.66	12.62[a] ± 3.98	16.58[a] ± 5.73
3-Hexanol	1200	1200	2.92[a] ± 1.92**	nd	1.85[a] ± 1.05
3-Methyl-1-butanol	1210	1203	111.76[a] ± 37.22**	42.98[a] ± 32.27	48.09[a] ± 22.78
(Z)-2-Penten-1-ol	1317	1314	7.82[a] ± 3.96	1.98[a] ± 0.57	4.87[a] ± 1.64
1-Hexanol	1347	1345	184.45[a] ± 79.21	9.78[b] ± 2.68	28.51[b] ± 20.88
(E)-3-Hexen-1-ol	1365	1365	9.23[ab] ± 4.93	42.12[a] ± 21.80	3.14[b] ± 2.33**
4-Octanol	1374	1376	0.71[a] ± 0.35**	nd	0.65[a] ± 0.09**
(Z)-3-Hexen-1-ol	1377	1370	302.51[a] ± 115.46	nd	136.41[a] ± 77.44
(E)-2-Hexen-1-ol	1398	1397	19.39[a] ± 8.85	3.40[a] ± 1.19**	10.10[a] ± 3.52
1-Octen-3-ol	1442	1456	nd	2.18[a] ± 0.00*	3.55[a] ± 1.20
2-Ethyl-1-hexanol	1480	1465	0.68[a] ± 0.00*	1.67[a] ± 0.00*	4.07[a] ± 1.67
1-Octanol	1556	1562	nd	nd	3.21 ± 1.85
(Z)-6-Nonen-1-ol	1721	1720	3.94 ± 0.30**	nd	nd
(E,Z)-3,6-Nonadien-1-ol	1758	1764	3.61 ± 2.63**	nd	nd
2-Phenylethanol	1931	1931	7.90 ± 2.24**	nd	nd
1-Dodecanol	1970	1973	3.43[a] ± 0.64**	nd	2.89[a] ± 0.00*
1-Tridecanol	2063	2041	2.08[a] ± 1.48**	0.40[a] ± 0.00*	1.35[a] ± 0.00*
1-Hexadecanol	2398	2381	nd	nd	6.35 ± 5.14**
Total (%)			*33.59*	*32.60*	*32.30*
Aldehydes					
Ethanal	724	727	257.80[a] ± 81.93	345.10[a] ± 264.49	117.45[a] ± 17.54
Propanal	797	798	2.57[b] ± 1.15	11.23[a] ± 3.84	2.88[b] ± 1.24
2-Methyl-1-propanal	811	812	15.32[a] ± 11.50	24.83[a] ± 6.11	13.98[a] ± 3.98
Butanal	885	853	3.72[a] ± 4.06**	0.59[a] ± 0.16**	nd
2-Methyl-1-butanal	917	916	51.99[a] ± 37.16	46.02[a] ± 7.26	18.12[a] ± 6.27
3-Methyl-1-butanal	921	921	82.66[a] ± 50.95	90.53[a] ± 32.39	21.71[a] ± 9.96
Hexanal	1080	1080	235.40[a] ± 123.41	15.48[b] ± 1.94	34.28[b] ± 7.66
(Z)-2-Hexenal	1206	1208	14.63[a] ± 1.13**	nd	15.27[a] ± 1.90
(E)-2-Hexenal	1219	1218	760.50[a] ± 361.94	138.48[b] ± 35.92	562.78[ab] ± 105.84
(E,E)-2,4-Hexadienal	1429	1411	6.19[a] ± 0.00*	nd	6.62[a] ± 4.44**
(Z)-6-Nonenal	1445	1459	34.13 ± 15.14	nd	nd
(E)-2-Nonenal	1550	1556	3.91 ± 0.00*	nd	nd
(E,E)-2,6-Nonadienal	1596	1597	11.27[a] ± 7.12	nd	0.97[a] ± 0.60**
Phenylacetaldehyde	1661	1650	15.19[a] ± 8.62**	20.97[a] ± 6.93	16.69[a] ± 1.64**
Total (%)			*40.52*	*20.51*	*22.39*
Ketones					
2-Propanone	822	814	16.05[a] ± 4.48	26.13[a] ± 2.16	12.56[a] ± 0.00*
2-Butanone	913	905	6.85[a] ± 9.79	0.99[a] ± 0.00*	1.29[a] ± 0.25
3-Methyl-2-butanone	935	929	7.72[a] ± 10.84	6.49[a] ± 8.07	nd
2,3-Butanedione	993	984	94.74 ± 6.29	nd	nd
3-Hexanone	1052	1055	2.19 ± 0.00*	nd	nd
3-Hydroxy-2-butanone	1284	1270	135.21[a] ± 34.30	13.40[b] ± 3.36	nd
2,3-Octanedione	1318	–	7.23 ± 1.65**	nd	nd
6-Methyl-5-hepten-2-one	1331	1325	nd	2.64[a] ± 0.00*	9.64[a] ± 2.13
Isobutyl-2-heptenone	1342	–	nd	nd	8.10 ± 2.67
4-Methoxy-3-octen-2-one	1670	–	39.63[a] ± 3.76	218.50[a] ± 168.03	131.78[a] ± 122.55
3-Methyl-4-octanone	1994	1964	1.13[b] ± 0.00**	1.47[b] ± 0.13**	6.85[a] ± 1.88
Total (%)			*8.41*	*7.97*	*4.70*
Esters					
Ethyl ethanoate	897	890	324.77[a] ± 120.74	314.51[a] ± 27.76	115.45[b] ± 48.98
Ethyl isobutanoate	966	955	22.50[a] ± 17.16**	11.56[a] ± 10.66	0.78[a] ± 0.45
Ethyl butanoate	1035	1039	nd	8.83[a] ± 4.07	3.88[a] ± 1.92**
Ethyl 2-methylbutanoate	1047	1053	11.74[a] ± 5.58	9.48[a] ± 4.46	0.11[a] ± 0.05
Butyl ethanoate	1071	1078	nd	36.47 ± 8.43	nd
3-Methylbutyl ethanoate	1114	1119	nd	2.06 ± 0.44	nd
Ethyl (E)-2-butenoate	1162	1161	nd	11.68 ± 4.96[a]	2.28 ± 1.07[a]**
Ethyl 2-methyl-2-butenoate	1230	1234	6.83[b] ± 3.85	37.42[a] ± 13.62	nd
Ethyl 3-hydroxybutanoate	1524	1527	nd	7.56[a] ± 1.65	2.30[b] ± 0.95**
Methyl benzoate	1636	1628	nd	nd	122.13 ± 53.14
Ethyl benzoate	1678	1662	nd	0.95[a] ± 0.00*	28.04[a] ± 27.40
Ethyl benzenepropanoate	1896	1886	nd	0.79[b] ± 0.05**	2.48[a] ± 0.00*
Dibutyl (*Z*)-2-butenedioate	2096	–	0.41 ± 0.00*	nd	nd
Total (%)			*9.92*	*13.05*	*7.79*
Terpenoids					
α-Pinene	1012	1017	nd	0.78[b] ± 0.12	13.70[a] ± 1.99

(*continued on next page*)

Table 4 (*continued*)

Component	RI[1]	RI_{lit}[2]	U[3]	R[3]	RG[3]
β-Pinene	1085	1099	nd	$7.16^{b} \pm 0.82$	$27.58^{a} \pm 5.74$
Limonene	1175	1180	$2.26^{b} \pm 1.00$	$4.87^{ab} \pm 3.11^{**}$	$9.38^{a} \pm 0.89$
Eucalyptol	1190	1197	$5.20^{a} \pm 6.99$	nd	$11.11^{a} \pm 2.26$
(E)-β-Ocimene	1234	1240	$1.49^{b} \pm 0.31^{**}$	$12.02^{a} \pm 2.75$	$7.45^{ab} \pm 1.33^{**}$
o-Cymene	1249	1245	nd	nd	9.45 ± 2.54
(Z)-Linalool oxide	1432	–	nd	nd	9.41 ± 1.48
Linalool	1547	1550	nd	$2.19^{a} \pm 0.50$	$4.41^{a} \pm 2.07$
4-Terpineol	1601	1609	nd	nd	11.80 ± 3.71
β-Cyclocitral	1620	1616	nd	nd	$1.06 \pm 0.00^{*}$
(E)-Pinocarveol	1651	1664	$5.81^{b} \pm 2.74$	$9.13^{ab} \pm 0.78$	$15.49^{a} \pm 4.87$
α-Terpineol	1701	1708	nd	nd	74.43 ± 20.06
Myrtenol	1796	–	nd	nd	7.91 ± 1.43
Geranyl acetone	1869	1850	nd	nd	9.90 ± 2.30
Total (%)			*0.40*	*1.07*	*5.90*
Miscellaneous					
Hexane	600	600	nd	$181.01^{a} \pm 0.00^{*}$	$76.59^{b} \pm 3.23^{**}$
Dimethyl sulfide	751	752	$109.35^{a} \pm 28.45$	$143.24^{a} \pm 36.17$	$121.08^{a} \pm 15.76$
Propionic anhydride	960	966	nd	$24.03^{a} \pm 0.00^{*}$	$0.51^{b} \pm 0.35$
Methoxymethyl-benzene	1387	1396	nd	nd	9.27 ± 1.69
Acetic acid	1454	1455	$52.31^{a} \pm 14.83$	$7.05^{a} \pm 3.00^{**}$	$5.84^{a} \pm 0.00^{*}$
2,5-Dimethyl-2,4-dihydroxy-3(2H)-furanone	1502	1554	nd	$10.97^{b} \pm 7.56$	$56.93^{a} \pm 48.88$
Pyrrole	1514	1516	$2.26 \pm 0.58^{**}$	nd	nd
Furaneol	1692	–	$86.84^{b} \pm 26.15$	$465.53^{a} \pm 59.37$	$661.30^{a} \pm 190.93$
1,2-Dimethoxybenzene	1756	1741	nd	$0.69^{a} \pm 0.22^{**}$	$1.75^{a} \pm 1.52^{**}$
2,4-Di-tert-butylphenol	2328	2321	$13.68^{a} \pm 8.74$	$5.74^{a} \pm 1.51$	$12.48^{a} \pm 12.56$
Total (%)			*7.16*	*24.80*	*26.92*

U = unripe. R = ripe and collected from the tree. RG = ripe and collected from the ground. nd = not detected. Values expressed as mean ± standard deviation. Different letters in the same line indicate 5% significance by Tukey's test or different by *t*-Student test.

** Two values detected.

* One value detected.

[1] Retention indices exhibited by the compounds in the column.

[2] Retention indices according to data available in the NIST database; [3]Average area × 10^5 of the peak of the chromatogram obtained by HS-SPME.

to RG, and different odoriferous notes were equally accepted.

The interest in using fruits during the growth is due to the fact that there is no study to date with the sapota-do-Solimões along the ripening and also to know if the fruits collected from the tree, normally preferred for consumption, have characteristics similar to the ones fruits collected from the ground, what was evidenced in this work therefore can be appreciated by consumers.

3.5. Exploratory data analysis

Exploratory data analysis was performed using the principal component analysis (PCA). The criterion of selection for the compounds was the power of discrimination among the samples, i.e. those compounds that presented statistical significance values were used. The variables that were excluded were those that presented a low power of discrimination (equal areas) and also those that were only found in one sample. Fig. 1 shows the graphs of the scores (samples) and the loadings (compounds) of the first two principal components (PCs) resulting from the PCA, which accumulated 82.04% of the total data variance. Using PCA it was possible to easy access to relevant information about the correlation between the variables and samples. There was a separation of the samples in relation to the different ripening stages of the sapota-do-Solimões pulps, so that the U samples were positioned in the negative quadrants (PCI) and the ripe samples R and RG were located in the positive quadrants (Fig. 1a). The U and RG fruit were located in opposite quadrants because they had high concentrations of distinct quality characteristics, as well as different chemical composition and volatile compounds.

Table 5
Scores provided by consumers regarding sensory characteristics and acceptability index (%) for color, odor, flavor, texture and appearance for samples of sapota-do-Solimões (*Quararibea cordata* Vischer) at different ripening stages.

Ripening stages	Sensory characteristics - attributes				
	Color	Odor	Taste	Texture	Appearance
R	$5.82^{ns} \pm 1.27$	5.64 ± 1.10	5.70 ± 1.23	5.36 ± 1.31	5.78 ± 1.11
RG	$5.92^{ns} \pm 1.12$	5.60 ± 0.95	5.86 ± 1.01	5.34 ± 1.33	5.64 ± 1.19

Ripening stages	Acceptability index (%) - attributes				
	Color	Odor	Taste	Texture	Appearance
R	83.14	80.57	81.43	76.57	82.57
RG	84.57	80.00	83.71	76.29	80.57

R = ripe fruit collected from the tree. RG = ripe fruit collected from the ground. Values expressed as mean ± standard deviation. ns = not significant by *t*-Student test. Scores: 1 = disliked greatly; 2 = disliked a lot; 3 = moderately disliked; 4 = neither liked nor disliked; 5 = moderately liked; 6 = liked a lot; 7 = liked very much.

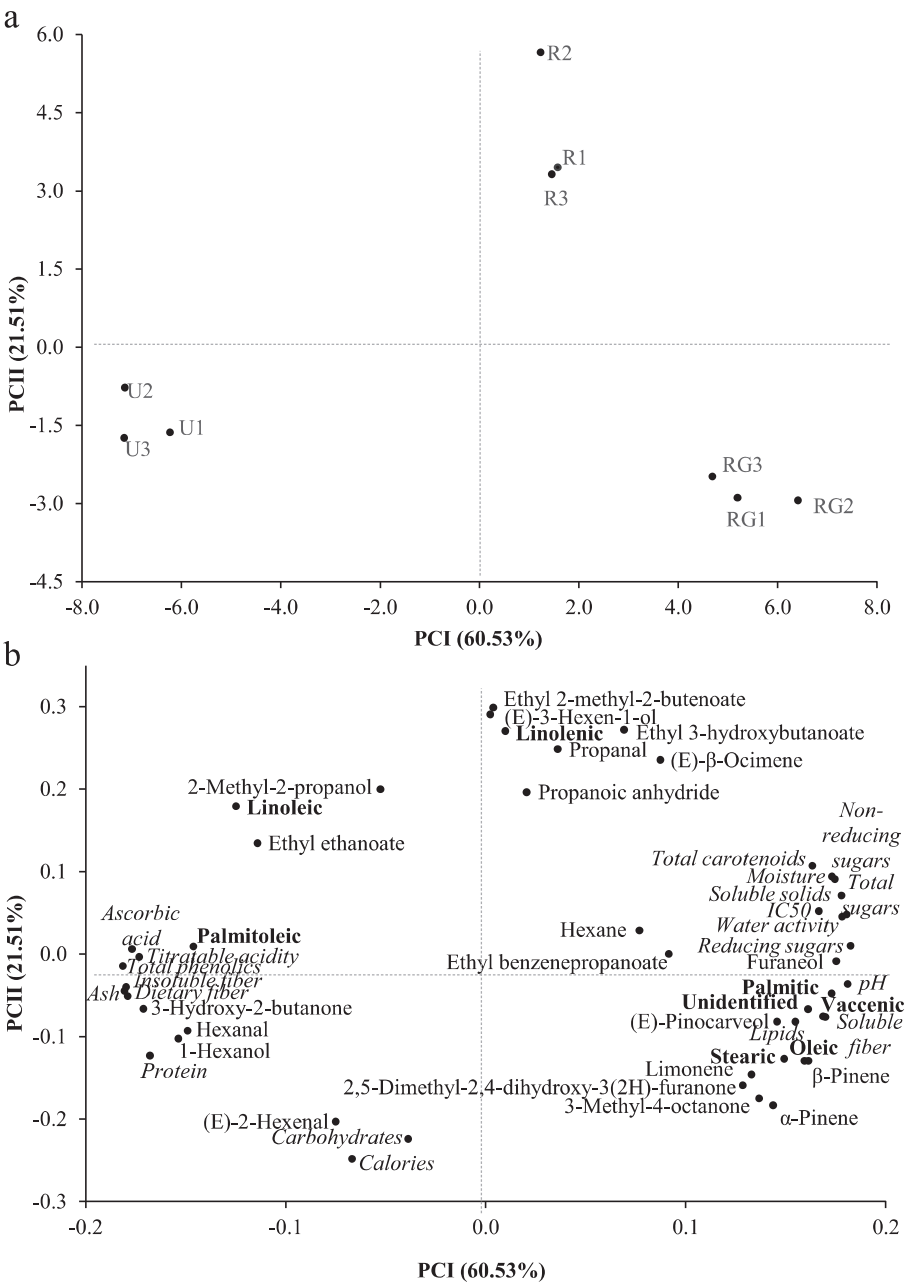

Fig. 1. Analysis of the main components of the chemical and volatile composition of sapota-do-Solimões (Quararibea cordata Vischer) pulp at different ripening stages. a - scoring plots (samples), U = unripe. R = ripe and collected from the tree. RG = ripe and collected from the ground. b - plots of weight (variables).

In relation to the parameters of quality, chemical composition and fatty acids (Fig. 1b), the main difference between the groups was regarding the higher concentration of titratable acidity, ascorbic acid, total phenolics, ash, protein, dietary fiber, insoluble fiber, carbohydrates, calories and fatty acids palmitoleic and linoleic from U fruit, while in the RG fruit there was a higher concentration of water activity, pH, soluble solids, total sugars, reducing sugars, non-reducing sugars, total carotenoids, moisture, lipids, soluble fiber and fatty acids palmitic, stearic, oleic and vaccenic.

The main difference between the groups in relation to volatile compounds (Fig. 1b) was the higher concentration of alcohols (2-methyl-2-propanol and 1-hexanol) and aldehydes (hexanal and (E)-2-hexenal), also showed ketone (3-hidroxy-2-butanone) and ester (ethyl ethanoate) in U samples, which had a negative influence on this ripening stage, while the RG samples stood out in terms of their content of furans (2,5-dimethyl-2,4-dihydroxy-3(2H)-furanone and furaneol), terpenes (α-pinene, β-pinene, limonene and (E)-pinocarveol), hydrocarbon (hexane) also showed ketone (3-methyl-4-octanone) and ester (ethyl benzenepropanoate), which had a positive influence at this ripening stage. Consequently, this analysis was useful in terms of visualizing the volatile characteristics of each sample, grouping them by similarity in relation to the content of the various volatile compounds.

The R samples were positioned in the positive quadrants, discriminated by *PcI*, and R fruit is positioned between the U and RG samples in the PCI. At this point of ripening, differs from others in relation to volatile compounds, there was the higher concentration of esters (ethyl 2-methyl-2-butenoate and ethyl 3-hidroxybutanoate), also showed terpene ((E)-β-ocimene), aldehyde (propanal), alcohol ((E)-3-hexen-1-ol) and anhydride (propanoic anhydride).

The aroma of the sapota-do-Solimões pulps was influenced by the ripening stage, so that some compounds, and even some chemical classes, were exclusively detected in one of these stages, thereby acting

as chemical markers of ripening. The sapota-do-Solimões at the U fruit was characterized by the presence of alcohols, aldehydes and ketones, while the main chemical characteristic of the ripe sapota-do-Solimões collected from the tree (R) and the ground (RG) was an increase in characteristically fruity odor compounds such as esters, terpenes and furans.

4. Conclusions

The results showed that fruit composition was influenced by the ripening stage of the pulps and the ripe samples presented higher content of carotenoids and lipids. The fatty acid profile found is important for the formation of flavor precursors of sapota-do-solimões fruit.

Volatiles, during the maturation of sapota-do-Solimões pulps, increased the presence of esters, furans and terpenes.

This study brings unprecedented results when presenting data on ripening in sapota-do-Solimões. It is also the first time that fatty acids and volatile compounds of sapota-do-Solimões pulp were studied.

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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