Heliyon 9 (2023) e18526

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

French Guiana honeys from the Amazon biome: First description of volatile fraction and antioxidant capacity

Weiwen Jiang [a,*], Julien Paolini [b], Didier Bereau [a], Marie-José Battesti [b], Yin Yang [b], Élodie Jean-Marie [a], Jean Costa [b], Jean-Charles Robinson [a]

[a] *Laboratoire COVAPAM, UMR QualiSud, Département Science et Technologies, Université de Guyane, 97300 French Guiana, France*
[b] *UMR 6134 CNRS Science pour l'environnement, Science and Techniques Faculty, University of Corsica, 22 Jean Nicoli Av. 20250 Corte, Corsica, France*

ARTICLE INFO

Keywords:
French Guiana Honey
Volatile compounds
Phenolics compounds
HS-SPME
Antioxidant activity
Guiana shield

ABSTRACT

Various honeys from French Guiana were collected and analyzed to investigate their volatile fraction composition and antioxidant activity. Volatile composition was assessed using HS-SPME/GC, GC-MS technique. Oxygenated monoterpenes like hotrienol (0.5–45.3%) were found as major molecules, followed by non terpenic compounds like phenylacetaldehyde (0.8–18.2%) or 3-hydroxy-4-phenyl-2-butanone (0.1–29.3%). Three chemical groups using statistical analysis were classified within investigated honey samples: norisoprenoids/shikimates, mevalonate and their combination. Total phenolics content (TPC) was determined by Folin-Ciocalteu method. Antioxidant activity was assessed by oxygen radical absorbance capacity (ORAC) and 2,2′-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) assays. TPC and anti-radical activity were compared with multifloral honeys from neighboring regions, indicating the possible presence of compounds from the polyphenol family. These results are promising for further biological studies involving honeys from French Guiana.

1. Introduction

Honey is renowned for its nutritional and therapeutic properties [1]. It primarily consists of sugars (70–88%; w/w), water (16–20%; w/w), but also contains element traces with biological significance such as vitamins, terpene compounds and polyphenols [2].

Despite the implementation of many agricultural regulations, tracing honeys botanical and geographical origins remain challenging. The classical approaches used to describe honeys origins involve melissopalynology and physicochemical analyses. Melissopalynology is a traditional method used to identify honey pollen content although its accuracy relies on analysts' experience. Physicochemical analyses typically include color, conductivity and moisture content measurements. These data, in addition to pollen analysis, contribute to describe the honey's botanical origin [3,4]. However, conventional methods are mainly limited by their accuracy and reliability. In this context, novel approaches have been performed to enhance honeys chemical characterization and biological properties assessment — from a health and commercial point of view. Among these approaches, antioxidant capacity and

* Corresponding author.
E-mail addresses: wein.jiang@univ-guyane.fr (W. Jiang), paolini_j@univ-corse.fr (J. Paolini), didier.bereau@univ-guyane.fr (D. Bereau), battesti_mj@univ-corse.fr (M.-J. Battesti), yangyin99@gmail.com (Y. Yang), elodie.jean-marie@univ-guyane.fr (É. Jean-Marie), Costa@univ-corse.fr (J. Costa), jean-charles.robinson@univ-guyane.fr (J.-C. Robinson).

https://doi.org/10.1016/j.heliyon.2023.e18526
Received 21 April 2023; Received in revised form 10 July 2023; Accepted 20 July 2023
Available online 22 July 2023

volatile fractions analysis are considered as rapid, reproducible, flexible, and affordable. For instance, volatile fraction analysis were useful to clarify Corsican honeys geographical and botanical origins [5–8]. Analyses of honeys antioxidant capacity have changed their business paradigm because of their potential impact on human health. They are even considered nutraceuticals by authors [9,10].

Among new approaches to understanding honey chemical composition, Head Space-Solid Phase MicroExtraction (HS-SPME) is widely used [11]. Volatile compounds are adsorbed on a coated fiber and then analyzed by gas chromatography (GC) coupled to a mass spectrometer (MS) [10]. Polyphenolics content is assessed according to Folin-Ciocalteau method, and antioxidant activity according to ABTS and ORAC assays.

French Guiana is part of the Amazon biome – known as the global biodiversity hotspot. French Guiana beekeeping flora is preserved and rich in thousands of species with nectariferous and polliniferous potentials [12]. This vast Amazonian flora covering more than 96% of the territory is mostly foraged by *Apis* and *Melipona* [13]. To our knowledge, little is known on honey's chemistry and its potential for human health [1]. Brazilian honeys issued from the Amazon biome were considered with high interest regarding their volatile fractions and antioxidant capacities [14–17]. Hence, it becomes conceivable that honeys from different biotopes in French Guiana (mangroves, forests, savannahs and grasslands) may present such consideration with distinct chemical signatures. Moreover, the exploration of these honeys could reveal new chemical compounds with potential biological interests for human health, such as antioxidants and anti-inflammatory properties [1].

In the absence of existing knowledge, the purpose of this study was to describe the volatile fractions and antioxidant capacity of French Guiana honeys, to generate new insights and facilitate the introduction of local Protected Geographical Indications.

2. Materials and methods

2.1. Samples

Eighty-seven *Apis mellifera* honeys (H1 to H87) with multifloral type issued from French Guiana, were obtained from beekeepers during the dry season at three different sampling campaigns (August 2014 to January 2015: samples H1 – H17; July 2015 to January 2016: samples H18 – H61 and September 2016 to May 2017: H62 – H87) (Fig. 1). All samples were stored at 15 °C. Apiaries were generally located near a forest, sometimes adjacent to fields with herbaceous plants (mainly *Mimosa pudica* L., *Hyptis atrorubens* Poit. And *Spermacoce verticillate* L.). No orchards or large plantations were present in the areas where apiaries were located.

2.2. Melissopalynological analysis

Melissopalynological analysis were carried out according to a protocol documented in articles by Marie Jose Battesti and Von-der-

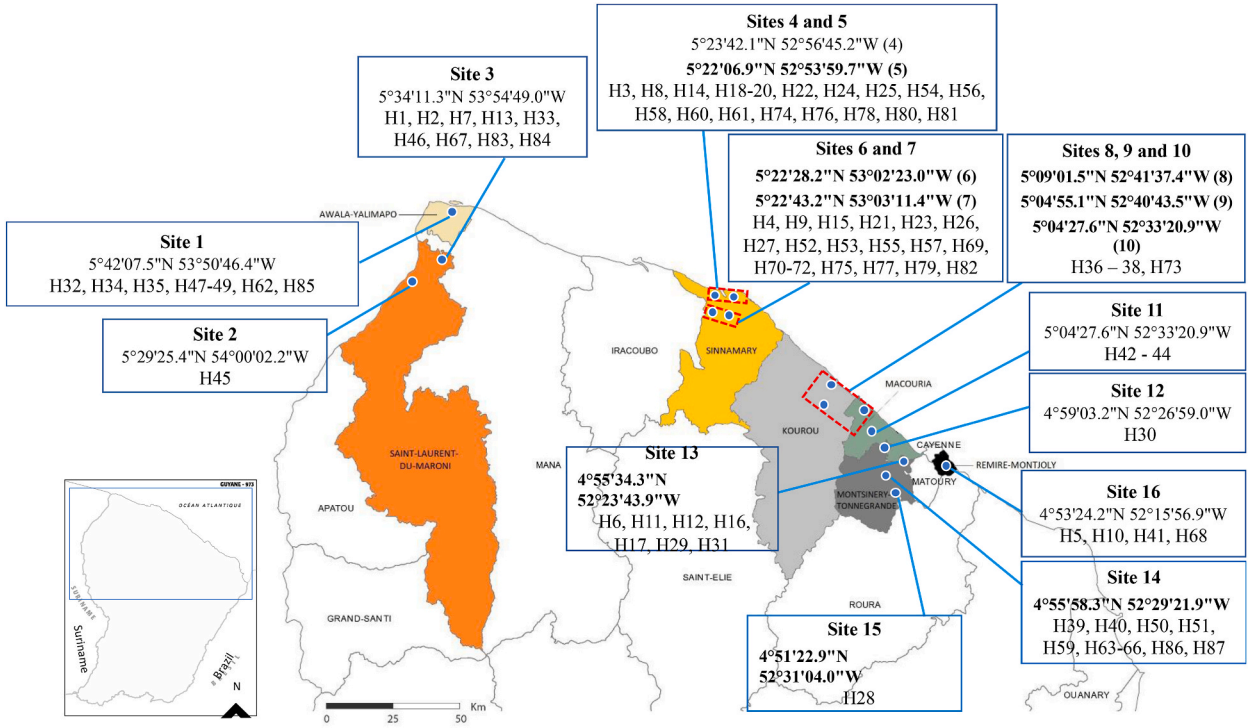

Fig. 1. Localization of the sampling sites.

Ohe and al [3,4]. Pollen identification was performed by comparing reference library slides and literature data. Then, each taxon distribution was estimated by counting with a microscope's field of view in order to assess the pollen spectrum of each honey sample. Relative Pollen relative frequencies (RF) were obtained by the following formula:

$RF_{species\ A}$ = (number of grain of species A / total pollen grains)

2.3. HS-SPME extraction

The HS-SPME extraction was performed according to Yang and al. study [5,18]. Each honey sample (5 g) were placed under magnetic agitation in a 20 mL vial containing 2 g Na_2SO_4 and 4 mL deionized Milli-Q water at 70 °C, with respective equilibrium and extraction times of 90 and 30 min. Volatile fraction was adsorbed on a divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS, 30 μm) coated fiber (Supelco Sigma Aldrich) previously activated for 5 min in GC injector at 280 °C. After sampling, SPME fiber was inserted consecutively into GC-FID and GC-MS injectors for 5 min to desorb volatiles, both using splitless mode.

Three French Guiana honeys were selected from different production sites (Sinnamary, Montsinéry-Tonnegrande, Rémire-Montjoly). Based on a study by Yang and al. [5,18], HS-SPME optimization focused on two parameters: temperature (50 °C, 70 °C and 90 °C) and mass of the sample (2 g, 4 g and 6 g). Other extraction conditions (fiber choice, salt mass (Na_2SO_4), fiber conditioning time, equilibrating time, extraction time, desorption time) described in Yang and al. publication were kept constant. Measurement of extraction efficiency was based on the calculation on the sum of total peak areas. Maximum sum of total peak area was obtained from 5 g of honeys with 2 g of Na_2SO_4 and 4 mL deionized Milli-Q water, at a temperature of 70 °C, an equilibrium time of 90 min, and an extraction time of 30 min.

2.4. GC-FID and GC-MS analysis

GC-FID analyses were performed using a PerkinElmer (Waltham, MA, USA) AutoSystem XL GC apparatus equipped with FID system and a fused-silica capillary column (30 m x 0.25, film thickness 1 μm) coated with Rtx-1 (PDMS). Oven temperature was programmed as following: from 60 to 230 °C at 2 °C/min and then held isothermally at 230 °C for 35 min. The injector and detector temperatures were maintained at 280 °C. Samples were injected with an SPME inlet liner (0.75 mm i.d. ; Supelco) using hydrogen as carrier gas (1 mL/min). Compounds retention index were determined in relation to the retention times of a series of *n*-alkanes (C_5–C_{30}) with linear interpolation. Relative concentrations of components were calculated from the GC peak areas without using correction factors. Samples were also analyzed with a PerkinElmer TurboMass detector (quadrupole), coupled to a GC PerkinElmer AutoSystem XL, equipped with a fused-silica Rtx-1 capillary column. Ion source temperature was 150 °C, and ionization energy was 70 eV. Electronic ionization (EI) mass spectra were acquired over the mass range of 35–350 Da (scan time 1s). Other GC conditions were the same as those described for GC-FID analysis. Components identification was based on: (1) comparison with their GC retention index (RI) on non-polar column; (2) comparison with standards RI and mass spectra issued from libraries [19,20]. The standards were obtained from Supelco Sigma Aldrich.

2.5. Statistical analysis

Principal component analysis (PCA) was carried out using the « PCA » function and canonical correspondence analysis (CCA) was performed with « CCA » function from R software (R Foundation – Institute for Statistics and Mathematics, Austria). CCA is a multidimensional exploratory statistical method that demonstrate correlation between two sets of variables obtained from the same individual.

2.6. Total polyphenol content

Protocol was performed according to the work of Singleton and al [21] with some modifications for microplate assay. Measurements were made in polystyrene microplate with 96 flat-bottomed wells and analyzed by a TECAN® 200 Pro microplate reader. For this purpose, 25 μL diluted honey (1 g/mL) was mixed with 125 μL Folin-Ciocalteu reagent (10%; v/v) and 100 μL of sodium carbonate (7,5%; v/v). The microplate was agitated by orbital shaking and remained in darkness at 25 °C for 2h. Absorbance was read at 750 nm against control. Concentration values were obtained from calibration lines established with gallic acid reference solution (concentration range 0–120 mg/L). TPC determination was carried out on 61 samples (H1-61). Results were expressed as μg gallic acid equivalent (GAE) per gram of honey.

2.7. Antioxidant capacity

ORAC and TEAC assays were performed by spectrophotometry on a TECAN® 200 Pro microplate reader.

ORAC protocol was performed according to Ghiselli and al [22] study with some modifications for the microplate test. Analyses were carried out in a phosphate buffer at a pH of 7.4 to 37 °C. The peroxyl radical was generated using 2,2′-azobis (2-amidino-propane) dihydrochloride which was freshly prepared for each run. Fluorescein was used as a fluorescent probe. Fluorescence conditions were as

Table 1
Statistical analysis and classification of pollen forms according to their maximum frequency.

Pollinic forms	Attendance rate (%)	Relative frequencies				Groups
		Min. (%)	Max. (%)	Mean ± SD (%)	Relative Standard Deviation (%)	
Mimosa pudica	100,0	1.1	98.7	67.6 ± 30.5	45.1	group 1: Taxa with an RF at least one
Tapirira guianensis	81.6	0.0	83.4	7.6 ± 16.2	212.0	greater than 45%
Protium sp.	58.6	0.0	45.0	1.6 ± 5.9	374.2	
Avicennia germinans	88.5	0.0	44.0	4.8 ± 8.6	177.8	group 2: Taxa with an RF at least one
Cecropia sp.	79.3	0.0	35.2	2.2 ± 5.9	267.5	between 16% and 45%
Spondias Mombin	44.8	0.0	34.2	1.8 ± 5.7	314.6	
Scrophulariaceae sp. type	4.6	0.1	33.8	0.5 ± 3.8	703.5	
Cocos sp. type	98.9	0.0	30.5	2.6 ± 4.1	159.2	
Solanum sp.	64.4	0.0	18.5	1.1 ± 2.9	270.9	
Mauritia flexuosa	70.1	0.0	16.7	1.8 ± 3.4	185.5	
NI.2	35.6	0.0	16.1	0.3 ± 1.8	525.8	
Emmotum fagifalum	27.6	0.0	15.4	0.3 ± 1.7	523.4	group 3: Taxa with an RF at least one
Spermacoce verticillata	83.9	0.0	15.2	0.7 ± 1.7	246.6	between 3% and 16%
Diplotropis purpurea	43.7	0.0	15.1	0.5 ± 2.2	437.2	
Rynchospora sp. type	89.7	0.0	15.1	1.0 ± 1.9	190.9	
Piper marginatum	33.3	0.0	14.7	0.3 ± 1.6	494.5	
Myrtaceae sp. type	75.9	0.0	14.3	0.8 ± 2.1	255.8	
Chenopodiaceae/ Amaranthaceae type	10.3	0.1	12.2	0.3 ± 1.6	477.9	
NI.5	29.9	0.0	12.1	0.4 ± 1.5	369.7	
Asteraceae sp.	42.5	0.0	10,0	0.2 ± 1.1	630.2	
Merremia sp.	16.1	0.0	9.6	0.3 ± 1.2	449	
Dalbergia ecastophyllum	4.6	0.1	9.2	0.1 ± 1.0	895.7	
Avicennia sp. type	5.7	0.0	9,0	0.1 ± 1.0	885.5	
NI.3	35.6	0.0	8.4	0.3 ± 1.0	367.4	
Myrcia tomentosa/sylvatica	9.2	0.0	6.9	0.1 ± 0.9	615.8	
Vismia guianensis	8.0	0.1	6.6	0.1 ± 0.7	668.5	
NI.12	3.4	0.1	6,0	0.1 ± 0.7	704.7	
Paspalum sp. type	88.5	0.0	4.1	0.5 ± 0.7	141	
Vismia latifolia	1.1	3.9	3.9	0.05 ± 0.4	886.5	
NI.15	1.1	3.0	3.0	0.03 ± 0.3	870.6	
Xyris sp.	18.4	0.0	2.9	0.1 ± 0.5	380.4	group 4: Taxa with an RF always less
Ceiba pentandra	9.2	0.1	2.6	0.1 ± 0.4	617.3	than 3%
Ilex guianensis	17.2	0.0	2.6	0.1 ± 0.4	601.6	
Rananculaceae type	6.9	0.1	2.6	0.05 ± 0.3	649.6	
Miconia sp.	19.5	0.0	2.4	0.07 ± 0.3	411.5	
Acacia mangium	42.5	0.0	2.1	0.31 ± 0.3	232.7	
Urticaceae type	1.1	1.6	1.6	0.02 ± 0.2	1073.0	
NI.1	41.4	0.0	1.5	0.13 ± 0.3	228.4	
NI.4	31.0	0.0	1.2	0.05 ± 0.2	372.7	
Ludwidjia sp.	5.7	0.1	1.0	0.03 ± 0.1	372.3	
NI.6	23.0	0.0	1.0	0.05 ± 0.1	202.8	
Elaeis sp.	34.5	0.0	0.9	0.08 ± 0.2	244.4	
Desmathus sp.	1.1	0.9	0.9	0.01 ± 0.1	1015.0	
Parinari sp.	36.8	0,0	0.8	0.07 ± 0.1	152.6	
Oxalidaceae type	3.4	0.1	0.7	0.01 ± 0.1	702.2	
NI.8	8.0	0.0	0.7	0.01 ± 0.1	711.7	
Davilla rugosa	12.6	0.0	0.6	0.02 ± 0.1	427.4	
Mimosa pigra	20.7	0.0	0.6	0.02 ± 0.1	419.7	
Vochysia sp.	5.7	0.0	0.4	0.01 ± 0.05	590.7	
Hyptis atrorubens	19.5	0.0	0.3	0.02 ± 0.1	614.3	
NI.14	2.3	0.0	0.3	0.004 ± 0.03	743.6	
Trema micrantha	3.4	0.0	0.3	0.004 ± 0.03	698.9	
NI.7	9.2	0.0	0.3	0.01 ± 0.04	431.6	
Anacardium occidentale	1.1	0.2	0.2	0.002 ± 0.02	758.6	
NI.9	8,0	0.0	0.2	0.01 ± 0.03	360.6	
NI.16	1.1	0.2	0.2	0.002 ± 0.02	845.8	
Couroupita guianensis	2.3	0.1	0.2	0.003 ± 0.02	564.7	
NI.11	5.7	0.0	0.2	0.01 ± 0.03	481.4	
Sapindaceae type	1.1	0.2	0.2	0.001 ± 0.02	1073.0	

(*continued on next page*)

Table 1 (*continued*)

Pollinic forms	Attendance rate (%)	Relative frequencies				Groups
		Min. (%)	Max. (%)	Mean ± SD (%)	Relative Standard Deviation (%)	
NI.13	3.4	0.1	0.2	0.004 ± 0.02	456.5	
NI.17	1.1	0.1	0.1	0.001 ± 0.01	690.8	
Citrus sp.	1.1	0.1	0.1	0.001 ± 0.01	852.6	
Rolandra fructicosa	3.4	0.0	0.1	0.002 ± 0.01	628.3	
Pachira aquatica	1.1	0.1	0.1	0.0008 ± 0.007	884.9	
NI.10	5.7	0.0	0.1	0.002 ± 0.008	501.4	
Serjania sp.	1.1	0.0	0.04	0.0005 ± 0.003	580.2	
Inga sp.	2.3	0.0	0.02	0.0004 ± 0.005	1095,0	
Sida sp.	1.1	0.0	0.02	0.0005 ± 0.002	937.2	
NI.18	1.1	0.0	0.02	0.0002 ± 0.002	952.1	

followed: excitation at 485 nm and emission at 530 nm. Trolow standard curve was linear between 0 and 70 μM. Results were expressed as μmol Trolox equivalent (TE) per gram of honey.

For ABTS assay, the performed method was described by Re and al [23] with some modifications for microplate test. Two stock solutions were prepared: the first one with a concentration of 7.4 mM ABTS, and the second one containing potassium persulfate solution at a concentration of 2.4 mM. Fresh $ABTS^{\bullet+}$ solution was prepared for each assay. The working solution was prepared by mixing the stock solutions in equal quantities and allowing them to react for 12 to 16h at room temperature in the dark before use. The working solution was then diluted to obtain an absorbance of 1.00 ± 0.01 at 734 nm for a total volume of 250 μL. Trolox standard solution (0 to 40 μg/mL) was prepared in methanol. In each well, 50 μL of diluted honey (1 g/mL), blank, or standard were placed. Then 200 μL of the $ABTS^{\bullet+}$ working solution was added. Mixture was homogenized. Absorbance was measured after 5 min of incubation. Results were expressed in μmol TE/g of honey. Antioxidant capacity (ORAC and ABTS) was carried out on 61 samples (H1-61).

2.8. Conductivity, water content and color

Electrical conductivity was measured with a CM2210 conductivity micrometer (CRISON, Spain) at 20 °C. Water content (moisture) was determined using refractometry with a PAL-22S refractometer (Atago®, Japan) reading at room temperature according to the method described by Bogdanov [24]. Honeys color was measured according to the Pfund method. Measurements were carried out with liquid honeys using a Lovibond type comparator with two chromatic discs: one for light honeys and the other one for dark honeys. Each disc had nine color spots with increasing density related to Pfund references. The liquid honey was poured into a tank and stored in the apparatus for comparison with the reference tablets. The results were expressed as a "Pfund index" ranging from 8 mm Pfund (white or very light honey) to over 114 mm Pfund (dark amber honey).

3. Results & discussions

3.1. Taxa statistical analysis in French Guiana honeys

Melissopalynological studies of French Guiana honeys allowed us to identify 51 taxa, while 18 pollinic forms remained unidentified (Table 1). They were categorized based on their maximum relative frequency (RF) and clustered according to the international melissopalynological nomenclature as follows: three taxa were considered as "dominant pollen" (RF>45%), eight as "accompanying pollen" (RF = 15–45%), nineteen as "important minor pollen" (RF = 3–15%) and thirty-nine as "minor pollen" (RF<3%) [3,4].

Mimosa pudica L. pollen grains were consistently observed in all analyzed samples, indicating their ubiquity. Due to its high RF, we hypothesized that *M. pudica* L. pollen may serve as a significant biomarker for French Guiana honeys. In fact, *M. pudica* L. was found to be over-represented (RF> 90%) in 33 honeys and acted as the dominant pollen form (RF>45%) in 63 honeys. Additionally, *Tapirira guianensis* Aubl. and *Protium* sp. Bum. f. emerged as two other highly representative and frequently encountered taxa (presence ratio >50%). The first one had a RF>45% in five samples (H37, H44, H46, H48 and H49) while the second taxa was only major in one honey (H47).

According to Louveaux [25], when honey collected in a temperate zone has a dominant pollen (RF>45%), the corresponding plant is generally the main source of nectar. However, there are particular cases where the percentage of pollen does not accurately reflect the nectar contribution of a plant. Currently, the absence of data on the pollen representation of tropical plants limits the interpretation

Table 2
Physicochemical properties (moisture, color, conductivity) of French Guiana Honey samples.

Samples	harvest time	Physico-chemical parameters		
		Moisture (%)	Color Pfund (mm)	Conductivity (μS/cm)
H1	2014/09/05	21.4	62	486.0
H2	2014/09/05	21.9	83	836.0
H3	2014/08/19	18.7	41	556.0
H4	2014/08/12	17.1	83	555.0
H5	2013/11/16	13.7	83	580.0
H6	2014/09/06	18.4	41	679.0
H7	2014/11/15	20.0	55	936.0
H8	2014/11/15	16.7	41	648.0
H9	2014/11/19	17.9	46	454.0
H10	2014/11/15	18.6	92	723.0
H11	2014/11/10	20.1	51	770.0
H12	2014/11/10	19.4	83	520.0
H13	2015/01/17	20.5	41	820.0
H14	2015/01/14	18.4	35	590.0
H15	2015/01/09	18.1	41	548.0
H16	2014/12/15	20.7	55	1040.0
H17	2014/12/15	18.5	55	630.0
H18	2015/07/30	17.6	62	777.0
H19	2015/07/30	17.2	83	777.0
H20	2015/08/22	17.3	71	641.1
H21	2015/08/28	17,0	92	636.8
H22	2015/09/02	17,0	71	878.3
H23	2015/09/12	17.1	83	865.8
H24	2015/09/14	16.6	51	930.2
H25	2015/09/21	17.3	55	935.3
H26	2015/09/18	17.6	55	963.4
H27	2015/10/20	16.5	27	744.2
H28	2015/09/25	19,0	62	1222
H29	2015/09/25	17.6	71	767.2
H30	2015/09/25	18.1	55	714.3
H31	2015/10/08	18.4	46	659.2
H32	2015/09/04	18.3	99	721.6
H33	2015/09/14	18.5	83	600.3
H34	2015/09/17	18.7	62	516.3
H35	2015/10/22	18.1	51	755.4
H36	2015/09/27	18.5	83	882.6
H37	2014/12/24	19.2	71	623.2
H38	2015/11/22	18.2	46	706.5
H39	2015/09/14	16.7	55	1090
H40	2015/10/12	17.5	51	1044
H41	2015/11/15	18.5	46	776.4
H42	2015/10/31	18.3	27	477.8
H43	2015/11/21	21.4	83	799.6
H44	2015/12/31	20.5	55	619.1
H45	2015/11/26	18.1	71	747.8
H46	2015/12/04	17.8	55	749.4
H47	2015/12/04	17.9	62	1025
H48	2015/12/12	18.5	51	915.2
H49	2015/12/16	17.8	71	754.5
H50	2015/11/23	17.3	55	996.7
H51	2015/12/28	16.4	51	834.8
H52	2015/09/30	16.7	35	625.6
H53	2015/10/14	17.1	62	714.5
H54	2015/10/21	16.7	35	622.2
H55	2015/10/28	17,0	83	658.8
H56	2015/11/08	16.8	27	499.8
H57	2015/11/25	16.4	51	570.9
H58	2015/11/20	16.8	27	503.7
H59	2016/01/18	15.8	62	851.6
H60	2015/10/04	16.8	62	656.8
H61	2015/11/20	16.8	35	490.5
H62	2017/03/07	19.8	41	658.3
H63	2016/09/28	21.0	62	797.0
H64	2016/10/14	19.0	51	809.1
H65	2016/10/24	19.7	46	980.8
H66	2016/11/15	17.9	51	878.3
H67	2017/03/08	18.5	99	920.9

(*continued on next page*)

Table 3
Globale volatile composition of French Guiana honeys and the three chemical groups proposed by the statistical analysis.

N° a	Compounds	IR (Lit) b	IR c	Group I			Group II			Group III			General			Identification e
				Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	
V1	Toluene[g]	749	747	0.4 ± 0.7	0.0	2.6	0.4 ± 0.5	0.0	1.5	0.6 ± 0.6	0.0	2.8	0.5 ± 0.7	0.0	2.8	RI, MS
V2	Hexanal[g]	770	770	0.1 ± 0.1	0.0	1.3	0.04 ± 0.1	0.0	0.5	0.2 ± 0.5	0.0	2.9	0.1 ± 0.4	0.0	2.9	RI, MS
V3	Octane[h]	800	790	0.1 ± 0.4	0.0	2.2	0.1 ± 0.2	0.0	0.6	0.1 ± 0.2	0.0	0.8	0.1 ± 0.3	0.0	2.2	RI, MS
V4	3-Furaldehyde[g]	782	790	1.2 ± 0.6	0.0	5.4	0.9 ± 0.5	0.3	1.8	1.2 ± 1.1	0.0	4.5	1.2 ± 0.9	0.0	5.4	RI, MS
V5	3-Methylbutanoic acid[g]	830	807	–	–	–	0.1 ± 0.2	0.0	0.6	0.2 ± 0.3	0.0	0.9	0.1 ± 0.2	0.0	0.9	RI, MS
V6	2-Furylmethanol[g]	828	820	0.02 ± 0.1	0.0	0.5	0.03 ± 0.1	0.0	0.4	0.02 ± 01	0.0	0.4	0.02 ± 0.1	0.0	0.5	RI, MS
V7	2-Methylbutanoic acid	860	820	0.02 ± 0.1	0.0	0.9	–	–	–	0.02 ± 0.1	0.0	0.3	0.02 ± 0.1	0.0	0.9	RI, MS, Ref
V8	Ethylbenzene	846	838	–	–	–	0.1 ± 0.2	0.0	0.5	0.01 ± 0.1	0.0	0.4	0.02 ± 0.1	0.0	0.5	RI, MS, Ref
V9	1-Hexanol[g]	850	850	0.007 ± 0.05	0.0	1.3	0.01 ± 0.02	0.0	0.1	0.01 ± 0.1	0.0	0.3	0.02 ± 0.1	0.0	1.3	RI, MS
V10	Anisole[g]	900	889	0.2 ± 0.4	0.0	2.4	0.2 ± 0.3	0.0	0.9	0.4 ± 0.9	0.0	3.4	0.3 ± 0.6	0.0	3.4	RI, MS
V11	Benzaldehyde[g]	929	921	1.6 ± 2.4	0.0	10.8	1.3 ± 2.4	0.0	9.0	1.8 ± 1.3	0.5	6.5	1.7 ± 2.1	0.0	10.8	RI, MS
V12	2,6-Dimethyloctane	936	933	0.8 ± 0.7	0.0	2.1	1.3 ± 0.7	0.0	2.5	0.4 ± 0.5	0.0	2.2	0.7 ± 0.7	0.0	2.5	RI, MS, Ref
V13	(3S)-3,7-Dimethyl-1,6-octadiene[h]	930	933	0.1 ± 0.2	0.0	0.9	0.1 ± 0.2	0.0	0.6	–	–	–	0.1 ± 0.2	0.0	0.9	RI, MS
V14	1-Octene-3-ol[g]	959	955	0.005 ± 0.03	0.0	0.2	–	–	–	0.1 ± 0.3	0.0	1.6	0.05 ± 0.2	0.0	1.6	RI, MS
V15	3-Octanone	963	959	–	–	–	–	–	–	0.4 ± 0.9	0.0	3.4	0.1 ± 0.6	0.0	3.4	RI, MS, Ref
V16	(*Z/E*)-3,7-Dimethyl-2-octene**	960	960	0.5 ± 0.8	0.0	2.7	0.9 ± 1.1	0.0	3.3	0.1 ± 0.5	0.0	2.2	0.4 ± 0.8	0.0	3.3	RI, MS, Ref
V17	(*Z/E*)-2,6-Dimethyl-2-octene**	966	960	1.1 ± 0.9	0.0	2.8	0.8 ± 0.9	0.0	2.4	0.2 ± 0.4	0.0	1.2	0.7 ± 0.9	0.0	2.8	RI, MS, Ref
V18	3-Octanol	978	976	–	–	–	–	–	–	0.4 ± 0.9	0.0	3.8	0.2 ± 0.6	0.0	3.8	RI, MS, Ref
V19	Octanal[g]	980	978	0.1 ± 0.2	0.0	1.2	0.1 ± 0.2	0.0	0.5	0.1 ± 0.2	0.0	0.7	0.1 ± 0.2	0.0	1.2	RI, MS
V20	1-Methoxy-4-methylbenzene[g]	1002	997	0.1 ± 0.2	0.0	1.0	0.1 ± 0.3	0.0	0.7	0.1 ± 0.3	0.0	1.6	0.1 ± 0.3	0.0	1.6	RI, MS
V21	Phenylmethanol[g]	1011	1003	0.4 ± 0.9	0.0	5.0	0.5 ± 0.4	0.0	1.2	0.3 ± 0.3	0.0	0.9	0.4 ± 0.7	0.0	5.0	RI, MS
V22	Phenylacetaldehyde[g]	1013	1006	3.7 ± 3.0	0.0	16.0	2.6 ± 1.6	1.2	6.7	3.5 ± 3.0	1.0	18.2	3.5 ± 2.9	0.0	18.2	RI, MS
V23	3,5,5-Trimethylcyclohex-3-en-1-one	1025	1015	–	–	–	–	–	–	**0.2 ± 0.3**	**0.0**	**1.0**	0.1 ± 0.2	0.0	1.0	RI, MS, Ref
V24	3,7-Dimethyl-1-octen-3-ol	1118	1021	2.9 ± 1.1	0.0	5.6	2.5 ± 0.9	1.4	4.2	0.8 ± 0.6	0.0	2.3	2.1 ± 1.4	0.0	5.6	RI, MS, Ref
V25	1-Phenylethanone	1044	1032	0.02 ± 0.1	0.0	0.6	–	–	–	0.05 ± 0.1	0.0	0.7	0.03 ± 0,1	0.0	0.7	RI, MS, Ref
V26	(*E*)-Furanoid linalool oxide	1057	1060	4.6 ± 4.2	0.0	11.7	6.3 ± 3.6	0.0	11.8	2.2 ± 1.9	0.0	7.2	4.0 ± 3.7	0.0	11.8	RI, MS, Ref
V27	Linalool	1173	1074	1.7 ± 0.9	0.0	4.8	1.3 ± 0.5	0.7	2.3	0.4 ± 0.4	0.0	1.4	1.2 ± 0.9	0.0	4.8	RI, MS, Ref
V28	(*Z*)-Furanoid linalool oxide	1073	1076	1.8 ± 0.9	0.0	6.0	1.0 ± 0.6	0.0	1.8	0.7 ± 0.6	0.0	2.4	1.3 ± 1.0	0.0	6.0	RI, MS, Ref
V29	2-Phenylethanol[g]	1086	1090	1.0 ± 1.7	0.0	8.2	1.6 ± 1.7	0.0	4.7	4.9 ± 4.9	0.0	20.0	2.5 ± 3.7	0.0	20,0	RI, MS
V30	Hotrienol	1083	1092	**21.3 ± 10.5**	**0.0**	**45.3**	**20.8 ± 10.5**	**2.1**	**41.5**	4.2 ± 4.1	0.0	16.9	14.9 ± 12.0	0.0	45.3	RI, MS, Ref
V31	Tetrahydrolinalol	1087	1093	**7.1 ± 6.9**	**0.0**	**21.6**	**3.6 ± 4.1**	**0.0**	**13.0**	3.0 ± 3.4	0.0	11.8	5.0 ± 5.7	0.0	21.6	RI, MS, Ref
V32	3,5,5-Trimethyl-2-cyclohexen-1-one[g]	1097	1097	1.6 ± 1.0	0.0	5.3	2.0 ± 1.0	0.9	4.0	**5.1 ± 2.1**	**1,9**	**9.6**	2.9 ± 2.3	0.0	9.6	RI, MS
V33	3,7-Dimethyl-7-octen-3-ol or 3,7-dimethyl-5-octen-3-ol	–	1111	3.0 ± 1.0	0.1	5.2	2.8 ± 1.0	1.4	4.4	0.9 ± 0.7	0.0	2.6	2.2 ± 1.4	0.0	5.2	RI, MS, Ref[f]
V34	4-Oxoisophorone[g]	1114	1117	1.2 ± 0.7	0.1	3.0	2.1 ± 1.2	0.4	4.2	**3.9 ± 1.4**	**0.0**	**7.2**	2.3 ± 1.6	0.0	7.2	RI, MS
V35	3,7-Dimethyloct-6-en-3-ol	1118	1127	**8.7 ± 2.6**	**1.2**	**14.5**	**8.7 ± 2.9**	**4.2**	**13.0**	2.6 ± 1.9	0.0	7.3	6.4 ± 3.8	0.0	14.5	RI, MS, Ref
V36	2,2,6-Trimethyl-1,4-cyclohexanedione	1125	1131	0.3 ± 0.4	0.0	1.9	0.1 ± 0.3	0.0	1.1	1.6 ± 0.8	0.0	3.6	0.7 ± 0.9	0.0	3.6	RI, MS, Ref
V37	Neo-alloocimene	1129	1140	0.2 ± 0.2	0.0	0.6	0.1 ± 0.2	0.0	0.6	–	–	–	0.1 ± 0.2	0.0	0.6	RI, MS, Ref
V38	Nerol oxide	1140	1149	1.0 ± 0.5	0.2	2.3	0.6 ± 0.2	0.4	1.0	0.3 ± 0.3	0.0	1.2	0.7 ± 0.5	0.0	2.3	RI, MS, Ref
V39	Ethyl benzoate	1148	1156	0.1 ± 0.3	0.0	1.6	0.02 ± 0.1	0.0	0.3	0.01 ± 0.1	0.0	0.4	0.1 ± 0.2	0.0	1.6	RI, MS, Ref
V40	(*Z*)-Linalool oxide pyranoid	1170	1161	0.2 ± 0.3	0.0	1.5	0.04 ± 0.1	0.0	0.5	0.1 ± 0.2	0.0	0.8	0.1 ± 0.3	0.0	1.5	RI, MS, Ref
V41	(*E*)-Linalool oxide pyranoid	1173	1166	0.1 ± 0.2	0.0	0.7	–	–	–	0.04 ± 0.1	0.0	0.7	0.1 ± 0.1	0.0	0.7	RI, MS, Ref
V42	2,6-Dimethyl-3,7-octadiene-2-6-diol	1167	1178	0.3 ± 0.6	0.0	2.1	0.7 ± 0.9	0.0	2.2	0.03 ± 0.2	0.0	0.9	0.3 ± 0.6	0.0	2.2	RI, MS, Ref

(*continued on next page*)

Table 3 (*continued*)

N° a	Compounds	IR (Lit) b	IR c	Group I			Group II			Group III			General			Identification e
				Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	Mean ± SD d	min.	max.	
V43	Octanoic acid[g]	1172	1181	1.0 ± 1.5	0.0	7.2	0.8 ± 0.5	0.0	1.6	1.4 ± 0.7	0.0	3.3	1.1 ± 1.1	0.0	7.2	RI, MS
V44	Methyl 2-hydroxybenzoate	1181	1183	0.05 ± 0.2	0.0	1.1	0.04 ± 0.1	0.0	0.5	0.2 ± 0.2	0.0	0.9	0.1 ± 0.2	0.0	1.1	RI, MS, Ref
V45	Methyl 2-phenylacetate	1177	1189	2.4 ± 2.5	0.0	11.2	4.6 ± 3.8	0.0	10.2	**9.5 ± 3.3**	**3,6**	**20.7**	5.3 ± 4.4	0.0	20.7	RI, MS, Ref
V46	Decanal	1185	1195	0.1 ± 0.2	0.0	1.0	0.2 ± 0.2	0.0	0.7	0.2 ± 0.3	0.0	0.8	0.2 ± 0.2	0.0	1.0	RI, MS, Ref
V47	3,5,5-Trimethyl-4-methylene-2-cyclohexen-1-one	1200	1201	–	–	–	0.3 ± 0.9	0.0	3.3	0.05 ± 0.1	0.0	0.7	0.1 ± 0.4	0.0	3.3	RI, MS, Ref
V48	p-anisaldehyde[g]	1215	1234	2.5 ± 3.1	0.0	17.5	1.2 ± 1.3	0.0	4.5	1.7 ± 2.3	0.0	8.3	2.0 ± 2.6	0.0	17.5	RI, MS
V49	Ethyl phenylacetate	1243	1237	0.2 ± 0.4	0.0	2.1	0; 2 ± 0.5	0.0	1.6	0.4 ± 1.5	0.0	8.5	0.3 ± 1.0	0.0	8.5	IR, MS, Ref
V50	2-Phenylethyl acetate	1228	1243	0.04 ± 0.2	0.0	1.1	0.1 ± 0.4	0.0	1.4	0.4 ± 2.3	0.0	13.2	0.2 ± 1.4	0.0	13.2	IR, MS, Ref
V51	(*E*)-Cinnamaldehyde[g]	1230	1246	0.01 ± 0.1	0.0	0.6	0.1 ± 0.2	0.0	0.9	0.01 ± 0.1	0.0	0.4	0.03 ± 0.1	0.0	0.9	IR, MS
V52	Phenylacetic acid	1252	1249	0.1 ± 0.2	0.0	0.7	0.1 ± 0.2	0.0	0.6	0.3 ± 0.5	0.0	2.1	0.2 ± 0.3	0.0	2.1	RI, MS, Ref
V53	Anisyl alcohol[g]	1251	1265	0.03 ± 0.1	0.0	0.4	0.04 ± 0.1	0.0	0.4	0.05 ± 0.1	0.0	0.6	0.04 ± 0.1	0.0	0.6	IR, MS
V54	2,3,5-Trimethylphenol[g]	1250	1271	0.3 ± 0.3	0.0	1.9	0.3 ± 0.5	0.0	2.0	0.6 ± 0.4	0.0	1.8	0.4 ± 0.4	0.0	2,0	IR, MS
V55	4-Ethylguaiacol[g]	1257	1272	0.1 ± 0.2	0.0	1.3	0.2 ± 0?2	0.0	0.5	0.1 ± 0.2	0.0	0.5	0.1 ± 0.2	0.0	1.3	IR, MS
V56	2-Aminoacetophenone[g]	1282	1277	0.6 ± 0.7	0.0	2.4	0.1 ± 0.3	0.0	0.9	0.3 ± 0.4	0.0	1.5	0.4 ± 0.6	0.0	2.4	IR, MS
V57	Nonanoic acid[g]	1262	1287	0.9 ± 1.0	0.0	3.4	1.2 ± 0.6	0.1	2.1	1.5 ± 0.8	0.0	3.5	1.2 ± 0.9	0.0	3.5	IR, MS
V58	Thymol	1267	1298	0.1 ± 0.3	0.0	1.3	0.03 ± 0.1	0.0	0.4	0.1 ± 0.3	0.0	1.1	0.1 ± 0.3	0.0	1.3	RI, MS, Ref
V59	Carvacrol	1278	1307	0.3 ± 0.6	0.0	1.9	0.8 ± 0.8	0.0	2.3	0.6 ± 0.7	0.0	1.7	0.5 ± 0.7	0.0	2.3	IR, MS, Ref
V60	3,4,5 Trimethylphenol[g]	1293	1322	1.6 ± 1.4	0.0	4.4	2.8 ± 3.1	0.0	11.0	4.2 ± 2.5	0.0	10.7	2.8 ± 2.5	0.0	11.0	IR, MS
V61	3-Hydroxy-4-phenyl-2-butanone	1339	1340	2.0 ± 2.4	0.0	8.1	3.9 ± 4.4	0.0	14.3	**11.9 ± 5.9**	**0.0**	**29.3**	6.0 ± 6.3	0.0	29.3	IR, MS, Ref
V62	Dihydroeugenol[g]	1348	1374	0.01 ± 0.1	0.0	0.6	–	–	–	0.03 ± 0.1	0.0	0.5	0.02 ± 0.1	0.0	0.6	IR, MS
V63	Dihydrojasmone[g]	1363	1394	–	–	–	0.2 ± 0.5	0.0	1.7	0.1 ± 0.2	0.0	1.4	0.1 ± 0.3	0.0	1.7	IR, MS
V64	Decanoic acid[g]	1375	1403	0.5 ± 0.6	0.0	2.1	0.5 ± 0.4	0.0	1.1	0.7 ± 0.5	0.0	1.5	0.6 ± 0.5	0.0	2.1	IR, MS
V65	(*E*)-β-Damascenone	1362	1406	0.2 ± 0.3	0.0	1.0	0.3 ± 0.3	0.0	0.8	0.5 ± 0.4	0.0	1.3	0.3 ± 0.3	0.0	1.3	IR, MS, Ref
Total identification				80.8 ± 5.4	69.9	91.5	81.8 ± 5.1	72.8	87.8	75.7 ± 5.0	64.9	90.4	79.1 ± 5.7	64.9	91.5	
Presumed origin																
Compounds from the mevalonate pathway and/or methylerythritol pathway				**55.7 ± 12.2**	**20.1**	**72.6**	**52.6 ± 18.1**	**28.2**	**78.9**	16.9 ± 9.6	2.9	39.2	40,9 ± 22.5	2.9	78.9	
Compounds from the Shikimate pathway				17.2 ± 9.2	2.3	50.1	20.4 ± 10.7	3.8	35.2	**41.1 ± 8.3**	**23.4**	**57.5**	26,7 ± 14.4	2.3	57.5	
Degradation of amino acids				0.02 ± 0.1	0.0	0.9	0.1 ± 0.2	0.0	0.6	0.2 ± 0.3	0.0	1.2	0,1 ± 0.2	0,0	1.2	
Norisoprenoids				3.3 ± 1.8	0.8	10.1	4.8 ± 2.6	1.8	9.6	11.3 ± 3.8	3.7	20.3	6,4 ± 4.7	0.8	20.3	
Compounds derived from beeswax				2.6 ± 2.6	0.0	10.4	2.6 ± 1.2	0.5	4.4	4.2 ± 1.6	0.0	8.1	3,2 ± 2.2	0,0	10.4	
Compounds derived from hydroxymethylfurfural				1.3 ± 0.6	0.0	5.4	1.2 ± 0.5	0.3	1.8	**1.3 ± 1.0**	**0.0**	**4.5**	1,2 ± 0.9	0,0	5.4	
Classification according to the structure of the chemical skeleton																
Hydrocarbons				3.2 ± 1.8	0.9	9.7	3.7 ± 1.4	0.8	5.7	1.4 ± 1.2	0.0	4.5	2,6 ± 1.8	0.0	9.7	
Oxygenated compounds				77.6 ± 6.2	64.5	89.6	78.1 ± 6.0	71.2	83.5	74.3 ± 5.9	64.9	87.7	76,5 ± 5.1	64.5	89.6	
Phenolic compounds				18.2 ± 8.4	2.3	50.1	21.3 ± 8.2	4.6	35.2	41.8 ± 8.4	23.4	57.8	27.3 ± 14.6	2.3	57.8	
Furan compounds				7.7 ± 4.5	0.3	18.3	8.3 ± 3.7	2.1	14.7	4.2 ± 2.9	0.0	13.7	6,5 ± 4.3	0.0	18.3	
Pyran compounds				1.2 ± 0.6	0.3	2.6	0.7 ± 0.2	0.4	1.2	0.5 ± 0.4	0.0	1.5	0,9 ± 0.6	0.0	2.6	
Linear compounds				44.5 ± 9.7	14.8	61.7	41.2 ± 12.1	25.3	62.5	16.2 ± 7.4	4.3	33.0	33,6 ± 16.5	4.3	62.5	
Isophorone derivates				3.3 ± 1.8	0.8	10.1	4.8 ± 2.6	1.8	9.6	11.3 ± 3.8	3.7	20.3	6,4 ± 4.7	0.8	20.3	
Terpenic compounds				54.9 ± 10.6	20.1	71.2	51.3 ± 16.1	27.5	78.0	16.5 ± 8.2	2.9	37.8	40.2 ± 22.2	2.9	78.0	
Classification of terpene compounds																
Hydrocarbone monoterpenes				1.9 ± 1.3	0.0	6.1	1.9 ± 1.1	0.8	4.3	0.4 ± 0.6	0.0	2.2	1,3 ± 1.3	0.0	6.1	

(*continued on next page*)

Table 3 (*continued*)

Oxygenated monoterpenes	53.2 ± 10.1	20.7	69.2	49.7 ± 15.1	27.2	75.4	16.6 ± 7.9	2.9	36.9	39.2 ± 21.2	2.9	75.4
No terpenic hydrocarbons compounds	1.2 ± 1.2	0.0	4.5	1.8 ± 1.1	0.0	3.6	1.0 ± 0.9	0.0	3.2	1,3 ± 1.1	0.0	4.5
No terpenic oxygenated compounds	24.4 ± 9.8	3.7	56.8	28.4 ± 11.5	8.1	48.5	57.7 ± 8.8	38.5	71.8	37,2 ± 19.4	3.7	71.8

a: Order of elution is given on apolar column (Rtx-1); b: Retention index from litterature on the apolar column reported from reference (Konig et al., 2008; NIST WebBook, 2017); c: Retention indices on the Rtx-1 apolar column.

d: Mean, Min. and Max. values expressed as percentage of the volatile composition; e: RI, Retention indices; f: NIST library's spectrum of dihydrolinalool was employed to elucidate the structure of V33; MS, mass spectra in electronic impact mode; Ref. compounds identified from commercial data libraries: Konig et al. (2008) (V18, V23, V25, V26, V27, V28, V30, V35, V38, V40, V41, V46, V47, V49, V58, V59, V61, V65) and NIST (2017) (V7, V8, V12, V15, V16, V17, V23, V24, V25, V31, V36, V37, V39.

V42, V44, V45, V50, V52); g: Reference standards supplied by Sigma-Aldrich; h: Reference standards supplied by Supelco.

**: V16 and V17 were two very similar compounds, our data does not allow us to accurately assign these two isomers.

Table 2 (*continued*)

Samples	harvest time	Physico-chemical parameters		
		Moisture (%)	Color Pfund (mm)	Conductivity (μS/cm)
H68	2016/11/15	20.7	55	636.5
H69	2016/09/01	18.6	110	556.4
H70	2016/10/10	19.2	110	350.3
H71	2016/09/18	18.7	110	448.3
H72	2016/10/01	19.1	92	364.6
H73	2016/10/30	20.0	92	644.0
H74	2016/10/09	18.2	71	460.9
H75	2016/10/13	18.3	92	432.6
H76	2016/10/22	18.3	55	469.2
H77	2016/10/27	18.2	71	489.3
H78	2016/11/05	18.8	41	447.9
H79	2016/11/18	18.4	62	537.5
H80	2016/12/02	19.1	41	469.9
H81	2016/12/18	19.1	35	445.3
H82	2016/12/22	19.3	35	519.8
H83	2016/11/16	20.1	83	920.8
H84	2016/11/27	19.4	71	795.3
H85	2016/11/08	18.9	35	591.9
H86	2016/12/23	18.4	35	953.1
H87	2017/01/20	18.7	62	990.4
Mean ± SD		18.3 ± 1.4	60.8 ± 20.7	704.4 ± 188.3
Minimum		13.7	27	350.3
Maximum		21.9	110	1222

of the botanical origin of the samples. Further studies will be conducted to determine the pollen representation of the main species found in this study.

3.2. Physicochemical analysis

French Guiana honeys exhibited a high average water content of 18.3 ± 1.37 g/100g (range: 13.7–20.7 g/100g), which aligns with the moisture content standards established by Codex Alimentarius [26]. Average electrical conductivity value was 700 ± 200 μS/cm ranging from 350 to 1222 μS/cm. Among the 87 samples, some honeys showed conductivity above 800 μS/cm (Table 2). In accordance with Codex Alimentarius [26], it is presumed that French Guiana honeys may contain honeydew.

Based on United States Department of Agriculture (USDA) standard color values and designations, most of honeys harvested in French Guiana had a color range between 35 mm Pfund and 85 mm Pfund. Ten samples were darker in color (>85 ≤ 114 mm Pfund), while four samples were lighter (between 17 and 34 mm Pfund). These honeys were sampled at the beginning (July–August) and the end (December–January) of French Guiana beekeeping season, respectively. Twenty-one samples had very light amber coloration (between 34 and 50 mm Pfund) and fifty-two samples were classified as light amber (between 50 and 85 mm Pfund). These results are summarized in Table 2. These results are consistent with observations made by beekeepers, who noted a correlation between color and harvest period.

3.3. Volatile constituents of honeys collected in French Guiana

Analysis of volatile fractions in 87 French Guiana honeys using GC and GC/MS techniques identified 65 distinct chemical compounds. The peak areas of these compounds ranged from 64.9 to 91.5% of the total peak area. Of these, 30 components were successfully matched with the apolar and EI-MS retention index of our laboratory library compounds, while 35 components were identified using external libraries [19,20]. Volatile fractions were dominated by oxygenated compounds (which accounted for 64.5% to 89.6%) (Table 3).

Compounds belonging to the mevalonate pathway, including terpenes and terpenoids compounds, as well as those from shikimate pathway, such as phenolic compounds, were an important part of the volatile fraction, averaging 40.9 ± 22.5% and 26.7 ± 11.4%, respectively. This suggests that a substantial proportion of the molecules identified are related to plants metabolism, making them potential biomarkers [27,28]. On the other hand, molecules derived from the degradation of amino acids (V7 and V5), norisoprenoid derivatives (V23, V32, V34, V36, V47 and V65) and compounds derived from beeswax (V3, V9, V14, V18, V43, V57 and V64) were found in relatively low abundance.

In addition, different volatile fractions contained very few compounds derived from hydroxymethylfurfural (e. g. V4 and V6) – the samples studied were properly preserved [26,29].

Of the compounds derived from terpenes and terpenoids, several molecules had a structural analogy to linalool. Thus, the presence of V26, V28, V30, V31, V33, V35, V40 – V42 could be attributed to an enzymatic or thermal action [30,31]. The abundance of linalool-derived compounds could also be explained by the omnipresence of linalool in flower fragrances, which can passively diffuse into the nectar [32,33]. The main linalool derivative compounds observed in French Guiana honeys was hotrienol (V30) (16 ± 11.7%).

Table 4
Melissopalynological data of French Guiana honeys belonged chemical group I.

Geographical origin	Except for sites 2. 11 and 16 the other sites is concerns by this samples			RMJ	SLM	RMJ	M-T	RMJ	M-T	M-T	M-T	SLM	RMJ	SIN	M-K	SIN	SIN	SIN	SLM	SLM	M-T	Overall average of the 42 samples of chemical group I		
	Honey with RF*Mimosa pudica* > 90%			Honey with RF*Mimosa pudica* < 90%																				
Sample	H1. H2. H6. H12. H20-23. H25. H26. H28-33. H36. H39. H63. H64. H66. H69-71			H5	H7	H10	H16	H41	H51	H59	H65	H67	H68	H72	H73	H74	H75	H77	H83	H84	H87			
	Mean ± SD	min.	max.	Site 16	3	16	13	16	14	14	14	3	16	6; 7	8; 9;10	4; 5	6; 7	6; 7	3	3	14	Mean ± SD	min.	max.
Mimosaceae																								
Mimosa pudica	95.3 ± 2.3	91.0	98.6	34.4	54.0	48.4	47.1	56.5	58.3	54.1	87.6	56.3	40.3	89.2	78.5	78.8	86.9	84.1	85.0	59.2	85.4	82.6 ± 19.0	34.4	98.6
Arecaceae																								
Cocos sp.	0.4 ± 0.4	0.0	1.9	2.9		0.4	10.5	0.9	3.0	6.8	0.3	1.3	4.2	1.0	0.9	3.0	1.8	0.7	0.1	2.7	0.8	1.2 ± 2.0	0.0	10.5
Verbenaceae																								
Avicennia germinans	0.3 ± 0.4	0.0	1.3	5.0	–	1.1	0.5	1.7	1.8	2.7	1.4	2.0	2.9	1.9	3.1	8.8	2.1	3.9	0.1	0.7	0.6	1.1 ± 1.7	0.0	8.8
Anacardiaceae																								
Tapirira guianensis	0.8 ± 1.6	0.0	6.9	1.6	17.8	13.6	20.3	8.1	14.8	10.9	4.9	14.4	19.6	2.7	9.6	2.3	3.1	2.1	6.5	22.3	4.2	4.7 ± 6.6	0.0	22.3
Spondias mombin	0.02 ± 0.03	0.0	0.1	34.2		15.4	–	27.8	4.2	11.1	–	–	21.6	–	0.1	–	–	–	–	–	–	2.8 ± 7.8	0.0	34.2
Cecropiaceae																								
Cecropia sp.	0.4 ± 0.5	0.0	1.9	–	3.1	–	–	–	–	–	–	13.5	–	0.3	–	–	0.1	–	1.7	3.0	–	0.8 ± 2.1	0.0	13.5
Burseraceae																								
Protium sp.	0.05 ± 0.1	0.0	0.7	–	0.7	–	0.1	–	0.9	0.1	1.0	–	–	0.1	–	0.2	–	0.1	–	–	0.6	0.1 ± 0.3	0.0	1.0
Scrophulariaceae																								
Scrophulariaceae sp. type	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pollen not identified (NI)																								
NI.2	0.01 ± 0.03	0.0	0.1	–	–	–	–	–	0.5	–	0.04	–	–	0.2	0.2	–	0.3	–	–	0.3	3.0	0.1 ± 0.5	0.0	3.0
Honeydew indicators	cf tab. 1.2.3			I	F	F	I	F	I	I	–	VF	–	I	–	–	I	F	–	F	–			
Conductivity (μS/cm)	747.2 ± 205.2	350	1222	580	936	723	1040	776	851	851	980	920	636	364	644	460	432	489	920	795	990			

RF > 45%: **dominant pollen** forms; RF = 16–45%: **secondary pollen** forms; RF = 3–16%: **important minor** pollen; RF < 3%: **minor pollen**; Capital letters represent the frequency of Honeydew indicators: **I**. isolated; **F**.frequent; **VF**. very frequent; **RMJ**: Rémire-Montjoly; **SLM**: Saint-Laurent-du-Maroni; **M-T**: Montsinéry-Tonnégrande; **SIN**: Sinnamary; **M-K**: Macouria-Kourou.

Table 5
Melissopalynological data of French Guiana honeys belonged chemical group II.

Geographical origin	M-T	SLM	AYM	AYM	M-K	M-K	SLM	SLM	AYM	AYM	AYM	AYM	AYM	Overall average of the 13 samples of chemical group II		
Sample	H11	H13	H34	H35	H37	H44	H45	H46	H47	H48	H49	H62	H85			
	Site 13	3	1	1	8; 9;10	11	2	3	1	1	1	1	1	Mean ± SD	min.	max.
Mimosaceae																
Mimosa pudica	34.7	24.5	39.4	27.8	20.0	9.4	18.1	14.2	2.9	1.1	6.3	20.4	9.1	17.5 ± 11.9	1.1	39.4
Arecaceae																
Cocos sp.	30.5	9.2	9.0	5.9	2.2	0.4	1.0	2.5	5.3	4.8	0.3	9.0	8.4	6.8 ± 7.9	0.3	30.5
Verbenaceae																
Avicennia germinans	4.4	–	0.2	0.3	6.7	0.7	1.0	0.2	9.9	5.9	–	7.1	16.0	4.0 ± 4.9	0.0	16
Anacardiaceae																
Tapirira guianensis	**0.5**	**8.7**	-	**0.1**	**50.1**	**83.4**	**1.0**	**56.8**	–	**70.8**	**65.3**	**14.9**	**32.4**	**29.5 ± 31.6**	**0.0**	**83.4**
Spondias mombin	6.5	–	–	–	–	–	–	0.3	–	–	–	–	–	0.5 ± 1.8	0.0	6.5
Cecropiaceae																
Cecropia sp.	**0.6**	**16.8**	**22.6**	**20.3**	–	–	**35.2**	**3.5**	**11.1**	**4.8**	**0.3**	**20.4**	**10.9**	**11.3 ± 11.1**	**0.0**	**35.2**
Burseraceae																
Protium sp.	6.0	–	–	29.9	0.9	–	1.0	2.5	45.0	1.1	–	0.8	0.4	6.7 ± 14.1	0.0	45
Scrophulariaceae																
Scrophulariaceae sp. type	–	–	–	–	0.1	–	33.8	10.8	–	2.4	–	–	–	3.6 ± 9.5	0.0	33.8
Pollen not identified (NI)																
NI.2	0.4	–	–	–	–	–	–	–	–	1.5	16.1	0.4	–	1.4 ± 4.4	0.0	16.1
Honeydew indicators	–	–	–	I	–	–	–	I	I	I	I	I	VF			
Conductivity (μS/cm)	770	820	516	755	623	619	747	749	1025	915	754	658	591			

RF > 45%: dominant pollen forms; RF = 16–45%: secondary pollen forms; RF = 3–16%: important minor pollen; RF < 3%: minor pollen; Capital letters represent the frequency of Honeydew indicators: I. isolated; F.frequent; VF. very frequent; M-T: Montsinéry-Tonnégrande; SLM: Saint-Laurent-du-Maroni; AYM: Awala-Yalimapo; M-K: Macouria-Kourou.

Table 6
Melissopalynological data of French Guiana honeys belonged chemical group III.

Geographical origin	Majority from Sinnamary (SIN) except for H40 and H86 (from M-T)			SIN	SIN	SIN	SIN	M-T	SIN	M-K	M-K	M-K	M-T	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	SIN	Overall average of the 32 samples of chemical group III		
	Honey with RF*Mimosa pudica* > 90%			Honey with RF*Mimosa pudica* < 90%																									
	H3. H4. H18. H19. H24. H40. H53. H55. H86			H8	H9	H14	H15	H17	H27	H38	H42	H43	H50	H52	H54	H56	H57	H58	H60	H61	H76	H78	H79	H80	H81	H82			
	Mean ± SD	min.	max.	Site 4; 5	6; 7	4; 5	6; 7	13	6; 7	8; 9;10	11	11	14	6; 7	4; 5	4; 5	6; 7	4; 5	4; 5	4; 5	4; 5	4; 5	6; 7	4; 5	4; 5	6; 7	Mean ± SD	min.	max.
Mimosaceae																													
Mimosa pudica	95.6 ± 1.9	93.1	98.7	80.3	32.8	33.9	51.9	82.3	67.1	67.5	88.8	81.2	73.3	75.7	76.3	55.2	68.9	41.0	88.4	14.7	79.5	31.1	32.3	40.7	22.6	35.9	68.2 ± 26.3	14.7	98.7
Arecaceae																													
Cocos sp.	0.4 ± 0.4	0.0	1.0	0.7	6.6	10.8	1.2	3.2	3.4	1.0	1.0	0.6	3.9	3.8	2.9	4.1	2.1	4.0	1.8	5.5	1.5	2.9	2.7	6.0	7.2	4.6	2.7 ± 2.5	0.0	10.8
Verbenaceae																													
Avicennia germinans	0.7 ± 0.5	0.0	1.2	6.7	7.6	14.1	5.0	1.1	7.1	7.3	5.2	0.4	1.4	6.1	6.3	21.6	9.6	23.1	3.5	17.7	10.0	44.0	15.3	29.1	41.6	30.7	10.0 ± 12.1	0.0	44
Anacardiaceae																													
Tapirira guianensis	0.1 ± 0.1	0.0	0.3	–	2.1	4.8	3.9	1.2	–	–	0.1	0.2	–	0.1	–	–	0.3	14.8	0.0	38.1	1.9	2.4	0.8	5.3	4.7	2.7	2.6 ± 7.1	0.0	38.1
Spondias mombin	0.1 ± 0.2	0.0	0.6	–	0.2	0.4	–	0.3	–	0.2	–	–	7.9	0.1	0.1	0.2	–	5.6	–	10.9	0.0	0.2	0.1	0.7	4.7	2.7	1.1 ± 2.6	0.0	10.9
Cecropiaceae																													
Cecropia sp.	0.2 ± 0.2	0.0	0.5	–	–	–	–	0.3	0.1	0.2	2.2	–	0.2	0.5	0.9	0.3	0.1	0.3	1.1	0.4	0.2	0.3	–	0.4	1.3	–	0.3 ± 0.5	0.0	2.2
Burseraceae																													
Protium sp.	0.1 ± 0.1	0.0	0.2	4.1	6.1	–	0.2	5.4	0.6	1.3	–	–	0.1	8.5	8.2	3.6	0.9	0.9	1.3	0.6	0.1	–	0.4	0.8	0.2	0.6	1.4 ± 2.4	0.0	8.5
Scrophulariaceae																													
Scrophulariaceae sp. type	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pollen not identified (NI)																													
NI.2	0.03 ± 0.03	0.0	0.1	–	–	–	–	–	–	–	0.1	–	–	0.5	0.4	2.3	–	0.7	0.3	0.6	0.1	–	0.2	0.8	0.2	–	0.2 ± 0.5	0.0	2.3
Honeydew indicators	" I " for all samples except for H19 and H24		I	I	–	F	I	I	I	–	I	I	I	I	I	I	I	I	–	–	F	F	F	F					
Conductivity (μS/cm)	773.8 ± 173.9	555	1044	648	454	590	548	630	744	706	477	799	996	625	622	499	570	503	656	490	469	447	537	469	445	519			

RF > 45%: **dominant pollen** forms; RF = 16–45%: **secondary pollen** forms; RF = 3–16%: **important minor** pollen; RF < 3%: **minor pollen**; Capital letters represent the frequency of Honeydew indicators: **I**. isolated; **F**.frequent; **SIN**: Sinnamary; **M-T**: Montsinéry-Tonnégrande; **M-K**: Macouria-Kourou.

This compound is often co-eluted with tetrahydrolinalool (V31) (7,9 ± 5,4%). Hotrienol had already been reported in the composition of honeys harvested in temperate zones [30,34–36]. It is a major volatile compound found in purple milk thistle (*Galactites tomentosa* Moench) and winter savory (*Satureja montana* L.) honeys [35,37]. In addition, it has been designated as a chemical marker of *Citrus* L. honeys with lilac aldehyde and 1-p-menthen-al [10,30]. To our best knowledge, hotrienol has been cited in only four publications related to harvested honeys harvested in tropical climates. This include the predominant compound *Coffea* L. honeys [38–41].

Tetrahydrolinalool (V31), a stable fragrance compound, has not yet been reported in the volatile composition of honey. Its content varied between 0.4% and 21.6%. It was the major compound in the volatile fraction of 10 samples (H10, H25, H28, H62, H63, H66, H68, H74, H76, H87). The natural appearance of tetrahydrolinalool in flower aroma is very rare [32]. To our best knowledge, V31 has been identified in the volatile fraction of *Listea guatemalensis* Mez. leaves (as the main volatile compound), *Fagopyrum tataricum* L. and Virginia tobacco [15,42].

In our studies, thymol (V58) and its carvacrol isomer (V59) were detected at low concentrations (0.2%–1.3% and 0.1%–2.3% respectively). The presence of these compounds can be attributed to their use against parasites and microbes [43]. However, concentrations of thymol and carvacrol were negligible and did not significantly affect the taste of the honey. Unlike terpenic compounds, there are few publications describing the origin of shikimate pathway products in honey. Among the shikimate pathway-derived compounds found in French Guiana honeys: V22, V29, V45, V48, V60 and V61 seemed to be the most interesting and the only ones with contents that could exceed 10%. These compounds have been previously identified as potential botanical markers. Indeed, Shikimate pathway-derived compounds are widely cited as important biomarkers for determining the botanical and geographical origin of honeys [5,6,18,44–46].

For instance, 2-phenylethanol (V29) is a very common molecule in floral fragrances [32]. It could spread into the nectar and contribute to the chemical signature of honey. In our samples V29 represented a minor portion of the volatile fraction with an average 2.5 ± 3.7%. It is generally not present in the volatile fraction of honeys [32,41,47]. To the best of our knowledge, it has only been reported as major (>50%) in the volatile fraction of *Amorpha fruticosa* L. honeys, making it a distinctive botanical marker for these honeys [45]. In the tropical context, its presence (1.2%) has been reported in the volatile fraction of a mangrove honey (*Avicennia germinans (L.) Stearn*) [41]. Given its presence in French Guiana honeys with other compounds in the volatile fraction, it may be considered a potential marker for these honeys.

Methyl 2-phenylacetate (V45) has been previously reported in organic extractions from Leatherwood (*Eucryphia lucida* (Labill.) Baill.) and *Erica* L. honey. It has also been found in the flowers of *Eucryphia lucida* and Passifloraceae [32,36,48]. V45 was particularly remarkable as it represented the main compound in the volatile fraction of 5 samples (H15, H30, H42, H58 and H81). To our knowledge, this molecule has not yet been suggested as a chemical marker for honey.

Para-anisaldehyde (V48) is known to be a botanical marker for *Erica arborea* L. honeys where its content can reach up to 21.0% [5]. It has also been used in combination with other molecules to geographically distinguish *Tilia cordata*'s honey [49]. In tropical regions, its presence has only been reported once in Cuban honey, with a content of about 1.0% [38]. This is close to the levels obtained with honeys from French Guiana (2.5 ± 2.7%).

3,4,5 trimethylphenol (V60), rarely reported in honeys, was identified in French Guiana honeys at mean level of 3%. This compound is used as a differentiating factor for various types of Manuka honey from the *Leptospermum* J.R.Forst. & G.Forst. genus [50]. Notably, V60 is predominantly present in honeys from *Arbutus unedo* L [18]. V60 is believed to be formed by demethylation and methylation processes involving p-methylanisole during honey storage and maturation in the hive [18].

3-hydroxy-4-phenyl-2-butanone (V61) was the major compound in 16 honeys (H14, H27, H40, H52, H53, H55–57, H60–62, H78–80, H82, H86). It is know to be present in the floral fragrance of several plants belonging to the Orchidaceae, Sapotaceae and Fabaceae families. Additionally, it has been identified as a marker of thyme honeys [32,44].

Phenylacetaldehyde (V22) is derived from phenylalanine by Strecker degradation or enzymatic catalysis. It serves as a marker of the botanical origin of *Asphodelus microcarpus* Viv. Honey, where its concentration is particularly high (40.6 ± 6.2%) [46,51]. In our samples, its content was often less than 10%, except in H1 (16%), H4 (18,2%) and H16 (10%).

Finally, in volatile fraction of French Guiana honeys, norisoprenoid compounds were also present. They were essentially C9-norisoprenoids (V23, V32, V34, V36), C10-norisoprenoids (V47) and C13-norisoprenoids (V65). These compounds are derived from the degradation of abscisic acid or carotenoids [31]. Although present in small quantities within the volatile fraction of honeys, norisoprenoid compounds have already been suggested as markers for determining the botanical origin of honey [10,52,53].

Furthermore, the presence of 2,2,6-trimethyl-1,4-cyclohexanedione (V36) in French Guiana honeys is of particular interest, as this compound has not been previously reported in the volatile composition of honey in existing literature.

3.4. Correlation between volatile composition and palynology

In order to explore a potential correlation between melissopalynological and volatile data of honey samples, CA (dendrograms) and PCA were applied. However, two chemical families (compounds derived from HMF and compounds derived from beeswax) were excluded from the analysis as they did not contribute to the understanding of the botanical origin. Compounds from the degradation of amino acids were also removed due to their insignificant proportions (0.1% ± 0.2). For pollen parameters, we selected nectariferous taxa with relative frequency (RF) of at least 16% (refer to Table 1, Table 4, Table 5 and Table 6). *Solanum* L. and *Mauritia flexuosa* L.f. which function solely as pollinators, were removed from the statistical analysis. We chose to include NI.2 in the statistical treatment as it botanical origin has not yet been determined.

The dendrogram (Fig. 2) revealed of three groups: Group I included 42 samples, Group II included 13 samples and Group III included 32 samples. This dendrogram clarified the clusters observed in the PCA analysis (Figs. 3 and 4). However, Group II (H11, H13,

H34, H35, H37, H44–49, H62 and H85) was not as clearly defined in the PCA results. Interestingly, one sample (H5), which was classified within Group I according to CA, appeared to be mixed with samples belonging to Group III in the PCA analysis. The combined variance explained by the two PCA axes accounted for 47.44% of the total variability observed in the 87 honey samples. Fig. 3 showed the distribution of variables, while Fig. 4 showed the distribution of different honey samples. Dimension 1 (26.51%) showed a negative correlation with mevalonate derivative compounds, $RF_{NI.2}$, $RF_{Schrophulariaceae\ sp.}$, $RF_{\textit{Tapirira guianensis}}$ and $RF_{\textit{Cecropia}\ sp.}$; while demonstrating positive correlation with ther variables. Dimension 2 (20.93%) was negatively correlated to shikimate derivative compounds and $RF_{\textit{Mimosa pudica}}$. With the exception of the samples belonging to chemical Group II, the distribution of samples based on the two axes (Fig. 4) showed two important chemical groups (Group I and Group III).

Group I included 42 samples (H1, H2, H5-7, H10, H12, H16, H20–23, H25, H26, H28, H29–33, H36, H39, H41, H51, H59, H63–75, H77, H83, H84 and H87), representing 48% of honey samples. This group was characterized by a higher average concentration of compounds derived from mevalonate and/or methylerythritol pathways. Notably, it had a prominent composition rich in hotrienol (V30), tetrahydrolinalool (V31) and 1,2-dihydrolinalol (V35). Melissopalynological analysis of honey belonged Group II showed that they would be representative of honeys sold under the trade name “forest honey”. Except for samples rich in *Mimosa pudica* L., these honeys were characterized by the presence of *Tapirira Guianensis* Aubl., *Spondias mombin* L. or *Cecropia* Loefl. (see Table 4). Three samples from Saint-Laurent-du-Maroni (H7 and H67) and Montsinéry-Tonnégrande (H39) had high conductivity (>800 μS/cm) with a significant presence of honeydew indicators. According to Codex Alimentarius [26] these three samples may contain honeydew.

Group II included 13 samples (H11, H13, H34, H35, H37, H44–49, H62 and H85). The general chemical composition of this group was similar to Group I, although values for V30, V31 and V35 were slightly lower. In Group II, the presence of compounds derived from the mevalonate pathway was lower (52.6% versus 55.7%), while the content of compounds from the Shikimate pathway was higher (20.4.1% versus 17.2%). Consequently, the phenolic content was higher in Group II (21.3% versus 18.2%). Pollen analysis showed that honeys of this group were mainly dominated by *Tapirira guianensis* Aubl. (H37, H44, H46, H48, H49, H85), *Cecropia* Loefl. (H45 and H62) or *Protium* sp. (H35 and H47) — see Table 5. The majority of Group II honeys were harvested in Saint-Laurent-du-Maroni and Awala-Yalimapo. All samples from Awala-Yalimapo were present in this chemical group and were the only samples where *M. pudica* L. was not dominant (RF < 45%). Three samples (H13, H47, H48) had a conductivity above 800 μS/cm. But in theses sample, honeydew indicators were isolated or non-existent. Further studies must be carried out to determine the origin of this high conductivity.

Group III (H3, H4, H8, H9, H14, H15, H17–19, H24, H27, H38, H40, H42, H43, H50, H52–58, H60, H61, H76, H78–82 and H86) had a high average of norisoprenoid compounds (11.3 ± 3.8% versus 3.3 ± 1.8% and 4.8 ± 2.6% for Group I and Group II,

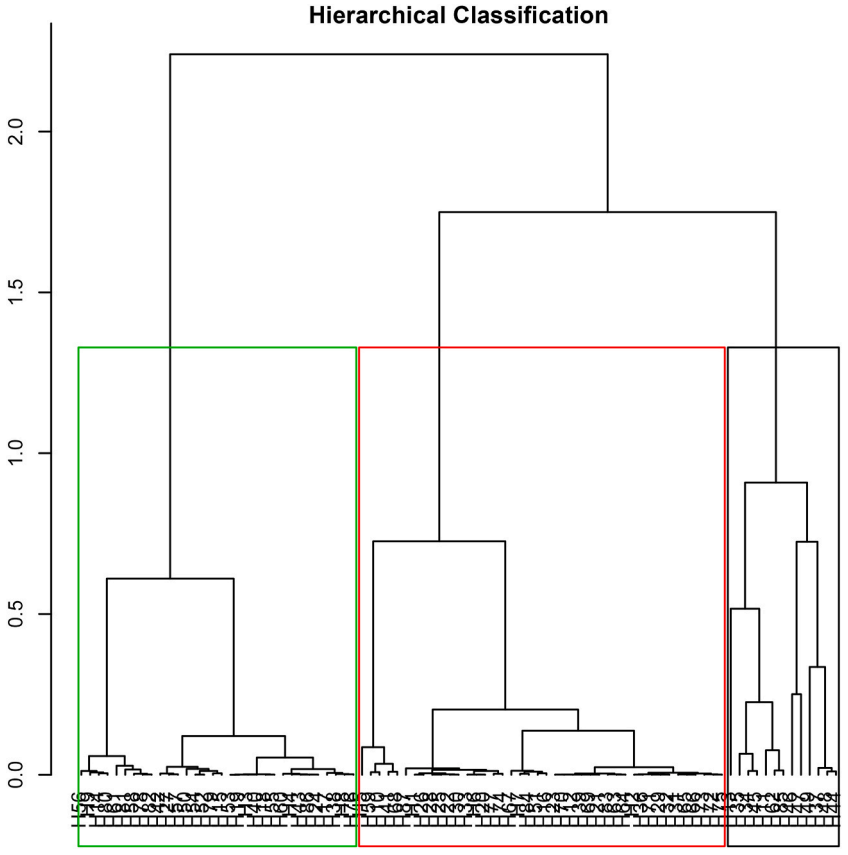

Fig. 2. Dendrogram of melissopalynological and chemical data from French Guiana Honeys.

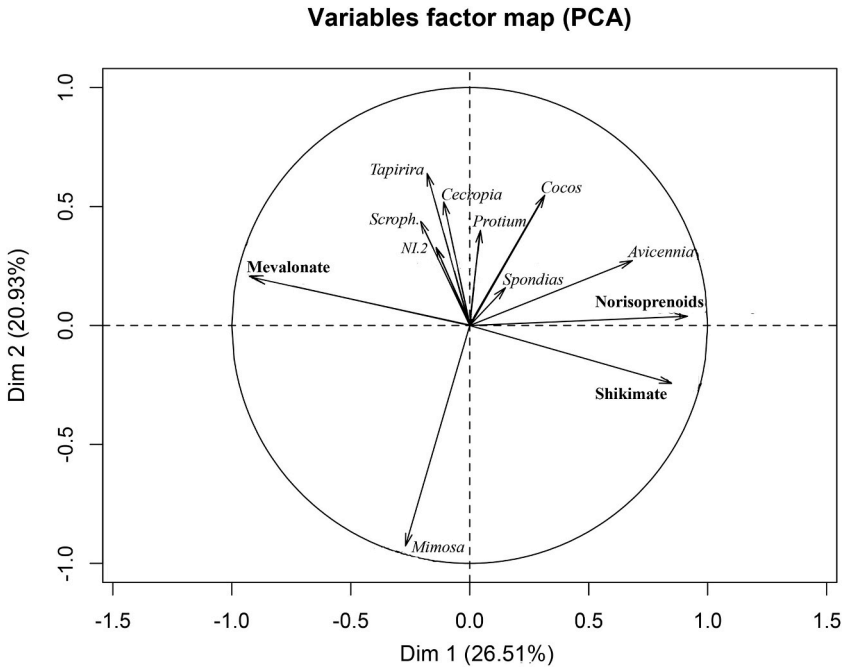

Fig. 3. PCA of melissopalynological and chemical data of French Guiana Honeys: PCA distribution of variable.

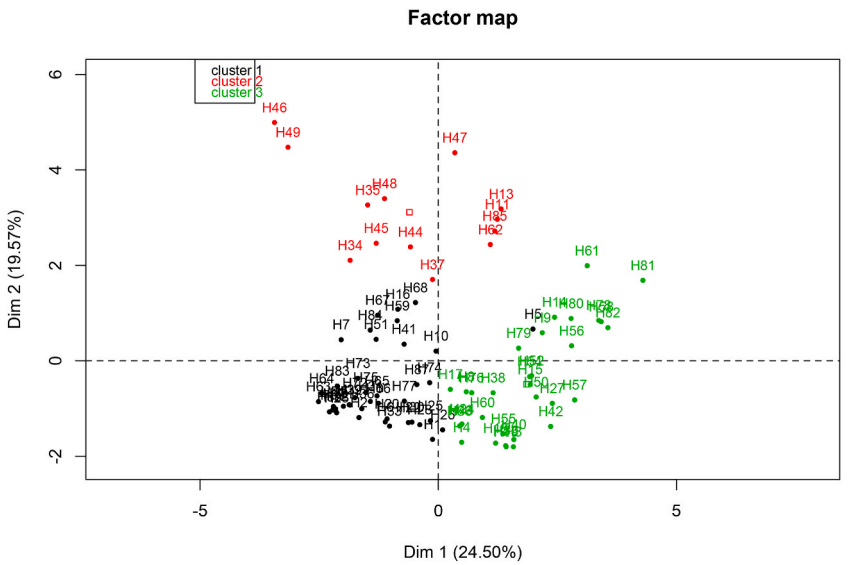

Fig. 4. PCA of melissopalynological and chemical data of French Guiana Honeys: PCA distribution of samples.

respectively). The average content of shikimate-derived compounds was higher in Group III compared to Groups I and II (41.1 ± 8.3% versus 17.2 ± 9.2% and 20.4 ± 10.7% respectively). Relative Frequency of *Mimosa pudica* L. remained quite high (>45%) in most samples of this group (refer to Table 6). When the RF of *Mimosa pudica* L. decreased, other taxa such as *Cocos* L., *Avicennia germinans* L. (Stearn), *Tapirira guianensis* Aubl. And *Protium* Burm.f. appeared. A clear presence *Avicennia germinans* L. (Stearn) pollen (10.0 ± 12.1 versus 1.1 ± 1.7 and 4.0 ± 4.9 respectively) was observed when comparing Groups III, I and II. Over 78% of the samples in this chemical group were from Sinnamary. The conductivity was often below 800 μS/cm, except for H24, H40, H86 (930 μS/cm, 1044 μS/cm and 953 μS/cm, respectively) which had low honeydew indicators.

Overall, the statistical analysis revealed that the vast majority of honey samples was clustered around the vectors of "mevalonate", "shikimate" and "*Mimosa*". The division of the samples along dimension 1 (26.51%) of the PCA showed the presence of two main groups (groups I and III). Samples belonged to Group II were distributed on both sides of dimension 1. Groups I and III had samples

with *Mimosa pudica* L. over-represented (RF>90%).

According to Barneby [54], *M. pudica* L. is not considered a nectariferous specie. Statistical results pointed to this conclusion. Interestingly, samples with a dominant presence of *M. pudica* L. (RF>45%) were not grouped but rather found in two different chemical groups. This suggested that the high occurrence of *M. pudica* L. pollen in honeys might be caused by anemophilous pollution.

According to this distribution, it is assumed that *M. pudica* L. does not significantly contribute to the elaboration of the sampled honeys. If *M. pudica* L. were indeed a nectariferous plant, the honeys with an overrepresentation of this species would have formed a distinct chemical group.

Furthermore, the combination of high conductivity values and the presence of honeydew indicators in some samples suggested that honeydew may be present in French Guiana honeys. To our best knowledge, no previous publication in the Guianas shield area reported honeydew collection by bees.

3.5. Total polyphenolic content and antioxidant activity

Total polyphenolic contents in our samples ranged from 450 to 140 μg GAE/g of honey. By comparing our results to literature data obtained under the same test conditions, our samples showed similar values to Cuban honeys (213–320 μg GAE/g honey) and to certain multifloral honeys collected in the Brazilian region of Para and Roraima (366 and 315–442 μg GAE/g honey, respectively) [16,17,29,55].

A certain correlation ($R^2 = 0,63$) was observed between the total polyphenolic content (TPC) and the color of the honey samples. This finding supports previous studies suggesting a link between color intensity in honey and the presence of pigment compounds such as flavonoids or carotenoids. It appears that the intensity of honey color is associated with the concentration of these compounds [17,29].

ORAC activity of the honey samples ranged from 1 to 4,5 μmol TE/g honey. Previous studies in tropical regions reported values ranging from 4 to 5 μmol TE/g for *Turbina corymbosa* (L.) Raf. honey. On the other hand, *Gouania polygama* (Jacq.) Urb. and *Avicennia germinans* L. (Stearn) honeys show ed values ranging from 7.4 to 13.0 μmol TE/g of honey [29,55].

In terms of TEAC values, they ranged from 0.2 to 1 μmol ET/g of honey. Lower concentrations (less than 2 μmol ET/g of honey) have already been reported in Cuban honeys (*Avicennia germinans* L. (Stearn), *Lysolima* Benth. and *Turbina corymbose* (L.) Raf.) by Alvarez-Suarez et al. [29,55].

These results suggest that the tested samples contain compounds of biological interest with ORAC and TEAC activity, which differ from those reported in the existing literature. Further investigations are required to identify the chemical family of these compounds.

4. Conclusion

Apis mellifera bees living in the Amazon biome have a wide range of resources. It is therefore crucial to identify biomarkers that can determine the botanical origin of honey and add commercial value to French Guiana honey productions. This work presents, for the first time, data on the composition of the volatile fraction and the biological activity of honey harvested from the western coastal strip of French Guiana. Our HS-SPME, TPC, ORAC and TEAC results are particularly interesting because they reveal several molecule markers, including hotrienol (V30), tetrahydrolinalool (V31), 2-phenylethanol (V29) and (E)-β-Damascenone (V65). Furthermore, they confirm the presence of molecules of biological interest.

Statistical analysis showed three possible categories of honeys: multifloral honeys with a *Tapirira guianensis* Aubl. and/or *Spondias mombin* L. and/or *Cecropia* Loefl. and/or *Protium* Burm.f. trend (chemical group I and II); multifloral honeys with *Avicennia germinans* (L.) Stearn (chemical group III) trend; and honeys dominated by *Mimosa pudica* L whose botanical origin remains complex.

Studies on polyphenols in French Guiana honeys would be intriguing because, in addition to their activities, they can serve as excellent chemicals markers.

Author contribution statement

Weiwen JIANG: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Julien PAOLINI: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Didier BEREAU, Élodie JEAN-MARIE: Analyzed and interpreted the data; Wrote the paper.

Marie-José BATTESTI: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Yin YANG: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Jean COSTA: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Jean-Charles Robinson: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We express our gratitude to Bruno Gaucher, Arnaud Berthelous, Patrick Erre, Pascal Prévot, Nicolas Hibon, Nicolas Birebent, Pascal Gombauld and the French Guiana beekeepers' association (APIGUY) for generously providing us with honey samples. We also extend our appreciation to Françoise Crozier for her valuable assistance and companionship throughout this research. Furthemore, we would like to acknowledge the financial support provided by the Collectivité Territoriale de Guyane (CTG ; grant number 22/cr/2015).

References

[1] O.O. Erejuwa, S.A. Sulaiman, M.S. Ab Wahab, Honey: a novel antioxidant, Molecules 17 (2012) 4400–4423.
[2] S. Bogdanov, T. Jurendic, R. Sieber, P. Gallmann, Honey for nutrition and health: a review, J. Am. Coll. Nutr. 27 (2008) 677–689.
[3] M.-J. Battesti, Contribution à la mélissopalynologie méditerranéenne - Les miels de Corses, Université D'Aix-Marseille III, 1990.
[4] W. Von der Ohe, L. Persano Oddo, M. Lucia Piana, M. Morlot, P. Martin, Harmonized methods of melissopalynology, Apidologie 35 (2004) 18–25.
[5] Y. Yang, et al., Melissopalynological origin determination and volatile composition analysis of Corsican "Erica arborea spring maquis" honeys, Food Chem. 134 (2012) 37–47.
[6] Y. Yang, et al., Melissopalynological origin determination and volatile composition analysis of Corsican "chestnut grove" honeys, Food Chem. 132 (2012) 2144–2154.
[7] Y. Yang, M.-J. Battesti, J. Paolini, J. Costa, Pollen diversity and volatile variability of honey from Corsican anthyllis hermanniae L. Habitat, Chem. Biodivers. 11 (2014) 1900–1913.
[8] Y. Yang, et al., Characterization of botanical and geographical origin of Corsican "spring" honeys by melissopalynological and volatile analysis, Foods 3 (2014) 128–148.
[9] R. Consonni, L.R. Cagliani, Recent developments in honey characterization, RSC Adv. 5 (2015) 59696–59714.
[10] A.C. Soria, J. Sanz, I. Martínez-Castro, SPME followed by GC–MS: a powerful technique for qualitative analysis of honey volatiles, Eur. Food Res. Technol. 228 (2009) 579–590.
[11] L.F. Cuevas-Glory, J.A. Pino, L.S. Santiago, E. Sauri-Duch, A review of volatile analytical methods for determining the botanical origin of honey, Food Chem. 103 (2007) 1032–1043.
[12] M. Canova, B. Gaucher, Note sur l'apiculture et les abeilles africanisées en Guyane française, Revue d'élevage et de médecine vétérinaire des pays tropicaux 44 (1991) 497–500.
[13] D.W. Roubik, Foraging behavior of competing africanized honeybees and stingless bees, Ecology 61 (1980) 836–845.
[14] A.C.V. da Costa, et al., Volatile profile of monofloral honeys produced in Brazilian semiarid region by stingless bees and key volatile compounds, LWT (Lebensm.-Wiss. & Technol.) 94 (2018) 198–207.
[15] S.C.B. Domingos, et al., Antibacterial activity of honeys from Amazonian stingless bees of Melipona spp. and its effects on bacterial cell morphology, J. Sci. Food Agric. 101 (2021) 2072–2077.
[16] P.S. Oliveira, et al., Phenolic acids, flavonoids and antioxidant activity in honey of Melipona fasciculata, M. flavolineata (Apidae, Meliponini) and Apis mellifera (Apidae, Apini) from the Amazon, Quím. Nova 35 (2012) 1728–1732.
[17] J.A. Pontis, L.A.M.A. Costa, S.J.R. da Silva, A. Flach, Color, phenolic and flavonoid content, and antioxidant activity of honey from Roraima, Brazil, Food Sci. Technol. 34 (2014) 69–73.
[18] Y. Yang, M.J. Battesti, J. Costa, J. Paolini, Melissopalynological and volatile analysis of honeys from Corsican Arbutus unedo habitat, Nat. Prod. Commun. 9 (2014) 1523–1526.
[19] W.A. König, D.H. Hochmuth, D. Joulain, Terpenoids and Related Constituans of Essential Oils: Library of Mass Finder, Institute of Organic Chemistry, 2008.
[20] Available at:, NIST WebBook, National Institute of Standards and Technology, 2017 http://webbook.nist.gov/chemistry/.
[21] V.L. Singleton, J.A. Rossi, Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents, Am. J. Enol. Vitic. 16 (1965) 144–158.
[22] A. Ghiselli, M. Serafini, G. Maiani, E. Azzini, A. Ferro-Luzzi, A fluorescence-based method for measuring total plasma antioxidant capability, Free Radic. Biol. Med. 18 (1995) 29–36.
[23] R. Re, et al., Antioxidant activity applying an improved ABTS radical cation decolorization assay, Free Radic. Biol. Med. 26 (1999) 1231–1237.
[24] S. Bogdanov, Harmonised methods of the international honey commission, IHC 61 (2009).
[25] J. Louveaux, A. Maurizio, G. Vorwohl, Commission internationale de BOTANIQUE APICOLE de L'U.I.S.B. : les méthodes de la mélisso-PALYNOLOGIE, Apidologie 1 (1970) 211–227.
[26] Codex Stan 12-1981, Codex normé pour le miel, 2001.
[27] F. Chen, D. Tholl, J. Bohlmann, E. Pichersky, The family of terpene synthases in plants: a mid-size family of genes for specialized metabolism that is highly diversified throughout the kingdom, Plant J. 66 (2011) 212–229.
[28] T. Goto, N. Takahashi, S. Hirai, T. Kawada, Various terpenoids derived from herbal and dietary plants function as PPAR modulators and regulate carbohydrate and lipid metabolism, PPAR Res. 2010 (2010), 483958.
[29] J.M. Alvarez-Suarez, et al., Antioxidant and antimicrobial capacity of several monofloral Cuban honeys and their correlation with color, polyphenol content and other chemical compounds, Food Chem. Toxicol. 48 (2010) 2490–2499.
[30] E. Alissandrakis, P.A. Tarantilis, P.C. Harizanis, M. Polissiou, Aroma investigation of unifloral Greek citrus honey using solid-phase microextraction coupled to gas chromatographic–mass spectrometric analysis, Food Chem. 100 (2007) 396–404.
[31] I. Jerković, P.M. Kuś, Terpenes in honey: occurrence, origin and their role as chemical biomarkers, RSC Adv. 4 (2014) 31710–31728.
[32] J.T. Knudsen, R. Eriksson, J. Gershenzon, B. Ståhl, Diversity and distribution of floral scent, Bot. Rev. 72 (2006) 1.
[33] Nectaries and Nectar, Springer Netherlands, 2007, https://doi.org/10.1007/978-1-4020-5937-7.
[34] G. Barra, M. Pía, M.C. Ponce-Díaz, C. Venegas-Gallegos, Volatile compounds in honey produced in the central valley of ñuble province, Chile, Chil. J. Agric. Res. 70 (2010) 75–84.
[35] I. Jerković, C.I.G. Tuberoso, Z. Marijanović, M. Kranjac, M. Malenica-Staver, Antioxidant capacity and chemical profiles of Satureja Montana L. Honey: hotrienol and syringyl derivatives as biomarkers, Chem. Biodivers. 12 (2015) 1047–1056.
[36] C.Y. Rowland, A.J. Blackman, B.R. D'Arcy, G.B. Rintoul, Comparison of organic extractives found in Leatherwood (Eucryphia lucida) honey and Leatherwood flowers and leaves, J. Agric. Food Chem. 43 (1995) 753–763.
[37] I. Jerković, et al., Bioorganic research of galactites tomentosa Moench. Honey extracts: enantiomeric purity of chiral marker 3-phenyllactic acid, Chirality 26 (2014) 405–410.
[38] L. Ceballos, J.A. Pino, C.E. Quijano-Celis, A. Dago, Optimization of a HS-SPME/GC-MS method for determination of volatile compounds in some CUBAN unifloral honeys: CUBAN unifloral honeys, J. Food Qual. 33 (2010) 507–528.

[39] L. Cuevas-Glory, E. Ortiz-Vázquez, J.A. Pino, E. Sauri-Duch, Floral classification of Yucatan Peninsula honeys by PCA & HS-SPME/GC–MS of volatile compounds, Int. J. Food Sci. Tech. 47 (2012) 1378–1383.
[40] I. Jerković, C.I.G. Tuberoso, P.M. Kuś, Z. Marijanović, M. Kranjac, Screening of Coffea spp. honey by different methodologies: theobromine and caffeine as chemical markers, RSC Adv. 4 (2014) 60557–60562.
[41] J.A. Pino, Analysis of odour-active compounds of black mangrove (Avicennia germinans L.) honey by solid-phase microextraction combined with gas chromatography–mass spectrometry and gas chromatography–olfactometry, Int. J. Food Sci. Tech. 47 (2012) 1688–1694.
[42] S. Cruz, et al., Chemical composition of essential oil of litsea guatemalensis (Mexican bay) from different provenances of Guatemala, Acta Hortic. 964 (2012) 47–58.
[43] S.R. Fuselli, et al., Efficacy of indigenous plant essential oil andean thyme (acantholippia seriphioides A. Gray) to control American foulbrood (AFB) in honey bee (Apis mellifera L.) hives, J. Essent. Oil Res. 19 (2007) 514–519.
[44] E. Alissandrakis, P.A. Tarantilis, P.C. Harizanis, M. Polissiou, Comparison of the volatile composition in thyme honeys from several origins in Greece, J. Agric. Food Chem. 55 (2007) 8152–8157.
[45] I. Jerković, Z. Marijanović, J. Kezić, M. Headspace Gugić, Volatile and semi-volatile organic compounds diversity and radical scavenging activity of ultrasonic solvent extracts from Amorpha fruticosa honey samples, Molecules 14 (2009) 2717–2728.
[46] I. Jerković, C.I.G. Tuberoso, A. Kasum, Z. Marijanović, Volatile Compounds of Asphodelus microcarpusSalzm. et Viv. Honey Obtained by HS-SPME and USE Analyzed by GC/MS, Chem. Biodivers. 8 (2011) 587–598.
[47] L. Piasenzotto, L. Gracco, L. Conte, Solid phase microextraction (SPME) applied to honey quality control, J. Sci. Food Agric. 83 (2003) 1037–1044.
[48] M.S. Rodríguez-Flores, S.I. Falcão, O. Escuredo, M.C. Seijo, M. Vilas-Boas, Description of the volatile fraction of Erica honey from the northwest of the Iberian Peninsula, Food Chem. 336 (2021), 127758.
[49] I. Blank, K.-H. Fischer, W. Grosch, Intensive neutral odourants of linden honey Differences from honeys of other botanical origin, Z. Lebensm. Unters. Forsch. 189 (1989) 426–433.
[50] N. Beitlich, I. Koelling-Speer, S. Oelschlaegel, K. Speer, Differentiation of Manuka honey from kanuka honey and from jelly bush honey using HS-SPME-GC/MS and UHPLC-PDA-MS/MS, J. Agric. Food Chem. 62 (2014) 6435–6444.
[51] E. Anklam, A review of the analytical methods to determine the geographical and botanical origin of honey, Food Chem. 63 (1998) 549–562.
[52] I. Jerković, Z. Marijanović, C.I.G. Tuberoso, D. Bubalo, N. Kezić, Molecular diversity of volatile compounds in rare willow (<Emphasis Type="BoldItalic">Salix</Emphasis> spp.) honeydew honey: identification of chemical biomarkers, Mol. Divers. 14 (2010) 237–248.
[53] D. Mannaş, T. Altuğ, SPME/GC/MS and sensory flavour profile analysis for estimation of authenticity of thyme honey, Int. J. Food Sci. Tech. 42 (2007) 133–138.
[54] R.C. Barneby, Sensitivae Censitae : A Description of the Genus Mimosa Linnaeus (Mimosaceae) in the New World, The New-York botanical garden, 1991.
[55] J.M. Alvarez-Suarez, A.M. González- Paramás, C. Santos-Buelga, M. Battino, Antioxidant characterization of native monofloral Cuban honeys, J. Agric. Food Chem. 58 (2010) 9817–9824.