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ORIGINAL RESEARCH PAPER

STUDY ON THE PHYSICOCHEMICAL, ANTIOXIDANT PROPERTIES AND MINERAL CONTENT OF FIVE HONEYS PRODUCED IN THE CENTRAL REGION OF ALGERIA

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Abstract: The present study evaluated the physicochemical, antioxidant properties and mineral content of five Honeys from the Central Region of Algeria (Laghouat). Physicochemical properties were examined according to the official methods of analysis of AOAC (Association of Official Analytical Chemists); antioxidant activities were determined by DPPH (2,2-diphenyl-1-picrylhydrazyl) and FRAP (Ferric reducing ability of plasma) assays**,** the minerals were analyzed by atomic absorption spectrometry. The results compared to those recommended by Codex Alimentarius indicated that the quality of the tested honey was very good. The samples exhibited good antioxidant activity. A linear positive relationship existed between antioxidant activity and total phenolics (R^2 = 0.95)/flavonoids (R^2 = 0.99). The analyzed honey samples possess valuable antioxidants for culinary and medicinal uses. The analysis revealed the presence of (K) 220.88 ± 1.72 ppm, (Na) 85.84 ± 1.72 ppm, (Fe) 0.1922 ± 0.47 ppm, (Co) 0.9144 ± 1.63 ppm, (Cu) 0.1252 ± 1.76 ppm and nickel (Ni) 0.0463 ± 0.10 ppm in the collected samples. Toxic elements identified in the studied honeys are safe because they are below the maximum residual limit. Therefore, these results indicate that the areas of production of these honeys are unpolluted by the toxic elements.

Keywords: *Algerian honey, Antioxidant, DPPH, flavonoids, FRAP, heavy metal, physicochemical parameters, polyphenols*

INTRODUCTION

Honey is the natural sweet substance produced by honey bees *Apis mellifera* from the nectar of flowers or exudates from trees and plants giving honey from nectar or honeydew respectively [1]. Honey has very variable sensory and physicochemical characteristics due to climatic and environmental conditions and the diversity of the origins of the plants from which they are harvested [2].
Mainly the chemical composition of honey is carbohydrates and water. It also contains minerals, proteins, free amino acids, enzymes, vitamins, organic acids, flavonoids, phenolic acids and other phytochemicals. The composition of honey depends mainly on flower sources and some external factors such as environmental factors and treatment methods [3]. Honey is valuable for the treatment of cardiovascular disease, cancer, cataract, and several inflammatory diseases as well as wound healing. The therapeutic actions of honey are due to antioxidant and antimicrobial properties [4]. Antioxidants are endogenous or exogenous substances capable of neutralizing or reducing the damage caused by free radicals in the human body. The human body produces the antioxidants, and it is also found in several foods. Antioxidants help ensure that our foods retain their taste, color and remain edible for a long time [5]. Antioxidant activity is the ability and potential of honey to reduce oxidative reactions in food production systems and human health. Honey is known to be rich in enzymatic and non-enzymatic antioxidants, including glucose oxidase, catalase, ascorbic acid, organic acids, Maillard reaction products, amino acids, and proteins [6]. Phenolic compounds are considered quasi-universal compounds which form the most important group of phytochemicals in plants [7]. Mainly the quantitative and qualitative nature of phenolic contents is an essential factor for the variations in the antioxidant activities of honeys [8]. Paramas et al [9] reported that honey phenolic compounds contribute significantly to its antioxidant power, as well as other, less important compounds. In addition, several studies have shown that the antioxidant activity of honey varies widely depending on the floral source [6]. For the needs of the colony, the bee harvest nectars, honeydews and pollens in the environment that are exposed to various bacteriological and chemical contaminants such as toxic elements. These elements can be found in the finished product that is consumed by humans [10]. On the other hand, elements such as cadmium, lead, and mercury are well known to be toxic to humans [11]. The sources of contamination of honey with heavy metals may be due to external environments such as plant emissions, non-ferrous metallurgy, leaded petrol, use of cadmium-containing pesticides, organic mercury, and pesticides-based Arsenic which are still in use in some countries [12].
Our work aims to study the physicochemical, antioxidant activity and mineral content of five honeys from the central region of Algeria (Laghouat).

MATERIALS AND METHODS

Chemicals

3,4,5-Trihydroxybenzoic acid (Gallic acid; GA) (99 %), ascorbic acid (AA) (99 %), 2,2-diphenyl-1-picrylhydrazyl 95 % (DPPH), ferric chloride (99 %), potassium ferricyanide, trichloroacetic acid (99 %) were procured from Sigma-Aldrich (Darmstadt, Germany). Sodium hydroxide (NaOH), chloric acid (HCl) (36.6 %), aluminium chloride

($AlCl_3$), sodium carbonate (Na_2CO_3) were purchased from Honeywell Fluka (France). The Folin-Ciocalteu reagent (FCR), ethanol (EtOH) and methanol (MeOH) were obtained from Biochem chemopharma Co (France). All other reagents used were of analytical grade.

Honey samples

Five samples of honey (H1–H5) produced in various regions of Laghouat (Central Region of Algeria) were collected from beekeepers in 2014. The regions from which the samples of honey were collected are indicated in in Table 1.

Table 1. *Presentation of studied honey samples*

Honey code	Date of harvest	Harvesting area	Presumed floral origin
H1	August 2014	Laghouat (Laghouat)	*Ziziphus lotus*
H2	July 2014	Aflou (Laghouat)	*Berwag*
H3	August 2014	Ain Madi (Laghouat)	*Mountain Honey*
H4	June 2014	El Assafia (Laghouat)	*Polyfloral*
H5	June 2014	El Assafia (Laghouat)	*Peganum harmala*

Physicochemical parameters

Free, lactone and total acidity, *p*H (InoLab pH Level 1 (Germany)), ash content, total solids, electrical conductivity (Ohaus starter 3000c electrical conductivity meter, Korea), density and moisture content (Digital Abbe refractometer AR2008, Germany) were determinate. The measurements were performed according to AOAC, 1990 [13].

Total phenolic content

The determination of the total polyphenols in the extracts of the different types of honey was carried out spectrophotometrically (OPTIZEN 2120UV Single beam UV/Vis spectrophotometer, Korea) according to the method of Folin Ciocalteu [14]. The content of total phenolics was expressed as mg of gallic acid equivalents per 100 g of honey [mg GAE·$(100\ g)^{-1}$].

Total flavonoid content

Total flavonoids were measured by the aluminum chloride spectrophotometric assay [15] using an OPTIZEN 2120UV Single beam UV/Vis spectrophotometer (Korea). Total flavonoid content was expressed as mg of rutin equivalents per 100 g of honey [mg RE·$(100\ g)^{-1}$].

Total protein content

The determination of the total protein in the extracts of the different types of honey was carried out spectrophotometrically according to [16] using OPTIZEN 2120UV Single beam UV/Vis spectrophotometer (Korea); it's based on the formation complex present

in Folin-Ciocalteau reagent. Bovine serum albumin (BSA) (0 – 50 mg·mL^{-1}) was used as a standard for preparing the calibration curve.

Analysis of antioxidant activities

DPPH radical scavenging activity

To determine the antioxidant activity of honey, the DPPH test was used according to the protocol described by [17] with some modifications. Honey samples were dissolved in ethanol at a concentration of 100 mg·mL^{-1}, and 0.75 mL of each sample was mixed with 1.5 mL of DPPH in methanol (0.02 mg·mL^{-1}), with methanol serving as the blank sample. The mixtures were left for 15 min at room temperature and the absorbance then measured at 517 nm (OPTIZEN 2120UV Single beam UV/Vis spectrophotometer, Korea). Ascorbic acid (0 – 100 mg·mL^{-1}) was used as positive controls. The radical scavenging activity was calculated following Eq. (1):

% Inhibition = [(blank absorbance - sample absorbance)/blank absorbance] * 100 (1)

The mean of three IC_{50} (concentration causing 50 % inhibition) values of each honey sample was determined graphically.

Reducing power

An aliquot (0.5 mL) of each honey extract (10 %) was mixed with 0.5 mL of 200 mmol·L^{-1} sodium phosphate buffers (*p*H 6.6) and 0.5 mL of 1 % potassium ferricyanide. The mixture was incubated at 50 °C for 20 min. After 0.5 mL of 10 % trichloroacetic acid (w/v) was added, the mixture was centrifuged at 3000 rpm for 8 min. The upper layer (0.5 mL) was mixed with 0.5 ml of deionized water and 0.1 mL of 0.1 % of ferric chloride and the absorbance was measured spectrophotometrically at 700 nm, using an OPTIZEN 2120UV Single beam UV/Vis spectrophotometer (Korea), higher absorbance indicates higher reducing power [18]. Acid ascorbic was used as a standard.

Minerals and heavy metals

Analytik Jena AG - novAA350 - Atomic Absorption Spectrometer (Germany) was used to determine mineral content (Fe, Ni, Pb, Co, Cd and Cu). Ten grams of the sample was placed in a silica dish and then calcined at 550 °C in a muffle furnace (Protherm furnace MOS 170/20, Turkey) for 5 hours. The calcined ash of honey was dissolved in 100 mL 2N HCl. It was then measured in an atomic absorption spectrometer with the appropriate lamp for each ion measured. Approximately a 2300 °C was used for temperature. Standard stock solutions of the respective metals were also prepared. The K and Na contents were determined by using a PFP7 Industrial Flame Photometer (United Kingdom). All the samples were analyzed in triplicates [13, 19].

Statistical analysis

All measurements were carried out in triplicate and presented as mean ± SD. Correlation and linear regression analyses were performed using Microsoft Office Excel 2010.

RESULTS AND DISCUSSION

Physicochemical analyses

The results of the physicochemical analyzes are summarized in Table 2.

Table 2. *Physicochemical characteristic of Laghouat honey*

Physicochemical characteristic	Honey code				
	H1	H2	H3	H4	H5
Moisture content [%]	20.41 ± 0.11	19.70 ± 0.10	17.75 ± 0.18	16.08 ± 0.11	18.7 ± 0.09
Total solids [%]	79.58 ± 0.11	80.3 ± 0.10	82.24 ± 0.18	83.91± 0.11	81.2 ± 0.09
Density	1.43 ± 0.05	1.45 ± 0.03	1.47 ± 0.08	1.48 ± 0.30	1.46 ± 0.07
*p*H	3.90 ± 0.01	3.54 ± 0.04	3.64 ± 0.03	3.38 ± 0.03	3.41 ± 0.02
Electrical conductivity [mS·cm^{-1}]	0.28 ± 0.02	0.46 ± 0.03	0.39 ± 0.03	0.60 ± 0.02	0.59 ± 0.03
Ash content [%]	0.23 ± 0.05	0.38 ± 0.07	0.32 ± 0.01	0.49 ± 0.09	0.48 ± 0.03
Free Acidity [meq·kg^{-1}]	12.33 ± 0.76	17.16 ± 0.76	16.1 ± 0.76	17.0 ± 0.50	21.50 ±1
Lactonic acidity [meq·kg^{-1}]	04.50 ± 0.50	14.66 ± 0.91	11.0 ± 0.28	05.0 ±0.57	18 ± 0.28
Total acidity [meq·kg^{-1}]	16.83 ± 0.57	31.83 ± 2.51	27.16 ± 1.15	22.00 ± 1.32	39.5 ± 1.32

The moisture content

The results of the moisture content of the samples studied are shown in Table 2. The moisture content of the samples studied is ranged from 16.08 ± 0.11 (H4) to 20.41 ± 0.11 (H1). These values are well below the maximum limit recommended by [20]. The variation in moisture content is due to different environmental conditions such as climate, floral origin of honey samples, the water content of nectars, processing techniques and storage conditions [21]. Moisture content is an important element in assessing the degree of honey maturity and shelf life [22]. Generally, a high amount of water causes honey fermentation, loss of flavor and loss of its quality. It could also accelerate the crystallization of certain types of honey and increase its water activity to values where certain yeasts can develop [3]. The fermentation of undesirable honey during storage is caused by the action of osmotolerant yeasts leading to the formation of ethyl alcohol and carbon dioxide. The alcohol can also be oxidized to acetic acid and water causing a bitter taste [23].

The total solid

The total solid is primarily consisted of sugars; fructose, glucose, and sucrose. Moreover, organic compounds such as acids and minerals also contributed to the total soluble solid in honey. H4 honey showed the highest soluble solid (83.91 ± 0.11 %), followed by H3 (82.24 ± 0.18 %), 81.27 ± 0.09 % for H5 and H2 with 80.3 ± 0.10 %, whereas that from the H1 had the lowest percentage with 79.58 ± 0.11 % of total solids. The difference of soluble solid might due to the difference in chemical composition of honey.

pH, free, lactonic and total acidity

The *p*H is a measure of quality and contained in international standards. The *p*H values of the studied varieties of honey obtained are summarized in Table 2. Examination of the results shows that the measured *p*H varies between 3.38 ± 0.03 to 3.90 ± 0.01. The values obtained are acidic and it falls within the international standards [24]. These values are similar to those reported for other honey samples from India, Brazil, Spain and Turkey, which would have a *p*H between 3.49 and 4.70, the variation in *p*H would be due to the buttered flora, the salivary secretion of the bee and the enzymatic and fermentative processes during the transformation of the raw material [25].

Acidity is an important quality criterion. The fermentation of honey causes an increase in acidity in honey, so a maximum value is very useful, although there are considerable natural fluctuations. The acid content is used by international standards [20]. The results summarized in Table 2 show that the free acidity values vary between 12.33 ± 0.76 and 21.5 ± 1 meq·kg^{-1}. As regards the acidity of lactones, values obtained vary between 4.5 ± 0.5 and 14.66 ± 0.91 meq·kg^{-1}. However, examination of the results shows that the values of total acidity of the varieties studied are between 22 ± 1.32 and 39.5 ± 1.32 meq·kg^{-1}. All registered results are falls within the international standards (below 50 meq·kg^{-1}) [20]. The fermentation of honey causes an increase in acidity in honey, so a maximum value is very useful, although there are considerable natural fluctuations [26].

Electrical conductivity

The electrical conductivity is a good criterion for determining the botanical origin of honey and today it is designated during routine checks honey and replacing the ash content. It is used by the new standards of [20]. The results are shown in Table 2. The electrical conductivity was the highest in H4 and H5 respectively, the H1 is showed the lowest electrical conductivity Table 2. The electrical conductivity expresses the ability of the aqueous solution to conduct an electric current. It is positively correlated with the soluble salt content. The content of the latter in the diluted solutions is proportional to the conductivity [27]. According to [28] the electrical conductivity is influenced by the *p*H of the solution, the valence of the ions and the degree of ionization. It is a good criterion linked to the botanical origin of the honey, and very often used in the routines of control of the honey instead of the ash content [3].

Ash content

The ash content is a quality criterion which depends on the botanical origin of the honey. Mineral content is a criterion used in international standards [28]. In the present study, H1 showed the lowest ash content 0.23 ± 0.02 %. On the other hand, the H5 showed the highest values of ash content 0.49 ± 0.02 %. Ash content of all samples was within the acceptable codex range [20]. Research also shows that the ash content is related to the botanical origin of honey [30]. Currently, the determination of the ash content is being replaced by the measurement of the electrical conductivity. Thus, the ash content could be maintained temporarily until the electrical conductivity is recognized as an international standard [30, 31].

Total phenolic and flavonoid contents

The total polyphenol dosage gives us an overall estimate of the content of different classes of phenolic compounds contained in the samples analyzed [32]. The total phenolic content [mg GAE·(100 g)$^{-1}$of honey] of Laghouat honeys was found in the range of 53.93 ± 1.01 to 123.05 ± 1.41, the results are presented in Table 3. For Slovenian and Romanian honeys, the content of phenolic compounds varied from 64 to 1304 and from 23.0 to 125.0 mg GAE·(100 g)$^{-1}$ respectively [33]. The phenolic content of the five samples of honey we analyzed is similar to the average values found for some Algerian honey [34]. Recent studies have shown that the concentration and type of phenolic substances depend on the floral origin of the honey; they are the main factors responsible for the biological activities of honey [35].
The results recorded for the flavonoid content [mg RE·(100 g)$^{-1}$ of honey] of honey samples ranged 12.57 ± 0.92 to 58.75 ± 0,73; it is presented in Table 3. These values are similar to the average values found for some Romanian honeys from 5.46 to 28.27 mg RE·(100 g)$^{-1}$ [33].
In honey, most phenolic compounds are in the form of flavonoids whose concentration depends on various factors, including plant species used by bees, plant health, season and environmental factors [36]. The amount and type of flavonoids found in honey vary according to the floral source. As a rule, the darker honeys, such as sunflower and buckwheat, contain higher amounts of flavonoids than the paler honeys, as well as greater antioxidant capacity [37]. According to [34, 38], the variation in polyphenol content could be due to the geographical origin of honey and specific climate and the conditions of plant sources in the region. Honey species from different floral sources have strong antioxidant activities.

The protein content

As regards the protein content in honey varieties, it is recorded that the protein content is between 3.15 ± 0.80 to 16.79 ± 0.47 mg·g^{-1} of honey (Table 3).

Table 3.*Total phenolic, flavonoids and protein contents for honey samples*

Honey code	Total phenolic content [mg GAE·(100 g)$^{-1}$]	Total flavonoids content [mg RE·(100 g)$^{-1}$]	Total protein content [mg·g^{-1}]
H1	80.62 ± 0.73	29.52 ± 0.96	13.44 ± 1.98
H2	53.93 ± 1.01	12.57 ± 0.92	9.77 ± 0.17
H3	70.50 ± 2.91	18.32 ± 1,22	16.79 ± 0.47
H4	64.22 ± 0.74	19.91 ± 0.79	3.15 ± 0.80
H5	123.05 ± 1.41	58.75 ± 0.73	12.12 ± 0.30

The results of this study are higher than those obtained by [38]. The protein content in Laghouat honeys was comparable to that found in another Algerian honeys where it varied from 3.7 to 9.4 mg·g^{-1} [39].
The level of protein is dependent on the type of flora and thus it is variable. The results obtained showed that protein richness essentially peptones, albumins, globulins and nucleo-proteins from the plant, and/or the bee and differs according to the botanical origin of honey [40].

Analysis of antioxidant activities

DPPH radical scavenging activity

DPPH is a stable nitrogen-based radical that is widely used to test the free radical scavenger and the ability of various substances. High DPPH trapping activity confers high levels of antioxidant activity in the sample. The DPPH radical is one of the substrates most commonly used for the rapid and direct evaluation of antioxidant activity due to its stability in radical form and the simplicity of the analysis [41].

The antioxidant activity is determined by the reduction in the absorbance of an alcoholic solution of DPPH at 515 nm which is due to its reduction to a non-radical form DPPH-H by the hydrogen-forming antioxidants present in the sample [42, 43]. The evaluation of the antioxidant activity of each honey sample was determined based on the scavenging activity against the free radical 2,2-diphenyl-1-picryl-hydrazyl (DPPH˙) through the IC_{50} parameter, which represents the concentration of the material in question necessary to inhibit 50 % of free radicals. Thus, a lower IC_{50} value in honey indicates a high free radical scavenging capacity. This method is commonly used to evaluate honey samples [44 – 49]. The results of the antiradical activity determined using a DPPH test is represented in Table 4. There were marked differences between honey. Again the least active is H4 (IC50 = 9.39 ± 0.36 $mg \cdot mL^{-1}$); the most active H5 (IC_{50} = 0.75 ± 0.05 $mg \cdot mL^{-1}$). The results obtained by [44]. Ranged from 7.2 to 53.8 $mg \cdot mL^{-1}$. In a study conducted by [48], the antioxidant values ranged from 106.67 to 168.94 $mg \cdot mL^{-1}$, and according to data from [49], they ranged from 1.63 to 47.62 $mg \cdot mL^{-1}$. These results showed that the honey samples collected in the present study have greater antioxidant potential compared to the results reported in the literature. The high radical scavenging may be due to its content of phenolic compounds because the antioxidant potential of honey is proportional to the content of polyphenols present [50].

Reducing power

This method is based on the ability of antioxidants to reduce iron ferric Fe^{3+} to ferrous iron Fe^{2+}. Reducing power is one of the antioxidant mechanisms [50]. It has been found that the total phenolic content and the Fe^{2+} content formed in the presence of the honey antioxidants are significantly correlated. Similar findings were reported by others [8, 44, 50, 52]. In fact, all the honey samples from different sources exhibited the reducing power. The results of the antioxidant activity assayed by the test of the studied samples are represented in Table 4.

However, the values in Table 4 show that H5 is higher reducing power (AEAC = 0.42 ± 0.001 CE $mg \cdot g^{-1}$, Abs (700 nm) = 1.64 ± 0.02), while H2 seems to exert the lowest reducing power (0.101 ± 0.03 CE $mg \cdot g^{-1}$, Abs (700 nm) = 0.41 ± 0.0243). These results are similar to those obtained by [18] for chestnut honey and acacia which showed that less active honey are monofloral origin (acacia, sulla, dandelion and clover). Similar findings were also observed in different Geographical Origins honeys [53]. The reducing properties are generally related to the presence of phenolic compounds that are the main factors responsible for antioxidant activities. [54]. According to [55], the antioxidant activity of the different samples of honey analyzed depends mainly on the floral source of honey. However, they suggested that the botanical species is the main source of honey, but is not the only factor that contributes to its antioxidant properties.

Table 4. *Reducing power and IC_{50} value for different types of honey samples*

Honey code	Reducing power		DPPH
	Absorbance [700 nm]	AEAC* [CE mg·g^{-1}]	IC_{50} [mg·mL^{-1}]
H1	0.83 ± 0.031	0.2 ± 0.007	2.74 ± 0.08
H2	0.41 ± 0.0243	0.10 ± 0.03	No Actif
H3	0.61 ± 0.009	0.14 ± 0.01	8.55 ± 0.26
H4	0.549 ± 0.023	0.13 ± 0.01	9.39 ± 0.36
H5	1.64 ± 0.02	0.4 ± 0.001	0.75 ± 0.05

*AEAC : Ascorbic acid equivalent antioxidant capacity

Correlations

Correlation between antioxidant activity and total phenolics had a correlation coefficient of R^2 = 0.98 (Figure 1), while correlation between antioxidant activity and flavonoids had a correlation coefficient of R^2 = 0.99 (Figure 2); both indicating that a greater percentage of the antioxidant activity of the studied honey from the Central Region of Algeria may be attributed to the presence of phenolic compounds.

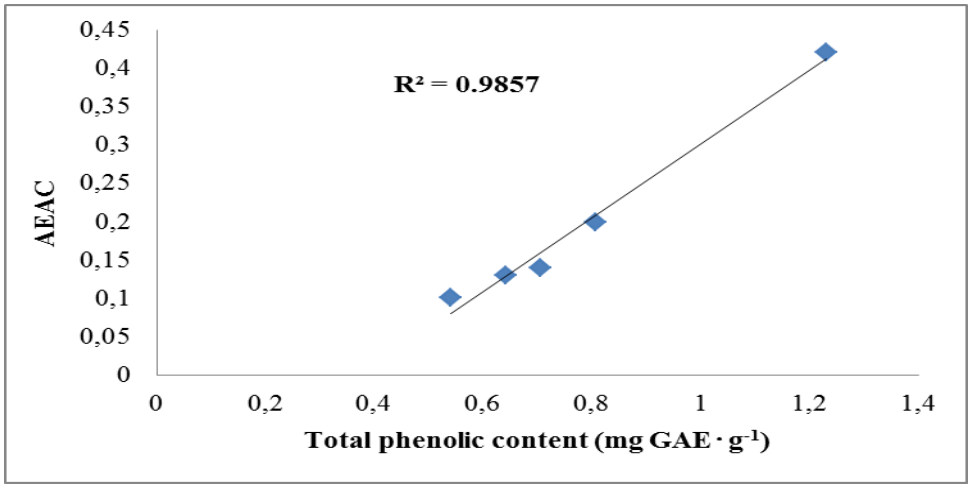

Figure 1. *Correlation between antioxidant activity and total phenolic content*

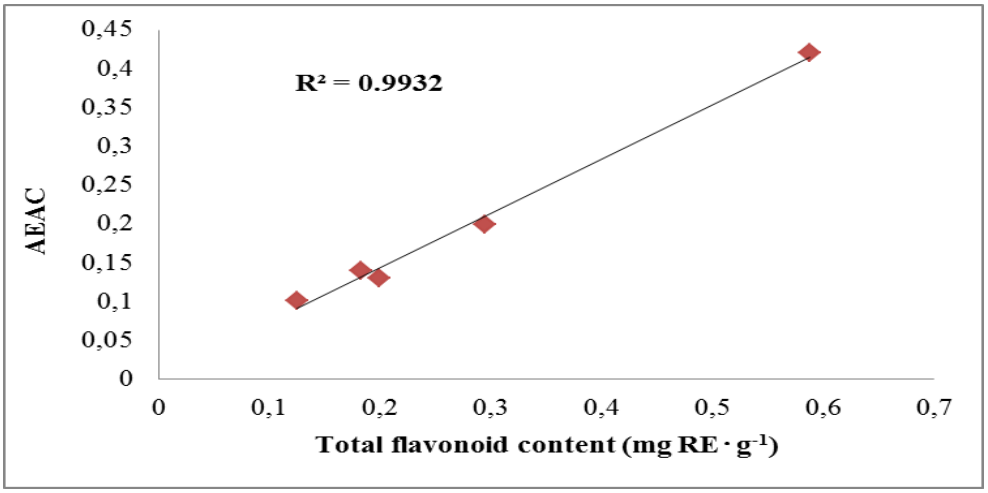

Figure 2. *Correlation between antioxidant activity and flavonoid content*

In honey, the components responsible for the antioxidant effect are flavonoids and phenolic compounds [56]. Several studies have shown that antioxidant activity is strongly correlated with the content of total phenolic compounds. Alongside this, a strong correlation was found between the antioxidant activity and the flavonoids content in the honey [57].

Minerals and heavy metals

The result of minerals heavy metal concentrations of five honey samples from different places of Laghouat are presented in Table 5. Concerning minerals, potassium appeared in the greatest content (220.88 ± 1.72 ppm) followed by sodium (85.84 ± 1.72 ppm). Noticeable contents of tested heavy metals (as environmental pollutants) were detected (Fe: 0.1922 ± 0.47 ppm, Co: 0.9144 ± 1.63 ppm, Cu: 0.1252 ± 1.76 ppm), while Ni had the lowest content (0.0463 ± 0.10 ppm). Cadmium and lead were ND (not detected) in all honey samples.

Table 5. *Minerals and heavy metals concentrations in analyzed honey samples*

Minerals and heavy metals concentrations [ppm]	**Honey code**				
	H1	**H2**	**H3**	**H4**	**H5**
K	141.32 ± 1.2	228.8 ± 1.2	288.9 ± 2.27	401.27 ± 3.1	264.92 ± 5
Na	28.67 ± 1.2	89.6 ± 1.2	69.89 ± 2.27	104.83 ± 3.2	136.20 ± 3
Fe	0.11 ± 0.52	0.16 ± 1.5	0.36 ± 0.47	0.15 ± 0.34	0.17 ± 0.87
Cu	0.121 ± 0.96	0.13 ± 1	0.09 ± 4.95	0.176 ± 0.78	0.09 ± 1.3
Co	0.27 ± 0.45	0.27 ± 0.45	1.6 ± 3.54	0.66 ± 0.123	ND
Ni	ND	0.074 ± 0.21	ND	0.001 ± 0.01	0.06 ± 0.08
Pb	ND	ND	ND	ND	ND
Cd	ND	ND	ND	ND	ND

Approximated values of potassium and sodium were also observed for Spanish honeys [58, 59], reported 285.60 ppm, 77.7 ppm respectively. Variability in iron content can be attributed to environmental, botanical, or geographic factors. Copper can contaminate the environment through the use of pesticides against pests that damage crops. Contact with stainless steel surfaces during harvesting, processing and/or preparation of honey may contaminate it with chromium due to the corrosive effect of the acidity of the honey. Nickel is present in small quantities or not detected for studied, these concentrations may be accidental or mostly natural [59].

Cadmium and lead were not detected in all honey samples. It has been reported that cadmium and lead are non-essential elements in plant nutrition and are one of the most toxic substances that accumulate in biological systems [60].

It is possible to conclude that the elemental composition of honey depends on soil composition, plant type, season, and environmental conditions. Also based on the results obtained, the quality of most natural raw honey from Laghouat meets international standards.

CONCLUSION

This is the first study to investigate the physicochemical, antioxidant properties and mineral analysis of five honeys from the Central Region of Algeria (Laghouat). The results of different physicochemical parameters allow us to assess the quality of the five samples studied and show that honeys collected are of good quality by international standards. This honey has a high antioxidant potential, as indicated by their high phenolic and flavonoid contents. This fact is of great economic and/or industrial interests on account of the applications of these components in the food, cosmetics and pharmaceutical industries. The DPPH radical scavenging activity and the reducing power test indicated that honey sample possessed excellent antioxidant properties and the Algerian honey is a good source of antioxidants. Eventually, honey is a natural product with a number of salient therapeutic properties. Within the mineral contents, it is obvious that these honeys are rich in potassium, sodium minerals and could be more beneficial for human nutrition. The trace elements that are present in our honey samples present no health hazards as long as they are in low doses. On the other hand, they contribute to the proper functioning of the organism. It is important to take the necessary precautions to ensure the standardization and rationalization of beekeeping techniques, manufacturing processes and storage processes to improve the quality of honey.

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