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To cite this article: P. Mondragón-Cortez , J.A. Ulloa , P. Rosas-Ulloa , R. Rodríguez-Rodríguez & J.A. Resendiz Vázquez (2013) Physicochemical characterization of honey from the West region of México, CyTA - Journal of Food, 11:1, 7-13, DOI: [10.1080/19476337.2012.673175](https://doi.org/10.1080/19476337.2012.673175)

To link to this article: <http://dx.doi.org/10.1080/19476337.2012.673175>



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Published online: 11 May 2012.



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Physicochemical characterization of honey from the West region of México

Caracterización fisicoquímica de miel de la región Occidente de México

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(Received 27 November 2011; final version received 29 February 2012)

Physicochemical properties of eight samples of Mexican honeys from the West region were measured over 23 parameters, including moisture, water activity, soluble solids, hydroxymethylfurfural (HMF), ash, electrical conductivity, acidity (free, lactic, and total), sugar content (fructose and glucose), color (L^* , a^* , b^*), and mineral content. In addition, honey samples were classified according to the pollen quantitative analysis. According to the physicochemical parameters studied, the samples showed the values typical of honey. All honey samples were classified as dark according to the values of the L^* color parameter. Only two honey samples were classified as monofloral and six as multifloral type. In general, the honey samples presented a good level of quality because they meet the physicochemical specifications of international regulation.

Keywords: honey; physicochemical characteristics; sugar; color; minerals

Las propiedades fisicoquímicas de ocho muestras de miel Mexicana de la región Occidente fueron determinadas a través de 23 parámetros, incluyendo humedad, actividad de agua, sólidos solubles totales, hidroxi-metil-furfural, cenizas, conductividad eléctrica, acidez (libre, láctica y total), contenido de azúcares (glucosa y fructosa), color (L^* , a^* , b^*) y contenido mineral. Además, las muestras fueron clasificadas de acuerdo al análisis cuantitativo de polen. De acuerdo a los parámetros fisicoquímicos estudiados, las muestras presentaron los valores típicos de la miel. Todas las muestras fueron clasificadas como oscuras de acuerdo al parámetro L^* . Dos muestras de miel fueron clasificadas como monoflorales y el resto como multiflorales. En general las muestras de miel presentaron un buen nivel de calidad, ya que cumplieron las especificaciones fisicoquímicas de la regulación internacional.

Palabras claves: miel; características fisicoquímicas; azúcares; color; minerales

Introduction

Honey is the natural complex food product produced by bees from the nectar of plants. Bee honey has significant nutritional and medicinal benefits. It is a rich source of readily available sugars, organic acids, various amino acids, and in addition source of many biologically active compounds (Anupama, Bhat, & Sapna, 2003; Azeredo, Azeredo, de Sousa, & Dutra, 2003; Lazaridou, Biliaderis, Bocandritsos, & Sabatini, 2004; Saxena, Gautam, & Sharma, 2010).

Each honey possesses a unique combination of components and properties, due to the variety of flora located in its geographical region of production, climatic conditions of the producing area and processing and storage methods (Abu-Tarboush, Al-Kantani, & El-Sarrage, 1993; Turhan, Tetik, Karhan, Gurel, & Tavukcuoglu, 2008).

The physical properties and chemical composition of honey from different countries have been published by many researchers (Bogdanov, Ruoff, & Persano-Oddo, 2004; Corbella & Cozzolino, 2006; Gomes, Dias, Moreira, Rodrigues, & Estevinho, 2010; Ojeda de Rodríguez, Sulbarán de Ferrer, Ferrer, & Rodríguez, 2004; Ouchemoukh, Louaileche, & Schweitzer, 2007). Honeys also are analyzed for the pollen content and to control their origin. This kind of

analysis has become more popular in recent years since the characterization of honey, one of the most highly valued apicultural products, is an important aspect with respect to beekeeping development (Horn & Aira, 1997).

Mexican beekeeping has a high social and economic value. Currently, Mexico is the fifth largest producer of honey with about 57,000 tons and the third largest exporter in the World. Mexico exports honey principally to Germany, England, and United States, but the problem is that generally beekeepers are selling their honey without a characterization (Ramírez-Arriaga, Navarro-Calvo, & Díaz-Carbajal, 2011).

Some studies have reported the physicochemical characteristics of honey from the Southwest of México (Mogel-Ordoñez, Echatarreta-González, & Mora-Escobedo, 2005; Mora-Escobedo, Mogel-Ordoñez, Jaramillo-González, & Gutiérrez-López, 2006; Viuda-Martos et al., 2010); however, there is no reported information from other regions of the country. Therefore, the generation of information on honey from regions of México where its characteristics are unknown, could be useful for the integration of a national map of honey quality and its comparison with the international standards and parameters of honey from other countries.

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The objective of this research was the physicochemical characterization and pollen quantification of honey from the West region of México.

Material and methods

Honey samples

The study was conducted on eight samples (H1–H8) of the typical honeys produced in eight different locations of the State of Nayarit, from the West region of México. All collected samples were taken from the local beekeepers with a guarantee of genuineness. All samples were collected and stored in holders and transferred to the laboratory, where they were kept at room temperature ($\sim 22^\circ\text{C}$) until analysis.

Physicochemical parameters

Moisture and soluble solids were determined according to the official method of the Association of Official Analytical Chemists (AOAC, 1990) using an Abbe refractometer (Leica, Buffalo, New York, USA). Moisture and soluble solids were expressed as g kg^{-1} and $^\circ\text{Brix}$, respectively.

Determination of water activity (a_w) was made by means of an Aqualab CX-2 water activity meter (Decagon Device, Inc., Pullman, Washington, USA) according to the procedure reported by Zamora, Chirife, and Roldan (2006).

The determination of hydroxymethylfurfural (HMF) was made according to the spectrophotometric method recommended by Zappala, Fallico, Arena, and Verzera (2005) using a Cintra 6 UV–Vis spectrophotometer (GBS Scientific Equipment, Victoria, Australia). Results were expressed in HMF mg kg^{-1} of honey.

Ash content was determined by calcination, at 550°C in a furnace, until constant mass was attained according to the method of the AOAC (1990) and the results were expressed as g kg^{-1} .

Electrical conductivity of a honey solution at 20% (dry matter basis) in deionized water was measured in an Orion conductivity meter model 126 (Thermo-Orion, Boston, Massachusetts, USA) according to the method reported by Bogdanov (1997) and the results were expressed as $\mu\text{S cm}^{-1}$.

The free, lactic, and total acidity were determined by the titrimetric method as follows: The addition of 0.05 M NaOH was stopped at pH 8.50 (free acidity), immediately a volume of 10 mL 0.05 M NaOH was added, without delay, back-titrated with 0.05 HCl to pH 8.30 (lactic acidity). Total acidity results were obtained by adding free and lactic acidities (AOAC, 1990). Results were expressed in meq NaOH kg^{-1} .

The fructose and glucose concentrations were determined using the HPLC method according to the AOAC (1990). The chromatographic mobile phase consisted of a mixture of water–acetonitrile (25–75), whose flow was kept constant at 1 mL min^{-1} . The HPLC equipment comprised a binary pump, an auto sampler, and a refractive index detector, all from Varian Prostar (Varian Inc., Palo Alto, CA, USA). Separation was performed on a $5 \mu\text{m}$ LC- NH_2 column (Supelco, Bellefonte, PA, USA) of $250 \text{ mm} \times 4.6 \text{ mm}$.

Determination of mineral elements

Nine elements: Potassium (K), calcium (Ca), phosphorus (P), sodium (Na), sulfur (S), magnesium (Mg), silicon (Si), iron (Fe), and zinc (Zn) were determined by heating 10 g honey at

550°C overnight, dissolving the resulting ash in 10 mL of a mixture (1:1) of HCl (1 M) and HNO_3 (1 M), completing the volume of the solution to 50 mL with Milli Q water (González-Paramás et al., 2000). Matrix modifiers were added for minerals that presented spectral interference, for instance, La_2O_3 and KCl was added for measuring calcium and magnesium; and CsCl for potassium and sodium. Elemental analysis was carried out on an Optima 3200RL absorption atomic spectrophotometer (Perkin Elmer, Connecticut, USA) using a flame of air: Acetylene and equipped with AA WinLabTM instrument control software. Quantitation was achieved by reference to a calibration curve and averaged over three independent measurements.

Analysis of each sample was carried out in triplicate. To control the stability of the analytical signals, the measurements of the standard solutions were repeated before and after the measurements of the samples. Repeatability of the measurements was usually 2–3%.

Color analysis

Color characteristics were assessed by the CIE $L^*a^*b^*$ method, where lightness L^* and two color coordinates, a^* (redness–greenness) and b^* (yellowness–blueness), were determined by means of a Minolta CR-300 Chromameter (Minolta Ltd, Tokyo, Japan). Honey samples were placed in a plastic container of 7 cm in diameter and covered with a plastic plate. The measured layer was 1 cm thick. L^* , a^* , and b^* parameters were measured against a white background and were directly obtained from the apparatus (González-Miret, Terrab, Hernanz, Fernández-Recamales, & Heredia, 2005; Viuda-Martos et al., 2010).

Pollen analysis

The botanical origin of the honeys was studied using the techniques described by Maurizio (1979). Slides were prepared by acetolysis by centrifuging 10 g of honey dissolved in 20 mL of diluted sulfuric acid ($5 \text{ g H}_2\text{SO}_4 \text{ L}^{-1}$) for 10 min at 2500 rpm. The supernatant was decanted and the sediment washed twice with 10 mL distilled water and then centrifuged. The sediment was extended on a slide and dried at 70°C , then mounted with stained glycerine gelatin. Pollen grains were identified and counted by using a microscope model BH-2 (Olympus Optical Ltd, Tokyo, Japan) a magnification of $\times 200$. After pollen grains were counted, they were classified in the following frequency classes: Predominant pollen ($>45\%$ of the pollen grains counted); secondary pollen (16–45%); important minor pollen (3–15%), and minor pollen ($<3\%$), according to Louveaux, Maurizio, and Vorwohl (1978).

Statistical analysis

All analyzes were carried out in triplicate and the data were expressed as means \pm standard deviations (SD), which were calculated using Excel (Microsoft Office, Version 2003).

Results and discussion

Physicochemical properties

The data obtained are presented in Table 1 and show in general a good quality of the studied honey samples.

Table 1. Physicochemical parameters of honey samples from West region of México.

Tabla 1. Parámetros fisicoquímicos de muestras de miel de la región Occidente de México.

Honey sample	Moisture (g kg ⁻¹)	Water activity	Soluble solids (°Brix)	HFM (mg kg ⁻¹)	Ash (g kg ⁻¹)	Conductivity (mS cm ⁻¹)	Acidity (meq kg ⁻¹)		
							Free	Lactone	Total
H1	170.4 ± 0.6	0.577 ± 0.001	81.2 ± 0.10	9.01 ± 1.79	1.27 ± 0.011	0.345 ± 0.013	21.7 ± 0.58	6.2 ± 1.26	27.8 ± 0.76
H2	162.2 ± 0.2	0.573 ± 0.001	81.6 ± 0.05	12.91 ± 2.94	1.18 ± 0.012	0.325 ± 0.016	19.3 ± 0.57	7.0 ± 0.50	26.3 ± 0.76
H3	176.2 ± 0.2	0.590 ± 0.001	80.3 ± 0.06	21.96 ± 5.04	3.34 ± 0.010	0.615 ± 0.014	25.1 ± 0.57	11.5 ± 1.80	36.6 ± 2.02
H4	162.5 ± 0.3	0.569 ± 0.001	81.7 ± 0.11	16.54 ± 3.05	1.31 ± 0.016	0.359 ± 0.011	19.8 ± 0.27	9.3 ± 0.57	29.2 ± 0.77
H5	180.3 ± 0.5	0.610 ± 0.001	80.0 ± 0.05	14.17 ± 0.93	1.53 ± 0.019	0.412 ± 0.020	14.5 ± 0.58	2.8 ± 0.29	17.3 ± 0.83
H6	170.6 ± 0.5	0.570 ± 0.003	81.0 ± 0.11	12.10 ± 1.74	2.45 ± 0.021	0.480 ± 0.015	18.6 ± 0.29	6.1 ± 1.44	24.8 ± 1.59
H7	188.9 ± 0.7	0.613 ± 0.002	79.1 ± 0.15	10.12 ± 2.32	1.96 ± 0.014	0.430 ± 0.010	24.7 ± 2.21	10.8 ± 0.76	35.5 ± 1.60
H8	178.3 ± 0.2	0.606 ± 0.002	80.1 ± 0.10	14.26 ± 1.58	4.11 ± 0.012	0.737 ± 0.016	31.8 ± 1.17	4.9 ± 1.33	36.4 ± 1.27
Mean	173.6 ± 0.9	0.588 ± 0.018	80.6 ± 0.86	13.87 ± 4.48	2.12 ± 0.103	0.463 ± 0.138	21.9 ± 5.08	7.3 ± 2.99	29.2 ± 6.47

Note: Results are expressed as mean values ± standard deviation.

Nota: Los resultados son expresados como la media ± desviación estándar.

Moisture values between 162.2 and 188.9 g kg⁻¹ were obtained and they are included in the water range limits (<200 g kg⁻¹) approved by the international regulations (Codex Alimentarius [CA], 2001). The moisture content of honeys of different origins shows varietal differences and it may range from 130 to 290 g kg⁻¹ (Kayacier & Karaman, 2008). Higher moisture contents could lead to undesirable honey fermentation during storage, caused by the action of osmotolerant yeasts, resulting in the formation of ethyl alcohol and carbon dioxide. The alcohol can be further oxidized to acetic acid and water resulting in a sour taste (Chirife, Zamora, & Motto, 2006). The moisture content of honey depends on various factors such as harvesting season, degree of maturity reached in the hive and climatic factors (Finola, Lasagno, & Marioli, 2007).

The a_w of the honey samples varied from 0.569 to 0.613 (Table 1). Lazaridou et al. (2004) reported a_w values ranging from 0.53 to 0.67 for Greek honeys. The a_w in honey can reach values between 0.49 and 0.65, due to its high content of monosaccharides (fructose and glucose in particular) and its relatively low water content (Gleiter, Horn, & Isengard, 2006; Zamora & Chirife, 2006). The a_w is an important factor, which governs the honey stability by preventing or limiting microbial growth. The osmotolerant yeasts are able to grow at a minimal a_w of 0.6 (Abramovic, Jamnik, Burkan, & Kac, 2008; Chirife et al., 2006); therefore, the honey samples in this study identified as H5, H7, and H8, with a_w values of 0.610, 0.613, and 0.606, respectively, could be candidates for fermentation.

Using the values of a_w and moisture, we found a linear correlation, which was as follows: $a_w = 0.26207 + 0.018795A$, where A is the moisture content ($R^2 = 0.831$). This equation is similar (intercept and slope) to that calculated by several authors using honey from different countries (Cavia, Fernández-Muiño, Huidobro, & Sancho, 2004; Kayacier & Karaman, 2008; Zamora et al., 2006). This correlation may be useful to calculate the water activity value using only the water content, which is a measurement relatively simple and fast (by refractometry) compared with the measurement of the a_w of honey.

Soluble solids content expressed as °Brix of the honey samples of this study ranged from 79.1 to 81.7 (Table 1). These values are in agreement with those reported for other types of honey. According to Silva, Videira, Monteiro, Valentao and Andrade (2009), the soluble solid content of

honey samples from Portugal ranged from 79.0 to 82.2 °Brix, whereas, for honey samples from India, it ranged from 76.0 to 88.0 °Brix.

The HMF content of honey is an indicator of freshness, because this compound is not generally present in a fresh honey. The analyzed honey samples in the study showed HMF content values between 9.01 and 21.96 mg kg⁻¹. No honey sample in this experiment (Table 1) exceeded the international regulation which sets a maximum HMF of 40 mg kg⁻¹ (CA, 2001; European Union [EU], 2002). Other studies on honey from various countries have reported the HMF content value: Argentina honey 14.8 mg kg⁻¹, Portugal honey 6.5 mg kg⁻¹, and Turkey honey 7.26 mg kg⁻¹ (Chirife et al., 2006; Feas, Pires, Estevinho, Iglesias, & Pinto de Araujo, 2010; Yardibi & Gumus, 2010).

Ash content is an indicator of the mineral content. It is considered as a quality criterion indicating the possible botanical origin of honey. Its value in the analyzed samples ranged from 1.27 to 4.11 g kg⁻¹ (Table 1). Blossom, nectar or floral honey is honey which is produced from the nectar of plants, whereas honeydew honey is that which is obtained mainly from the excretions of plant sucking insects (*Hemiptera*) on the living part of plants or secretions of living parts of plants (EU, 2002). Generally, the ash content of blossom honey is ≤6.0 g kg⁻¹ as compared to honeydew honey or blends of honeydew and blossom honeys, where this value is ≥12.0 g kg⁻¹ (Ouchemoukh et al., 2007). Thus based on this criterion, the analyzed honeys in this work are classified as blossom honey. Ash content of honeys from other regions of the world ranging from 0.8 to 5.5 g kg⁻¹ have been reported (Acquarone, Buera, & Elizalde, 2007; Ahmed, Prabhu, Raghavan, & Ngadi, 2007; Kahraman, Buyukunal, Vural, & Altunatmaz, 2010; Liviu-Al et al., 2009). The variability in the ash content of honeys could be due to the harvesting processes, beekeeping techniques, and the material collected by the bees during the foraging on the flora (Finola et al., 2007).

Electrical conductivity varies with botanical origin and depends on the mineral content, organic acids, proteins, some complex sugars and polyols (Terrab, Díez, & Heredia, 2003). Floral honeys should have electrical conductivity values below 0.8 mS cm⁻¹, whereas honeydew should have values above 0.8 mS cm⁻¹ (Downey, Hussey, Kelly, Walshe, & Martin, 2005). All samples had conductivity measurements below 0.8 mS cm⁻¹, which suggests that honeys collected in

this work were of a floral origin. Conductivity values ranged from 0.325 to 0.737 mS cm⁻¹, which are similar to the published by others (Kaskoniene, Venskutonis, & Ceksteryte, 2010; Terrab et al., 2003) and the mean conductivity value for the eight honey samples in this study was 0.436 mS cm⁻¹ (Table 1). A linear relationship is known to exist between the ash content and the electrical conductivity, which is expressed as $C = 0.14 + 1.74 A$, where C is the electrical conductivity and A is the ash content (Saxena et al., 2010). In this study, the linear relationship between the ash content and the electrical conductivity was expressed as $C = 0.182 + 1.32 A$ ($R^2 = 0.973$), where C is the electrical conductivity and A is the ash content. Other equations that describe the relationship between the ash content and the electrical conductivity have been reported (Downey et al., 2005; Nasiruddin-Khan, Qaiser, Mubashir-Raza, & Rehman, 2006).

Acidity in honey is calculated as free, lactic, and total acidity. Free acidity is due to the presence of organic acids, particularly gluconic acid, which are in equilibrium with the corresponding lactones and some inorganic ions such as phosphate or sulfate. Lactic acidity is considered as the acidity reserve when the honey becomes alkaline and total acidity is the sum of free and lactic acidities (Terrab, Diez, & Heredia, 2002). International regulations specify a free acidity of not more than 50 meq kg⁻¹ (CA, 2001; EU, 2002). The values for free acidity in samples of this study were between 14.5 and 31.8 meq kg⁻¹, while the lactic acidity ranged from 2.8 to 11.5 meq kg⁻¹, and total acidity from 17.3 to 36.6 meq kg⁻¹ (Table 1). The average for total acidity of the honey samples of this study (29.2 meq kg⁻¹) was similar (31.70 meq kg⁻¹) to the average reported for Turkish honey, but lower (48.27 meq kg⁻¹) than the reported for Venezuelan honey (Vit, Persano-Oddo, Marano, & Salas de Mejía, 1998; Yardibi & Gumus, 2010). Also, a total acidity value lower (18.4 meq kg⁻¹) than that reported here has been found in honey from Argentina (Acquarone et al., 2007). The acidity of the honey contributes to its flavor, improves antioxidant activity and influences against the action of microorganisms (Cavia, Fernández-Muiño, Alonso-Torre, Huidobro, & Sancho, 2007). Variations in total acidity have been attributed to the floral source and harvest season (Ojeda de Rodríguez et al., 2004).

Honey consists mostly of the monosaccharides glucose and fructose. The actual proportion of fructose to glucose, in a particular honey, depends largely on the source of the nectar (Anklam, 1998). According to White (1978), the average ratio of fructose/glucose is 1.2/1 which was observed in this study (Table 2). On the other hand, all honey samples contained more fructose (371.9–409.1 g kg⁻¹) than glucose (305.7–334.4 g kg⁻¹). honeys with high fructose/glucose ratio would remain liquid for longer periods because of the modification of the saturated level of glucose by the presence of the larger amount of fructose (White, Kushnir, & Subers, 1964). In addition, the fructose/glucose ratio may have an impact on honey flavor, since fructose is much sweeter than glucose (Ojeda de Rodríguez et al., 2004). All honey samples met the requirement (650 g kg⁻¹) of reducing sugars according to the specific legislations of some countries (Codex Honey Standards, 1986; Covenin, 1984) and agree with the results obtained on honey samples of other studies (Baroni et al., 2009; Tewari & Irudayaraj, 2004).

Table 2. Sugar mean composition in honey samples from West region of México.

Tabla 2. Composición media de azúcares en muestras de miel de la región Occidente de México.

Honey sample	Fructose (g kg ⁻¹)	Glucose (g kg ⁻¹)	Fructose + glucose (g kg ⁻¹)	Fructose/glucose
H1	377.5 ± 7.3	318.7 ± 5.8	696.2	1.18
H2	409.1 ± 5.2	309.3 ± 4.2	718.4	1.25
H3	383.5 ± 5.8	306.1 ± 4.6	689.6	1.25
H4	384.3 ± 2.5	334.4 ± 12.7	718.7	1.15
H5	371.9 ± 10.9	307.1 ± 1.8	679.0	1.21
H6	381.1 ± 9.8	325.6 ± 15.5	706.7	1.17
H7	391.8 ± 11.4	305.7 ± 5.7	697.5	1.28
H8	372.8 ± 5.8	321.0 ± 2.8	693.8	1.16
Mean	384.0 ± 13.2	321.0 ± 2.8		

Note: Results are expressed as mean values ± standard deviation.

Nota: Los resultados son expresados como media ± desviación estándar.

Mineral content

Apart from the nutritional significance of minerals and the fact that they affect color, mineral content is also an important indicator of possible environmental pollution and a potential indicator of geographical origin of honey (Bogdanov et al., 2004; Conti, 2000; Pisani, Protano, & Riccobano, 2007). In this study, a total of nine elements were quantified: K, Ca, P, Na, S, Mg, Si, Fe, and Zn (Table 3). K, quantitatively, was the most abundant mineral found in honey samples; it accounted for 66.4% of total minerals, with an average content of 716.7 mg kg⁻¹ and content values ranging from 369.7 to 1760 mg kg⁻¹. Studies on honey from other geographical locations also showed K to be the most abundant element; K was the most abundant element in honeys from Portugal (2590 mg kg⁻¹) and from Israel (3768 mg kg⁻¹) (Dag, Afik, Yeselson, Schaffer, & Shafir, 2006; Silva et al., 2009).

With an average content of 118.5 mg kg⁻¹, P was the second most abundant mineral in the honey samples of this study, whose values ranged from 47.8 to 394.6 mg kg⁻¹. This mineral also has been found as the second most abundant in avocado honey (ranged from 47 to 651 mg kg⁻¹) from Israel (Dag et al., 2006) and monofloral honey (ranged from 49 to 258 mg kg⁻¹) from Spain (González-Miret et al., 2005).

Na, Ca, and Si levels in this study occurred at average values of 96.4, 57.4, and 40.7 mg kg⁻¹, respectively (Table 3). Two honey samples (H5 and H6) presented the higher Na contents with values of 242.6 and 302.0 mg kg⁻¹, probably because they were produced in coastal environment with high salinity contents in agreement with the high Na content in honey samples from Spain, India, and Portugal (Nanda, Sarkar, Sharma, & Bawa, 2003; Silva et al., 2009; Terrab, Hernanz, & Heredia, 2004b). Ca is a mineral commonly present in honeys from different regions of the World, which has been found in values ranging from 32 to 270 mg kg⁻¹ (Nanda et al., 2003; Rodríguez-García et al., 2006). In this study, Ca content of honey samples ranged from 38.0 to 127.3 mg kg⁻¹ and an average content of 57.4 mg kg⁻¹. Si is another mineral element reported in honey samples by others (Dag et al., 2006; González-Miret et al., 2005) with an average content from 8.7 to 140.5 mg kg⁻¹, while the content values in this study ranged from 23.7 to 90.9 mg kg⁻¹.

Table 3. Mineral element content of honey samples from West region of México (mg kg⁻¹).Tabla 3. Contenido de elementos minerales de muestras de miel de la región Occidente de México (mg kg⁻¹).

Honey sample	K	Ca	P	Na	S	Mg	Si	Fe	Zn
H1	369.7 ± 10.8	38.6 ± 1.4	56.9 ± 2.1	23.9 ± 3.0	13.1 ± 4.3	16.3 ± 1.0	23.7 ± 1.1	0.92 ± 0.13	1.51 ± 0.11
H2	407.4 ± 8.7	44.2 ± 4.1	78.3 ± 2.5	20.5 ± 3.2	25.2 ± 3.6	19.8 ± 2.8	27.7 ± 4.5	0.66 ± 0.13	2.72 ± 0.23
H3	1383.3 ± 55.0	127.3 ± 5.6	104.8 ± 14.0	41.8 ± 4.7	41.1 ± 7.5	21.6 ± 1.8	90.9 ± 5.6	1.60 ± 0.10	2.69 ± 0.29
H4	558.3 ± 44.1	49.3 ± 4.4	84.7 ± 12.9	36.5 ± 3.2	23.4 ± 4.4	22.9 ± 2.2	34.9 ± 3.7	0.82 ± 0.09	1.60 ± 0.16
H5	276.7 ± 25.1	57.6 ± 4.9	47.8 ± 47.8	242.6 ± 48.2	23.7 ± 4.6	18.8 ± 2.4	50.7 ± 3.5	1.22 ± 0.11	4.94 ± 0.24
H6	429.6 ± 26.3	51.5 ± 5.5	96.9 ± 3.5	302.0 ± 17.2	39.3 ± 3.8	23.1 ± 1.8	29.3 ± 1.2	1.31 ± 0.16	1.84 ± 0.12
H7	649.0 ± 49.8	38.0 ± 3.8	83.9 ± 4.3	44.3 ± 4.5	21.6 ± 3.1	13.1 ± 1.7	26.9 ± 1.8	1.33 ± 0.32	2.75 ± 0.20
H8	1760.0 ± 36.1	52.4 ± 1.4	394.6 ± 58.5	59.3 ± 4.0	62.9 ± 6.1	61.3 ± 2.1	42.1 ± 2.7	4.72 ± 0.27	6.80 ± 0.45
Mean	716.7 ± 530.7	57.4 ± 28.0	118.5 ± 109.6	96.4 ± 106.5	31.3 ± 15.5	24.6 ± 14.6	40.7 ± 21.3	1.57 ± 1.26	3.11 ± 1.77

Note: Results are expressed as mean values ± standard deviation.

Nota: Los resultados son expresados como media ± desviación estándar.

Table 4. Color characteristics of honey samples from West region of México.

Tabla 4. Características de color de muestras de miel de la región Occidente de México.

Honey sample	Color parameter		
	<i>L*</i>	<i>a*</i>	<i>b*</i>
H1	31.98 ± 0.21	3.11 ± 0.31	25.59 ± 1.01
H2	27.72 ± 0.17	5.45 ± 0.53	20.46 ± 1.92
H3	22.40 ± 0.87	8.00 ± 0.55	12.05 ± 1.85
H4	35.26 ± 2.60	2.07 ± 0.07	29.91 ± 0.23
H5	32.74 ± 0.47	0.90 ± 0.03	20.06 ± 0.30
H6	25.89 ± 1.14	1.04 ± 0.09	5.57 ± 0.98
H7	27.16 ± 0.48	6.14 ± 0.24	20.69 ± 0.74
H8	21.17 ± 0.90	8.33 ± 0.30	9.66 ± 0.10
Mean	28.16 ± 4.74	4.39 ± 2.87	18.01 ± 7.93

Note: Results are expressed as mean values ± standard deviation.

Nota: Los resultados son expresados como media ± desviación estándar.

Average values of S, Mg, Zn, and Fe represented only 2.8, 2.2, 0.28, and 0.14% of the total mineral content. Average value of S and Mg for honey in this work was similar to the reported by other studies (Baroni et al., 2009; Downey et al., 2005); however, very high relative values of Mg content have been reported (137–303 mg kg⁻¹) in other studies (Rodríguez-García et al., 2006; Terrab et al., 2004b) in comparison with the results obtained in this work (16.3–61.3 mg kg⁻¹). On the other hand, average values for Fe and Zn ranged from 0.66 to 4.72 mg kg⁻¹ and from 1.51 to 6.80 mg kg⁻¹, respectively. Some studies have reported similar values of Zn for honey samples from other countries (Bogdanov, Halldimann, Luginbuhl, & Gallmann, 2007; Terrab et al., 2004b), although Nanda et al. (2003) reported 16.77 mg kg⁻¹ Zn for honey from India. Fe contents in honey samples of this study were lower than those found for honeys from Ireland (Downey et al., 2005) and Morocco (Terrab et al., 2003), however, a similar average content was reported by Bogdanov et al. (2007) for honey from Switzerland.

Color characteristics

Color is the first sensory property perceived by the consumers, which could determine if they will buy the product or not. However, there is little information about

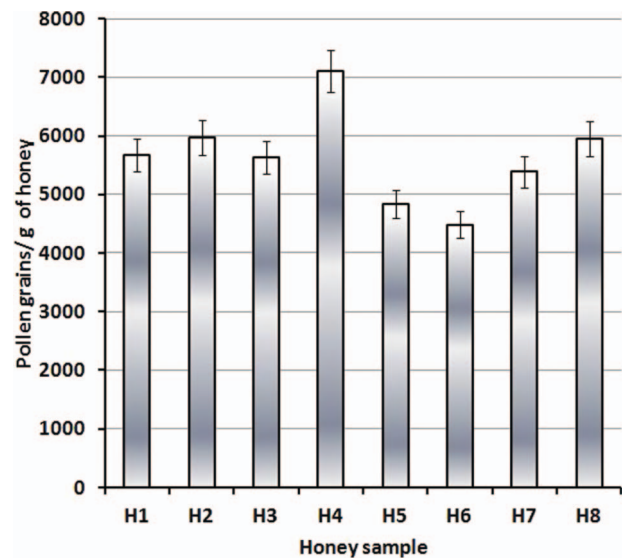


Figure 1. Pollen grains content in the honey samples from West region of México.

Figura 1. Contenido de granos de polen en muestras de miel de la región Occidente de México.

consumer color acceptability of honey. Bogdanov et al. (2004) reported that in Germany, Austria, and Switzerland, dark honeydew honeys are specially appreciated. According to Murphy, Cowan, Henchion, and O'Reilly (2000), Irish consumers prefer honeys with a dark golden color. The color of honey is one of the most variable attributes and it is mainly determined by its botanical origin, but it also depends on its ash content, temperature, and time of storage, as well as the presence of antioxidant pigments such as carotenoids and flavonoids (Baltrusaityte, Venskutonis, & Ceksteryte, 2007; Terrab, González-Miret, & Heredia, 2004a). Honey samples having an *L** value > 50 are lighter honeys, whereas samples having an *L** value < 50 are dark honeys (González-Miret et al., 2005). Therefore, based on this classification, the Mexican honeys from the West region studied can be regarded as dark honeys because the *L** values of the samples ranged from 21.17 to 35.26 (Table 4). The *a** values varied from 0.90 to 8.33 and *b** values ranged from 5.57 to 29.91, thus it is apparent that all the samples being darker had red and yellow components.

Pollen analysis

Results of the quantitative pollen analysis for the honey samples are showed in Figure 1. The number of pollen grains g^{-1} ranged from 3830 to 7100. According to classification of Maurizio (1979), all honey samples in this study belonged to class II (honey content: 2000–10,000 pollen grains g^{-1} of honey). With respect to the qualitative pollen analysis, only two honey samples identified (honey samples H5 and H6) showed dominant pollen and for this reason they can be considered as monofloral. The botanical origin of the dominant pollen was from *Laguncularia racemosa* flowers, because the hives of the studied honey samples are located in a coastal environment where this type of flora predominates. The remaining six honey samples contained a wide diversity of pollen grains (between 1 and 40%); therefore, they can be classified as multiflorals.

Conclusions

In general, the Mexican honeys from the West region had a good level of quality according to the results obtained for the physicochemical analysis, which are in agreement with the international regulations. With respect to the color parameter L^* , all honey samples can be classified as dark honeys. Mineral contents were found to be in the range of honeys from other countries. Within the mineral contents, the high values for K (average 716.7 mg kg^{-1}) must be highlighted. High Na content was found in two honey samples (242.6 and 302.0 mg kg^{-1}) which came from coastal areas. According to the pollen quantitative analysis, two honey samples were classified as monofloral and six as multifloral.

Acknowledgments

The authors are grateful to Fomix Conacyt-Gobierno de Estado de Nayarit (México) for funding this research as part of the Project Nr 92632.

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