

# Physico-Chemical Characterization of Some Honeys from the Savannah-Gallery Forest Complex and Primary Forest in Gabon

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## Abstract

Honey harvesting throughout beekeeping is a technology recently introduced in Gabon comparing to the other African countries well known in international honey trade. The purpose of this study is to contribute to the knowledge of the quality of multi-flower honeys from the savannah-gallery forest complex and primary forest not well documented in Gabon. Physical and chemical parameters of different honeys were analyzed using the official methods of analysis of the Association of Official Analytical Chemists. The results of physico-chemical analysis show variations in pH (3.4 to 3.9), free acidity (37.12 to 76.65 meq·kg<sup>-1</sup>), water content (17.49% to 21.21%), electrical conductivity (0.64 to 1.24 mS·cm<sup>-1</sup>), density (1.02 to 1.03) and total sugar content (77% to 82%). These variations were significantly different ( $p < 0.05$ ) between certain honeys, but independent of the type of ecosystem considered. The pH values confirmed the botanical origin of the five honeys. The physico-chemical parameters of the honeys show significant correlations ( $p < 0.05$ ). Moisture content is negatively correlated with conductivity ( $r = -0.628$ ), pH ( $r = -0.631$ ), density ( $r = -0.552$ ) and total sugar content ( $r = -0.890$ ). Conductivity is positively correlated with free acidity ( $r = 0.688$ ) and total sugar content ( $r = 0.776$ ), and negatively correlated with water content ( $r = -0.628$ ). All honeys were in line with Codex Alimentarius standards, except for 3 types of honey (M1, M2 and M4) for free acidity and electrical conductivity, showing possible fermentation of these honeys.

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## Keywords

Physico-Chemical Parameters, Honey, Gabon, Codex Alimentarius

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### 1. Introduction

In Gabon, the management of natural resources likely to ensure both their protection and reconstitution to guarantee their sustainability is framed by the Law 007/2014. Protecting the environment is a key issue to mankind, and he takes an interest in his environment, observing, analyzing and drawing inspiration from the beauty offered by the pollinating honeybees that are essential to life. Honey is the main and most sought-after bee product [1] (Tchoumboué *et al.*, 2010). It is a natural sweet substance produced by bees of the species *Apis mellifera adansonii* Latreille, from plant nectar or secretions from living plant parts, or from the excretions of foraging insects [2] (Codex Alimentarius, 2022). Bees gather these substances, which they transform by combining them with other, more specific substances they secrete themselves, deposit, dehydrate, store and allow to refine and mature in the hive's wax combs [2] (Codex Alimentarius, 2022), [3] (Koudegnan *et al.*, 2012). Honey is a complex nutritional sweetener composed mainly of carbohydrates (60% - 85%) and water (12% - 23%) [4] (Machado De-Melo *et al.*, 2018). It also contains small quantities of other compounds, such as organic acids, minerals, vitamins, enzymes, proteins, amino acids, Maillard reaction products, volatile substances and several bioactive substances (phenols and flavonoids among others), as well as pollen grains [4] (Machado De-Melo *et al.*, 2018), [5] (Abselami *et al.*, 2018). The chemical composition of honey and its physico-chemical properties are variable and depend on the botanical origin of the plants foraged, the geo-climatic conditions of the sites considered and anthropic influence [6] (Belhaj *et al.*, 2015), [7] (Mbogning *et al.*, 2011). For several millennia until the early 18<sup>th</sup> century, honey was the main source of sugar for man [8] (Darigol, 1996). Honey is highly prized for its dietary, therapeutic virtues due to its antioxidant, microbial, inflammatory, proliferative, cancerous and metastatic properties, but also its cosmetic properties [9] (Kunat-Budzyńska *et al.*, 2023).

In Gabon, as in other African countries, honey is a non-timber forest product (NTFP) used mainly in traditional medicine and for its nutritional virtues. It is a source of income for rural populations. Honey is produced mainly by harvesting in primary or secondary forests and is then sold locally. Honey can be packaged in glass bottles or in different types of containers that can alter its physico-chemical parameters [10] (Djossou *et al.*, 2013). The growing national demand for honey in the local market, can only be met by introducing the practice of beekeeping among the rural population [11] (FAO, 2017). Over time, honey undergoes a few modifications resulting in the loss of its essential qualities [6] (Belhaj *et al.*, 2015). Considering the factors of honey composition and quality according to Codex Alimentarius standard CXS 12-2022, honey must not contain unknown materials, nor

have unacceptable taste, aroma or contamination from foreign materials absorbed during processing and storage. Honey must not reach the stage of fermentation or effervescence [2] (Codex Alimentarius, 2022).

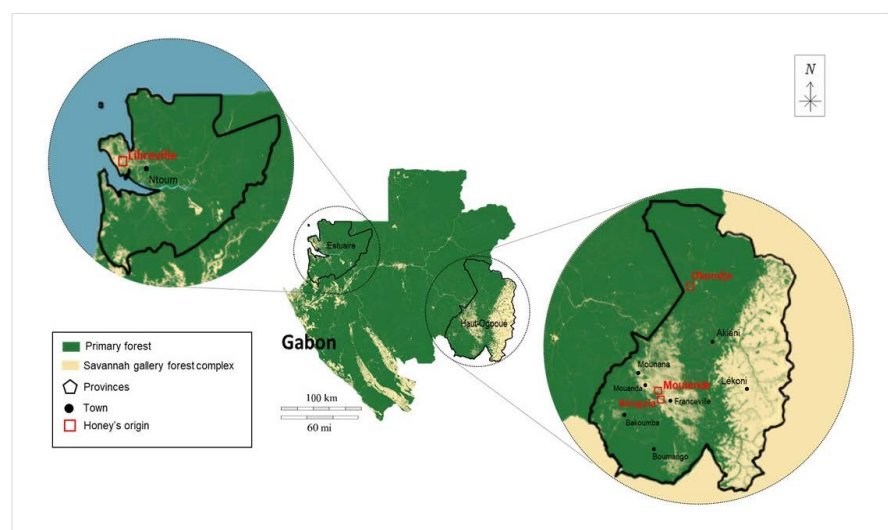
In general, counterfeit honeys, whether intentional or unintentional, are difficult to distinguish from natural honeys by the naked eye after production, extraction and packaging [3] (Koudegnan *et al.*, 2012). The authenticity of honey is defined by the Codex Alimentarius applicable to all types of honey intended for human consumption. There is a Gabonese standard for honey based on the international setting essential compositional and quality factors such as free water content, pH, electrical conductivity, total sugar content, free acidity, etc. [2] (Codex Alimentarius, 2022).

The general aim of our study is to evaluate physico-chemical parameters of honeys from the savannah-gallery forest complex (3 honeys) and primary forest honeys (2 honeys) in Gabon. Specifically, it aims to evaluate the quality of honeys from the Moulendé savannah-gallery forest complex and marketed honeys to facilitate the integration of beekeeping into the culture of the population in savannah areas.

## 2. Materials and Methods

### 2.1. Sampling Sites

The present study was conducted between June 2018 and June 2022 and the honeys collected in several localities. Some of the honeys were collected in the Mpassa and Sébé-Bricolo departments of the Haut-Ogooué province in south eastern of Gabon, the other honey was obtained from Komo-Mondah department of Estuaire province (Figure 1). The Mpassa department is located in the central part of the province, with the town of Franceville as its capital. The village Moulendé (S 1°37'74", E 13°27'18.46") on the Franceville-Moanda axis (Figure 2), around 15 km from Franceville, was selected as the experimental site



**Figure 1.** Origin of the different types of honeys.

for two of the five honey samples. The Moulendé and Benguia areas, in the Mpassa Department, are characterized by vast expanses of grassy and shrubby savannahs surrounding smaller areas of forest known as savannah-gallery forest complexes or forest-savannah mosaics [12] (Demichelis *et al.*, 2022), [13] (Maloba Makanga, 2011), [14] (Mikissa *et al.*, 2008), [15] (Orijemie, 1990).

## 2.2. Sampling

The beekeeping in the experimental apiary in Moulendé was carried out using Kenyan-type hives with mobile bars. The priming to attract the bees was done by inducing a bait consisting of honey and inflorescences of *Ocimum gratissimum* on each bar and on the internal walls of the hive. The honeys were harvested in the traditional way but with care in handling. Honey extraction was carried out by manual pressing of the wax comb. The honey obtained was filtered using strainers with various orifices of 2 mm and 0.5 mm, respectively.

Five honey samples (M1 to M5) were collected in 2019 and 2022 in several localities. Honey samples M1 and M3 come directly from the experimental apiary in a savannah-gallery forest complex of Moulendé (Haut-Ogooué province).

The honey sample M4 was purchased from a beekeeper in the savannah-gallery forest Complex of Benguia (Haut-Ogooué province). The honey samples M2 and M5 were respectively purchased from beekeepers in Okondja primary forest (Haut-Ogooué province) and in Libreville primary forest (Estuaire province). In **Table 1**, honeys are classified according to their ecosystem (savannah-gallery forest complex and Primary forest) and origin. Glass bottles (250 ml) for samples M1 and M3 were first sterilized with 3% diluted bleach (NaClO), rinsed several times with distilled water and oven-dried at 105°C for 24 hours. After sampling, the bottles were sealed and stored in a dark place at room temperature. The packaging and storage methods used for M2, M4 and M5 honeys are not known. The M4 and M5 honeys were purchased in 1L glass bottles, while the M2 honey was in a 500 ml plastic container. As soon as purchased, they were transferred into 250 ml sterilized glass bottles and stored in a dark place at room temperature.

**Table 1.** Details of the various honey samples.

Sample	Year	Origin	Location	Ecosystem
M1	2022	Extracted (Moulendé Apiary)	Moulendé Apiary	Savannah gallery forest
M2	2022	Purchased (Franceville)	Libreville (Ntoum)	Primary forest
M3	2019	Extracted (Moulendé Apiary)	Moulendé Apiary	Savannah gallery forest
M4	2019	Purchased (Benguia)	Benguia	Savannah gallery forest
M5	2019	Purchased ( Franceville)	Okondja	Primary forest

*M1 to M5: Various honeys.*

## 2.3. Physico-Chemical Parameters

Physico-chemical parameters were analyzed using the official methods of analysis of the Association of Official Analytical Chemists [16] (AOAC, 1990) and the harmonized methods of the International Honey Commission [17] (Bogdanov, 1999). Samples were analyzed over the same period to ensure uniformity of conditions and comparability.

### 2.3.1. pH

Hydrogen potential (pH) was measured according to the method described by [16] (AOAC, 1990) using a pH meter (Consort C860 (USA), with an accuracy of  $\pm 0.002$  pH units). To measure the pH of honey samples diluted to 10% (w/v), 10 g of honey were diluted in 75 ml of distilled water before the probe was immersed.

### 2.3.2. Free Acidity

Free acidity was measured according to the method described by [2] (Codex Alimentarius, 2022) using a 10% honey solution. In the 10% honey solution used to determine the pH of each sample, NaOH (0.1 N) was added dropwise using a burette, until a pH of 8.3 was obtained. The volume of NaOH used was then reported. Free acidity, expressed in milli equivalents of free acid per kilogram ( $\text{meq}\cdot\text{kg}^{-1}$ ), is calculated according to equation 1 [18] (MAFF, 1992).

$$AL = \frac{1000 \times V \times N}{m} \quad (1)$$

Where AL: Free Acidity ( $\text{meq}\cdot\text{kg}^{-1}$ ), V: volume (mL) of NaOH used to neutralize honey to 10%, N: normality of NaOH used and m: mass of honey (g) actually used for measurement.

### 2.3.3. Water content

Water content was determined using an Abbé refractometer (ZEISS refractometer, West Germany). All measurements were taken at 28°C and corrected to 20°C. A drop of honey is placed on the refractometer. The water content of the honey sample was determined according to Equation (2) [19] (Dailly, 2008).

$$\text{Water content}(\%) = \frac{[-0,2681 - \log(n_d^{20} - 1)]}{0,002243} \quad (2)$$

Where  $n_d^{20}$  is the Abbé refractive index determined at 20°C.

### 2.3.4. Electrical Conductivity

The electrical conductivity (EC) of a 10% solution of each type of honey was measured using a WTW-LF 330 conductivity meter (Bioblock, Germany). The technique is based on measuring the electrical resistance at 20°C in a 10% honey solution with 10 g honey in 75 ml distilled water [6] (Belhaj *et al.*, 2015), [16] (AOAC, 1990). Results were expressed in milli Siemens per centimeter ( $\text{mS}\cdot\text{cm}^{-1}$ ) according to the Codex Alimentarius standard.

### 2.3.5. Density

To determine honey density, 5 ml of distilled water were weighed, followed by 5 ml of honey on a Highland® Portable Precision Balances-HCB 153. Density is expressed according to Equation (3).

$$\text{density} = \frac{m \text{ honey}}{m \text{ water}} \quad (3)$$

### 2.3.6. Total Sugar Content

The total sugar content of each sample was obtained by analyzing a drop of honey using a portable Brix refractometer, type ATC, at 20°C with direct reading. The result is expressed in Brix (equivalent to 1 g sucrose per 100 g solution).

## 2.4. Statistical Analysis

Data were obtained from three replicates of each honey sample and results expressed as means  $\pm$  mean standard deviation. Results were processed using XLSTAT 2022 software. An analysis of variance (ANOVA) was performed at the 5% probability threshold between the different honeys for the physico-chemical parameters to assess possible differences. The Pearson correlation test with 95% confidence interval was used to determine the correlation between the different physico-chemical parameters of the honeys studied, and the covariance matrix was subjected to principal component analysis (PCA).

## 3. Results and Discussion

The results related to physico-chemical parameters (pH, free acidity, water content, electrical conductivity, density and total sugar content) are presented in **Table 2**.

**Table 2.** Physico-chemical characteristics of the honeys studied.

Physico-chemical parameters	M1	M2	M3	M4	M5	Codex Alimentarius 2022
pH	3.9 $\pm$ 0.17a	3.7 $\pm$ 0.17ab	3.7 $\pm$ 0.20ab	3.8 $\pm$ 0.16a	3.4 $\pm$ 0.10b	3.5 - 4.5*
Free acidity (meq·kg <sup>-1</sup> )	71.54 $\pm$ 4.38b	76.65 $\pm$ 5.77b	37.12 $\pm$ 5.08a	75.50 $\pm$ 18.94b	38.83 $\pm$ 17.11a	$\leq$ 50
Water content (%)	20.69 $\pm$ 0.77bc	19.47 $\pm$ 0ab	21.21 $\pm$ 1.25b	17.49 $\pm$ 1.25a	20.90 $\pm$ 0c	$\leq$ 20
Electrical conductivity (mS·cm <sup>-1</sup> )	1.09 $\pm$ 0.02b	1.24 $\pm$ 0.012a	0.64 $\pm$ 0.01d	1.07 $\pm$ 0.017b	0.72 $\pm$ 0.003c	$\leq$ 0.8
Density	1.02 $\pm$ 0.008a	1.03 $\pm$ 0.006a	1.02 $\pm$ 0.007a	1.03 $\pm$ 0.014a	1.02 $\pm$ 0.007a	$\leq$ 1.4
Total sugar content (%)	79.5 $\pm$ 0.31a	82 $\pm$ 0b	78.2 $\pm$ 1.81a	82 $\pm$ 0b	77 $\pm$ 0a	$\geq$ 60
Ecosystem	Savannah gallery forest complex	Primary forest	Savannah gallery forest complex	Savannah gallery forest complex	Primary forest	-

On the same line, values bearing the same letter are not significantly different at  $p < 0.05$ . \* Nectar honey, M1 to M5: Different honeys.

### 3.1. pH

The pH of honey samples is crucial during the extraction process, as it affects the stability, texture and life expectancy of different honeys. The pH is sufficiently acidic to slow or inhibit the growth of many species of bacteria [5] (Abselami *et al.*, 2018), [20] (Naman *et al.*, 2005). The values obtained in **Table 2** show average pH values for the different honeys collected ranging from  $3.4 \pm 0.10$  (M5) to  $3.9 \pm 0.17$  (M1). A significant difference ( $p < 0.05$ ) is observed between M1 and M4 honeys. These values (pH between 3.5 and 4.5) are in line with the recommendations of [2] (Codex Alimentarius, 2022). These pH results are similar to those reported for other honey samples originating from Burkina-Faso, Brazil, Morocco, and Algeria [5] (Abselami *et al.*, 2018) and [21] (Backchiche *et al.*, 2018), [22] (Meda *et al.*, 2005). The conformity of these pH values gives an indication of the freshness of the honey and helps to confirm the botanical origin (nectar honey), both of honeys from the savannah-gallery forest complex (M1, M3 and M4) and those from the primary forest ecosystem (M2 and M5). However, [7] (Mbogning *et al.*, 2011) found a pH value higher than both our results and those of [2] (Codex Alimentarius, 2022) and [23] (Conseil de l'Union Européenne, 2002) for honey harvested during the rainy season in north-west Cameroon. Similarly, [3] (Koudegnan *et al.*, 2012) found higher values for some sustainably preserved honeys with an average pH of 5.11 than in the present study. Honey is naturally acidic, regardless of its geographical origin. This acidic pH is due to the presence of various organic acids (gluconic acid, acetic acid and citric acid) contained in the nectar [24] (Khalil *et al.*, 2012), but above all to the bee's salivary secretions and enzymatic processes [20] (Naman *et al.*, 2005). Organic acids contribute to honey's flavor and stability against microbial deterioration. As a result, whatever the ecosystem - savannah-gallery forest or primary forest the pH of our honey samples is naturally acidic, in compliance with [2] (Codex Alimentarius, 2022).

### 3.2. Free Acidity

Honey acidity is an important parameter for assessing its quality. It gives very important indications of its condition [25] (Bogdanov, 1997). In fact, the determination of free acidity makes it possible to determine the possible alteration of honey over time. The values obtained from the analysis of the five (5) honeys (**Table 2**) show that average acidity values vary between  $37.12 \text{ meq}\cdot\text{kg}^{-1}$  for honey M3 (Moulendé savannah-gallery forest) and  $76.65 \text{ meq}\cdot\text{kg}^{-1}$  for honey M2 (Libreville forest). A significant difference ( $p < 0.05$ ) was observed between M3, M5 and M1, M2 and M4 honeys. The values for M3 (Moulendé savannah-gallery forest) and M5 (Okondja forest) are in line with the [2] (Codex Alimentarius, 2022) standard of  $50 \text{ meq}\cdot\text{kg}^{-1}$ , while the acidity values for M1 ( $71.54 \text{ meq}\cdot\text{kg}^{-1}$ ), M2 ( $76.65 \text{ meq}\cdot\text{kg}^{-1}$ ) and M4 ( $75.50 \text{ meq}\cdot\text{kg}^{-1}$ ) are significantly higher. Regarding our values (**Table 2**), the variation in free acidity does not seem to depend on the type of complex savannah-gallery forest or primary forest ecosystem. According to [26] (Pérez-Arquillué *et al.*, 1995), this

variation in free acidity can be attributed to the floral origin of the honey [27] (Schweitzer, 2004), on the other hand, shows that the natural acidity of honey increases with the stage of ripening (aging), whether it contains propolis or is altered by fermentation. These results are in line with the values obtained by [10] (Djossou *et al.*, 2013), which range from 36.92 and 64.38 meq·kg<sup>-1</sup> for honeys marketed in Benin. The values obtained for honeys M3, M4 and M5 are in agreement with the value of multifloral honey from Morocco obtained by [6] (Belhaj *et al.*, 2015).

### 3.3. Water Content

Determining the water content of honey is very important for its preservation during storage. The water content of honey can be favorable either to undesirable fermentation of this honey due to the action of osmo-tolerant yeasts, or to hygroscopy of the honey [4] (Machado De-Melo *et al.*, 2018). For example, when the water content of honey is below 18% and air humidity is above 60%, honey absorbs moisture from the air. Moisture content also depends on the honey's stage of ripening at the time of harvest. The honey's state of ripeness depends on the moment chosen between the start of the ventilation and nectar trophallaxis process by the bees and the harvesting of the honey [5] (Abselami *et al.*, 2018), [20] (Naman *et al.*, 2005), [25] (Bogdanov, 1997), [28] (Gomes *et al.*, 2010). Water content varied between honey samples, ranging from 17.49 ± 1.25 to 21.21 ± 1.25 (Table 2). A significant difference ( $p < 0.05$ ) was observed between honey samples M3, M4 and M5. Honey M4 has the lowest water content (17.49% ± 1.25%), while M3 has the highest (21.21% ± 1.25%). According to [2] (Codex Alimentarius, 2022) on honey quality, water content must be less than 21%. The values of the honey samples studied comply with this Codex requirement irrespective of the different ecosystems. The significant differences between the water contents of all the honeys can be explained by the large number of factors influencing the moisture content of honey mentioned above. Numerous authors have obtained water content values for natural multi-floral honeys similar to those in the present study and in compliance with the Codex Alimentarius standard [5] (Abselami *et al.*, 2018), [10] (Djossou *et al.*, 2013), [29] (Albu *et al.*, 2021) [30], (Krishnasree and Ukkuru, 2017). The lowest water content values are comparable to those found by [10] (Djossou *et al.*, 2013) in their work on honeys marketed in Benin (9.84% - 19.76%) and the highest values comparable to those of [31] (Buveka Ngoma *et al.*, 2018) on natural honeys in the dry season in the Democratic Republic of Congo (20% - 21%).

### 3.4. Electrical Conductivity

Electrical conductivity expresses the ability of an aqueous solution to conduct an electric current. It is positively correlated with soluble salt content [6] (Belhaj *et al.*, 2015). According to [29] (Albu *et al.*, 2021), electrical conductivity is influenced by solution pH, ion valency and degree of ionization. According to [32]

(Ghorab *et al.*, 2021), it depends on mineral salts, organic acids and proteins. It can also vary with botanical origin (mono or multifloral nectar). The average values obtained from analysis of the five honeys range from  $0.64 \pm 0.01 \text{ mS}\cdot\text{cm}^{-1}$  for M3 honey to  $1.24 \pm 0.012 \text{ mS}\cdot\text{cm}^{-1}$  for M2 honey (**Table 2**). Only honeys M1 and M4 are not statistically different from each other. Otherwise, all honeys have statistically different electrical conductivities. Honeys M3 and M5 are in line with value of  $\leq 0.8 \text{ mS}\cdot\text{cm}^{-1}$  [2] (Codex Alimentarius, 2022). Honeys M1, M2 and M4 are above the standard. In our study, the variation in conductivity values does not seem to depend on the type of ecosystem.

The results of the present analysis are close to the work carried out by [3] (Koudegnan *et al.*, 2012), whose values for honeys from the plains and mountains of the Guinean zone of Togo vary between  $0.26$  and  $1.39 \text{ mS}\cdot\text{cm}^{-1}$ . However, the electrical conductivity values of the five honeys are higher than those of honeys from Algeria, Morocco and Tunisian honeys, which range from  $0.12$  to  $0.41 \text{ mS}\cdot\text{cm}^{-1}$  and Ethiopian honeys which range from  $0.4$  to  $0.43 \text{ mS}\cdot\text{cm}^{-1}$  [6] (Belhaj *et al.*, 2015), [33] (Doukani *et al.*, 2014), [34] (Gebeyehu and Jalata, 2023). Given that the pH values of the five honeys are within the norm, it is difficult to assess the relationship between electrical conductivity and pH in the case of our study.

### 3.5. Density

The density of honey is closely linked to its water content and the quantity and nature of suspended solids (pollen dust, soil dust, fibers, crystallized sugars, wood particles) it contains [35] (Aparna and Rajalakshmi, 1999), [36] (Ayodele *et al.*, 2006). The higher the density of a honey, the less water it contains, and vice versa. Knowing the density of natural honey is a simple and very useful way of detecting poor storage or packaging conditions, or bad commercial practices (counterfeiting). The average density values of the honey samples analyzed ranged from  $1.02$  (M1, M3 and M5 honeys) to  $1.03$  (M4 honey) (**Table 2**). The density of the honeys studied is not statistically different whatever the ecosystem of origin of these Gabonese honeys. On average, the density of the honeys was  $1.024$ . The honey densities found comply with the requirements of the Codex Alimentarius standard for nectar honeys ( $\leq 1.4$ ). Some authors have also found honey density values lower than or equal to the Codex standard [3] (Koudegnan *et al.*, 2012), [37] (Amir *et al.*, 2010). The more water a honey contains, the less dense it is [38] (Jean-Prost, 1987). However, some authors have published density values for multi-flower honeys that are higher than the Codex standard ( $1.414 - 1.446$ , *i.e.*  $1.431$  on average) [29] (Albu *et al.*, 2021), [31] (Buveka Ngoma *et al.*, 2018). However, it should be noted that in the case of [29] (Albu *et al.*, 2021) study, the honeys had been analyzed between 3 and 8 years after harvest. In this case, the hypothesis that storage conditions and shelf life had favoured possible evaporation of water from their samples could explain this high-density value for natural multi-floral honey.

### 3.6. Total Sugar Content

The total sugar content of honey is determined by a Brix refractometer in Brix or % equivalent to the quantity of sugars (g) contained in 100 g of honey at 20°C [19] (Dailly, 2008). **Table 2** shows that there is a significant difference ( $p < 0.05$ ) between the different honeys, with average values ranging from 77% to 82%. The sugar content of honeys M1, M3 and M5 is not statistically different, with an overall average of 78.2%. This is statistically different from honeys M2 and M4, both of which have a total sugar content of 82%. Despite the significant differences observed, total sugar content does not depend on the geographical origin of the honey (savannah-gallery forest complex and primary forest). On the other hand, the low total sugar content can be explained by the high-water content of M5 honey (20.90%). Additionally, the higher total sugar content in honeys M2 and M4 could be due to their low free water content M2 (19.47%) and M4 (17.49%). These total sugar contents are close to the values obtained by [3] (Koudegnan *et al.*, 2012), [10] (Djossou *et al.*, 2013), [21] (Backchiche *et al.*, 2018). These results meet Codex Alimentarius standards, which indicate that honey values exceeding 65% correspond to nectar honeys [2] (Codex Alimentarius, 2022).

### 3.7. Statistical Interpretations

The Pearson correlation matrix following confidence intervals of 95% is presented in **Table 3** and the principal component analysis (PCA) using the covariance matrix is illustrated in **Figure 2**. The correlations between the physico-chemical parameters of the honeys studied shows significant correlations at the 5% threshold. Moisture content is negatively correlated with conductivity ( $r = -0.628$ ), pH ( $r = -0.631$ ), density ( $r = -0.552$ ) and total sugar content ( $r = -0.890$ ). On the other hand, conductivity is positively correlated with free acidity (0.688) and total sugar content ( $r = 0.776$ ), and negatively correlated with water content ( $r = -0.628$ ). These correlations were shown by [3] (Koudegnan *et al.*, 2012) in their work on the analysis of honeys marketed in Togo.

The various correlations obtained in this study are confirmed by principal component analysis (PCA). PCA transforms  $p$  inter-correlated quantitative variables into  $p$  new uncorrelated variables called principal components [39] (Conti *et al.*, 2007). PCA applied to physico-chemical characteristics yielded two principal components (PC1 and PC2) represented 64.29% of the total variance and the next principal 16.54%, respectively of the concentrated information, *i.e.* a total of 80.86% of the total variance (**Figure 2**). PC1 can be linked on the negative side to water content and the positive side to conductivity, total sugar content and pH, while PC2 is linked to density on the positive side.

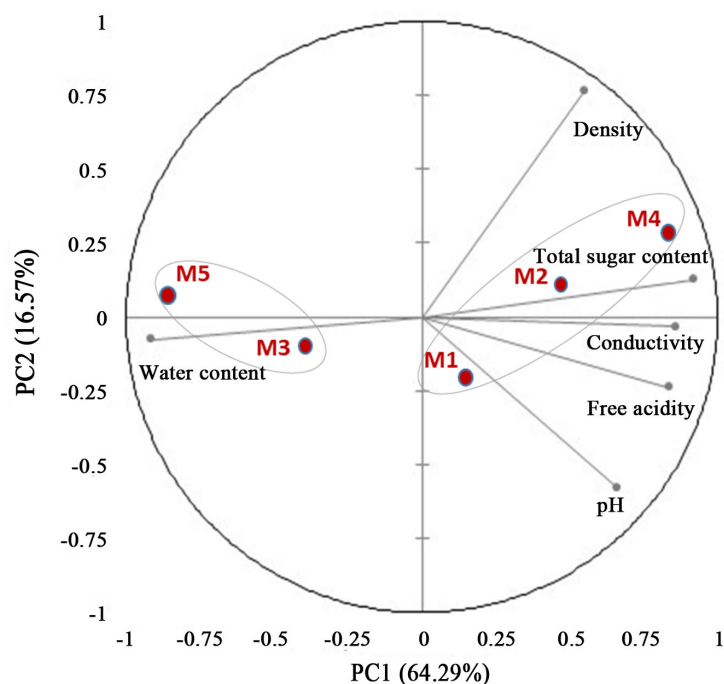
The distribution of the studied honeys based on the physico-chemical parameters showed two distinct groups. The first group characterized by high free acidity and high electrical conductivity includes M1 (Moulendé 2022), M2 (Libreville 2022) and M4 (Benguia 2019). The second group with high free water

content comprises M3 (Moulendé 2019) and M5 (Okondja 2019).

**Table 3.** Pearson correlation matrix between different physico-chemical parameters of some honeys.

Variables	Water content	Conductivity	pH	Density	Total sugar content	Free acidity
Water content	<b>1</b>	<b>-0.628</b>	<b>-0.631</b>	<b>-0.552</b>	<b>-0.890</b>	<b>-0.633</b>
Conductivity	<b>-0.628</b>	<b>1</b>	0.455	0.396	<b>0.776</b>	<b>0.785</b>
pH	<b>-0.631</b>	0.455	<b>1</b>	0.056	0.461	<b>0.553</b>
Density	<b>-0.552</b>	0.396	0.056	<b>1</b>	0.502	0.275
Total sugar content	<b>-0.890</b>	<b>0.776</b>	0.461	0.502	<b>1</b>	<b>0.676</b>
Free acidity	<b>-0.633</b>	<b>0.785</b>	<b>0.553</b>	0.275	<b>0.676</b>	<b>1</b>

Values in bold are the most significant.



**Figure 2.** Distribution of physico-chemical parameters of the different honeys in the 1 - 2 plane revealed from the principal component analysis.

#### 4. Conclusion

This study, based on a few physico-chemical parameters of five honeys harvested in two ecosystems (savannah-gallery forest complex and primary forest) in two provinces (Estuaire and Haut-Ogooué) of Gabon, confirmed that honeys from the savannah-gallery forest complex zone and the forest zone comply with international standards, with the exception of three types (M1, M2 and M4) whose free acidity and conductivity were significantly above the limit. The parameter values of these three honeys showed a susceptibility to alterations. To improve the quality and quantity of information available on savannah and forest honeys, studies on a larger number of samples and on other aspects are required, including mineral elements, viscosity, fructose and sucrose content, coloration as

well as the spatial and temporal diversity of melliferous plant species in Gabon. The physico-chemical data for all the samples show that all the honeys collected in both Haut-Ogooué in south-east Gabon and Estuaire in the north-west are authentic and meet the criteria laid down by the Codex Alimentarius.

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### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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