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Physicochemical characterization of local honeys marketed in Korhogo town

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Abstract

Local honeys sold in public markets, small shops or by individuals are not controlled by public services. Currently, information about its quality is non-existent. The objective of this work was therefore to assess the quality of local honeys marketed in Korhogo town. Samples were collected from twenty local honey sellers located in markets and certain neighborhoods of Korhogo town. Then, their physicochemical parameters were determined. The results showed the existence of significant difference ($p < 0.5$) between the honey samples for all the parameters studied. The amber colored samples (86 – 113 mm Pfund) were the most numerous (55%) compared to the light amber colored ones and the dark colored ones. The electrical conductivity of these honeys oscillated between 115.67 and 765.67 µS/cm. The refractive index, degree brix and density ranged from 1.4884 to 1.5014; 79.15 to 84.45% and 1.4085 to 1.4442, respectively. The values of moisture content varied between 14.15 and 19.23 g/100g, those of pH and free acidity ranged from 3.42 to 4.49 and from 10.67 to 28.89 meq.kg^{-1}, respectively and those of total acidity and hydroxymethylfurfural content oscillated respectively from 14.67 to 40.22 meq.kg^{-1} and from 0.56 to 30.05 mg.kg^{-1}. All these physicochemical parameters varied within the limits proposed by the Codex Alimentarius Commission. This suggests that the honeys marketed in Korhogo town meet the quality criteria required for its consumption. However, for further study, their nutrients should be identified and quantified, and their microbiological quality assessed.

Keywords: Korhogo; Nectar honey; Honey color; Electrical conductivity; Hydroxymethylfurfural content

1. Introduction

Honey is a natural sweet substance produced by bees of the species *Apis mellifera* from the nectar of flowers or secretions from the living parts of plants (honeydew) or excretions left on them by sucking insects [1]. Its sugar consists mainly of carbohydrates including monosaccharides such as glucose and fructose (main components) and polysaccharides such as maltose, sucrose, melezitose, erlose. The proportion of different sugars present in honey directly depends on the type of flowers foraged by bees [2]. In addition, it contains other compounds such as water, proteins, vitamins, minerals, lipids, amino acids, organic acids (free or combined in the form of lactones), phenolic compounds, flavonoids, carotenoids, enzymes, volatile compounds [3]. Finally, 5-Hydroxy-2-methylfurfural (HMF) is a component systematically found in trace amounts in honey. It comes from the breakdown of fructose and is an excellent indicator of quality.

Honey is a natural food that has several nutritional and therapeutic virtues, and is used for the treatment of many diseases [4]. Nutritionally, honey is widely used as a concentrated form of sugars and/or a food preservative [5]. In addition, its consumption is a very good complement to the usual food ration. It ensures a better balance of vital elements essential for the proper functioning of the body. It facilitates the digestion and assimilation of other foods

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leading generally to a better metabolism. It provides greater resistance to physical and intellectual fatigue [6]. Honey is therefore a product with market value both on national and international markets, also playing an important role in certain cultural traditions [5].

Increasingly in demand for its multiple uses, honey must meet all quality and purity criteria. It is with this in mind that the International Honey Commission, created in 1990, has standardized certain honey analysis methods: moisture, reducing sugar levels, pH, acidity, electrical conductivity and hydroxymethyl furfural content [7]. These parameters are used as quality criteria for honey.

According to Hume-Ferkatadji [8], Côte d'Ivoire produces at least 30 tons of honey per year; and the North of the country is known for its honey production. Korhogo is the largest city in the north of the country, 635 km from Abidjan [9], and one of the main areas for the production and marketing of local honey. However, in this city, local honeys purchased in public markets, small shops or from individuals are not subject to quality control by public services. In addition, in Côte d'Ivoire, studies on the physicochemical analysis of honey from northern localities [10, 11] focused on harvested products. However, depending on the storage conditions, honey undergoes a certain number of modifications over time, leading to the loss of its essential qualities [12], and considerably reducing the time required for its consumption. It is therefore to fill this lack of information on the quality of local honeys sold in Korhogo town that this study was carried out. Its general objective is to contribute to a better knowledge of the quality of the honeys marketed in the Poro region.

2. Material and methods

2.1. Biological material

The biological material consisted of local honey (Figure 1) marketed in public markets, small shops and by individuals in Korhogo town.

Figure 1 Local honeys marketed in Korhogo town

2.2. Equipment used in the laboratory

The equipment used for the work in the laboratory consisted mainly of:

- a color comparator (Lovibond 2000 MIEL 45-85, Tintometer Limited, Amesbury, United Kingdom) equipped with two chromatic discs to determine the color;
- a conductometer (HI5321, Hanna Instruments, Woonsocket, USA) to measure electrical conductivity;
- a 10 ml glass pycnometer to quantify the density;
- a refractometer (AR200, Leica Microsystems, New York, USA) with built-in thermometer to determine the refractive index, degree brix and moisture content;
- a ph-meter (HI 9025, Hanna Instruments, Woonsocket, USA) to measure ph and acidity;
- a UV-Visible spectrophotometer (V-530, Jasco International, Tokyo, Japan) at 284 and 336 nm to estimate the hydroxymethylfurfural content.

2.3. Chemicals and reagents

The chemicals and reagents used for laboratory work were:

- Bromothymol blue at 0.4% (w/v), sodium hydroxide (NaOH) at 0.05 N and sulfuric acid (H_2SO_4) at 0.05 N to measure acidity;
- Carrez I (potassium hexacyanoferrate ($K_4Fe(CN)_6(H_2O)_3$) at 15% (w/v) in distilled water), Carrez II (zinc acetate ($Zn(CH_3COOH)(H_2O)_2$) 30% (w/v) in distilled water), and 0.2% w/v sodium bisulphite solution to quantify hydroxymethylfurfural.

All chemicals and reagents used in the experiment were of analytical grade and were products of VWR International, Leuven, Belgium.

2.4. Sampling of local honey

First, a prospecting of the town of Korhogo was carried out in order to locate the sale points of honey. Then, three half-liter bottles of honey were purchased from each seller met randomly at sales points previously located in markets and certain neighborhoods of the town. A total of 20 sellers were met and 60 bottles of honey were collected and labeled stating: the sample identification number, the date and place of sampling, and the name of the seller. Finally, these samples were sent to the biochemistry laboratory, where they were kept in the refrigerator at 4°C until the time of the physicochemical analysis.

2.5. Determination of physico-chemical parameters of local honey

2.5.1. Color

The color was measured according to the method used by Yahia and Yahaia [13]. This method is based on the comparison of honeys with reference filters of a visual comparator of the Lovibond type. The latter is equipped with two chromatic discs A and B; the first for light honeys, the second for dark honeys. Each disc features nine colored glass pellets of increasing intensity calibrated to Pfund references. The results were translated into a Pfund index, thanks to the correspondence table between the graduation of Lovibond chromatic disks and the Pfund scale (Tables 1 and 2).

2.5.2. Electrical conductivity

Electrical conductivity is the measure of the ability of a sample of honey to transmit an electrical flow in an aqueous solution at 20% relative to the dry matter of honey. Its value was determined at 20°C according to the standardized method of Bogdanov [7] using a HANNA brand conductivity meter. This value was read directly from the device screen. The results were expressed in micro Siemens per centimeter (µS/cm).

2.5.3. Density

The density was obtained by dividing the volumic mass of honey by that of distilled water under the same conditions. A 10 ml glass pycnometer was used for this purpose. The density at 20°C (d_{20}) was calculated as follows:

$$d_{20} = \frac{(M_2 - M_0)/V}{(M_1 - M_0)/V} \quad \text{......................} (1)$$

where, M_0, M_1 and M_2 represent the masses (in g) of the pycnometer respectively empty, filled with water and filled with honey; and V is the volume of the pycnometer.

Table 1 Correspondence between the Lovibond color and the Pfund scale

A-scale honeys		B-scale honeys	
LOVIBOND (Color filter number)	**Pfund (Conventional Expression in millimeters)**	**LOVIBOND (Color filter number)**	**Pfund (Conventional Expression in millimeters)**
30	11	120	62
40	18	150	71
50	27	200	83
60	35	250	92
70	41	300	99
80	46	400	110
90	51	500	119
100	55	650	130
120	62	850	140

Source: Gonnet [14]

Table 2 Scale (mm Pfund) established by the USDA, for the determination of the color

Color	**P fund unit in mm**
Water white	0 – 8 mm
Extra light	8 – 16 mm
Light	16 – 34 mm
Extra light amber	35 – 50 mm
Light amber	51 – 84 mm
Amber	85 – 114 mm
Dark	115 – 140 mm

Source: Homrani [15]

2.5.4. Refraction index, degree brix and moisture content

The refractive index, degree brix and moisture content of the honey samples were determined by the refractometric method described by Bogdanov *et al*. [16] using a refractometer with built-in thermometer. The values of the refractive index and degree brix were read directly through the eyepiece of the device. Since the prism temperature (T_{read}) recorded on the refractometer thermometer was above 20°C, an additive correction was applied to the refractive index value (IR_{read}) noted on the device:

$$\text{Refractive index at } 20°\text{C} = IR_{read} + [0{,}00023 \times (T_{read} - 20)] \quad \text{………………(2)}$$

0.00023 is the correction coefficient added per additional degree Celsius.

The moisture content corresponding to the refractive index at 20°C was calculated using formula (3) developed from the CHATAWAY conversion table (Table 3).

$$\text{Moisture content (\%)} = \frac{-0{,}2681 - \log(n-1)}{0{,}002243} \quad \text{.....................(3)}$$

with: n = refractive index of honey at 20 °C.

Table 3 Correspondence between refractive index and moisture content

Moisture content (%)	Refractive index at 20 °C	Moisture content (%)	Refractive index at 20 °C
13	1.5044	17	1.4940
13.2	1.5038	17.2	1.4935
13.4	1.5033	17.4	1.4930
13.6	1.5028	17.6	1.4925
13.8	1.5023	17.8	1.4920
14	1.5018	18	1.4915
14.2	1.5012	18.2	1.4910
14.4	1.5007	18.4	1.4905
14.6	1.5002	18.6	1.4900
14.8	1.4997	18.8	1.4895
15	1.4992	19	1.4890
15.2	1.4987	19.2	1.4885
15.4	1.4982	19.4	1.4880
15.6	1.4976	19.6	1.4875
15.8	1.4971	19.8	1.4870
16	1.4966	20	1.4865
16.2	1.4961	20.2	1.4860
16.4	1.4956	20.4	1.4855
16.6	1.4951	20.6	1.4850
16.8	1.4946	20.8	1.4845

Source: Chataway [17]

2.5.5. pH

The pH of the honey samples was determined according to the potentiometric method (the standard procedure) described by Bogdanov *et al*. [18], using a HI 9025–HANNA type pH-meter. The pH value was read directly on the display screen of the device, after the stabilization of this value.

2.5.6. Free, combined and total acidity

Total acidity is the sum of free acidity and combined acidity (of lactones). The free and combined acidities were determined according to the method described by Bogdanov *et al*. [18] based on the colorimetric acid-base assay in the presence of bromothymol blue (BBT) as end-of-equivalence indicator. This method consists of performing a first dosage with NaOH (0.05 N) and noting the volume in ml (V_1) poured; then, after pouring the excess NaOH into the beaker, performing a second back titration with H_2SO_4 (0.05 N) and also recording the volume in ml (V_2) poured. The results of the free, combined and total acidities, expressed in milliequivalents of acid per 1 kg of honey, were obtained by the formulas (4), (5) and (6), respectively:

$$\text{Free acidity (meq/kg)} = \frac{1000 \times V_1 \times N}{m} \quad \text{.................(4)}$$

$$\text{Combined Acidity (meq/kg)} = \frac{1000 \times (10 - V_1) \times N - 0{,}05 \times V_2}{m} \quad \text{.................. (5)}$$

$$\text{Total acidity (meq/kg)} = \text{Free acidity} + \text{Combined Acidity} \quad \text{..................... (6)}$$

where,

V_1 : volume of NaOH in ml necessary to reach the equivalent point;
V_2 : Volume of H_2SO_4 in ml necessary to reach the equivalent point;
N : normality of NaOH (0,05 N);
m : test sample (5 g).

2.5.7. Hydroxymethylfurfural content

The amount of hydroxymethylfurfural (HMF) in the honey samples was obtained by White's method described by Bogdanov *et al*. [16]. The principle is based on reading the absorbance of HMF at a wavelength of 284 nm then at 336 nm using a Jasco type UV-Visible spectrophotometer. Interference from other compounds is corrected by differentiating between the absorbances of the honey solution in the presence and absence of sodium bisulfite. The HMF content, expressed in mg/kg, was calculated using the following formula:

$$\text{HMF (mg/kg of honey)} = (A_{284} - A_{336}) \times 149{,}7 \times 5 \times D / W \quad \text{............ (7)}$$

where,
A_{284} : absorbance at 284 nm;
A_{336} : absorbance at 336 nm;
5 : theoretical nominal weight of the sample;
D : dilution = (volume of the sample solution) / 10;
W : weight in g of the sample;
149,7 = (126 × 1000 × 1000) / (16830 × 10 × 5) = constant.

2.5.8. Statistical processing of data

All the tests were carried out in three repetitions. The results of the physicochemical analysis were expressed by the mean ± standard deviation, then subjected to the analysis of variance (ANOVA) in order to verify the existence of significant differences between the means. ANOVA was followed by Tukey's HSD test to rank means. Statistical tests were performed using XLSTAT 2014 software, and statistical significance was set at $p < 0.05$.

3. Results

3.1. Physical characteristics of local honey

Table 4 summarizes physical parameters of 20 local honey samples. All the physical parameters studied showed a significant difference ($p < 0.05$) due to at least one sample. The color index was between 71 and 140 mm Pfund, and had an average of 104.60 ± 20.40 mm Pfund. Amber colored samples (86 – 113 mm Pfund) were the most numerous (55 %), followed by dark colored ones (116 – 140 mm Pfund) representing 30 % of the analyzed samples. Only three samples (15%) were light amber in color. With an average of 471.20 ± 203.74 µS/cm, the electrical conductivity oscillated between 115.67 and 765.67 µS/cm. Samples S7, S8, S15 and S18 had the highest values (from 705.37 to 765.67 µS/cm); while those S3, S6 and S20 demonstrated the lowest values (respectively 160.49, 115.67 and 154.67 µS/cm). Nevertheless, all the samples analyzed were nectar honeys since their electrical conductivities were lower than 800 µS/cm. Density, refractive index and degree brix ranged from 1.4085 to 1.4442; 1.4884 to 1.5014 and 79.15 to 84.45%, respectively; with respective means of 1.4260 ± 0.0105, 1.4948 ± 0.0038 and 81.75 ± 1.56%. Samples S2, S3 and S15 had the highest values (1.4442, 1.5014 and 84.45%; 1.4418, 1.5005 and 84.07%; 1.4425, 1.5007 and 84.18%, respectively); in contrast, the values of samples S8, S13 and S16 (1.4116, 1.4895 and 79.61%; 1.4140, 1.4904 and 79.97%; 1.4085, 1.4884 and 79.15 %, respectively) were the lowest.

3.2. Chemical characteristics of local honey

Chemical parameters of 20 local honey samples are recorded in Table 5. All the chemical parameters studied were significantly different ($p < 0.05$) between the samples. The moisture contents varied between 14.15 and 19.23 g/100g, with an average of 16.72 ± 1.49 g/100g. Samples S8, S13 and S16 had the highest values (respectively 18.78, 18.43 and 19.23 g/100g); while those of samples S2, S3 and S15 (14.15, 14.50 and 14.40 g/100g, respectively) were the lowest. pH and free acidity ranged from 3.42 to 4.49 and from 10.67 to 28.89 meq.kg^{-1}, respectively; with means of 3.93 ± 0.37 and 20.41 ± 5.20 meq.kg^{-1}, respectively. Samples S7, S15 and S18, whose free acidity values (respectively 27.51, 27.70 and 28.89 meq.kg^{-1}) were the highest, had low pH values (3.53, 3.50 and 3.42, respectively). In contrast, sample S6, which had the lowest free acidity (10.67 meq.kg-1), had a high pH (4.49). The total acidity and the HMF content oscillated respectively from 14.67 to 40.22 meq.kg^{-1} and from 0.56 to 30.05 mg.kg^{-1}; with means of 28.66 ± 7.03 meq.kg^{-1} and 15.96 ± 7.51 mg.kg^{-1}, respectively. Sample S18, which had the highest HMF content (30.05 mg.kg^{-1}), also had a high total acidity (40.22 meq.kg^{-1}). As for sample S6, whose HMF content (0.56 mg.kg^{-1}) was the lowest, it also had a low total acidity (14.67 meq.kg^{-1}). Despite the existence of significant differences between the honey samples, all of its physico-chemical parameters complied with the standards proposed by the Codex Alimentarius Commission.

4. Discussion

Table 4 Physical parameters of 20 local honey samples marketed by different sellers in Korhogo town

Samples	Color (mm Pfund)	EC (µS/cm)	Density	Refractive index	Degree brix (%)
S1	113.00 ± 5.20^{bc}	598.33 ± 1.53^{cd}	1.4326 ± 0.0014^{cde}	1.4972 ± 0.0005^{cde}	82.74 ± 0.21^{cde}
S2	99.00 ± 0.00^{d}	453.33 ± 36.47^{fg}	1.4442 ± 0.0005^{a}	1.5014 ± 0.0002^{a}	84.45 ± 0.08^{a}
S3	71.00 ± 0.00^{f}	160.49 ± 31.19^{j}	1.4418 ± 0.0014^{ab}	1.5005 ± 0.0004^{ab}	84.07 ± 0.17^{ab}
S4	110.00 ± 0.00^{c}	505.33 ± 6.66^{ef}	1.4224 ± 0.0018^{gh}	1.4935 ± 0.0006^{gh}	81.21 ± 0.26^{gh}
S5	99.00 ± 0.00^{d}	379.50 ± 11.82^{gh}	1.4263 ± 0.0011^{fg}	1.4949 ± 0.0004^{fg}	81.80 ± 0.17^{fg}
S6	71.00 ± 0.00^{f}	115.67 ± 8.08^{j}	1.4165 ± 0.0008^{hij}	1.4913 ± 0.0003^{ijk}	80.33 ± 0.11^{hij}
S7	133.33 ± 5.77^{a}	727.50 ± 36.81^{ab}	1.4293 ± 0.0015^{def}	1.4960 ± 0.0005^{def}	82.25 ± 0.22^{def}
S8	122.67 ± 6.35^{b}	705.37 ± 0.78^{ab}	1.4116 ± 0.0015^{jk}	1.4895 ± 0.0006^{kl}	79.61 ± 0.23^{jk}
S9	119.00 ± 0.00^{bc}	673.33 ± 30.55^{bc}	1.4184 ± 0.0011^{hi}	1.4920 ± 0.0004^{hij}	80.63 ± 0.18^{hi}
S10	86.00 ± 5.20^{e}	253.67 ± 35.13^{i}	1.4366 ± 0.0013^{bc}	1.4986 ± 0.0005^{bc}	83.33 ± 0.18^{bc}
S11	96.67 ± 4.04^{d}	373.33 ± 17.16^{h}	1.4289 ± 0.0019^{ef}	1.4958 ± 0.0007^{ef}	82.19 ± 0.28^{ef}
S12	116.00 ± 5.20^{bc}	628.00 ± 17.69^{cd}	1.4193 ± 0.0010^{hi}	1.4923 ± 0.0004^{hij}	80.77 ± 0.16^{hi}
S13	110.00 ± 0.00^{c}	564.67 ± 38.70^{de}	1.4140 ± 0.0014^{ijk}	1.4904 ± 0.0005^{jkl}	79.97 ± 0.21^{ijk}
S14	96.67 ± 4.04^{d}	366.33 ± 35.64^{h}	1.4215 ± 0.0027^{gh}	1.4931 ± 0.0010^{ghi}	81.08 ± 0.39^{gh}
S15	136.67 ± 5.77^{a}	759.33 ± 14.01^{a}	1.4425 ± 0.0029^{a}	1.5007 ± 0.0010^{ab}	84.18 ± 0.43^{ab}
S16	92.00 ± 0.00^{de}	308.00 ± 6.00^{hi}	1.4085 ± 0.0017^{k}	1.4884 ± 0.0006^{l}	79.15 ± 0.26^{k}
S17	110.00 ± 0.00^{c}	477.73 ± 22.46^{f}	1.4272 ± 0.0011^{efg}	1.4952 ± 0.0004^{efg}	81.94 ± 0.16^{efg}
S18	140.00 ± 0.00^{a}	765.67 ± 14.01^{a}	1.4350 ± 0.0029^{cd}	1.4981± 0.0010^{cd}	83.10 ± 0.42^{cd}
S19	99.00 ± 0.00^{d}	453.67 ± 35.73^{fg}	1.4289 ± 0.0019^{ef}	1.4958 ± 0.0007^{ef}	82.19 ± 0.28^{ef}
S20	71.00 ± 0.00^{f}	154.67 ± 10.41^{j}	1.4145 ± 0.0010^{ij}	1.4906 ± 0.0004^{jk}	80.04 ± 0.15^{ij}
Averages	104.60 ± 20.40	471.20 ± 203.74	1.4260 ± 0.0105	1.4948 ± 0.0038	81.75 ± 1.56
Standard values*	-	Nectar honey: < 800 honeydew honey: >800	1.39 - 1.44 à 20°C	-	-

EC : Electrical conductivity; * Standard values according to Codex Alimentarius [1]
In the same column, means with different letters (a, b, c, d, e, f, g, h, i, j, k, l) are significantly different (Turkey's HSD test, $p < 0, 05$).

The results of the physicochemical analysis of the local honey samples showed that the values of the parameters differed significantly ($p < 0.05$) due to at least one sample. These variations would be due to the origin of the nectar or honeydew, to the geo-climatic and environmental conditions of the regions concerned, to the harvest period [19], as well as to the storage conditions and durations of the honey [12].

The color index (between 71 and 140 mm Pfund) is lower than those ranging from 106.96 to 3152.85 mm Pfund [20] and from 197.69 to 637.98 mm Pfund [21] reported for honeys from Benin. The differences with our results would be partly due to the difference in the method of measuring the color. Indeed, these authors had used the spectrophotometric method (635 nm); while we used a Lovibond-type (visual) comparator.

Amber colored honeys (55%) were the most numerous, followed by dark colored ones (30%). The color of honey is a commercially very important characteristic [22]. Previous studies have shown that there are positive correlations between the color of honeys and their ash content [23] and the contents of phenolic compounds and total flavonoids [20]. Therefore, honeys (S7, S8, S9, S12, S15 and S18) of dark color would have good contents of ash, phenolic compounds and total flavonoids.

Table 5 Chemical parameters of 20 local honey samples marketed by different sellers in Korhogo town

Samples	Moisture content (g/100g)	pH	Free acidity (meq.kg^{-1})	Combined acidity (meq.kg^{-1})	Total Acidity (meq.kg^{-1})	HMF content (mg.kg^{-1})
S1	15.77 ± 0.20^{hij}	3.75 ± 0.16^{def}	23.13 ± 0.81^{bcd}	7.50 ± 0.46^{gh}	30.63 ± 0.40^{de}	17.24 ± 0.36^{g}
S2	14.15 ± 0.07^{l}	4.10 ± 0.03^{abcd}	19.47 ± 0.50^{e}	5.23 ± 0.28^{i}	24.69 ± 0.32^{gh}	11.53 ± 0.15^{ij}
S3	14.50 ± 0.17^{kl}	4.32 ± 0.14^{ab}	13.67 ± 1.15^{g}	2.58 ± 0.40^{jk}	16.25 ± 1.37^{k}	4.90 ± 0.46^{l}
S4	17.23 ± 0.25^{ef}	3.80 ± 0.10^{def}	22.08 ± 0.33^{cd}	2.20 ± 0.20^{k}	24.28 ± 0.44^{ghi}	11.31 ± 0.24^{j}
S5	16.67 ± 0.16^{fg}	4.10 ± 0.10^{abcd}	19.41 ± 0.48^{e}	8.00 ± 0.40^{fgh}	27.42 ± 0.28^{f}	14.24 ± 0.14^{h}
S6	18.08 ± 0.10^{bcd}	4.49 ± 0.25^{a}	10.67 ± 0.58^{h}	4.00 ± 0.44^{ij}	14.67 ± 0.85^{k}	0.56 ± 0.21^{m}
S7	16.24 ± 0.21^{ghi}	3.53 ± 0.25^{ef}	27.51 ± 0.49^{a}	6.99 ± 0.33^{h}	34.50 ± 0.81^{bc}	21.66 ± 0.27^{de}
S8	18.78 ± 0.22^{ab}	3.57 ± 0.15^{ef}	24.67 ± 0.58^{b}	9.83 ± 0.29^{cde}	34.50 ± 0.50^{bc}	21.43 ± 1.10^{de}
S9	17.80 ± 0.17^{cde}	3.59 ± 0.35^{ef}	24.29 ± 1.19^{bc}	9.39 ± 0.35^{def}	33.69 ± 1.22^{bc}	20.67 ± 0.28^{ef}
S10	15.21 ± 0.18^{jk}	4.30 ± 0.11^{ab}	14.00 ± 1.00^{g}	8.02 ± 0.21^{fgh}	22.02 ± 1.19^{ij}	9.66 ± 0.49^{k}
S11	16.30 ± 0.26^{gh}	4.12 ± 0.09^{abcd}	19.12 ± 0.23^{e}	10.06 ± 1.00^{cd}	29.17 ± 1.11^{ef}	17.07 ± 0.68^{g}
S12	17.67 ± 0.15^{cde}	3.61 ± 0.31^{ef}	24.00 ± 1.00^{bc}	8.10 ± 0.20^{fgh}	32.10 ± 0.92^{cd}	19.75 ± 0.14^{f}
S13	18.43 ± 0.21^{abc}	3.78 ± 0.18^{def}	23.00 ± 0.50^{bcd}	11.83 ± 0.76^{b}	34.84 ± 1.26^{b}	22.66 ± 1.08^{cd}
S14	17.37 ± 0.38^{def}	4.27 ± 0.06^{abc}	16.69 ± 0.80^{f}	10.02 ± 0.14^{cd}	26.71 ± 0.89^{fg}	5.69 ± 0.11^{l}
S15	14.40 ± 0.40^{kl}	3.50 ± 0.27^{ef}	27.70 ± 0.52^{a}	8.04 ± 0.62^{fgh}	35.74 ± 0.13^{b}	24.18 ± 0.17^{c}
S16	19.23 ± 0.25^{a}	4.27 ± 0.26^{abc}	14.47 ± 0.50^{fg}	7.00 ± 0.40^{h}	21.47 ± 0.76^{j}	13.07 ± 0.51^{hi}
S17	16.53 ± 0.15^{fgh}	3.83 ± 0.12^{cdef}	21.21 ± 1.07^{de}	17.64 ± 0.34^{a}	38.85 ± 0.80^{a}	26.37 ± 0.21^{b}
S18	15.43 ± 0.40^{ij}	3.42 ± 0.18^{f}	28.89 ± 0.95^{a}	11.33 ± 1.26^{bc}	40.22 ± 0.31^{a}	30.05 ± 0.75^{a}
S19	16.30 ± 0.26^{gh}	3.90 ± 0.02^{bcde}	20.87 ± 0.90^{de}	8.17 ± 0.76^{efgh}	29.03 ± 0.93^{ef}	16.57 ± 0.32^{g}
S20	18.37 ± 0.15^{bc}	4.38 ± 0.41^{a}	13.37 ± 0.55^{f}	9.01 ± 0.49^{defg}	22.38 ± 0.99^{hij}	10.68 ± 0.40^{jk}
Averages	16.72 ± 1.49	3.93 ± 0.37	20.41 ± 5.20	8.25 ± 3.38	28.66 ± 7.03	15.96 ± 7.51
Standard values*	< 20	3.2 - 4.5	-	-	< 50	< 40

HMF = hydroxylmethylfurfural; * Standard values according to Codex Alimentarius [1]

In the same column, means with different letters (a, b, c, d, e, f, g, h, i, j, k, l) are significantly different (Turkey's HSD test, $p < 0, 05$).

The electrical conductivity (between 115.67 and 765.67 µS/cm) is in the same order of variation as that (varying between 100 – 720 µS/cm) reported for some honeys from the region of Bejaia in Algeria [24]. All the honeys analyzed would be of nectar origin since their electrical conductivities were less than 800 µS/cm [1]. On the other hand, honeys (S7, S8, S15 and S18) of dark color were the best conductors of electric current (705.37 - 765.67 µS/cm); while honeys (S3, S6 and S20) of light amber color had the lowest values (respectively 160.49, 115.67 and 154.67 µS/cm). These results suggest the existence of a correlation between the electrical conductivity and the color of the honeys.

The density ranged from 1.4085 to 1.4442, and complies with the standard assigned to honey which is 1.39 to 1.44 at 20 °C [25]. The densest honeys (S2, S3 and S15) also had the highest refractive index and degree brix values; while those (S8, S13 and S16) the least dense gave the lowest refractive index and degree brix values. These results suggest the existence of a positive correlation between these three parameters, which are a function of the concentration of sugars (major constituent of dry matter) and the moisture content of honey [26]. Thus, honeys S2, S3 and S15 would be the richest in sugars; while those S8, S13 and S16 would have the lowest sugar content. In addition, these parameters, in particular the refractive index, could be used to measure the moisture content of honeys much faster than with other methods.

The moisture content is a criterion of quality and maturity of honey which determines the conservation of the product: the higher it is, the more the honey risks fermenting [19]. The risk of fermentation is very low for honeys that contain less than 18% [27]. The moisture content (between 14.15 and 19.23%) falls within the variation range (between 14 and 19%) obtained in previous studies carried out on honeys in Algeria [13]. The values obtained are less than 20%, the maximum authorized by the Codex Alimentarius for tropical honeys [1]. This indicates a good quality and a good degree of maturity of the honeys. However, honeys S6, S8, S13, S16 and S20, with values above 18%, would present the highest risks of fermentation during storage; in contrast, with values below 15%, honeys S2, S3 and S15 could be stored for a longer period. Indeed, according to Gonnet and Vache [28], below 15% water, fermentation never occurs.

The pH values obtained (varying from 3.42 to 4.49) are similar to those found by Iritié *et al.* [29] (3.7 - 4.3) and Diomandé *et al.* [10] (3.7 - 4.77) on Ivorian honeys. These results indicate that all the honeys analyzed are acidic and in conformity with the standards of the Codex Alimentarius [1]. They also testify that all the honeys studied would be of nectar origin. Indeed, according to Pesenti *et al.* [30], nectar honeys most often have low pH values (3.3-4.6) and honeydew honeys have higher pH values (4.2-5.5). The values of the total acidity of the honeys analyzed varied from 14.67 to 40.22 meq.kg^{-1}. These results are similar to those obtained by Coulibaly *et al.* [11] (16.67 - 33.33 meq.kg^{-1}) on Ivorian honeys. The total acidity values of the samples are within the normal range set by the Codex Alimentarius [1] which is 50 meq.kg^{-1}. This indicates the absence of unwanted fermentations. According to Schweitzer [31], the natural acidity of honey increases when the honey ages, when it is extracted from the combs with propolis and in particular when it deteriorates by fermentation. This parameter is therefore an important quality criterion since it gives very important indications of the state of the honey [14]. In addition, acidity strongly influences the rate of degradation of sugars and enzymes: high acidity of the medium promotes the degradation of hexoses into HMF which depreciates the quality of honey [32]. Being the least acidic sample (pH = 4.49; total acidity = 14.67 meq.kg^{-1}), honey S6 would be little subject to degradation. In contrast, honey S18, being the most acidic (pH = 3.42; total acidity = 40.22 meq.kg-1), could degrade more quickly; it will then be necessary to take special precautions for its conservation.

Hydroxymethylfurfural (HMF) is a breakdown product of fructose, it occurs in trace form in fresh honey; however, it increases with storage temperature, overheating and natural aging of honeys [26]. The concentration of HMF is recognized as an indicator of the freshness level of honey and an important criterion for the detection of overheated honeys, especially since HMF is present in small quantities or absent in fresh honeys [33]. The HMF content of the honeys analyzed varied from 0.56 to 30.05 mg.kg^{-1}. All the HMF values complied with the standards set by the Codex Alimentarius [1] which is ≤ 40 mg.kg^{-1}. However, according to Zappala *et al.* [34], good quality honey should not have an HMF level higher than 25 mg.kg^{-1}. The honeys S15 and S18 had respective levels of 38.85 and 40.22 mg.kg^{-1}; which means that these honeys would have been overheated during harvesting or stored in poor conditions. In contrast, the HMF content of honey S6 was very low (0.56 mg.kg^{-1}), which reflects the freshness of this sample and compliance with good harvesting practices. This honey would therefore not have undergone an inappropriate heat treatment during the harvest and storage chain.

5. Conclusion

The physicochemical analysis results of the local honey samples showed that the values of the parameters differed significantly ($p < 0.05$) due to at least one sample. Among the honey samples analyzed, amber colored samples (86 – 113 mm Pfund) were the most numerous (55%); some were light amber in color and others were dark in color. The electrical conductivity of these honeys oscillated between 115.67 and 765.67 µS/cm. The refractive index, degree brix and density ranged from 1.4884 to 1.5014; 79.15 to 84.45% and 1.4085 to 1.4442, respectively. The chemical parameters studied were also significantly ($p < 0.05$) different between the samples. The moisture contents varied between 14.15 and 19.23 g/100g, pH and free acidity values ranged from 3.42 to 4.49 and from 10.67 to 28.89 meq.kg^{-1}, respectively and total acidity values and HMF contents oscillated respectively from 14.67 to 40.22 meq.kg^{-1} and from 0.56 to 30.05 mg.kg^{-1}. Despite the existence of significant differences between the samples of local honey, the values of their physico-chemical parameters all complied with the standard values proposed by the Codex Alimentarius Commission. Ultimately, the honeys studied were generally of good quality. However, to deepen this study, it would be interesting to identify and quantify the nutrients of these honeys; to carry out their organoleptic analysis; and to assess their microbiological quality.

Compliance with ethical standards

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Disclosure of conflict of interest

All the authors declare that they do not have any conflict of interest.

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