

Physicochemical and Nutritional Characteristics of Honey from *Plebeina armata*, a Stingless Bee Species That Nests Underground in the Sudanese *savannah* Region of Burkina Faso

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Abstract

In Burkina Faso, honey from melipona is used for therapeutic purposes and for rituals. This honey is gradually gaining popularity among consumers because of its contrasting and attractive flavor and aroma. Several species of meliponas have been identified in Burkina Faso, including *Plebeina armata*. There is little data on the physicochemical composition of *P. armata* honey. Knowledge of the physicochemical parameters of honey could generate more enthusiasm among producers and beekeepers to practice meliponiculture. It is in this context that this study was carried out. Its objective is to evaluate the physicochemical properties of *P. armata* honey in three ecosystems (fields, fallow land and classified forests). *P. armata* honey samples were collected from these ecosystems in Burkina Faso. About twenty *P. armata* nests were excavated. The honey was placed in 60 ml jars, labeled and brought back to the laboratory. In the laboratory, the physicochemical composition, nutritional composition and phytochemical compound content of the honey samples were determined. The results show that the color of *P. armata* honeys varied from one landscape structure to another. The moisture content varied from 25.36% to 28.69%, and conductivity and pH varied from 824.5 to 985.6 $\mu\text{S}/\text{cm}$ and from 3.2 to 3.7 respectively. Reducing sugar increased from 20.59% to 21.54%, and ash from 1.45% to 2.3%. The polyphenol content in *P. armata* honey varied from 3.39 mg GAE/100g to 5.67 mg GAE/100g. These results

show that *P. armata* honey has very interesting physicochemical properties from a food and medicinal point of view.

Keywords

Burkina Faso, Compounds, Honey, Melipone, Physicochemical

1. Introduction

Honey is a complex product derived from nectar primarily composed of sugars and various secondary compounds, which is made by social bees [1]. Honey is mainly known to be produced by bees of the genus *Apis* from nectar or honeydew and is a complex mixture composed mainly of sugars and other substances [2] [3]. However, besides *Apis mellifera*, stingless bees (SB) constitute another unexplored group of honey producing bees within the family Apidae [4].

Stingless bees live mainly in tropical regions, where the Meliponini tribe is found mainly in Australia, Southeast Asia, Africa and Latin America (Brazil and Cuba) [5]-[7].

Worldwide there are approximately 600 known species of stingless bees (SB) belonging to 60 genera [6] [8]. In Sub-Saharan Africa, 21 species of SB have been described so far and divided into six genera: *Cleptotrigona*, *Dactylurina*, *Hypotrigona*, *Liotrigona*, *Meliponula*, and *Plebeina* [9] [10].

Stingless bee colonies are made up of thousands or tens of thousands of workers who build their nests underground, in termite nests, tree cavities or walls [11]. SB tend to build broods in horizontal or vertical positions and have the habit of storing nectar and pollen in pots rather than combs as in the case of *A. mellifera* [12] [13]. However, stingless bee colonies can be maintained in man-made hives and this practice is known as meliponiculture [6] [14].

Compared with *Apis* honey, stingless bee honey (SBH) generally has higher levels of acidity, moisture and reducing sugars [15]. In addition, SBH is characterized by a fluid texture, slow crystallization and a characteristic sweet-and-sour flavor [16].

Honey has been valued for its nutritional and therapeutic qualities for over 5500 years [17]. The unique characteristics of SBH have contributed to its recognition as a possible functional food, thanks to its bioactive components and other substances, such as sugars and organic acids, which are associated with numerous nutraceutical and medicinal properties [18]-[20].

Recent studies have highlighted several functional properties of SBH, including wound healing [21], antimicrobial properties [19] [22], anti-diabetic properties [20] and anti-cancer properties [23].

In Africa, this type of honey is well known to local rural communities who use the honey for therapeutic purposes or rituals; however, the honey is mostly gathered from wild colonies [24] [25].

Despite these new discoveries, research on the physicochemical composition of

honey from SB remains insufficient. Indeed, the physicochemical composition of honey varies according to SB species and the vegetation composition from which nectar is collected at a particular harvesting season [26]. Study on SB honey composition is more advanced in Neotropical regions compared to sub-Saharan Africa, where meliponine bees are least known [27]. Very few studies have been reported in Kenya, Zanzibar, Tanzania and Ethiopia [25] on the honey composition of some African stingless bee species.

In Burkina Faso, very few studies have been conducted on stingless bees. Studies on these bees in Burkina Faso mainly focus on species diversity [28] [29].

In this study, we set out to fill this gap by investigating the impact of geographical origin on the physico-chemical composition of a stingless bee species, *P. armata*. This study had two objectives: 1) to compare *P. armata* honey samples from three ecosystems (fallow, forest and field), and 2) to compare them with *Apis mellifera adansonii* honey samples from the Sudanese savanna zone of Burkina Faso.

2. Materials and Methods

2.1. Study Site

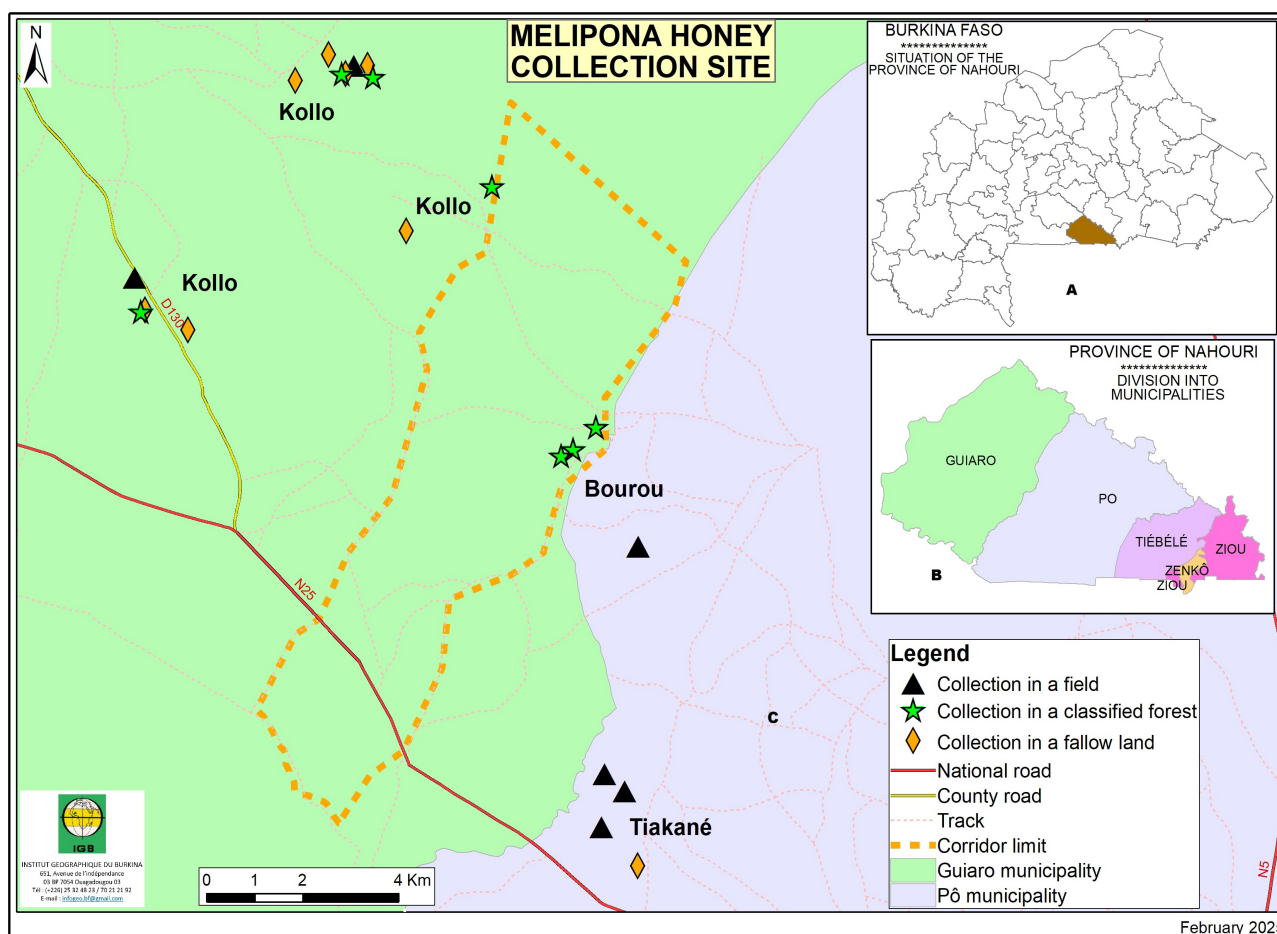


Figure 1. Map of the study area A: Situation of the province of Nahouri on the map of Burkina Faso B: Division into minicipalities of the province of Nahouri C: *Plebeina armata* honey collection sites.

The study was conducted in Burkina Faso along corridor No. 1 of the Pô-Nazinga-Sissil ecological complex (PONASI). The PONASI ecological complex is located between the south-central and west-central regions in the South Sudanienne zone of Burkina Faso (**Figure 1**). It is one of the largest areas of preserved forest-savannah ecosystems and the largest ecological region of biodiversity conservation which constitutes an ecological continuum sheltering a great diversity of flora and fauna in the country [30]. The PONASI ecological complex brings together: the Kaboré Tambi National Park (PNKT) and its two corridors, the classified forest and the game ranch of Nazinga, the classified forest of Sissili as well as the Village Zone [31]. It covers an area of 3792 km² and includes the network of contiguous protected areas of the Po National Park (155.000 hectares), the Nazinga Game Ranch (94.000 hectares), the Sissili classified forest conceded as a hunting zone (32.700 hectares), and the village hunting areas around Nazinga (54.300 hectares).

Three villages in the PONASI served for sample collection: Kollo (latitude: 11.347862 and longitude: -1.3241) and Tiakané (latitude: 11.1851223 and longitude: -1.2054836) in the commune of Guiaro and Bourou (latitude: 11.2932322 and longitude: -1.2231052) in the commune of Pô were selected for this study.

2.2. Collection of Honey Samples

Wild colonies of *Plebeina armata* were identified in three landscape structures, namely farmlands, fallow ground and forests. The choice of habitats is intended to assess the impact of the degradation of these habitats on the physicochemical composition of the honey. The flowering plants in farmlands were composed of divers crops such as cereals (millet, sorghum, corn), leguminous (cowpea *Vigna unguiculata*: Fabales, Fabaceae, voandzou *Vigna subterranea*: Fabales, Fabaceae), oilseed (soybean *Glycine max*: Fabales, Fabaceae, peanuts *Arachis hypogaea*: Fabales, Fabaceae, sesame *Sesamum indicum*: Scrophulariales, Pedaliaceae), horticulture crops (okra *Abelmoschus esculentus*: Malvales, Malvaceae) and fibre (cotton *Gossypium hirsutum*: Malvales, Malvaceae). Among the tree species in the farmlands, the shea tree (*Vitellaria paradoxa*: Ericales, Sapotaceae) was the most abundant. Fallow grounds of at least five years were chosen for nest harvesting and their vegetation was mainly composed of shea trees and shrubs such as *Piliostigma thonningii*: Fabales, Fabaceae. Nests of *P. armata* have also been identified in protected forests (*i.e.* forests where logging is prohibited by the local population) in the villages of Kollo and Bourou. These protected forests are rich in several species of shrubs and trees.

A total of 21 nests of *P. armata* were excavated, including six in fields, seven in fallow grounds and eight in forests. The nests were carefully excavated to avoid damaging the honey pots. Once the nest was removed from the ground, the honey pots, pollen, propolis and brood were separated. Furthermore, honey from *A. mellifera adansonii* was also harvested in each of these ecosystems. However, honey from *A. mellifera adansonii* was collected from fallow land, fields and for-

ests in Kollo, Tiakané and Bourou respectively. Honey from *A. mellifera adansonii* was harvested from three apiaries located in each of these ecosystems. In this study, the *A. mellifera adansonii* honeys were treated as control samples. All the honey was collected between April and May 2025. The honey pots from each nest were placed separately in sterilized one-litre glass containers and brought back to the laboratory in Ouagadougou for honey extraction and physicochemical property analyses.

2.3. Honey Analysis

2.3.1. Physicochemical Composition

The physicochemical composition analyses of the honey samples were carried out according to the methodology recommended by the International Honey Commission (IHC) published by [32] and updated by [33].

1) Honey color

The color of the honey samples was measured using the spectrophotometric method (635 nm) described by [34] on a honey solution (50%). The honeys were classified according to Pfund's scale [33].

2) Moisture content (MC) and Refractive Index (RI)

The refractive index and moisture content were determined using the Abbe refractometer through the refractometric technique, as outlined by [33]. An amount of 10 g of honey sample was placed in a tightly closed 50 ml flask and placed in a water bath at 50°C for dissolution of any sugar to obtain a homogenized sample. One millimeter of the homogenized sample was then spread evenly on the surface of the prism, and the refractive index readings were taken after 2 minutes at 20°C. Each sample was measured in triplicate. The mean refractive index reading obtained was used to determine the moisture content from the [35] table that contains refractive index values and their corresponding moisture content values.

3) Electrical conductivity

Electrical conductivity was measured using a pH and conductivity meter for a 20% (w/v) solution of honey suspended in distilled water. The meter was calibrated with a conductivity solution before taking the readings of honey solutions and conductance was given in mS/cm [33].

4) pH and free acidity

A pH and conductivity meter was used to measure the pH of 10 g of honey in 75 ml of carbon dioxide-free distilled water. Free acidity was determined by titrating the same sample solution with 0.1 M NaOH until a pH of 8.3 was attained [33].

5) Density (ρ)

Density was determined by using a 10 ml measuring cylinder. 10 cm³ of honey was put in the measuring cylinder whose mass had been determined. The mass of honey was then obtained and was determined to 0.0001 g accuracy and density was calculated using the equation $\text{Density } (\rho) = \text{mass (g)}/\text{volume (cm}^3\text{)}$ [33].

2.3.2. Nutritional Composition

The nutritional composition (Ash, protein, lipid, sugars) analyses of the honey

samples were determined based on the official analysis methods from the Association of Official Analytical Chemists [36] [37].

1) *Ash content*

A 5 g portion of the honey sample to which two drops of olive oil were added was placed in a dish and preheated at temperatures rising between 350°C - 400°C. Ashing was then done at a temperature of 600°C for one hour, and the residue was weighed to an accuracy of 0.001 g after cooling in a desiccator. Ashing was continuously done until a constant weight was achieved. The ash content of honey in the sample was calculated using the equation

$$W = (M1 - M2/M0) \times 100.$$

where:

W = ash content of the honey

M0 = weight of honey sample taken (10 g)

M1 = weight of dish and honey

M2 = weight of dish

100 = Multiplying the result by 100 to convert it into a percentage

2) *Sugars (Brix)*

The total sugars (soluble solids) were determined according to [37], by recording a reading of the honey sample in a handheld digital refractometer. The total sugars were expressed as a percentage (%).

3) *Glucose, Fructose and Sucrose*

Honey sugar analysis was conducted using high-pressure liquid chromatography (HPLC), which allows for the identification of various sugars in honey. This method, originally described by [38], involves filtering the solution and subsequently determining sugar content using HPLC with refractive index (RI) detection. Peaks were recognized by their specific retention times, and quantification was accomplished using the external standard method based on peak areas or peak heights. 5.0 g of honey was dissolved in 40 ml of distilled water in a beaker, and 25 ml of HPLC grade methanol was added. The mixture was then quantitatively transferred to a 100 ml volumetric flask and filled to the mark with distilled water. After that, the solution was then filtered, and the resulting solution was collected in sample vials using a syringe and a premounted filter and analyzed for fructose, glucose, and sucrose. HPLC separation was carried out on an analytical column Shodex Asahipak® NH2P-50 4E packed with amino-modified silica gel, using a mobile phase consisting of acetonitrile and water in a ratio of 78:22 (v/v). The flow rate was set at 1.4 ml/min, and a 0.45 µm pore size membrane filter was employed for filtering aqueous solutions. The column and detector were maintained at a temperature of 30°C. A 5 µl injection volume for standards and 2 µl for samples was used, and the analytical column, made of stainless steel, had a diameter of 4.6 mm and a length of 250 mm. It contained amine-modified silica gel with particle sizes ranging from 5 to 7 µm. The analysis time was 45 minutes per sample, and prior to injection, solvents and diluents were filtered through 0.45 µm corona filters.

4) Total protein content (TP)

The total protein content was determined by the method of [39]. To 0.1 ml honey solution (50% w/v), 0.9 ml of the Coomassie Brilliant Blue reagent was added. After 2 min of incubation, the absorbance was measured at 595 nm against the blank (*i.e.* the reactive solution without the sample) using a spectrophotometer. Bovine serum albumin was used to generate the calibration curve (0 - 300 $\mu\text{g}\cdot\text{ml}^{-1}$) in 0.15 M sodium chloride solution. The TP content was calculated and expressed as mg of BSA/100g of honey.

5) Lipid

The fat content was determined using the Soxhlet extraction procedure following AOAC, Official Method 988.05 [36]. The wet honey sample was freeze-dried prior to extraction. The percentage of fat content was calculated according to the following equation: Fat content (%) = Weight of fat obtained (g)/Weight of sample (g) $\times$ 100.

2.3.3. Phytochemical Composition

The phytochemical composition of the honey samples was conducted only on total phenols content (TPC). We referred to the methodology recommended by [40]. One gram of honey was diluted with 20 ml of distilled water. To 1 ml of the honey solution in a test tube, 5 ml of 0.2 N Folin-Ciocalteu reagent was added. After 5 min, 4 ml of 75 g/l sodium carbonate was added before the mixture was incubated at room temperature (20°C to 25°C) for 2 hours. The absorbance was read at 760 nm against a water blank. Gallic acid (GA) standard was used to yield a calibration curve (0 - 250 $\mu\text{g}/\text{ml}$). The TPC was expressed as mg of GAE/100g honey.

2.4. Statistical Analysis

For data from laboratory analyses, the mean of the technical replicates was calculated, and each of these means was treated as a single value. The Shapiro-Wilk test was used to check whether the data followed a normal distribution using R software version R-4.4.2 (R Development Core Team, 2024). When the distribution was normal, an ANOVA was performed and the comparison of means was made using the Student-Newman-Keuls test at the probability level of 0.05 using SAS software version 9.1. A principal component analysis (PCA) was performed using R software version R-4.4.2 (R Development Core Team, 2024).

3. Results

3.1. Physicochemical Composition

1) Honey color

The color of *P. armata* honeys varied from one landscape structure to another (Figure 2). Honey samples collected from wild nests in fallow ground were all maroon in color. In the farmlands, honeys were of three colors: maroon, dark maroon, and brown. All honeys from colonies nesting in the forests were brown

in color. In comparison to honey of *A. mellifera adansonii*, a significantly distinct color was observed in those of *P. armata*. The honey of *A. mellifera adansonii* from Bourou was light brown, golden yellow for honey collected from Kollo, and brown for that from Tiakané.

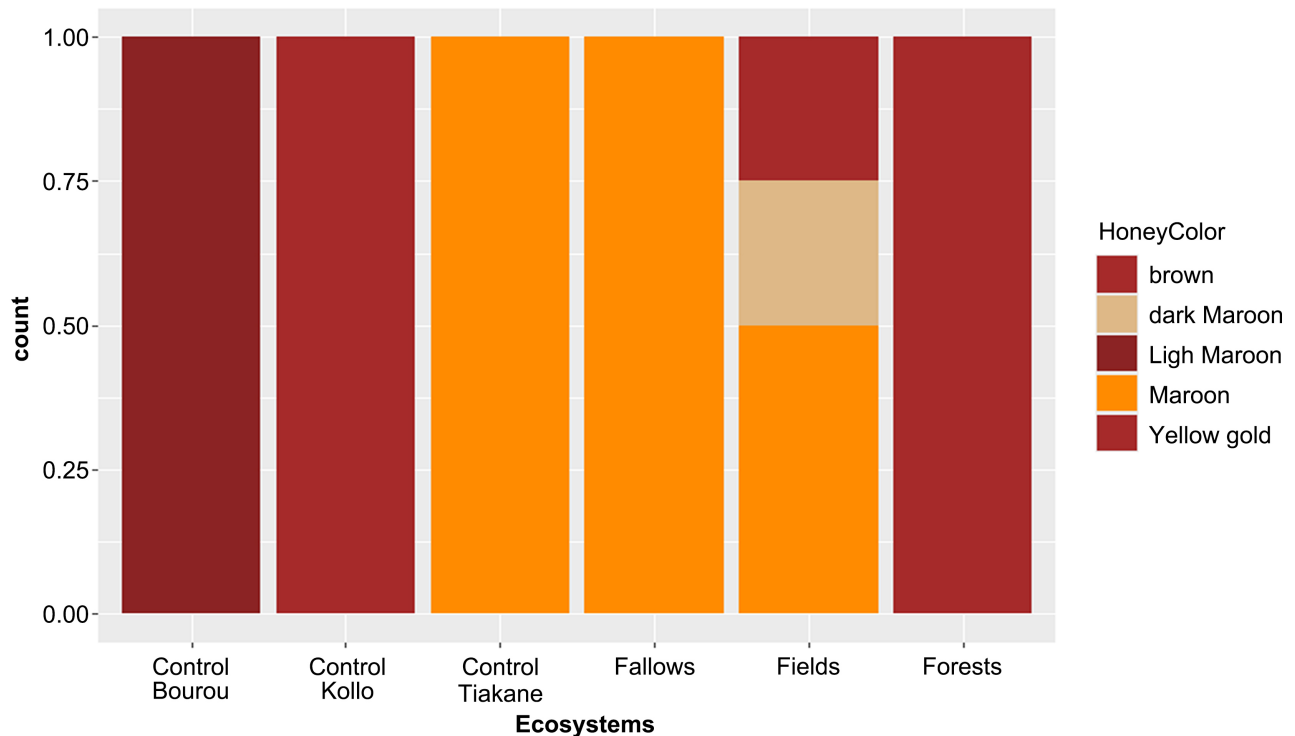


Figure 2. Color of *P. armata* honeys from different ecosystems and control honeys from *A. mellifera adansonii* in fallows, forests and fields in Nahouri Province, in South-Central region of Burkina Faso.

2) Moisture content

There was a significant difference in water content between the landscapes ($P < 0.0001$). The average moisture content of *P. armata* honey varied from $25.36\% \pm 0.19\%$ to $28.69\% \pm 0.03\%$ within the three landscape structures (**Table 1**). Highest moisture content was recorded in honey from colonies nesting in fallow grounds ($28.69\% \pm 0.03\%$) compared to honey from colonies in the farmlands ($25.36\% \pm 0.19\%$) and forest ($26.82\% \pm 0.33\%$). Regarding differences in moisture content from that of *A. mellifera adansonii* honey, a significant difference ($P < 0.0001$) was also observed for *P. armata* honey (**Table 1**). The average moisture content for *A. mellifera adansonii* honey, was lower and varied from $14.01\% \pm 0.03\%$ in Tiakané, to $16.50\% \pm 0.04\%$ in Kollo and to $20.17\% \pm 0.04\%$ in Bourou villages.

3) Refractive index

The refractive index of *P. armata* honeys varied between 1.44 ± 0.04 and 1.49 ± 0.02 and was not significantly different ($P = 0.96$) within the three landscape structures. Similarly, the refractive index values for *A. mellifera adansonii* honey, did not differ to those of *P. armata* and varied between 1.49 ± 0.2 (honey from Tiakané) and 1.50 ± 0.04 (honey from Kollo and Bourou villages) (**Table 1**).

4) Conductivity

The conductivity of *P. armata* honey ranged from $824.5 \pm 11.85 \mu\text{S/cm}$ to $985.6 \pm 0.04 \mu\text{S/cm}$ among the studied landscapes and was not significantly different (**Table 1**). However, a significant difference ($P < 0.0001$) in honey conductivity was observed between the bee species *A. mellifera adansonii* and *P. armata* (**Table 1**). Lowest conductivity values in honey was obtained in Apis bee; with those colonies domesticated in Kollo village producing honey with the lowest conductivity value ($427 \pm 0.05 \mu\text{S/cm}$) compared to Tiakané as well as in Bourou villages.

5) pH

The pH of *P. armata* honey varied significantly ($P < 0.0001$) from one landscape structure to another (**Table 1**). The highest pH value (3.7 ± 0.04) was recorded in honey collected from colonies nesting in forest habitat. Moreover, the pH of *P. armata* honeys was also significantly different ($P < 0.0001$) from the honey of *A. mellifera adansonii*. Low pH value (1.7 ± 0.04) of Apis honey was obtained from colonies in apiaries at Kollo compared to those at Tiakané (3.3 ± 0.02) villages.

6) Free acidity

The free acidity of *P. armata* honey varied between 77.19 ± 6.10 and $219.31 \pm 0.03 \text{ mg GAE/100g}$ while the free acidity of *A. mellifera adansonii* honey varied from 99.11 ± 0.04 to $125.98 \pm 0.03 \text{ mg GAE/100g}$. A significant difference ($P < 0.0001$) was obtained between free acidity values of *P. armata* honey from each landscape structures. Free acidity values were highest in *P. armata* honey from colonies nesting in fallow grounds ($219.31 \pm 0.03 \text{ mg GAE/100g}$) and lowest ($77.19 \pm 6.10 \text{ mg GAE/100g}$) in those nesting in forest landscape (**Table 1**). However, free acidity of Apis honey was significantly different ($P < 0.0001$) and highest in colonies nesting in Tiakane ($125.98 \pm 0.03 \text{ mg GAE/100g}$) compared to Bourou ($104.06 \pm 0.05 \text{ mg GAE/100g}$) and Kollo village ($99.11 \pm 0.04 \text{ mg GAE/100g}$).

7) Density

The density of *P. armata* honey was between 1.40 ± 0.02 and 1.42 ± 0.04 while that of *A. mellifera adansonii* was between 1.42 ± 0.02 and 1.43 ± 0.05 . No significant differences were found between the density of *P. armata* honey from the three landscape structures and that of honey from *A. mellifera adansonii*.

3.2. Nutritional Composition

1) Ash

The ash content of *P. armata* honey ranged from $1.45\% \pm 0.30\%$ to $2.3\% \pm 0.04\%$; while that of *A. mellifera adansonii* honey ranged from $1.68\% \pm 0.04\%$ to $6.84\% \pm 0.04\%$ (**Table 1**). No significant differences were observed in ash content between *P. armata* honey from the three landscape structures and that of *A. mellifera adansonii* honey; with exception of *A. mellifera adansonii* honey from Kollo village whose ash content was higher ($6.84\% \pm 0.04\%$).

2) Total sugars soluble solids

The total sugars soluble solids content was significantly different ($P < 0.0001$) for *P. armata* honeys within different landscape structures. There was also a sig-

nificant difference ($P < 0.0001$) between the total sugars soluble solids of these honeys and that of honeys from *A. mellifera adansonii* (Table 1). High total sugars soluble solids values of *P. armata* honey were obtained from colonies nesting in the farmlands ($72.92\% \pm 0.19\%$). As for *A. mellifera adansonii* honey, total sugars soluble solids content ranged from $78.70\% \pm 0.05\%$ to $82.2\% \pm 0.02\%$ in apiaries at Bourou and Tiakané villages respectively.

3) Reducing sugars: fructose and glucose

The mean reducing sugar content of *P. armata* honeys ranged from 20.59 ± 0.04 to $21.54\% \pm 0.08\%$, while that of *A. mellifera adansonii* honeys ranged from 23.29 ± 0.04 to $24.40\% \pm 0.03\%$ (Table 1). The mean reducing sugar content of *P. armata* honeys from the three landscape structures was significantly different ($P < 0.0001$). The highest value of reducing sugars was recorded in honey produced by colonies nesting in farmlands and forests compared to fallow grounds. Compared to *A. mellifera adansonii* honeys, a significant difference ($P < 0.0001$) was also observed within honey of the two bee genera. Honey produced by honey bees had higher reducing sugar content compared to *P. armata* honey. However, *A. mellifera adansonii* honey from Tiakane had highest reducing sugar content compared to honey from colonies reared in Kollo and Bourou.

4) Total sugars

The total sugar content in *P. armata* honey, ranged from 68.62 ± 0.04 to 71.91 ± 0.22 g/100g. For *A. mellifera adansonii* honey, the total sugar content varied between 77.64 ± 0.04 and 78.72 ± 0.04 g/100g (Table 1). There was a significant difference ($P < 0.0001$) in total sugar content between *P. armata* honey produced by colonies nesting in fallow grounds (lower sugar content) compared to those nesting in forest and farmlands (higher sugar content). A significant difference ($P < 0.0001$) in honey total sugar content was also observed between *A. mellifera adansonii* and *P. armata* honey. Total sugar content was higher in all *A. mellifera adansonii* honey regardless of the rearing sites compared to *P. armata* honey.

5) Proteins

The amount of protein in *P. armata* honey ranged from 0.34 ± 0.04 to 0.46 ± 0.02 mg/100g while that observed in *A. mellifera adansonii* honey ranged from 0.39 ± 0.02 to 0.49 ± 0.05 mg/100g. There were no significant difference ($P = 0.11$) between the amount of protein in *P. armata* honey from the three landscape structures and from that in *A. mellifera adansonii* honey.

6) Lipid

We did not detect the presence of lipid in honey of *P. armata*; however, very low concentration was observed in *A. mellifera adansonii* honey from Kollo ($0.05\% \pm 0.02\%$) and Tiakane ($0.03\% \pm 0.01\%$).

3.3. Phytochemical Compounds

The polyphenol content in *P. armata* honey varied from 3.39 ± 0.1 mg GAE/100g to 5.67 ± 0.03 mg GAE/100g. For *A. mellifera adansonii* honey, the polyphenol content varied from 4.60 ± 0.05 mg GAE/100g to 3.14 ± 0.04 mg GAE/100g. The

average polyphenol content of *P. armata* honeys was significantly ($P < 0.0001$) different and higher in honey from colonies nesting in fallow grounds compared to that of honeys from colonies in farmlands and forests landscapes. Similarly, a significant difference ($P < 0.0001$) was observed within honey produced by *A. mellifera adansonii* and *P. armata*. Honey produced by *P. armata* colonies foraging in fallow grounds had higher polyphenol content than all *A. mellifera adansonii* honey reared in the three village sites (Table 1). For those colonies of *P. armata* foraging in the forest and farmlands, their honey polyphenol content was similar to Apis bee honey produced at Kollo and significantly lower than for *A. mellifera adansonii* reared in Bourou and Tiakane.

Table 1. Physicochemical characteristics of *P. armata* honey and control honey from *A. mellifera* in fallows, forests and fields in Nahouri Province, in South-Central region of Burkina Faso.

Ecosystems	Humidity (%)	Conductivity $\mu\text{S}/\text{cm}$	Refractor index	pH	Density	Brix degree	Free acidity (mg GAE/100g)	Ashes (%)	Polyphenols (mg GAE/100g)	Reducing sugars (g/100g)	Proteins (mg/100g)	Total sugars (%)
Fallows	28.69 $\pm$ 0.03A	985.6 $\pm$ 0.04A	1.44 $\pm$ 0.04A	3.19 $\pm$ 0.03B	1.42 $\pm$ 0.04A	69.80 $\pm$ 0.04D	219.31 $\pm$ 0.03A	2.3 $\pm$ 0.04B	5674.2 $\pm$ 105.03A	20.59 $\pm$ 0.04D	0.34 $\pm$ 0.04A	68.62 $\pm$ 0.04D
Fields	25.36 $\pm$ 0.19C	902 $\pm$ 74A	1.49 $\pm$ 0.02A	3.29 $\pm$ 0.02A	1.40 $\pm$ 0.02A	72.92 $\pm$ 0.19C	168.77 $\pm$ 0.02B	2.26 $\pm$ 0.41B	3397.8 $\pm$ 103.14D	21.54 $\pm$ 0.08C	0.46 $\pm$ 0.02A	71.91 $\pm$ 0.22C
FForests	26.82 $\pm$ 0.33B	824.5 $\pm$ 11.85AB	1.46 $\pm$ 0.02A	3.66 $\pm$ 0.04A	1.42 $\pm$ 0.02A	71.95 $\pm$ 0.51C	77.19 $\pm$ 6.10E	1.45 $\pm$ 0.30B	3420.9 $\pm$ 165.62D	21.38 $\pm$ 0.04C	0.44 $\pm$ 0.02A	71.27 $\pm$ 0.64C
Control Bourou	20.17 $\pm$ 0.04D	585 $\pm$ 0.05BC	1.5 $\pm$ 0.04A	3.26 $\pm$ 0.05B	1.43 $\pm$ 0.05A	78.70 $\pm$ 0.05B	104.06 $\pm$ 0.05D	1.68 $\pm$ 0.04B	4602.3 $\pm$ 201.05B	23.29 $\pm$ 0.04B	0.49 $\pm$ 0.05A	77.64 $\pm$ 0.04B
Control Kollo	16.50 $\pm$ 0.04E	427 $\pm$ 0.04C	1.5 $\pm$ 0.04A	1.7 $\pm$ 0.04A	1.42 $\pm$ 0.03A	79.70 $\pm$ 0.04A	99.11 $\pm$ 0.046D	6.84 $\pm$ 0.04A	3139.6 $\pm$ 106.04D	23.29 $\pm$ 0.04B	0.41 $\pm$ 0.04A	78.72 $\pm$ 0.04B
Control Tiakane	14.01 $\pm$ 0.03F	738 $\pm$ 0.02AB	1.49 $\pm$ 0.02A	3.30 $\pm$ 0.02A	1.42 $\pm$ 0.02A	82.20 $\pm$ 0.02A	125.98 $\pm$ 0.03C	1.74 $\pm$ 0.02B	4023.2 $\pm$ 106.03C	24.40 $\pm$ 0.03A	0.39 $\pm$ 0.02A	81.35 $\pm$ 0.03A
Probability	F5;30 = 441.92 P < 0.0001	F5;30 = 9.44 P < 0.0001	F5;30 = 0.19 P = 0.96	F5;30 = 227.64 P < 0.0001	F5;30 = 0.13 P = 0.98	F5;30 = 171.43 P < 0.0001	F5;30 = 176.45 P < 0.0001	F5;30 = 18.41 P < 0.0001	F5;30 = 42.87 P < 0.0001	F5;30 = 100.08 P < 0.0001	F5;30 = 2.04 P = 0.11	F5;30 = 113.26 P < 0.0001

3.4. Principal Component Analysis (PCA)

The correlations between the different physicochemical, nutritional and phytochemical parameters of honey are indicated in Figure 3. There is a strong positive correlation between color and ash content. On the other hand, there was also a strong positive correlation between the content of reducing sugars and total sugars. In addition, the study reveals a positive correlation between density and refractory index, then between density and protein content of honeys. The polyphenol content is passively correlated with the free acid of honeys. There is also a positive correlation between humidity and conductivity of honeys. Finally, the pH and ash content of honeys are negatively correlated (Figure 3). It is observed that *P. armata* honey from the three landscape structures are different. Forest honey has a higher pH than farmlands and fallow grounds honey (Figure 3). Fallow grounds honey has a higher polyphenol content than farmlands and forest honey.

Farmlands honey has intermediate characteristics of fallow ground and forest honey. *A. mellifera adansonii* honey is distinguished from *P. armata* honey by characteristics such as color, reducing sugar total sugar, Brix degree, and ash contents (Figure 3).

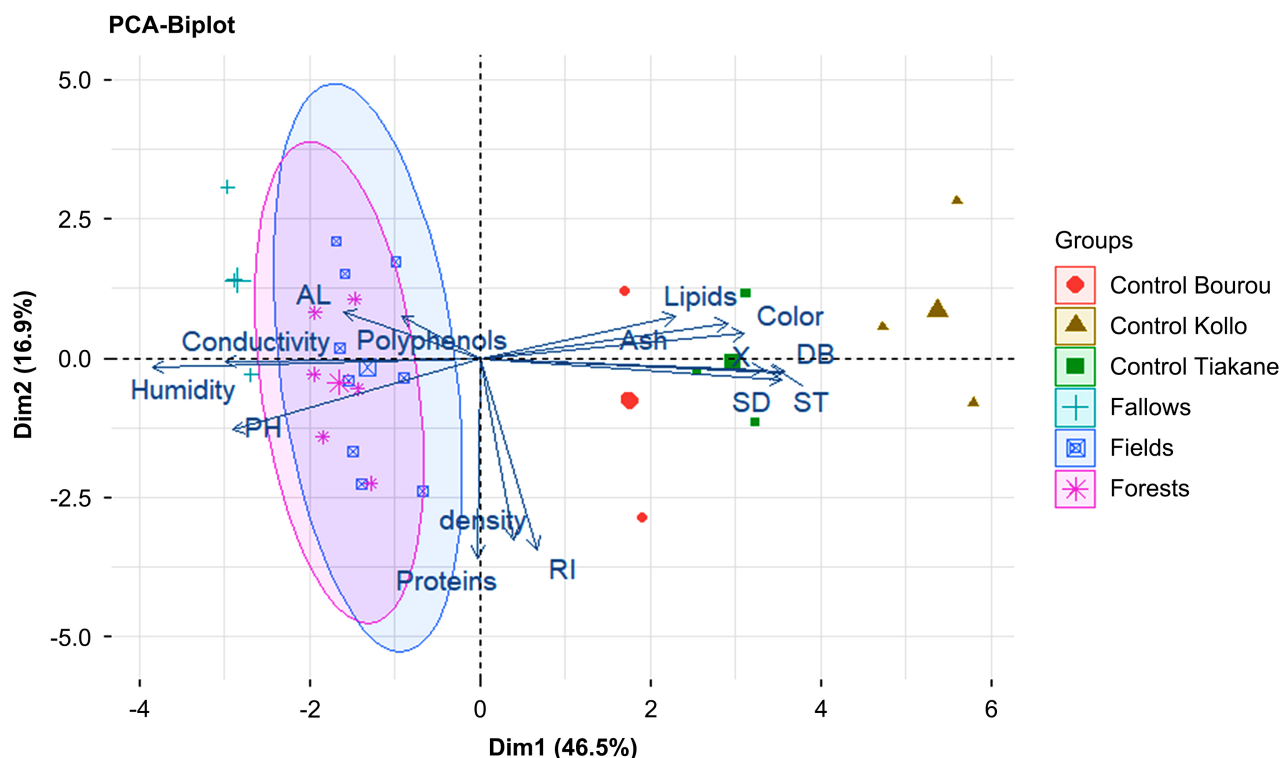


Figure 3. Representation in the factorial plane of Physicochemical characteristics of *P. armata* honey and control honey from *A. mellifera* in fallows, forests and fields in Nahouri Province, in South-Central region of Burkina Faso. AL: Free acidity; RI: Refractive index; DB: Brix degree; SD: Reducing sugar; ST: Total sugars soluble solids.

4. Discussion

4.1. Physicochemical Property

a) Color

The colour of *P. armata* honey depends on the type of ecosystem. Similarly, for *A. mellifera adansonii* honey, the colour varies depending on the collection site. It has been shown that the colouration of honey depends on its chemical composition. Indeed, several compounds are involved in the colouration of honey, notably carotenoids, phenolic compounds, minerals and amino acids [41] [42]. Colour is also important for assessing the bioactivity of honey; it has been reported that darker honeys exhibit higher antioxidant activity [43] [44]. The composition of honey even depends on the species of plants visited by the bees. For example, the acidity of honey is mainly influenced by the organic acids derived from the nectar [45].

b) Moisture content

The moisture content is an important parameter for the conservation of honey. It allows to estimate the level of maturity of honeys, provides information on its

stability against fermentation and crystallization [46]. According to [47], a honey low in water is preserved longer than a honey rich in water regardless of its yeast content. *P. armata* honeys had a higher average humidity level than *A. mellifera adansonii* honeys. From the above, *P. armata* honeys would be more difficult to preserve, and therefore to preserve from fermentation. Variations in the humidity levels of honeys would be linked to the period of their harvest and their floral origins. For example, monofloral honeys would have a high humidity level due to their botanical [48].

c) Conductivity

Electrical conductivity of honey is a quality criterion to determine its botanical origin. It indicates the mineral salts present that can dissolve in water to form ions and conduct electric currents [49]. Being a standard, it has a limit of not more than 0.8 Ms/cm for *A. mellifera adansonii* honey and is correlated to the ash content and are directly proportional [50]. *P. armata* honey had higher conductivity denoting that the honey is rich with minerals. Also this is associated with the organic acids in the honey and due to higher moisture content of *P. armata* honey, it is prone to fermentation which increases the organic acids [51]. This parameter also indicates the geographical origin of the honey and also can be used to denote environmental pollution [52]. This explains why honey from the forest had lower conductivity. Despite the variations, the reported values on *P. armata* is lower than that of stingless bee honey of 2.51 Ms/cm [53].

d) Ash

The ash values found in this study are higher than the maximum limit (0.6%) set by the Codex Alimentarius for Apis honey. Ash content is a quality criterion that depends on the botanical origin of the honey. It is a criterion used in international standards [54]. The ash content is made up of inorganic components which include minerals and environmental pollutants such as dust [55] [56], report that the permissible limit for ash content of nectar honeys is 0.6% while that of honeydew honey is 1.2%. The ash values obtained in this study are higher than those reported by [57] (0.08% to 0.09%) in honeys from the arboretum of the National Agronomic School of Yamoussoukro (Côte d'Ivoire). These variations could be linked to the floral origin of the honeys or to the nature of the soils. Indeed, the ash content of honeys varies according to the soils of the honey-producing plants, to atmospheric conditions, and to the physiology of the plants [58].

e) Refractive index

The refractive index is an optical property that characterizes any transparent substance. The refractive index of honey is a function of water content and temperature. The refractive index of honey is higher as its water content is lower [59]. It varies between 1.5041 and 1.4915 for a water content between 13% and 18% [60].

f) pH

Eleven honey samples were acidic. [40] showed that *P. armata* honey had a pH of 4 in Kenya. This pH was the lowest among the pH of honey from other melipona

species in this country. Brazilian stingless bee honeys had a pH of 3.3 - 6.6 and 3.1 - 3.9 [19], and Thai stingless bee honey samples had a pH of 3.3 - 6.6 and 3.1 - 3.9 [61]. A study on *Scaptotrigona pectoralis* honey also found a low pH value (3.6) [62]. The low pH of honey is important because it inhibits the growth of microbes, which helps maintain the stability and shelf life of honey [63]. The pH values of *A. mellifera adansonii* honey samples obtained in our study are lower than those of honey samples analyzed by [64] in Benin which were between 3.57 and 5.30.

g) *Density*

The average density of the honeys analyzed is close to those of the Codex alimentarius (densities of 1.39 and 1.44) [37] [65].

4.2. Nutritional Property

a) Total Sugars Soluble Solids

The Brix degree of honey indicates the quantity of dry matter, expressed in (g) per 100 g of honey [66]. In our study only honey from *A. mellifera adansonii* from Tiakané has a Brix degree in accordance with the standards of the Food Codex and the European Union ($\geq 80\%$). The dry matter content can influence the crystallization of honeys; the higher the dry matter content, the greater the tendency of this honey to crystallize [67]. The variation in the dry matter rate is due to many factors: botany, nature of the flower, the time of the bee's passage and the meteorological factors that influence the honey flow [68].

b) Reducing Sugar

It is a natural product characterized by a variation in sugar composition, which includes more than 20 disaccharides and polysaccharides in addition to the monosaccharide's glucose and fructose [69]. The sugar profile of honeys produced by *Melipona* is similar to that of *A. mellifera*, *i.e.* they are low in oligosaccharides. The sugar composition of honeys depends on plant sources and the activity of enzymes produced by bees. In the case of *Melipona* honeys, the sugar content is low and fructose is the main sugar component, responsible for their sweetness and hygroscopicity [32]. The effectiveness of using the reducing sugar content to determine the entomological origin of stingless bee honeys was evaluated by [70]. The average values of reducing sugars in honeys of other *Melipona* species range from 50.13% to 74.82% [71].

c) *Total sugar*

All our honey samples (all types of origin combined) had total sugar values within the limits recommended by [37]. Indeed, according to [37], the total sugar content must be greater than 60%. Our results corroborate those of [19] on Brazilian honeys whose total sugar content was between 67.6 and 72.4 g/100g.

d) *Protein*

Honey contains few proteins, 0.1% to 0.2% of the fresh weight. These proteins are generally proteins and amino acids (notably apoline). The origin of proteins is diverse since they can come from nectar, bee secretions or pollen present in honey [72].

e) *Lipid*

The lipid content in honey samples is considered negligible, this has already been shown by some studies such as [2] where the lipid content was around 0.04% to 0.5%. Lipids in honey consist essentially of glycerides, sterols, and various acids such as phospholipid, palmitic, oleic, lauric lauric acids, [73]. Lipids in honey come from plants and mainly from wax remains [74].

4.3. Phytochemical Property

Polyphenols are part of the groups of natural compounds, important, of high therapeutic interest. The total phenolic contents of honey samples reported by [63] ranged from 27.88 to 248.80 mg GAE/100g. These values are significantly lower than those obtained in this study. Studies by different authors [74] [75] have shown that phenolic compounds varied depending on the geographical and floral origins of the honey. This could explain the variation in the polyphenol content in *P. armata* honey depending on the ecosystems.

5. Conclusion

P. armata honeys had a higher average moisture content than *A. mellifera adansonii* honeys. As a result, *P. armata* honey would be less stable than *A. mellifera adansonii* honey and would be favorable to the fermentation and crystallization process. This type of honey should undergo treatments to limit these types of alteration for good conservation. The conductivity of *P. armata* was higher than that of *A. mellifera adansonii*. It also emerged that the pH of the different types of honey was acidic with that of *P. armata* being higher than that of *A. mellifera adansonii*. However, both types of honey had a fairly high free acidity (higher than the regulations) which makes it difficult to preserve both types of honey. *P. armata* and *A. mellifera adansonii* honeys had high values of polyphenols which are molecules with antioxidant properties. The total sugar contents of *P. armata* and *A. mellifera adansonii* honeys were quite low compared to what is recommended by the Codex Alimentarius standard. These low sugar contents of honey could be explained by the unstable nature of honey due to its water content, the high value of which could lead to fermentation and crystallization processes of the honey, thus reducing its sugar content. Both types of honey are also very low in protein and have almost zero lipid content. Overall, *P. armata* honey has a high-water content and free acidity and quite low sugar, protein and lipid contents. This type of honey would be difficult to preserve and would require stabilization before preservation. It would have an advantage from a nutritional point of view because with a low sugar content it would be suitable for diabetics.

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Author Contributions

Souleymane Koussoubé, Josefa Somé, Fidèle W. Tapsoba: Conceptualization, honey harvesting, honey analyses in the laboratory, writing: original draft formal analysis software writing: revision and editing.

Farûk Koirra, Issouf Ouédraogo, Gérald Nana, Frédéric Soubandé: participate honey harvesting.

Timothy Kegode, Kiatoko Nkoba, Mamoudou Traoré, Mamounata Bélem: Conceptualization, validation; methodology; supervision, original draft in English.

Souleymane Nacro: Conceptualization, honey harvesting, original draft in English; writing: review and editing; validation; methodology; supervision.

Conflicts of Interest

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

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