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Major and Trace Elements in Different Types of Moroccan Honeys

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Abstract: Forty-eight honey samples from different regions in Morocco were collected from beekeepers between 2005 and 2008. The levels of trace elements Mn, Cu, Ba, Ni, Cr, Co, Se, As, Ag and Be; major elements K, Na, Ca, Mg, Al, Fe and Zn; and toxic elements Cd and Pb were determined. Mg, K, Ca and Na were determined by atomic absorption spectrometry and the other mineral elements by inductively coupled plasma-mass spectrometry (ICP-MS) following acid digestion. Potassium was the most abundant element (71.22% of the total minerals), followed by sodium and calcium (15.64% and 7.24%, respectively). Ten honey types, *Euphorbia echinus*, *Euphorbia resinifera*, *Ziziphus lotus*, *Citrus*, *Eucalyptus*, rosemary, thyme, carob, lavender and honeydew were studied, and a statistical analysis was carried out using analysis of variance (ANOVA), Kruskal-Wallis test, principal component analysis (PCA) and discriminant analysis (DA) to classify them. PCA showed that the cumulative variance was 76.57%, and the DA analysis indicated that 73.3% of samples were correctly classified. Carob, rosemary and lavender honey were 100% classified.
The mineral content of *Euphorbia echinus*, *Ziziphus lotus*, rosemary, carob and lavender Moroccan honey types has been determined for the first time.

Key words: ICP-MS; AAS; Morocco; Honey; Minerals; PCA; DA

INTRODUCTION

Honey is recognized as a biological indicator of environmental quality (Przybylowski & Wilczynska, 2001; Rodríguez García *et al*., 2001) and floral biodiversity. It is intrinsically connected to the territory in which it is produced and it is closely tied to the flora visited from the bees for its production. Pollen grains from the flowers visited by bees collecting nectar occur naturally in honey**,** as well as trace elements that the plants receive from the ground, water and air.

The average ash of honey is 0.17, with a range 0.02-1.03% (White, 1975). According to the EU honey regulation (2002), the water-insoluble content in general is not more than 0.1 g/100 g. The content is higher for honeydew and chestnut honeys (Persano Oddo *et al*., 1995).

Potassium is the most abundant element in honeys. Sodium, iron, copper, manganese, silicon, calcium, and magnesium are all present in honey (White, 1975; Belouali *et al*., 2008; Pisani *et al*., 2008; Downey *et al*., 2005; Rashed & Soltan, 2004; Sulbaran de Ferrer *et al*., 2004, Terrab *et al*., 2003; Nanda *et al*., 2003). There is great variability in the mineral content of honeys, due to botanical origin rather than geographical and environmental exposition of nectar sources (Bogdanov *et al*., 2007). To verify the relationship between the botanical and geographic origin and mineral content in honey, many authors have used the principal component analysis (PCA) (Seif Eldin & Elfadil 2010; Pisani *et al*., 2008; Fernández-Torres *et al*., 2005; Terrab *et al*., 2003).

In Morocco the honey is widely used in traditional medicine, therefore it is necessary to preserve it from adulterations and contaminations. Moroccan honeys coming from various floral origins were examined by means of melissopalynological and some physicochemical analyses (Díez *et al*. 2004, Terrab *et al*. 2003a, 2003b, 2003c); mineral contents of some honeys from Northwest and East Morocco have been studied (Terrab *et al*., 2003; Belouali *et al*., 2008).

The goal of this study was to determine major, trace and toxic elements in honey samples produced in

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different regions of Morocco, considering also new kinds of melliferous productions never investigated before, as *Euphorbia echinus*, *Ziziphus lotus*, rosemary, carob and lavender. The PCA and DA were applied to evaluate the possibility of differentiating Moroccan honeys from different botanical origin according to mineral content and to choose the elements with a higher discriminant power.

MATERIALS AND METHODS

Honey Samples:

The present study analyzed forty-eight honey samples collected from beekeepers in different regions of South, Center-South and East Morocco between 2005 and 2008. These samples included nine types of unifloral honey, 2 from *Euphorbia echinus*, 10 from *Euphorbia resinifera*, 3 from *Ziziphus lotus*, 11 from *Citrus*, 6 from *Eucalyptus*, 2 from rosemary, 3 from thyme, 3 from carob and 2 from lavender, honeydew and multifloral honeys. The honey samples were stored at 4 °C until analysis.

Sample Preparation:
Mineral Content:

One gram of the sample was dissolved in 10 mL of analytical-reagent grade concentrated nitric acid (HNO_3, 65%). Samples were evaporated at 100-120° C to almost complete dryness. Then, 10 mL of nitric acid was added, and the volume was brought to 25 mL with Milli-Q water.

Statistical Analysis:

Statistical Package for Social Science (SPSS 17.0) was used to establish the difference between the ten honey types by mean of their mineral content. The results are expressed as mean values, minimum (Min), maximum (Max) and standard deviation (SD). In order to check if the correlation matrix can be presumed to correspond, Bartlett test of sphericity and the KMO test (Kaiser-Meyer-Olkin) were performed. We proceeded to carry out a study of the bivariate correlations among all the variables, detecting which of them were significant. Using Kruskal-Wallis test only elements which differences were statistically significant were used. With the aim of evaluating which of these main identified factors will explain most of the variability, the data matrix was submitted to the principal component analysis (PCA), using the covariance matrix. A discriminant analysis (DA) technique was performed in attempt to classify the honey samples.

Apparatus:
ICP-MS:

The analytical method is based on UNI EN ISO 17294:2005. An Agilent 7500c ICP-MS system was used. The solution was introduced into a radiofrequency plasma equipped with a pneumatic nebulizer, atomised and ionised. The instrumental conditions are presented in Table 1.

Table 1: Instrumental characteristics and settings for ICP-MS.

Parameters and instrumental characteristics	
Spectrometer	Quadrupole
Nebulizer	Babington
Interface	Sampling Cone, Skimmer Cone
RF generator (MHz)	27.12
Argon flows (mL/min)	15.0
Nebulizer pump (rps)	0.10
Scanning condition	2-260 amu
Internal standards	Li , Sc, Ge, In, Tb, Bi
He gas flow rate (mL/min)	4.2
Integration time	from 0.30 to 1.5 seconds
RF power (W)	1500
Sampling depth (mm)	8.5
Carrier gas flow rate (Ar) (L/min)	1.1
Auxiliary gas flow rate (Ar) (L/min)	0.9
Acquisition mode	Nogas and He
Number of replicates	3
Quadruple bias (V)	- 4.0

Flame atomic absorption spectrometry (AAS)

The AAS determinations were conducted using an AAnalyst 100 (Perkin Elmer) atomic absorption spectrometer equipped with a flame to atomize the sample; the operating parameters are presented in Table 2. The main advantages of atomic absorption spectrometry are relatively inexpensive costs, ease of using the method and reasonably good analytical performance. Flame atomic absorption spectrometry is used to determine the concentration of alkaline and earth alkaline elements.

Table 2: Operating parameters for AAS.

Ion	Wavelength (nm)	Lamp intensity (mA)	Split (nm)
Na	589.0	12	0.2
K	766.5	12	0.7
Ca	422.7	15	0.7
Mg	285.2	15	0.7

Reagents and Solutions:

All solutions were prepared using high-purity deionized water obtained from a Milli-Q water (resistivity 18 MO cm^{-1}) purification system (Millipore); Standard solutions were prepared from 1 g L^{-1} stock solutions.

RESULTS AND DISCUSSION

Mineral Content:

Nineteen minerals were quantified for each honey (K, Na, Ca, Mg, Al, Fe, Zn, Mn, Cu, Ba, Ni, Pb, Cr, Co, Se, Cd, As, Ag and Be). Table 3 and Table 3 (continued) show the mean, maximum, minimum and standard deviation of the mineral content in honey samples.

Table 3: Major elements (mg kg^{-1}) in different types of honey from Morocco

Honey type		K	Na	Ca	Mg	Al	Fe	Zn
Citrus	Mean	458.20	78.59	38.40	8.59	10.23	2.20	3.63
	Min	180	47	28	6.50	7.53	1.30	0.42
	Max	850	160	56	12	14.14	2.95	10.78
	SD	239.93	34.31	8.85	2.40	1.84	0.47	2.99
Eucalyptus	Mean	695.83	308	103.33	29.42	13.32	3.82	4.18
	Min	450	181.50	50	20.50	6.91	1.97	0.66
	Max	950	488.50	196	40.50	20.30	5.37	9.27
	SD	232.60	113.36	67.70	7.45	4.72	1.42	3.67
Carob	Mean	749.17	223.67	135.33	67.83	21.45	4.86	3.05
	Min	500	170	106	56.50	9.84	4.36	2.09
	Max	997.50	312.50	170	75	41.83	5.63	4.92
	SD	248.75	77.49	32.33	9.93	17.71	0.68	1.62
Thyme	Mean	554.17	153.17	68.33	22.50	17.60	7.84	3.91
	Min	325	73	65	10	12.08	4.43	2.76
	Max	700	205	70	38.50	27.70	13.95	4.81
	SD	200.91	70.41	2.89	14.57	8.76	5.30	1.05
E. resinifera	Mean	641	127.40	71.80	32.60	17.95	6.55	2.41
	Min	190	5	30	15	3.11	3.37	0.47
	Max	1900	176	180	48.50	31.45	9.76	7.07
	SD	474.59	46.57	48.86	12.49	7.09	2.18	1.87
E. echinus	Mean	575	92	51	24	15.67	5.92	4.02
	Min	450	82.50	38	18.50	12.34	5.46	1.20
	Max	700	101.50	64	29.50	19	6.37	6.85
	SD	176.78	13.44	18.38	7.78	4.71	0.65	4
Lavender	Mean	605	243.25	65	32	13.64	3.27	3.17
	Min	425	240	48	20	11.13	3.21	3.15
	Max	785	246.50	82	44	16.15	3.33	3.18
	SD	254.56	4.60	24.04	16.97	3.55	0.09	0.02
Ziziphus	Mean	1268.33	146.17	63.33	30.17	22.80	9.34	2.48
	Min	450	112	42	19.50	16.51	2.64	1.08
	Max	2305	196.50	76	43	30	13.19	3.72
	SD	946.58	44.51	18.58	11.90	6.79	5.83	1.33
Rosemary	Mean	375	45	24	10	8.66	1.42	2.46
	Min	350	40	20	4	6.38	1.14	0.82
	Max	400	50	28	16	10.93	1.71	4.10
	SD	35.36	7.07	5.66	8.49	3.22	0.41	2.32
Honeydew	Mean	1298	122.67	74.33	45.17	22.81	7.71	2.49
	Min	740	101	32	19.50	12.52	5.67	2.09
	Max	2250	142.50	135	69	41.08	11.33	3.05
	SD	828.52	20.81	53.89	24.80	15.86	3.14	0.50
Multifloral	Mean	317.33	63	39.33	15.33	11.27	4	2.28
	Min	300	6.50	26	15	2.40	3.62	1.37
	Max	335	102	54	16	16.91	4.55	3.32
	SD	17.50	50.10	14.05	0.58	7.77	0.49	0.98
Total	Mean	652.01	143.19	66.30	26.50	15.33	4.90	3.15
	Min	180	5	20	4	2.40	1.14	0.42
	Max	2305	488.50	196	75	41.83	13.95	10.78
	SD	454.78	94.96	44.48	18.16	8.15	3.12	2.29

SD: Standard Deviation, Min: Minimum, Max: Maximum, *E. resinifera: Euphorbia resinifera*, *E. echinus: Euphorbia echinus*

Table 3: (continued) Minor elements (mg kg^{-1}) in different types of honey from Morocco

Honey type		Mn	Cu	Ba	Ni	Pb	Cr	Co	As	Se	Ag	Cd	Be
Citrus	Mean	0.190	0.890	0.242	0.358	0.107	0.077	0.133	0.005	0.030	0	0.003	0.004
	Min	0.106	0.185	0	0.011	0.046	0.031	0	0	0	0	0	0
	Max	0.491	1.863	0.608	1.239	0.164	0.262	1.435	0.033	0.234	0	0.018	0.036
	SD	0.112	0.592	0.146	0.341	0.039	0.066	0.432	0.011	0.069	0	0.006	0.011
Eucalyptus	Mean	4.168	0.370	0.410	0.118	0.086	0.048	0.003	0.008	0.036	0	0.003	0
	Min	0.903	0.050	0.140	0.058	0.025	0	0	0	0	0	0	0
	Max	9.375	0.619	0.853	0.271	0.142	0.098	0.014	0.045	0.081	0	0.016	0
	SD	3.687	0.196	0.255	0.079	0.044	0.041	0.006	0.018	0.040	0	0.006	0
Carob	Mean	2.410	1.677	0.508	0.536	0.204	0.063	0.061	0.019	0.027	0	0.001	0
	Min	1.999	0.294	0.283	0.295	0.054	0.048	0	0	0	0	0	0
	Max	2.875	3.108	0.945	0.764	0.451	0.086	0.176	0.032	0.081	0	0.002	0
	SD	0.441	1.407	0.378	0.235	0.215	0.020	0.100	0.017	0.047	0	0.001	0
Thyme	Mean	3.043	0.599	0.417	0.155	0.115	0.080	0.048	0	0.021	0	0.003	0
	Min	0.864	0.456	0.284	0.027	0.095	0.059	0	0	0	0	0	0
	Max	6.690	0.775	0.524	0.240	0.133	0.091	0.094	0	0.035	0	0.008	0
	SD	3.178	0.162	0.123	0.113	0.019	0.018	0.047	0	0.019	0	0.005	0
E. resinifera	Mean	1.156	0.584	0.279	0.321	0.127	0.051	0.057	0.007	0.030	0.007	0.006	0
	Min	0.572	0.162	0	0.058	0.042	0	0.032	0	0	0	0	0
	Max	1.998	1.080	0.400	1.158	0.196	0.083	0.106	0.041	0.095	0.073	0.031	0
	SD	0.397	0.317	0.107	0.377	0.046	0.025	0.025	0.015	0.034	0.023	0.010	0
E. echinus	Mean	1.025	1.232	0.255	0.092	0.122	0.047	0.053	0.017	0.022	0.020	0	0
	Min	0.825	1.038	0.248	0.028	0.101	0.044	0.035	0	0	0	0	0
	Max	1.226	1.426	0.263	0.156	0.144	0.050	0.072	0.034	0.045	0.040	0	0
	SD	0.284	0.274	0.010	0.091	0.031	0.005	0.026	0.024	0.032	0.028	0	0
Lavender	Mean	4.615	0.706	0.542	0.377	0.097	0.049	0	0.020	0.039	0	0	0
	Min	4.575	0.553	0.532	0.138	0.090	0.047	0	0	0	0	0	0
	Max	4.655	0.860	0.553	0.615	0.104	0.051	0	0.039	0.078	0	0	0
	SD	0.057	0.217	0.015	0.337	0.010	0.003	0	0.028	0.055	0	0	0
Ziziphus	Mean	0.772	1.667	0.392	0.233	0.146	0.072	0.037	0.010	0.018	0.023	0.013	0
	Min	0.456	1.003	0.286	0.145	0.122	0.049	0	0	0	0	0	0
	Max	1.023	2.638	0.469	0.282	0.192	0.104	0.085	0.030	0.054	0.034	0.026	0
	SD	0.289	0.860	0.095	0.077	0.040	0.028	0.043	0.018	0.031	0.020	0.013	0
Honeydew	Mean	0.733	1.387	0.313	0.293	0.133	0.068	0.089	0	0	0	0.097	0
	Min	0.669	0.859	0.263	0.230	0.102	0.036	0.017	0	0	0	0.006	0
	Max	0.835	1.848	0.374	0.411	0.194	0.097	0.211	0	0	0	0.276	0
	SD	0.089	0.498	0.056	0.103	0.053	0.030	0.106	0	0	0	0.155	0
Rosemary	Mean	0.128	0.464	0.193	0.120	0.087	0.027	0	0	0.030	0	0	0
	Min	0.106	0.287	0.157	0.090	0.086	0	0	0	0.027	0	0	0
	Max	0.149	0.641	0.230	0.149	0.088	0.054	0	0	0.034	0	0	0
	SD	0.030	0.250	0.052	0.042	0.001	0.038	0	0	0.005	0	0	0
Multifloral	Mean	0.423	0.593	0.220	0.255	0.101	0.061	0.005	0	0.030	0	0.001	0
	Min	0.303	0.233	0.127	0.078	0.047	0.057	0	0	0	0	0	0
	Max	0.609	0.878	0.284	0.420	0.129	0.068	0.014	0	0.064	0	0.004	0
	SD	0.164	0.329	0.083	0.171	0.046	0.006	0.008	0	0.032	0	0.002	0
Total	Mean	1.507	0.842	0.322	0.280	0.118	0.061	0.060	0.007	0.028	0.004	0.010	0.001
	Min	0.106	0.050	0	0.011	0.025	0	0	0	0	0	0	0
	Max	9.375	3.108	0.945	1.239	0.451	0.262	1.435	0.045	0.234	0.073	0.276	0.036
	SD	2.028	0.636	0.176	0.271	0.063	0.039	0.208	0.014	0.042	0.013	0.040	0.005

SD: Standard Deviation, Min: Minimum, Max: Maximum, E. resinifera: Euphorbia resinifera, E. echinus: Euphorbia echinus

The first group was formed by the major elements. The most abundant was potassium (71.22% of the total minerals), which agrees with other studies indicating that potassium is the most common element in honeys (Belouali *et al*., 2008; Pisani *et al*., 2008; Downey *et al*., 2005; Rashed & Soltan, 2004, Sulbaran de Ferrer *et al*., 2004; Terrab *et al*., 2003; Nanda *et al*., 2009). Sodium and calcium were the next most common elements (15.64% and 7.03%), followed by magnesium, aluminium, iron and zinc (2.89% and 1.67% respectively).

The second group was formed by the minor elements present in all samples: Mn, Cu, Ba, Ni, Pb and Cr, with average content of 1.5, 0.84, 0.32, 0.28, 0.12 and 0.06 mg/kg, respectively.

The third group was formed by other, low-concentration elements such as Be, Ag, As, Se, Cd and Co, their average content ranged between 0.0009 and 0.059 mg/kg. Values of Se found by Tuzen *et al*. (2007) in Turkish honey (range: 0.038-0.113 mg/kg) were within those found in the present study, while values of Cd were lower (0.0009-0.0179 mg/kg).

There are no specific MRL (Maximum Residue Levels) values for honeys, but values of 0.1 mg/kg for Cd and 1 mg/kg for Pb have been suggested by the European Union (Byrne, 2000; Bogdanov *et al*., 2007). The average concentration of the toxic elements Pb and Cd (0.12, 0.01 mg/kg respectively) were below the Maximum Residue Levels (MRL).

Table 4: Major and trace mineral content (mg kg^{-1}) in honey samples from some Mediterranean countries

	K	Mg	Na	Ca	Fe	Mn	Cu
Present study	652	26.5	143.1	66.3	4.89	1.5	0.84
Northwest Morocco[a,b]	13-2388	3.79-230	-	-	1.33-34	-	-
East Morocco[c]	511.2	26.83	-	102.9	13.52	1.41	1.32
Spain[a,d]	639-1845	13.26-74.38	11.69-218.5	111-257	-	0.133-7.825	-
Italy[e]	-	-	-	-	1,65	1,62	0,58
Italy[f]	1195	56.7	96.6	257	3.07	1.54	0.906
Turkey[g]	296	33	118	51	6.6	1	1.8
Turkey[h]	-	10.45	-	-	0.36	-	0.01
Egypt[a,i]	213-1500	102-300	378-478	-	58-202	0.5-1.70	1-1.75
Portugal[j]	1150	35.57	261.4	53.88			
Saudi Arabia[a,k]	-	18.3-23.2	-	-	0.31-3.19	0.18-0.37	0.2-0.38

[a]Range, [b]Terrab *et al*. (2003), [c]Belouali *et al*. (2008), [d]Fernández-Torres *et al*. (2005), [e]Porrini *et al*. (2002), [f]Pisani *et al*. (2008), [g]Yilmaz *et al*. (1999), [h]Erbilir *et al*. (2005), [i]Rashed & Soltan (2004), [j]Silva *et al* (2009), [k]Osman *et al*. (2007).

Table 4: (continued) Toxic elements (mg kg^{-1}) in honey samples from some Mediterranean countries

	Pb	Ni	Cd	Co	Zn
Present study	0.118	0.28	0.01	0.06	3.14
Northwest Morocco[a,b]	-	-	-	-	-
East Morocco[c]	0.34	-	0.005		0.31
Spain[a,d]	-	-	-	-	1.33-7.82
Italy[e]	0.013	0.1	-	-	1.44
Italy[f]	0.076	0.308	0.0039	0.011	1.8
Turkey[g]	4.2-6.3	1.25-4.1	0.01-0.5	1.75-2.52	5-9.3
Turkey[h]	-	-	-	1.0	2.7
Egypt[a,i]	-	-	-	-	-
Portugal[j]	-	-	-	-	-
Saudi Arabia[a,k]	0.038-0.08	-	0.002-0.037	-	0.2-0.74

[a]Range, [b]Terrab *et al*. (2003), [c]Belouali *et al*. (2008), [d]Fernández-Torres *et al*. (2005), [e]Porrini *et al*. (2002), [f]Pisani *et al*. (2008), [g]Yilmaz *et al*. (1999), [h]Erbilir *et al*. (2005), [i]Rashed & Soltan (2004), [j]Silva *et al* (2009), [k]Osman *et al*. (2007).

Belouali *et al*. (2008) reported that Zn and Cd concentrations in East Morocco honeys were lower (averages: 0.31 and 0.005 mg/kg respectively) than those found in the present study. On the other hand, Pd was present at higher concentrations (0.34 mg/kg) than were found in this study.

In this research, carob honey contained higher levels of Ca, Mg, Na, Ni, Cu and Pb than the other samples.

The average concentrations of Mg, Mn, Fe and Cu in honeydew honey were within those found by Üren *et al*. (1998) in the same type of Turkish honey, and lower than the levels found by Terrab *et al*. (2003).

Honeydew honey contained the highest level of Al (22.81 mg/kg), as reported by Madejczyk & Baralkiewicz (2008) in Polish honeydew honey (0.3-35.1 mg/kg); while Terrab *et al*. (2003) found in honeydew honey the highest concentration of iron. Al with a mean value of 14.3 mg/kg was found in Czech honeydew honey (Lachman *et al*., 2007). While high values of Al were found also in *Z. Lotus* and carob honeys. This element is not detected in all honeys; Al was found in 41% of analysed French honey samples (Devillers *et al*., 2002) with values ranging between 0.18 and 9.72 mg/kg and lower than those of the present study.

The higher content of aluminum in Moroccan honeys may be due to beekeeping activities and materials used, e.g. storage containers, as presumed for some Chilean honeys (Fredes & Montenegro, 2006).

The highest concentration of Cr was found in thyme honey. The amount of iron was high, and agreed with the concentrations found in Turkish thyme honey (Juszczak *et al*., 2009). This type of honey has similar levels of Ca, Mg, Na, K and Zn to those found by González-Miret *et al*. (2005) in Spanish honeys (69.18, 27.43, 175.93, 484.83 and 4.2 mg/kg respectively). However values of Ca, K, Mg and Na in the present study were lower than those found by Terrab *et al*. (2004) in Spanish honeys (185, 716, 78 and 388 mg/kg respectively).

Lavender honey is rich in Mn and Ba and González-Miret *et al*. (2005) found similar amounts of Fe to the value found in the present study. On the other hand, the concentrations of Ca, Mg, Na, K, Al, Mn, Cu and Zn found by the last authors were lower than those measured in the present study.

The highest levels of Fe and Cu were found in *Ziziphus lotus* honey; while Indian *Ziziphus mauritiana* honey (Nanda *et al*., 2009) showed slightly similar values of Fe (6.89 mg/kg) and Cu (1.93 mg/kg). However Ziziphus Honeydew and *Z. lotus* honeys contained the highest amount of potassium, with average concentrations of 1300 and 1268 mg/kg respectively. These results agree with Pisani *et al*. (2008) and Terrab *et al*. (2003), who found the highest concentration of potassium in honeydew honey (3440 and 1882 mg/kg respectively).

The levels of Ca, K and Ni were higher in *E. resinifera* than in *E. echinus* honeys.

Eucalyptus honey contained higher levels of Zn than the other honeys. Ca, Mg, Mn and Zn concentrations were similar to those found by González-Miret *et al*. (2005), but K and Cu levels were lower than those found by the last author and by Terrab *et al*. (2003).

Rosemary and *Citrus* honeys contained the lowest elements concentrations. In fact, these types of honey have a light colour (26 and 39.5 mm Pfund, respectively). This result agrees with Ankalm (1998). In rosemary Spanish honey González-Miret *et al*. (2005) found similar amounts of Mg, Cu and Zn (14.32, 0.42 and 2.4 mg/kg respectively).

The concentrations of K, Mn and Zn in *Citrus* honey were similar to the amounts found in the same type of Spanish honey (Fernàndez-Torres *et al*., 2005). On the other hand, the concentrations of Ca ranged between 42.59 and 89.6 mg/kg. Mg concentrations were between 13.26 and 42.34 mg/kg, and were higher than those in the present study. Terrab *et al*. (2003) found lower levels of K (285 mg/kg), Cu (0.58 mg/kg) and Zn (1.91 mg/kg). The amounts of Mg, Mn and Fe were lower than those found by the last authors (Terrab *et al*., 2003) as were Mg (21.01 mg/kg), Mn (0.45 mg/kg) and Fe (9.82 mg/kg) and than those found by Rashed & Soltan (2004) in Egyptian *Citrus* honey, as were Mg (225 mg/kg), Mn (0.5 mg/kg) and Fe (80 mg/kg). The concentration of K was similar to that reported by the same authors (Terrab *et al*., 2003; Rashed & Soltan, 2004), and higher than that found by Nanda *et al*. (2009) in Indian C*itrus* honey.

Statistical Analysis:

In order to check the accuracy of the complete correlation matrix, the Kaiser-Meyer-Olkin measure of sampling accuracy was examined (KMO 0.613). In an attempt to establish the relationship between mineral content and honey type, statistical methods such as CA, PCA and DA were applied. From principal component analysis (PCA), it can be concluded that 77.73% of the variation existing in the data can be explained by four factors.

Using Kruskal-Wallis test elements (Ca, Mg, Na, Al, Mn, Fe, Co, Cu, Ag and Ba) witch the difference was statistically significant were used in the PCA and DA procedures. The Table 5 summarizes the percentage of the variance explained by each factor.

Table 5: Component matrix

	Components			
	1	2	3	4
Ca	0.82	-0.16	-0.07	-0.02
Mn	0.76	-0.5	0.01	0.13
Na	0.76	-0.54	0.02	0.12
Ba	0.72	0.05	0.47	0.05
Mg	0.63	0.08	-0.35	-0.25
Cu	0.18	0.74	0.03	-0.1
Al	0.54	0.74	-0.06	0
Fe	0.48	0.64	-0.18	0.02
Co	0.04	0.16	0.89	-0.12
Ag	-0.05	0.24	-0.01	0.94

The variables that load highly to the first factor are based on Ca, Mn, Na, Ba and Mg. The variables that correlate highly with the second factor are Cu, Al and Fe. The third and fourth factors are associated with Co and Ag respectively.

From Table 6, it can be concluded that the variables selected by discriminant analysis were Mg, Na, Mn, Fe and Cu. This result is corroborated by the significance of the Wilks test ($p<0.001$). The ten samples were 73.3 % correctly classified.

Table 6: Discriminant analysis (DA) of mineral content

Parameters	Wilks' lambda	*F* statistic	*P* significance level
Ca	0.61	2.52	0.02
Mg	0.28	9.78	0.00
Na	0.31	8.75	0.00
Al	0.68	1.8	0.10
Mn	0.48	4.26	0.00
Fe	0.44	4.94	0.00
Co	0.95	0.19	0.99
Cu	0.58	2.83	0.01
Ag	0.75	1.31	0.27
Ba	0.7	1.66	0.14

Conclusion:

This study presents the concentrations of major, trace and toxic elements in nine types of unifloral honeys (i.e. *Euphorbia echinus*, *Euphorbia resinifera*, *Ziziphus lotus*, *Citrus*, *Eucalyptus*, rosemary, thyme, carob and lavender), honeydew honey and multifloral honeys from South, Center-South and East Morocco.

The present study investigated for the first time the mineral content of Moroccan honeys from five botanical origins: *Euphorbia echinus*, *Ziziphus lotus*, rosemary, carob and lavender honey, and these results are reported.

Potassium, sodium, calcium, and magnesium accounted for 96.81% of the total minerals present in honeys produced in Morocco. Potassium was the most abundant element. Honeydew honey was characterised by highest potassium concentrations.

Fe, Zn, Mn, Cu, Ba, Ni, Pb and Cr were present at low levels, with average concentrations between 4.9 and 0.06 mg/kg. Be, Ag, As, Se, Cd and Co were present at very low levels, with average concentrations ranging from 0.001 to 0.06 mg/kg.

Toxic elements such as Pb and Cd were not present at levels above those allowed by the Codex Alimentarius; therefore, it can be concluded that the honeys analysed present a good level for quality and the area in which the honeys were produced is free of these contaminants, which concords with results found by Seif Eldin & Elfadil (2009) and Nasiruddin Khan *et al*. (2006).

From principal component analysis (PCA), it can be concluded that 77.73% of the variation existing in the data can be explained by four factors. The variables selected by discriminant analysis were Mg, Na, K, Mn and Fe; and the ten sample types (including the honeydew honey) were 73.3% correctly classified. This concurs with the results obtained by Terrab *et al*. (2004) in Spanish thyme honey and in Canadian honeys (Féller-Demalsy *et al*., 1989), showing that the analysis of mineral content is insufficient to determine the floral origin.

Melissopalynological analyses, together with both physicochemical and sensorial analyses, are usually carried out to determine honey botanical and geographical origin and to get their characterization (Louveaux *et al*. 1978; Ferrazzi *et al*. 1997).

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