LWT - Food Science and Technology 43 (2010) 1564–1572

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Characterization of different fruit wines made from cacao, cupuassu, gabiroba, jaboticaba and umbu

Whasley F. Duarte[a,b], Disney R. Dias[c], José M. Oliveira[b], José A. Teixeira[b], João B. de Almeida e Silva[d], Rosane F. Schwan[a,*]

[a] Department of Biology, Federal University of Lavras (UFLA), Campus Universitário, 37.200-000, Lavras, MG, Brazil
[b] IBB – Institute for Biotechnology and Bioengineering, Centre of Biological Engineering, Universidade do Minho, Campus de Gualtar, 4710-057, Braga, Portugal
[c] Centro Universitário de Lavras (Unilavras), Rua Padre José Poggel, 506, 37.200-000, Lavras, MG, Brazil
[d] Department of Biotechnology, Engineering School of Lorena, University of São Paulo (USP), 12.602-810, Lorena, SP, Brazil

ARTICLE INFO

Article history:
Received 22 October 2009
Received in revised form
11 March 2010
Accepted 11 March 2010

Keywords:
Tropical fruits gas chromatography–mass spectrometry
Alcoholic beverages
Aroma

ABSTRACT

The main aim of this work was to produce fruit wines from pulp of gabiroba, cacao, umbu, cupuassu and jaboticaba and characterize them using gas chromatography–mass spectrometry for determination of minor compounds and gas chromatography-flame ionization detection for major compounds. Ninety-nine compounds (C_6 compounds, alcohols, monoterpenic alcohols, monoterpenic oxides, ethyl esters, acetates, volatile phenols, acids, carbonyl compounds, sulfur compounds and sugars) were identified in fruit wines. The typical composition for each fruit wine was evidenced by principal component analysis and Tukey test. The yeast UFLA CA 1162 was efficient in the fermentation of the fruit pulp used in this work. The identification and quantification of the compounds allowed a good characterization of the fruit wines. With our results, we conclude that the use of tropical fruits in the production of fruit wines is a viable alternative that allows the use of harvest surpluses and other underused fruits, resulting in the introduction of new products into the market.

1. Introduction

There is an abundance of exotic tropical fruits in Brazil with the potential to be used by the food industry. Different new uses and new methods for processing tropical fruits need to be developed to minimize production losses, generate more profits and promote the sustainable use of biomes, such as the *cerrado* (Brazilian savannah) and the Amazon forest. One possible use of these fruits is in the production of fruit wines (Dias, Schwan, Freire, & Serôdio, 2007; Duarte, Dias, Pereira, Gervásio, & Schwan, 2009).

There are many studies in the literature that demonstrate the feasibility of using fruits, such as cacao (Dias et al., 2007), gabiroba (Duarte et al., 2009), kiwi (Soufleros et al., 2001), cajá (Dias, Schwan, & Lima, 2003), mango (Reddy & Reddy, 2005) and orange (Selli et al., 2008) to produce alcoholic beverages.

There are several Brazilian fruits with the potential for use in the production of wines. In this study, we investigated the following fruits for this purpose: cupuassu (*Theobroma grandiflorum* Schum.), umbu (*Spondias tuberosa* L.), gabiroba [*Campomanesia pubescens* (DC.) O. Berg], cacao (*Theobroma cacao* L.) and jaboticaba (*Myrciaria jaboticaba* Berg).

Cupuassu is a fruit native to the Brazilian states of Maranhão and Pará and is one of the most consumed fruits in that region. Some authors consider cupuassu as one of the most promising fruits for commercialization among many others of the Amazon region (Quijano & Pino, 2007). The cupuassu pulp has an average pH of 3.4 and its sugar content is about 10.7 °Brix. It is used to produce juice, ice cream, jams, liqueur, filling for chocolates, and other products. Umbu is a fruit native to the semi-arid regions in the Brazilian northeast. It is consumed locally as fresh fruit, in juices and as ice cream. Umbu pulp has a pH of 2.2 and a sugar content of 14.8 °Brix; these values may vary according the climate of the region of origin of the plant (Lira Júnior et al., 2005). Gabiroba is a fruit native to the western and southern Brazilian savannah. This fruit has been rated as a potential food source for both domestic fowl and humans. Gabiroba is consumed fresh locally and is also used in the production of homemade ice cream, jams, juices and sweets. The pulp of the gabiroba has a pH of 4.1 and a sugar content of about 14 °Brix; these values, combined with good pulp yields, allow for the use of gabiroba fruits in wine production (Duarte et al., 2009). Cacao is known worldwide for its beans, which are used in the production of chocolate. The production and commercialization of

---

[*] Corresponding author. Tel.: +55 35 3829 1614; fax: +55 35 3829 1100.
E-mail address: rschwan@dbi.ufla.br (R.F. Schwan).

0023-6438/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.lwt.2010.03.010

cacao beans have long been the basis of the economy of some Brazilian states, especially Bahia (Dias et al., 2007). The pulp of the cacao fruit is a substrate rich in nutrients; it is a by-product of the processing of the fruit and can be used in the production of wines and other products (Schwan & Wheals, 2004). The jaboticaba tree, also known as the "Brazilian grape tree", is a tree native to Brazil that belongs to the Myrtaceae family. Its fruits are purplish black, and their skin and pulp have a sweet taste and low acidity. Jaboticaba fruits are consumed fresh and in processed forms such as jams, juices and liqueurs.

Alcoholic fermentation leads to a series of by-products in addition to ethanol. They include carbonyl compounds, alcohols, esters, acids and acetals, all of them influencing the quality of the finished product. The composition and concentration levels of the by-products can vary widely (ng L^{-1} to hundreds of mg L^{-1}) (Plutowska & Wardencki, 2008). Although the number of publications about fruit wines has increased in recent years the chemical characterization of these beverages has not been detailed. The purpose of this study was to elaborate alcoholic beverages from cacao, cupuassu, gabiroba, jaboticaba and umbu pulps and characterize them using gas chromatography–mass spectrometry (GC–MS) for determination of minor compounds and gas chromatography-flame ionization detection (GC-FID) for major compounds. Additionally, glycerol, ethanol, sugars and organics acids were also detected by high-performance liquid chromatography (HPLC). It is expected that the determination of the compositions of these beverages will allow for better use of these fruits in the production of fruit wines.

2. Materials and methods

2.1. Must preparation

The fruit wines made from the selected fruits were prepared according to Dias et al. (2007) and Duarte et al. (2009). The fruits of gabiroba, jaboticaba, umbu, cupuassu and cacao were harvested between September and December 2008 and 10 kg of each fruit were selected, washed and mechanically depulped for the must preparation. The fruit pulps were diluted with a sucrose solution to adjust the sugar content to 16 °Brix, and the pH was adjusted to 4.5 with the addition of calcium carbonate. Hydrolases were added to facilitate juice clarification and an enzyme solution with polygalacturonase and cellulase activities (Ultrazym AFP-L, Novozymes, Novo Nordisk Ferment Ltd, Fuglebakken, Denmark, 100 Units mL^{-1}) was added to a concentration of 0.7 mL L^{-1}. Sulfur dioxide, in the form of potassium metabisulfite, was added up to a concentration of 100 mg L^{-1} of free SO_2 to inhibit bacterial growth. Also, bentonite was added (10 gL^{-1}) to the must to facilitate the sedimentation of non-fermentable solids. The bentonite had been previously suspended in water to a concentration of 10 gL^{-1} to aid its dispersion in the must.

2.2. Fermentation assays

Six fermentations were performed: five of them (cacao, cupuassu, gabiroba (I), jaboticaba and umbu) were inoculated with 10^8 cells mL^{-1} of *Saccharomyces cerevisiae* UFLA CA 1162 and the other one (gabiroba (NI)) was allowed to ferment spontaneously with the gabiroba pulp. All vinifications were carried out in 5 L flasks in a cold room at 22 °C and the fermentation was monitored by the daily measurement of Brix value, CO_2 and temperature. The fermentation was considered complete when the Brix level was stable. At the end of fermentation, the vats were transferred to a 10 °C incubator to aid the sedimentation of solid material from the fruits pulp. After 10 days at this temperature, the wine transfer was carried out with some aeration and the beverages were incubated at 10 °C for another 30 days. After that period, another transfer without aeration was carried out and the fruit wines were left for another 10 days at 10 °C, prior to filtration (Dias et al., 2007). The fruit wines were then filtered using cellulose filters and stored at 10 °C in glass bottles fully filled to avoid oxygen entrance. All assays were carried out in triplicate.

2.3. Analytical methods

2.3.1. Chemicals

1-Hexanol, (*E*)-3-hexen-1-ol, (*Z*)-3-hexen-1-ol, (*E*)-2-hexenol, 2-pentanol, 3-methyl-3-butene-1-ol, 4-methyl-1-pentanol, 2-heptanol, 3-methyl-2-buten-1-ol, 3-methyl-1-pentanol, 3-ethoxy-1-propanol, 1-heptanol, ethyl propionate, ethyl butyrate, ethyl 2-methylbutanoate, ethyl 3-methylbutanoate, ethyl hexanoate, ethyl pyruvate, ethyl lactate, ethyl octanoate, ethyl 3-hydroxybutanoate, diethyl malonate, ethyl 2-furoate, diethyl succinate, diethyl glutarate, diethyl malate, mono-ethyl succinate, triethyl citrate, propyl acetate, linalool, myrtenol, methyl salicylate, 4-vinylguaiacol, vanillin, 3,4,5-trimethoxyphenol, propanoic acid, 2-methyl butyric acid, 3-methyl butyric acid, heptanoic acid, octanoic acid, octanal, 6-methyl-5-hepten-2-one, nonanal, 3-(methylthio)-1-propanol, benzothiazole, N-(2-phenylethyl)acetamide, tyrosol, tetradecanoic acid, methanol, 2-phenylethanol, malic acid were purchased from Aldrich Chemistry (Munich, Germany). 1-Butanol, 1-pentanol, 2-ethyl-1-hexanol, 1-octanol, furfurol, 1-phenylethanol, ethylphenyl acetate, 2-phenylethyl acetate, 2-methylpropyl acetate, (*E*)-furan linalool oxide, (*Z*)-furan linalool oxide, (*E*)-pyran linalool oxide, (*Z*)-pyran linalool oxide, geranic acid, isobutyric acid, butyric acid, hexanoic acid, nonanoic acid, octanoic acid, hexadecanoic acid, 3-hydroxy-2-butanone, 2-furaldehyde, 2-phenoxyethanol, acetaldehyde, 1,1-diethoxyethane, 1-propanol, 2-methyl-1-propanol, 2-methyl-1-butanol, 3-methyl-1-butanol were purchased from Fluka Analyticals (Seelze, Germany). Limentol, linalool hydrate, α-terpineol, 4-terpineol, ho-trienol, borneol, citronellol, geraniol, verbenone, δ-decalactone were purchased from Lluch (Barcelona, Spain). Menthol, benzyl alcohol, ethyl acetate, succinic acid, glucose and fructose were purchased from Sigma-Aldrich (Saint Luis, EUA) and acetic acid, ethanol, dichloromethane and sodium sulfate were purchased from Merck (Darmstadt, Germany).

2.3.2. Minor volatile components

Minor volatile components in the fruit wines were determined by extraction with dichloromethane according to the methods of Oliveira, Faria, Sá, Barros, and Araújo (2006), followed by analysis of the extracts by GC–MS using a Varian 3400 gas chromatograph equipped with a septum-equipped temperature programmable injector (SPI), and an ion-trap mass spectrometer (Varian Saturn II). Samples of 1 μL were injected into a capillary column (Factor Four VF-Wax_{MS} Varian, 60 m × 0.25 mm i.d., 0.25 μm film thickness). Helium was used as the carrier gas at 124 kPa (18 psi). The detector was operated in the electron-impact mode (70 eV), and mass spectra were acquired by scanning over the mass/charge (m/z) range of 29–360 with an acquisition rate of 610 ms. The temperature of the injector (SPI) was programmed to run from 20 °C to 250 °C at 180 °C min^{-1} and was then maintained at 250 °C during the analysis. The oven temperature was held at 60 °C for 5 min, then programmed to run from 60 °C to 220 °C at 3 °C min^{-1} and was finally maintained at 250 °C for 25 min.

Volatile compounds were identified using Varian Saturn GC/MS software (Version 5.2) by comparing mass spectra and linear retention indices with those of authentic standard compounds injected under the same conditions. 4-Nonanol was chosen as internal standard and added to each sample and standard to a final concentration of 305 μg L^{-1}. The quantification of the volatile compounds was expressed as 4-nonanol (internal standard) equivalents. The relative concentrations of the investigated compounds were calculated by relating the area of the internal standard to the area of the compound of interest.

2.3.3. Major volatile components

In order to identify the major volatile compounds, the beverages were analyzed directly without any previous treatment according to Fraile, Garrido, and Ancín (2000). A Chrompack CP-9000 gas chromatograph equipped with a Split/Splitless injector, a flame ionization detector, and a capillary column (50 m × 0.25 mm i.d., 0.2 μm film thickness; Chrompack) coated with CP-Wax 57 CB was used. The temperature of the injector and detector was set to 250 °C. The oven temperature was held at 50 °C for 5 min, then programmed to run from 50 °C to 220 °C at 3 °C min^{-1}, and then held at 220 °C for 10 min. Helium was used as the carrier gas at 125 kPa, with a split vent of 15 mL min^{-1}. Injections of 1 μL were made in the splitless mode (vent time, 15 s); 4-nonanol (internal standard) was added to the sample to a final concentration of 122.05 mg L^{-1}. The volatile compounds were identified by comparing the retention times of the samples with those of standard compounds. Quantification of volatile compounds was performed with Varian Star Chromatography Workstation software (Version 6.41) and expressed as 4-nonanol equivalents, after determining the detector response factor for each compound.

2.3.4. Organic acids, glycerol, ethanol and sugars

Ethanol, glucose, fructose, glycerol, and acetic, malic and succinic acids were quantified by HPLC, using a Jasco chromatograph equipped with a refractive index (RI) detector (Jasco 830-RI), UV–visible detector (Jasco 870-UV-visible) and a 67H Chrompack column (300 mm × 6.5 mm) at 37 °C, using 5 mmol L^{-1} sulfuric acid as the eluent, at a flow rate of 0.4 mL min^{-1} and a sample volume of 20 μL.

2.4. Statistical analysis

Statistical analysis was carried out with the Statistical Package for the Social Sciences (SPSS) Release 17.0 for Windows (SPSS Inc., Chicago, IL). Principal component Analysis (PCA) was used to summarize the information in a reduced number of principal components.

2.5. Sensory evaluation

The final beverages were evaluated by 50 panellists, males and females, 18–55 years of age (staff and students of the Universities Unilavras and UFLA). The panelists were selected for participation on the basis of their preference for wines, interest, and availability. Randomized, refrigerated (10 °C) samples of 20–25 mL were served in clear, tulip-shaped glasses with a volume of 100 mL; these were marked with three digit random numbers and covered with plastic Petri dishes. Distilled water was provided for rinsing of the palate during the testing. Evaluations took place in the mornings between 9:00 and 10:00 a.m. and were conducted at room temperature (20–22 °C) under white light. The fruit wines were evaluated for appearance (clarity and color), aroma, taste, and general acceptability according to the hedonic scale (Dias et al., 2007).

3. Results and discussion

Characterization of the fruit wines produced from the pulps of the gabiroba, umbu, cupuassu, jaboticaba and cacao revealed that a large number of compounds were present in these beverages. Eighty-three compounds were quantified by GC–MS, nine compounds by GC-FID and seven compounds by HPLC.

3.1. Minor volatile components

Table 1 lists the concentrations of the minor volatile compounds detected in the six fruit wines. GC–MS analysis allowed for the identification and quantification of eighty-three volatile compounds, including C_6 compounds, alcohols, ethyl esters, acetates, monoterpenic alcohols, monoterpenic oxides, volatile phenols, acids, carbonyl compounds, sulfur compounds and others compounds.

3.1.1. C_6 compounds

In this group, 1-hexanol and (*Z*)-3-hexen-1-ol were the two most often detected compounds (Table 1). However, some compounds were present in one fruit wine only, e.g., (*E*)-2-hexenol and (*E*)-3-hexen-1-ol were present only in the inoculated gabiroba (I) wine and cupuassu wine in concentrations of 1.8 μg L^{-1} and 2.1 μg L^{-1}, respectively.

3.1.2. Alcohols

This volatile fraction contained a large number of compounds, such as ethyl esters group. However, some alcohols were present in one only fruit wine, e.g., 2-heptanol in the cacao wine (6.8 μg L^{-1}), 3-ethoxy-1-propanol in the jaboticaba wine (0.6 μg L^{-1}) and 2-phenoxyethanol in the fruit wines produced from the gabiroba pulp (15.3 μg L^{-1} gabiroba (I) and 26.2 μg L^{-1} in the non-inoculated gabiroba (NI) wine). The cacao wine was the one that contained the greatest number of alcohols; only 3-ethoxy-1-propanol and 2-phenoxyethanol were not found in this fruit wine. The gabiroba wines (gabiroba (I) and gabiroba (NI)) showed, qualitatively, the same composition of alcohols (1-butanol, 1-pentanol + 3-methyl-3-butene-1-ol, 3-methyl-1-pentanol, 1-heptanol, 2-ethyl-1-hexanol, 1-octanol, furfurol, benzyl alcohol and 2-phenoxyethanol). The fact that one or more compounds were found exclusively in some of the fruit wines is probably directly related to the characteristics of the fruit used in the production of those fruit wines.

3.1.3. Ethyl esters

Esters were one of the most prevalent group, with a total of 16 compounds and ethyl esters were the compounds present in the highest concentrations. Diethyl succinate and ethyl lactate had the highest concentrations among the ethyl esters detected in the fruit wines (Table 1).

Ethyl esters are one of the most important groups of aroma compounds in wine, and their concentrations depend on several factors, such as yeast strain, fermentation temperature, aeration, and sugar content. These compounds contribute positively to the overall wine quality, and most of them have a mature flavor and fruity aroma that contribute to the “fruity” and “floral” sensory properties of wines (Perestrelo, Fernandes, Albuquerque, Marques, & Camara, 2006).

As proposed by Noguerol-Pato, González-Barreiro, Cancho-Grande, and Simal-Gándara (2009), to evaluate the contributions of the esters to the aromas of the fruit wines, the odor activity values (OAV) of the esters were calculated as the ratios between the concentration of each compound and its odor threshold, as found in the literature (Ferreira, López, & Cacho, 2000; Guth, 1997). The contribution of ethyl butyrate in the flavor of the gabiroba (I) and cupuassu wines was evidenced by high OAVs of 6.5 and 6.2 for the cupuassu and gabiroba (I) wines, respectively. According to some authors, ethyl butyrate is characterized as having a fruity aroma, as papayas and apples (Czerny et al., 2008; Meilgaard, 1975; Siebert et al., 2005). Ethyl-3-methylbutanoate (fruity, sweet fruity) had OAVs of 15.9 and 4.6 for the cupuassu and gabiroba (I) wines, respectively, while ethyl hexanoate (fruity and green apple) had OAVs of 5.2 and 3.5 for the gabiroba (I) and cupuassu wines, respectively. The compounds with higher OAVs contribute to the aroma of the fruit wines to a greater extent.

Table 1
Concentration of minor volatile compounds (μg L^{-1}) detected in the fruit wines by GC–MS; odor threshold and descriptors reported in literature.

No	Compounds	LRI	Fruit wines						Oth (μg L^{-1})	Descriptors
			Cacao	Cupuassu	Gabiroba (I)	Gabiroba (NI)	Jaboticaba	Umbu		
	C_6 compounds (4)									
1	1-Hexanol	1348	6.3 ± 1.1	28.4 ± 3.7	38.4 ± 7.6	35.7 ± 8.9	11.8 ± 0.7	3.6 ± 0.3	8000 (B)[b]	–
2	(*E*)-3-hexen-1-ol	1358	ND	2.1 ± 0.2	ND	ND	ND	ND	–	–
3	(*Z*)-3-hexen-1-ol	1379	5.6 ± 0.6	17 ± 1.1	43.5 ± 3.4	48.5 ± 3.1	16 ± 0.8	ND	3.9 (A)[a]	Lettuce-like (A)
4	(*E*)-2-hexenol	1400	ND	ND	1.8 ± 0.1	ND	ND	ND	–	Bitter, green leaves (E)
	Alcohols (16)									
5	2-Pentanol	1112	168.7 ± 32.2	ND	ND	ND	3.1 ± 0.4	ND	–	–
6	1-Butanol	1173	7.8 ± 1.3	97.1 ± 12.9	13 ± 1.5	15.6 ± 0.9	15.6 ± 1.5	4.8 ± 0.2	590 (A)[a]	Malty, solvent-like (A); fusel, spirituous (C)
7	1-Pentanol+3-Methyl-3-butene-1-ol	1244	4.2 ± 0.4	10.1 ± 1.1	3.8 ± 0.1	8.6 ± 3.1	2.1 ± 0.2	3.7 ± 1	–	–
8	4-Methyl-1-pentanol	1309	6.8 ± 0.8	7.1 ± 1.1	4.1 ± 0.9	1.5 ± 0.4	6.3 ± 0.5	8.9 ± 0.4	–	–
9	2-Heptanol	1315	6.8 ± 0.6	ND	ND	ND	ND	ND	–	Coconut (E)
10	3-Methyl-2-buten-1-ol	1317	15.8 ± 2.4	125.9 ± 14.1	ND	ND	ND	4.9 ± 0.7	–	–
11	3-Methyl-1-pentanol	1322	14.1 ± 1.7	14.5 ± 1.7	7.2 ± 0.9	3.6 ± 0.2	13.7 ± 0.4	22.8 ± 1.4	–	–
12	3-Ethoxy-1-propanol	1369	ND	ND	ND	ND	0.6 ± 0	ND	–	–
13	1-Heptanol	1449	8.2 ± 0.4	4.6 ± 2.8	6.9 ± 0.3	7.7 ± 0.4	2.3 ± 0.7	21.4 ± 1.3	–	Coconut, ketonic solvent, unpleasant (E)
14	2-Ethyl-1-hexanol	1486	19.8 ± 1	8.4 ± 1.1	24.1 ± 1.1	76.2 ± 7.2	12.6 ± 0.8	10.3 ± 0.5	–	–
15	1-Octanol	1552	2.7 ± 0.4	5.5 ± 3.8	3.5 ± 3	3.1 ± 0.4	6.8 ± 0.6	2.2 ± 0.6	900 (E)[c]	Coconut, walnut, oily (E)
16	Furfurol	1658	29.1 ± 4.1	38.6 ± 3.3	11.6 ± 3	12.5 ± 1.4	7.4 ± 0.2	20.2 ± 0.9	1000 (C)[a]	Moldy hay (D)
17	1-Phenylethanol	1812	83.1 ± 9.3	2.4 ± 0.7	ND	ND	ND	ND	–	–
18	Benzyl alcohol	1869	10.8 ± 1.9	8.9 ± 1.8	14.6 ± 1.5	17.7 ± 1.7	17.2 ± 0.7	9.5 ± 1.2	–	Almonds, bitter (E)
19	2-Phenoxyethanol	2144	ND	ND	15.3 ± 0.9	26.2 ± 4	ND	ND	–	–
20	Tyrosol	3008	33.9 ± 10.1	29.5 ± 1.8	ND	ND	ND	ND	–	Bitter, chemical (E)
	Ethyl esters (16)									
21	Ethyl propionate	971	7.3 ± 1.2	16.4 ± 2.4	55.7 ± 2.8	52.5 ± 9.1	23.4 ± 1.9	ND	45 (B)[b]	Fruity (C)
22	Ethyl butyrate	1032	17.7 ± 2.4	129.2 ± 16.1	124.1 ± 6.5	20.2 ± 1.7	12.8 ± 0.9	9.4 ± 2	20 (B)[b]	Fruity (A, C); papaya, butter, sweetish, apple, perfumed (E)
23	Ethyl 2-methylbutanoate	1049	ND	5.3 ± 0.2	11.6 ± 4.6	8.8 ± 3	1.5 ± 0.5	ND	18 (G)[d]	Fruity (A); sweet fruity (C)
24	Ethyl 3-methylbutanoate	1066	12.9 ± 0.7	47.7 ± 4.3	13.8 ± 3.5	8.1 ± 0.8	4.2 ± 0.8	ND	3 (G)[d]	Fruity, blueberry-like (A); sweet fruity (C)
25	Ethyl hexanoate	1234	32 ± 4.6	48.9 ± 5.8	73.3 ± 0.3	18.8 ± 11	10.6 ± 1.1	24 ± 3.4	14 (G)[d]	Fruity, green apple (C, E)
26	Ethyl pyruvate	1267	24.5 ± 3.7	ND	15.3 ± 1.2	1.2 ± 0.4	43.6 ± 1.2	8.9 ± 0.7	–	Herbaceous, oil painting, forage (E)
27	Ethyl lactate	1338	205.4 ± 32.4	255.6 ± 40.3	98.2 ± 10.5	56.6 ± 1.8	407.1 ± 7.8	99 ± 6.7	157,810 (H)[b]	Strawberry, raspberry, perfumed (C, E)
28	Ethyl octanoate	1434	5.4 ± 0.8	9.3 ± 3.5	130.6 ± 3.3	9.8 ± 2.7	2.3 ± 0.2	0.9 ± 0.2	5 (G)[d]	Apple, fruity (E); sweet (C)
29	Ethyl 3-hydroxybutanoate	1512	28.7 ± 4	69.6 ± 7.1	74.3 ± 6.2	88.7 ± 5.9	47.3 ± 1.1	35.6 ± 2.6	–	–
30	Diethyl malonate	1574	ND	ND	ND	ND	5 ± 0.5	ND	–	–
31	Ethyl 2-furoate	1618	ND	ND	41.7 ± 2.2	11.6 ± 1.5	2.5 ± 0.7	ND	1600 (G)[d]	–
32	Diethyl succinate	1672	1747.2 ± 108	546.2 ± 20.9	367.2 ± 18.1	29.4 ± 1.4	2191.5 ± 98	169.2 ± 10.5	200,000 (H)[b]	–
33	Diethyl glutarate	1774	5.1 ± 3.9	ND	1.2 ± 0.2	ND	11.9 ± 0.4	ND	–	–
34	Diethyl malate	2037	448.7 ± 59.7	259 ± 18.7	16.4 ± 8	ND	172.9 ± 6.2	14.6 ± 2.3	–	–
35	Mono-ethyl succinate	2377	1062 ± 91.5	358.6 ± 51.6	90 ± 16.3	ND	978.7 ± 179	309.3 ± 1.2	–	Sweat, sour, fruity (E)
36	Triethyl citrate	2461	23.1 ± 4.5	7.1 ± 1.5	ND	ND	75.3 ± 4.1	ND	–	–
	Acetates (5)									
37	Propyl acetate	982	ND	ND	ND	7 ± 1.2	ND	ND	–	Solvent, sweet, fragrant (E)
38	2-Methylpropyl acetate	1009	ND	ND	8.5 ± 2	39.1 ± 2.5	10.5 ± 0.6	ND	–	Banana, fruity (C)
39	3-Methylbutyl acetate	1125	17.3 ± 1.6	26 ± 0.7	50.1 ± 19.1	79.3 ± 4.9	29.9 ± 1.1	37.5 ± 3	30 (B)[b]	Banana (C)
40	Ethylphenyl acetate	1788	121.9 ± 17.4	22.8 ± 5	5.7 ± 1.6	6 ± 1.4	4.3 ± 0.2	ND	–	–
41	2-Phenylethyl acetate	1810	62.2 ± 11.1	58 ± 3.4	18 ± 9.4	26.8 ± 8.4	37.9 ± 2.8	26.1 ± 4.5	250 (B)[b]	Apple, honey, roses, sweet (E); flowery (C)
	Monoterpenic alcohols (10)									
42	Limentol	1113	ND	3.2 ± 0.2	ND	ND	ND	ND	–	–
43	Linalool	1541	8.5 ± 1.5	182.6 ± 4.1	185.7 ± 23.9	201 ± 17.1	17.7 ± 3.7	10.9 ± 0.1	25.2 (G)[d]	Citrus-like, bergamot (A)
44	4-Terpineol	1597	ND	ND	9.2 ± 1.8	12.3 ± 3.1	ND	5.4 ± 1.5	–	–
45	Ho-trienol	1605	5 ± 0.4	ND	ND	ND	ND	ND	–	Linden (F)
46	Menthol	1641	5.5 ± 1.4	ND	ND	ND	ND	ND	–	–
47	a-Terpineol	1691	14.4 ± 1.2	213.4 ± 9.9	51.5 ± 11.3	61.1 ± 15.6	43.9 ± 3	276.6 ± 23.2	250 (G)[d]	Pine, terpenoids (E)

(*continued on next page*)

Table 1 (*continued*)

No	Compounds	LRI	Fruit wines						Oth ($\mu g\ L^{-1}$)	Descriptors
			Cacao	Cupuassu	Gabiroba (I)	Gabiroba (NI)	Jaboticaba	Umbu		
48	Borneol	1703	ND	ND	2.3 ± 0.6	3.8 ± 0.9	ND	13.7 ± 1.3	–	–
49	Citronellol	1760	ND	2.5 ± 0.5	5.1 ± 0.6	15.2 ± 2	ND	9.5 ± 1.2	100 (B)[b]	Citronella (F)
50	Myrtenol	1793	ND	ND	3.6 ± 0.9	2.1 ± 0.8	ND	ND	–	–
51	Geraniol	1847	0.9 ± 0.3	17.9 ± 0.9	11.7 ± 0.9	4.1 ± 0.2	1.8 ± 0.3	5.3 ± 0.4	–	Rose-like, citrus-like (A)
	Monoterpenic oxides (6)									
52	(*E*)-Furan linalool oxide	1436	297.4 ± 31.8	40.6 ± 10	5 ± 0.2	ND	22.3 ± 1.1	ND	–	–
53	(*Z*)-Furan linalool oxide	1464	161.8 ± 8.3	60.6 ± 14.8	3 ± 0.1	7.2 ± 1.3	27.3 ± 6.4	0.8 ± 0.1	–	–
54	(*E*)-Pyran linalool oxide	1732	3 ± 1.1	22 ± 11.5	ND	ND	ND	ND	–	–
55	(*Z*)-Pyran linalool oxide	1756	35.2 ± 4	6.5 ± 1.1	ND	ND	ND	ND	–	–
56	Linalool hydrate	1967	ND	12.6 ± 2.8	ND	ND	4.4 ± 0.4	ND	–	–
57	Geranic acid	2347	ND	ND	ND	ND	ND	7.7 ± 0.5	–	–
	Volatile phenols (4)									
58	Methyl salicylate	1770	ND	ND	2.9 ± 0.3	ND	ND	ND	–	–
59	4-Vinylguaiacol	2192	ND	ND	ND	ND	ND	4.9 ± 0.7	21 (A)[a]	Clove-like, smoky(A)
60	Vanillin	2560	ND	ND	15.3 ± 1.7	10.7 ± 2.4	16.1 ± 4	ND	65 (D)[d]	Vanilla-like, sweet(A); vanilla (D)
61	3,4,5-Trimethoxyphenol	3060	ND	ND	ND	ND	ND	27.4 ± 5.8	–	–
	Acids (11)									
62	Propanoic acid	1552	6.4 ± 4.2	9.5 ± 1.4	9.9 ± 5.2	9.5 ± 2.8	5.9 ± 0.3	4.5 ± 0.8	8100 (H)[b]	Vinegar (C)
63	Isobutyric acid	1579	22.9 ± 2.7	49.1 ± 20.2	44.8 ± 5.2	32.1 ± 0.4	11.1 ± 2.2	13.7 ± 0.4	200,000 (B)[b]	Sweat, bitter (E); cheese, rancid (C)
64	Butyric acid	1626	19.7 ± 5.5	83 ± 10.3	29 ± 4.5	7.1 ± 1.1	4 ± 1.2	9.8 ± 0.9	173 (G)[d]	Sweaty (A); cheese, rancid (C)
65	2-Methyl butyric acid + 3-Methyl butyric acid	1667	143.8 ± 17.5	334 ± 50.7	110.0 ± 9.9	123.6 ± 13.1	18.8 ± 0.6	31.8 ± 2.8	3000 (B)[b] + 33 (G)[d]	Fruity, sweaty + Sweaty (A); cheese (C)
66	Hexanoic acid	1841	540.9 ± 68.9	630.3 ± 60.8	241.2 ± 45.4	77.1 ± 5.6	150.5 ± 16.7	392 ± 35.1	420 (G)[d]	Fatty acids, vegetable oil (E); cheese, sweaty (C)
67	Heptanoic acid	1962	11.5 ± 1.8	4 ± 1.2	3.2 ± 0.8	6 ± 1.2	5.5 ± 1.1	6.9 ± 0.7	–	–
68	Octanoic acid	2057	1149.2 ± 114	425.1 ± 7.6	528.8 ± 154.1	385.2 ± 21.2	454.4 ± 14.1	510.9 ± 50.7	500 (G)[d]	Fatty acids, vegetable oil (E); rancid, harsh (C)
69	Nonanoic acid	2174	9 ± 2.5	ND	16.5 ± 8.7	16.4 ± 0.8	13.7 ± 1.5	6.2 ± 1.4	–	–
70	Decanoic acid	2269	ND	29.7 ± 6.9	31.1 ± 6.4	59.4 ± 2.1	8.8 ± 2.2	7.3 ± 0.8	1000 (G)[d]	Wax, tallow, rancid, soap (E); fatty (C)
71	Tetradecanoic acid	2703	12 ± 3	14.1 ± 7.2	20.1 ± 0.7	26.6 ± 3.6	ND	6.1 ± 1.3	–	–
72	Hexadecanoic acid	2903	61.6 ± 12.1	73.7 ± 33.4	123.2 ± 16	52.4 ± 10.2	55.2 ± 1.1	109.1 ± 15.7	–	–
	Carbonyl compounds (5)									
73	3-Hydroxy-2-butanone	1285	204.1 ± 18.8	90.4 ± 14.3	60 ± 6.1	130.7 ± 39.8	38.2 ± 3.1	13.7 ± 0.7	152,600 (H)[b]	Fruity, moldy, wood (E)
74	Octanal	1291	1.4 ± 0.6	1.3 ± 1.2	1.6 ± 0	3.1 ± 0.5	1 ± 0.1	1.8 ± 0.8	3.4 (A)[a]	Citrus-like, Green (A)
75	6-Methyl-5-hepten-2-one	1338	3.7 ± 0.4	ND	1.1 ± 0.2	1.1 ± 0.1	ND	1.4 ± 0.3	–	–
76	Nonanal	1396	4.9 ± 3.9	3.3 ± 1	2.5 ± 0.6	3.9 ± 1.2	2 ± 0.5	4.9 ± 0	2.8 (A)[a]	Citrus-like, soapy (A)
77	2-Furaldehyde	1460	8.4 ± 0.9	26.8 ± 4	37 ± 3.6	9.6 ± 1.2	16.4 ± 0.8	6.7 ± 1.2	8000 (D)[a]	Almonds (D)
	Sulfur (3)									
78	3-(Methylthio)-1-propanol	1715	71.7 ± 11.1	205.4 ± 21.1	32.7 ± 3.5	7.3 ± 3.2	17.7 ± 1.5	29.9 ± 4	36 (A)[a]	Cooked potato-like (A)
79	2-Methyltetrahydrothiofeno-3-one	1533	ND	16.2 ± 2.6	19.3 ± 12.1	12 ± 1.9	ND	ND	–	–
80	Benzothiazole	1962	11.5 ± 1.8	4 ± 1.2	3.2 ± 0.8	6 ± 1.2	6.2 ± 0.9	6.9 ± 0.7	–	–
	Other (3)									
81	Verbenone	1712	ND	ND	ND	ND	1 ± 0.3	ND	–	–
82	δ-Decalactone	2151	ND	13.2 ± 2.6	ND	ND	ND	ND	31 (A)[a]	Coconut-like (A)
83	N-(2-phenylethyl)acetamide	2585	35 ± 5.5	15.6 ± 1.6	27.2 ± 6.1	29.2 ± 6.5	40.5 ± 3.7	26.4 ± 3	–	–

LRI, linear retention index; I, inoculated gabiroba wine. NI, non-inoculated gabiroba wine. Oth, odor threshold. ND, not detected.
Data are presented as mean ± SD of triplicate analysis.
(A) Czerny et al. (2008).
(B) Guth (1997).
(C) Siebert et al. (2005).
(D) Boidron, Chatonnet, and Pons (1988).
(E) Meilgaard (1975).
(F) Ribéreau-Gayon et al. (2000).
(G) Ferreira et al. (2000).

[a] Olfactory perception threshold in water.

[b] Olfactory perception threshold in hydro-alcoholic solution.

[c] Olfactory difference threshold in beer.

[d] Olfactory threshold in model wine.

3.1.4. *Acetates*

Acetates were found in small numbers in the fruit wines studied (Table 1). Compounds of this group such as hexyl acetate mixed with ethyl caprylate and ethyl caprate give an "apple-like" aroma; 3-methylbutyl acetate gives a "banana-like" aroma and 2-phenylethyl acetate gives a "fruity" and "flowery" flavor with a honey note (Rapp & Mandery, 1986). 3-Methylbutyl acetate (banana) and 2-phenylethyl acetate (apple, honey and roses) were found in all fruit wines (Table 1). The gabiroba (NI) wine showed the highest OAV for 3-methylbutyl acetate (2.6) and the cacao wine showed the highest OAV for 2-phenylethyl acetate (0.3). According to Perestrelo et al. (2006), acetates are the result of the reaction of acetylCoA with higher alcohols, which are formed through the degradation of amino acids or carbohydrates.

3.1.5. *Acids*

Short-chain fatty acids, such as isobutyric, butyric and isovaleric acids, are minor compounds in wines and their odor may be as strong as that of acetic acid; therefore, these acids can contribute significantly to the aromas of wines and spirits (Soufleros et al., 2001). The acids found to be present in the highest concentrations were octanoic and hexanoic acids. Among the fruit wines, the cacao wine had the highest concentration of octanoic acid (1149.2 $\mu g\,L^{-1}$) and the cupuassu wine had the highest concentration of hexanoic acid (630.3 $\mu g\,L^{-1}$) (Table 1). Despite the relatively high concentrations, all acids were present in quantities below their flavor threshold. Similar results have been reported for other wines (Perestrelo et al., 2006). The lowest concentrations of the octanoic ("fatty acids", "vegetable oil" and "rancid") and hexanoic ("fatty acids", "vegetable oil" and "cheese") acids were found in the gabiroba (NI) beverage (Table 1).

3.1.6. *Monoterpenics compounds*

The monterpenic volatile fraction was comprised of ten monoterpenic alcohols and six monoterpenic oxides. As can be seen in Table 1, some compounds were found only in one fruit wine, such as limentol (cupuassu), ho-trienol and menthol (cacao), myrtenol (gabiroba (I) and gabiroba (NI)) and geranic acid (umbu). Some of these compounds may be used as markers of the fruit wine produced from a specific fruit. The monoterpenic compounds play an important role in the varietal flavor of the must and other fruit juices (Mateo & Jimenez, 2000). According to Peña, Barciela, Herrero, and García-Martín (2005) obtaining a "terpenic profile" is extremely useful for differentiating the genuinely monovarietals wines from those made by a mixture of some other varieties.

The monoterpene alcohols linalool, α-terpineol and geraniol were found in all fruit wines (Table 1). The highest OAVs for linalool were 7.4 and 8.0 for the gabiroba (I) and gabiroba (NI) wines, respectively. The monoterpene alcohol α-terpineol had an OAV of 1.1 in the umbu wine and an OAV of 0.8 in the cupuassu wine. Some of the monoterpene alcohols are among the most odoriferous compounds, especially linalool, α-terpineol, nerol, geraniol, citronellol and ho-trienol, which have a floral aroma reminiscent of rose essence. The olfactory perception thresholds of these compounds are rather low – as little as a few hundred micrograms per liter (Ribéreau-Gayon, Glories, Maujean, & Dubourdieu, 2000). (*E*)-pyran linalool oxide and (*Z*)-pyran linalool oxide were identified only in the cacao and cupuassu wines; the highest concentration of (*E*)-pyran linalool oxide was 22 $\mu g\,L^{-1}$ (cupuassu) and the highest concentration of (*Z*)-pyran linalool oxide was 35.2 $\mu g\,L^{-1}$ (cacao).

The results of the monoterpenes shown in Table 1 were further analyzed using PCA to obtain a more simplified view of the relationships among these compounds (Fig. 1). The first and second principal components explain about 61.4% and 26.8%, respectively, of the total variance. The results in Fig. 1 show the formation of two groups. One of the groups is located on the positive part of the second factor, and includes the cacao, cupuassu and jaboticaba wines. The other group is closely related to the negative part of the axis, and includes the gabiroba (I), gabiroba (NI) and umbu wines. The umbu, gabiroba (I) and gabiroba (NI) wines were characterized by α-terpineol and linalool. In the other group, jaboticaba, cacao and cupuassu wines were correlated with (*Z*)-furan linalool oxide and (*E*)-furan linalool oxide.

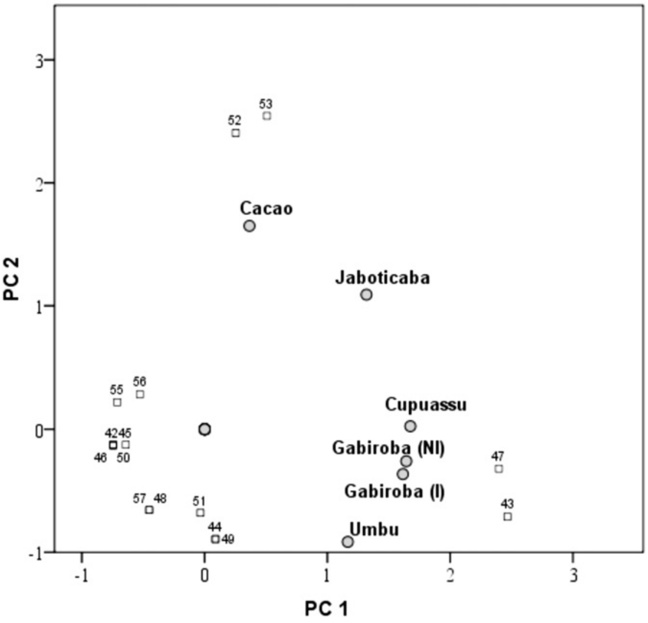

Fig. 1. Principal component analysis (PCA) of monoterpenics compounds in fruit wines by GC/MS. I: inoculated gabiroba wine; NI: non-inoculated gabiroba wine. The volatile compounds numbers are referred in Table 1.

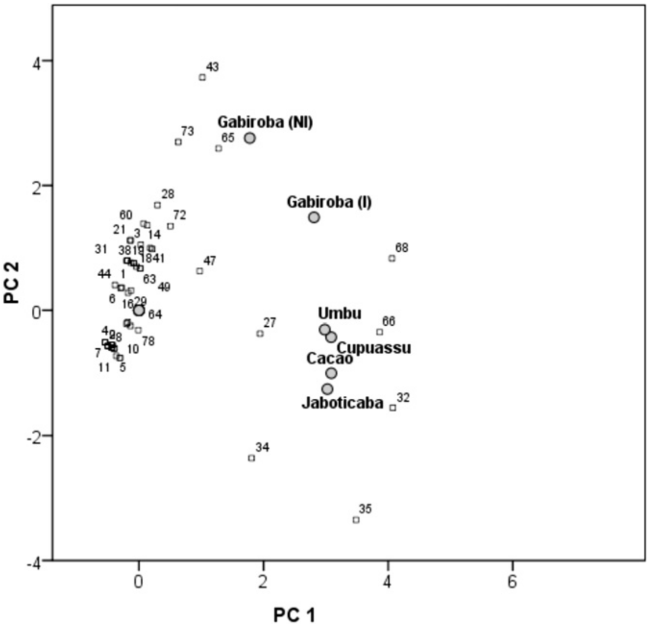

Fig. 2. Principal component analysis (PCA) of minor volatile compounds in fruit wines by GC/MS. I: inoculated gabiroba wine; NI: non-inoculated gabiroba wine. The volatile compounds numbers are referred in Table 1.

3.1.7. *Other compounds*

Other groups with fewer compounds were also identified, such as carbonyl compounds (five), volatile phenols (four) and sulfur compounds (three).

Although these compounds were present in smaller numbers, they contributed to the aroma of the fermented beverages. For example, sulfur compounds, which comprise a structurally diverse class of molecules with a wide range of aromatic notes, may be considered detrimental to wine quality (Anocibar Beloqui & Bertrand, 1995). The volatile phenols could originate from *p*-coumaric and ferulic acids via decarboxylation (Perestrelo et al., 2006). 3,4,5-Trimethoxyphenol and 4-vinylguaiacol were found only in the umbu wine (Table 1). 4-Vinylguaiacol contributes to "clove-like" and "smoky" odors (Czerny et al., 2008).

3.1.8. *Multivariate statistical analysis of minor volatile compounds*

The results obtained for the minor volatile compounds shown in Table 1 were submitted to PCA to obtain a more simplified view of the relationships among the volatile compounds analyzed. The results are shown in Fig. 2. The first (PC 1) and second (PC 2) principal components explain 70.9% and 18.7%, respectively, of the total variance. A plot of the results (Fig. 2) shows the formation of two groups. One of the groups is located on the positive part of the second factor, and includes the gabiroba (I) and gabiroba (NI) wines; the other group is closely related to the negative part of the axis, and includes the cacao, cupuassu, jaboticaba and umbu wines. Component 2 allowed for the differentiation of the wines produced from gabiroba pulp from the wines produced from the cacao, cupuassu, jaboticaba and umbu pulps.

The non-inoculated gabiroba (NI) and, to a lesser degree, inoculated gabiroba (I) wines were mainly associated with linalool, 2-methyl butyric acid + 3-methyl butyric acid and 3-hydroxy-2-butanone. The cacao, cupuassu, jaboticaba and umbu wines were associated with ethyl lactate, diethyl succinate, diethyl malate, mono-ethyl succinate and hexanoic acid.

3.2. *Major volatile components*

Table 2 lists the concentrations of the major volatile compounds detected in the six fruit wines. Nine compounds were quantified: acetaldehyde, 1,1-diethoxyethane, ethyl acetate, methanol, 1-propanol, 2-methyl-1-propanol, 2-methyl-1-butanol, 3-methyl-1-butanol and 2-phenylethanol.

Statistical analysis of the concentrations of the major volatile compounds in all fruit wines, using Tukey's test, showed significant differences in the concentrations of all compounds assayed.

The higher alcohols were found in the greatest number in all fruit wines. 3-Methyl-1-butanol was markedly the most abundant higher alcohol (Table 2). The umbu wine had a higher concentration (261.3 mg L^{-1}) of 3-methyl-1-butanol, above the perception threshold. Thus, its sensorial contribution of a "malty", "alcohol" and "harsh" odor was expected. According to Tukey's test, there were no significant differences in 3-methyl-1-butanol concentrations among the cacao, jaboticaba and gabiroba (I) wines (Table 2).

The 2-phenylethanol is an aroma carrier and its presence may contribute to the floral nuance of wines (Wondra & Berovic, 2001). The aroma character of this compound changes with its oxidation from rose to a hyacinth bouquet. Further oxidation produces esters with a fine honey nose. The cacao wine had the highest concentration of 2-phenylethanol (99.7 mg L^{-1}) and the gabiroba (I) wine had the lowest concentration (15.8 mg L^{-1}) (Table 2). In our study, the cupuassu wine had the highest concentration of 1-propanol (36 mg L^{-1}), about 5 times higher than that found in the cacao wine, which was the one with the lowest concentration of this compound.

The higher alcohols could be synthesized by yeast through either an anabolic pathway from glucose or a catabolic pathway from the corresponding amino acids (valine, leucine, *iso*-leucine and phenylalanine). Consequently, higher alcohols are released to the medium as secondary products of yeast metabolism and are responsible for the secondary aroma of wines (Noguerol-Pato et al., 2009).

The fermented cacao and jaboticaba beverages had the highest contents of methanol, (195 mg L^{-1} and 181 mg L^{-1}, respectively), but no significant differences in methanol concentrations were found among the fermented fruit beverages. Methanol is a toxic alcohol commonly found in wines; consequently its concentration must be measured. It is formed from the enzymatic hydrolysis of the methoxy groups of pectin during fermentation, and its content depends on the extent to which the solids – especially the skins, which have high pectin content – are macerated (Peinado, Moreno, Muñoz, Medina, & Moreno, 2004). Therefore, the differences in the concentrations of methanol between the fermented beverages could be related to the pectin content of each fruit.

Acetaldehyde was the major aldehyde compound found in the fruit wines. At low levels, it gives a pleasant fruity aroma to wines, but in higher concentrations, it has a pungent, irritating odor (Miyake &

Table 2
Concentration of major volatile compounds (mg L^{-1}) detected in the fruit wines by GC-FID; odor threshold and descriptors reported in literature.

Compounds	Fruit wines							
	Cacao	Cupuassu	Gabiroba (I)	Gabiroba (NI)	Jaboticaba	Umbu	Oth (μg L^{-1})	Descriptors
Acetaldehyde	28c ± 9.3	15.4ab ± 0.4	45.3bc ± 9.2	8.3ab ± 4.5	16.4ab ± 1.5	5.1a ± 0.6	25 (A)[a]	Fresh, green (A)
1,1-Diethoxyethane	16c ± 1.3	3a ± 0.2	3.3a ± 0.3	2.6a ± 0.2	7.2b ± 1.5	ND	50 (B)[b]	
Ethyl acetate	189.5b ± 63.9	27.2a ± 2.5	13.2a ± 1.3	105.9ab ± 0.1	54.7a ± 5.1	89.6ab ± 11.8	7500 (B)[b]	Solvent, fruity (E); nail polish (B)
Methanol	195c ± 42.7	137.7abc ± 2	57.2a ± 4.8	86.8ab ± 0.5	181c ± 7.8	144.9bc ± 26.4	–	–
1-Propanol	7.2a ± 1.6	36c ± 1.7	9.7a ± 1.3	17.9b ± 2.4	18.1b ± 0.1	21.6b ± 0	750 (E)[c]	–
2-Methyl-1-propanol	24.3a ± 0.1	58.5b ± 0.1	32.5a ± 4.7	77.9c ± 1.4	34.5a ± 1.5	101.7d ± 7.6	550 (A)[a]	Malty (A)
2-Methyl-1-butanol	26.1b ± 0.5	35.8c ± 0.9	24.1b ± 2.8	23.4ab ± 0.9	16.4a ± 0.04	56.8d ± 3.4	1200 (A)[a]	Malty, solvent-like (A)
3-Methyl-1-butanol	113.6abc ± 5.2	141.5c ± 0.8	103.4ab ± 9.6	133bc ± 2.8	80.8a ± 1.5	261.3d ± 17.4	220 (A)[a]	Malty (A)
2-Phenylethanol	99.7c ± 28.1	65bc ± 0.5	15.8a ± 0.7	52.2ab ± 3.1	29.3ab ± 1.4	41.6ab ± 5.8	140 (A)[a]	Flowery, honey-like (A)

I, inoculated gabiroba wine. NI, non-inoculated gabiroba wine. Oth, odor threshold. ND, not detected.
Values identified by the same letters are not significantly different at a significance level of 0.05 (Tukey's test). Data are presented as mean ± SD of triplicate analysis.
(A) Czerny et al. (2008).
(B) Guth (1997).
(E) Meilgaard (1975).

[a] Olfactory perception threshold in water.

[b] Olfactory perception threshold in hydro-alcoholic solution.

[c] Olfactory difference threshold in beer.

Table 3
Concentrations (g L^{-1}) of acids, glycerol, ethanol and residual sugars (glucose and fructose) detected in fruit wines by HPLC.

Compound	Fruit wines					
	Cacao	Cupuassu	Gabiroba (I)	Gabiroba (NI)	Jaboticaba	Umbu
Malic acid	0.29 ± 0.03	1.76 ± 0.10	0.07 ± 0.04	1.60 ± 0.04	0.62 ± 0.03	0.10 ± 0.04
Succinic acid	3.94 ± 0.11	2.32 ± 0.13	6.03 ± 0.30	6.12 ± 0.25	5.11 ± 0.19	3.18 ± 0.20
Acetic acid	0.37 ± 0.10	0.14 ± 0.07	1.45 ± 0.11	1.62 ± 0.10	0.78 ± 0.15	0.65 ± 0.03
Glycerol	7.14 ± 0.40	6.54 ± 0.30	5.35 ± 0.51	6.11 ± 0.85	7.56 ± 0.38	7.69 ± 0.54
Glucose	3.43 ± 0.57	1.97 ± 0.27	ND	0.65 ± 0.08	0.06 ± 0.02	2.41 ± 0.38
Fructose	ND	0.17 ± 0.05	ND	0.96 ± 0.07	ND	ND
Ethanol	64.20 ± 1.96	40.50 ± 0.45	57.49 ± 0.29	50.59 ± 0.51	57.21 ± 0.76	49.64 ± 0.70

I: inoculated gabiroba wine; NI: non-inoculated gabiroba wine. Data are presented as mean ± SD of triplicate analysis.

Shibamoto, 1993). The concentration of acetaldehyde in the umbu wine was 5.1 mg L^{-1}, the lowest concentration found in any of the fruit wines. There were no significant differences in the concentrations of acetaldehyde among the cupuassu wine (15.4 mg L^{-1}), jaboticaba (16.4 mg L^{-1}) and gabiroba (NI) (8.3 mg L^{-1}) wines. The highest concentration of acetaldehyde was found in the gabiroba (I) wine (45.3 mg L^{-1}) (Table 2). According to Perestrelo et al. (2006), aldehydes are formed from unsaturated fatty acids. Also, they can be considered as products of lipoxygenase catalysis.

Ethyl acetate is another compound whose presence may adversely affect the quality of wine due to its unpleasant flavor in high concentrations. On the other hand, at very low concentrations (50–80 mg L^{-1}) it has a positive impact on the flavor (Tešević et al., 2009). The concentration of this compound varied significantly among the fruit wines. The cacao wine had the highest concentration of ethyl acetate (189.5 mg L^{-1}) about 15 times higher than that found in the gabiroba (I) wine (Table 2).

3.3. Organic acids, glycerol, ethanol and sugars

The most important acids with regard to the acidity of wines are tartaric, malic, citric, lactic and succinic acids. However, several others acids can be present in wines. Most of them are organic acids, though inorganic acids may also be present in small quantities. Acidity is another important factor, since it contributes both directly and indirectly to the quality of wines (Clarke & Bakker, 2004).

Malic, succinic and acetic acids were identified in the fruit wines. Succinic acid had the highest concentrations, ranging from 2.3 g L^{-1} (cupuassu wine) to 6.1 g L^{-1} (gabiroba (NI) wine) (Table 3). Succinic acid is a common by-product of the alcoholic fermentation of yeast; it is the major carboxylic acid formed during fermentation. It has been reported that this acid gives an unusual salty, bitter taste to wine (Coulter, Godden, & Pretorius, 2004).

The gabiroba (NI) wine had the highest concentrations of acetic acid (Table 3). This fact could be associated with the presence of non-saccharomyces yeast in spontaneous fermentations that normally produce larger amounts of acetic acid. The inoculated gabiroba (I) and non-inoculated gabiroba (NI) wines were the only ones in which the concentration of acetic acid was higher than 1 g L^{-1} (Table 3). Acetic acid in high concentrations (>0.7 g L^{-1}) might give a taste and odor of vinegar.

The presence of malic acid is also important in wines, because it is directly related to the acidity of the wines. Since malic acid contains two carboxylic acid groups, it releases more protons to the solution, increasing the acidity. The cupuassu and gabiroba (I) wines had the highest (1.7 g L^{-1}) and lowest (0.1 g L^{-1},) concentrations of succinic acid, respectively.

All of the fruit wines had similar glycerol contents, except the gabiroba (I) wine, which had the lowest concentration of this compound (5.3 g L^{-1}) (Table 3). Glycerol is formed during alcoholic fermentation, and in the concentrations of 7–9 g L^{-1} give a hint of sweetness to the final beverage (Clarke & Bakker, 2004). According to Lubbers, Verret, and Voilley (2001) glycerol did not change the relative volatility of aroma compounds in the range of 5–20 g L^{-1} in model wine and the increase of the amount of glycerol from 5.3 to 17.3 g L^{-1} in a white wine did not produce a detectable effect in the perceived aroma. Therefore the differences in glycerol content between the gabiroba wine and the other fruit wines studied here were not the main compound to differentiate their aroma.

Residual sugars (glucose and fructose) were present in all fruit wines and in concentrations lower than 5 g L^{-1}, which characterize the fruit wines as dry wines.

Ethanol is the major component of wine and determines the viscosity (body) of the wine while also acting as a fixative. The ethanol yield depends on the initial total sugar concentration in the fruit, which is measured as the total dissolved sugar concentration in the liquid must (Tešević et al., 2009). The highest concentration of ethanol (64.2 g L^{-1}) was found in the cacao wine (Table 3). The ethanol concentrations in the jaboticaba and gabiroba (I) wines were approximately 57 g L^{-1}. In the umbu and gabiroba (NI) wines, ethanol concentrations were approximately 50 g L^{-1}. The lowest ethanol concentration (40.5 g L^{-1}) was found in the cupuassu wine (Table 3).

3.4. Sensory evaluation

The fruit wines were subjected to sensory analysis to assess its acceptance. Table 4 presents percentage of acceptance attributed to each beverage by 50 untrained tasters. For all attributes assessed the beverages showed greater acceptance (at least 50%). The differences in sensory analysis found among these six beverages analyzed here might be the result of the different chemical compounds compositions of these final products (Tables 1–3). It was observed (Table 4) that in general, the acceptability attribute showed highest values for cacao (70%) and umbu (68%). Cacao and umbu wines also showed the highest percentage of acceptance for aroma, 73% and 74% for cacao and umbu, respectively. These results can be associated with the beverages composition. As shown in Fig. 2 these wines showed concentrations of ethyl esters such as ethyl lactate, diethyl succinate, diethyl malate, and mono-ethyl succinate. The ethyl esters group makes a positive contribution to the general quality of wine being responsible for their “fruity” and “floral” sensory properties (Perestrelo et al., 2006). The fruit wines

Table 4
Percentage of the fruit wines acceptance

Wine	Appearance	Aroma	Taste	General acceptability
Cacao	68	73	58	70
Cupuassu	61	68	58	63
Gabiroba (I)	63	60	52	54
Gabiroba (NI)	69	62	54	60
Jaboticaba	72	65	61	56
Umbu	63	74	57	68

Data represents the grade attributed by tasters (50 untrained panelists) considering at least point 6 (liked slightly) until point 9 (liked extremely).

gabiroba (I) and gabiroba (NI) had a lower percentage of acceptances (Table 4) when aroma and flavor attributes were observed. In the Fig. 2, these wines were characterized by compounds as 2-methyl butyric acid + 3-methyl butyric acid and 3-hydroxy-2-butanone, that might have influenced the wine aroma. The lower taste acceptance of wines gabiroba (I) and gabiroba (NI) could be associated with high concentration of acetic acid found in these wines (Table 3), which gave particular organoleptic characteristics reminiscent of vinegar and nail varnish, generally considered undesirable in wines, and reducing their quality (Clarke & Bakker, 2004).

4. Conclusions

Our results revealed that the fruit wines produced using pulps of cacao, cupuassu, gabiroba, jaboticaba and umbu fruits presented several compounds that are also found in other types of wines, such as fruit and grape wines. The fact that these fruit wines had a composition similar to other beverages demonstrated that these fruits have the potential to be used to produce fermented beverages. Furthermore, the major components found in the fruit wines (alcohols, monterpenics compounds and ethyl esters) contributed to the formation of aromas which could be characterized as fruity, green apple, banana, sweet, citrus, citronella, vanilla, roses and honey. It was concluded that pulp of cacao, cupuassu, gabiroba, jaboticaba and umbu could be used to produce fruit wines with acceptable organoleptic characteristics. The typical volatile composition of minor compounds of each fruit wine, especially of the gabiroba wine, was evidenced by principal component analysis. Additionally, the yeast used for inoculation, *Saccharomyces cerevisiae* UFLA CA 1162 resulted in good must fermentation, especially with regard to the ethanol content, which ranged from 40.5 g L^{-1} (cupuassu) to 64.2 g L^{-1} (cacao). This variation could be attributed to differences in the pulp composition, which might be also responsible for the quality and quantity of volatile compounds in the final alcoholic beverages.

Acknowledgments

The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico do Brasil (CNPq) and CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for financial support and scholarships.

References

Anocibar Beloqui, A., & Bertrand, A. (1995). Study of sulfur compounds in wine: preliminary results. *Italian Journal of Food Science, 7*(3), 279–288.

Boidron, J. N., Chatonnet, P., & Pons, M. (1988). Influence du bois sur certaines substances odorantes des vins. *Connaissance de la Vigne et du vin, 22*(4), 275–294.

Clarke, R. J., & Bakker, J. (2004). *Volatile components. Wine flavour chemistry*. Oxford: Blackwell Publishing Ltd. pp. 120–188.

Coulter, A. D., Godden, P. W., & Pretorius, I. S. (2004). Succinic acid-how is it formed, what is its effect on titratable acidity, and what factors influence its concentration in wine? *The Australian and New Zealand Wine Industry Journal, 19*(6), 16–20, 22–25.

Czerny, M., Christlbauer, M., Christlbauer, M., Fischer, A., Granvogl, M., Hammer, M., et al. (2008). Re-investigation on odour thresholds of key food aroma compounds and development of an aroma language based on odour qualities of defined aqueous odorant solutions. *European Food Research and Technology, 228* (2), 265–273.

Dias, D. R., Schwan, R. F., Freire, E. S., & Serôdio, R. D. (2007). Elaboration of a fruit wine from cocoa (*Theobroma cacao* L.) pulp. *International Journal of Food Science and Technology, 42*(3), 319–329.

Dias, D. R., Schwan, R. F., & Lima, L. C. (2003). Metodologia para elaboração de fermentado de cajá (*Spondias mombin* L.). *Ciência e Tecnologia de Alimentos (Brazilian Journal of Food Science and Technology), 23*(3), 342–350.

Duarte, W. F., Dias, D. R., Pereira, G. V. M., Gervásio, I. M., & Schwan, R. F. (2009). Indigenous and inoculated yeast fermentation of gabiroba (*Campomanesia pubescens*) pulp for fruit wine production. *Journal of Industrial Microbiology and Biotechnology, 36*(4), 557–569.

Ferreira, V., López, R., & Cacho, J. (2000). Quantitative determination of the odorants of young red wines from different grape varieties. *Journal of the Science of Food and Agriculture, 80*, 1659–1667.

Fraile, P., Garrido, J., & Ancín, C. (2000). Influence of a Saccharomyces selected strain in the volatile composition of Rosé wines. Evolution during fermentation. *Journal of Agricultural and Food Chemistry, 48*(5), 1789–1798.

Guth, H. (1997). Quantitation and sensory studies of character impact odorants of different white wine varieties. *Journal of Agricultural and Food Chemistry, 45*(8), 3027–3032.

Lira Júnior, J. S., Musser, S., Melo, A., Maciel, S., Lederman, I. E., & Santos, V. F. (2005). Caracterização física e físico-química de frutos de cajá-umbu (Spondias spp.). *Ciência e Tecnologia de Alimentos, 25*(4), 757–761.

Lubbers, S., Verret, C., & Voilley, A. (2001). The effect of glycerol on the perceived aroma of a model wine and white wine. *LWT – Food Science and Technology, 34* (4), 262–265.

Mateo, J. J., & Jimenez, M. (2000). Monoterpenes in grape juice and wines. *Journal of Chromatography A, 881*(1–2), 557–567.

Meilgaard, M. C. (1975). Flavor chemistry of beer: part II: flavor and threshold of 239 aroma volatiles. *MBAA Technical Quarterly, 12*, 151–168.

Miyake, T., & Shibamoto, T. (1993). Quantitative analysis of acetaldehyde in foods and beverages. *Journal of Agricultural and Food Chemistry, 41*(11), 1968–1970.

Noguerol-Pato, R., González-Barreiro, B., Cancho-Grande, B., & Simal-Gándara, B. (2009). Quantitative determination and characterization of the main odorants of Mencía monovarietal red wines. *Food Chemistry, 117*(3), 473–484.

Oliveira, J. M., Faria, M., Sá, F., Barros, F., & Araújo, I. M. (2006). C_6-alcohols as varietal markers for assessment of wine origin. *Analytica Chimica Acta, 563*(1), 300–309.

Peinado, R. A., Moreno, J. A., Muñoz, D., Medina, M., & Moreno, J. (2004). Gas chromatographic quantification of major volatile compounds and polyols in wine by direct injection. *Journal of Agricultural and Food Chemistry, 52*(21), 6389–6393.

Peña, R. M., Barciela, J., Herrero, C., & García-Martín, S. (2005). Optimization of solid-phase microextraction methods for GC–MS determination of terpenes in wine. *Journal of the Science of Food and Agriculture, 85*(7), 1227–1234.

Perestrelo, R., Fernandes, A., Albuquerque, F., Marques, J., & Camara, J. (2006). Analytical characterization of the aroma of Tinta Negra Mole red wine: identification of the main odorants compounds. *Analytica Chimica Acta, 563*(1–2), 154–164.

Plutowska, B., & Wardencki, W. (2008). Application of gas chromatography–olfactometry (GC–O) in analysis and quality assessment of alcoholic beverages – a review. *Food Chemistry, 107*(1), 449–463.

Quijano, C., & Pino, J. (2007). Volatile compounds of copoazú (*Theobroma grandiflorum* Schumann) fruit. *Food Chemistry, 104*(3), 1123–1126.

Rapp, A., & Mandery, G. (1986). Wine aroma. *Experientia, 42*, 873–884.

Reddy, A., & Reddy, S. (2005). Production and characterization of wine from mango fruit (*Mangifera indica* L). *World Journal of Microbiology & Biotechnology, 21* (8–9), 1345–1350.

Ribéreau-gayon, P., Glories, Y., Maujean, A., & Dubourdieu, D. (2000). Varietal aroma. *Handbook of enology*. In: *The chemistry of wine and stabilization and treatments, Vol. 2*. New York: John Wiley and Sons Ltd. pp. 187–206.

Schwan, R. F., & Wheals, A. E. (2004). The microbiology of cocoa fermentation and its role in chocolate quality. *Critical Reviews in Food Science and Nutrition, 44*(4), 205–222.

Selli, S., Canbas, A., Varlet, V., Kelebek, H., Prost, C., & Serot, T. (2008). Characterization of the most odor-active volatiles of orange wine made from a Turkish cv. Kozan (*Citrus sinensis* L. Osbeck). *Journal of Agricultural and Food Chemistry, 56* (1), 227–234.

Siebert, T. E., Smyth, H. E., Capone, D. L., Neuwöhoner, C., Pardon, K. H., Skouroumounis, G. K., et al. (2005). Stable isotope dilution analysis of wine fermentation products by HS-SPME–GC–MS. *Analytical and Bioanalytical Chemistry, 381*(4), 937–947.

Soufleros, E. H., Pissa, P., Petridis, D., Lygerakis, M., Mermelas, K., Boukouvalas, G., et al. (2001). Instrumental analysis of volatile and other compounds of Greek kiwi wine, sensory evaluation and optimisation of its composition. *Food Chemistry, 75*(4), 487–500.

Tešević, V., Nikićević, N., Milosavljević, S., Bajić, D., Vajs, V., Vučković, I., et al. (2009). Characterization of volatile compounds of "Drenja", an alcoholic beverage obtained from the fruits of cornelian cherry. *Journal of the Serbian Chemical Society, 74*(2), 117–128.

Wondra, M., & Berovic, M. (2001). Analyses of aroma components of Chardonnay wine fermented by different yeast strains. *Chemical Analysis, 39*(2), 141–148.