

Influences of botanical and geographical origins on the mineral profile of honey: A comprehensive analysis

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Abstract

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Honey is a complex product of honeybees, well-known for its sweet taste, nutritional, and medicinal attributes. Enriched with a diverse array of constituents including sugars, enzymes, amino acids, vitamins, and minerals, it plays a pivotal role in promoting health through stimulating metabolism, enhancing circulatory and reproductive systems, and catalyzing biochemical reactions. The intricate composition of honey is influenced by its botanical and geographical origins, climatic variations, soil composition, beekeeping practices, and the specific species of honey bee contributing to its production. This study delves into the impact of the botanical and geographical origins of honey on its macro- and micro-mineral content.

Employing flame atomic absorption spectrometry, were analyzed sixty honey samples, collected from Kosovar beekeepers, categorized by their botanical origins into mountain (n = 19), meadow (n = 26), and acacia (n = 15) types, and further classified according to their geographical origins (rural (n = 28), suburban (n = 9), urban (n = 23)) from six main regions (Prishtina, Prizren, Gjilan, Ferizaj, Peja and Mitrovica) of Kosovo, for their content of macro-minerals (Na, Ca, K, Mg) and micro-minerals (Mn, Ni, Cu, Fe, Zn). Advanced statistical analyses, including ANOVA and various correlation tests, facilitated a comprehensive understanding of the data.

Our findings reveal a significant influence of both botanical and geographical origins on the mineral composition of honey, highlighting the intricate relationship between the natural environment and the nutritional properties of honey. This manuscript presents novelty as it is the first comprehensive study conducted in the Kosovo region, to analyze the impact of botanical and geographical origins on the mineral profile of honey, providing valuable insights previously unexplored in this context. This study underscores the importance of origin in determining the health-promoting qualities of honey, providing valuable insights for consumers, producers, and researchers alike. Additionally, it underscores the critical importance of preserving natural habitats and promoting sustainable beekeeping practices to maintain the high nutritional value of honey.

Keywords: honey mineral content; botanical and geographical origin; atomic absorption spectrometry; nutritional properties; environmental influence

Introduction

Honey is the naturally sweet substance, produced by honeybees from the nectar of plants or from secretions of living parts of plants or excretions of plant sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in the honey comb to ripen and mature (Codex Alimentarius Commission, 2001). This naturally sweet product is made up of sugars and other components including enzymes, amino acids, organic acids, carotenoids, aromatic compounds, vitamins, volatile chemicals, phenolic acids, flavonoids, and minerals (Ball, 2007; da Silva et al., 2016; Kadri et al., 2017). The composition of honey is affected by many factors, including floral sources, geographical region, climatic conditions, soil, and beekeeping practices, as well as the honey bee species involved in its production, processing, manipulation, packing, and storage time (Ball, 2007; Tornuk et al., 2013; Alqarni et al., 2014; Escuredo et al., 2014; Jonathan and White, 2015).

Honey has had a substantial impact on human nutrition, healing, and sickness prevention due to its chemical. Minerals have an important part in the nutritional value of honey, even though they are found in little concentrations: 0.1–0.2% in blossom honeys and > 1% in honeydew (Hernández et al., 2005). The amounts of macro- and micro-minerals in honey are affected by the floral source, and can change significantly between honey from various regions (Chua et al., 2012; Jonathan and White, 2015; Sajtos et al., 2019). Mineral content is a significant consequence of honey's geographical origin, and plant and soil types can impact mineral composition (de Alda-Garcilope et al., 2012; Karabagias et al., 2014; Uršulin-Trstenjak et al., 2015). Increased mineral concentration results in darker and stronger-flavored honeys, which are appealing qualities given the health advantages of eating foods high in minerals (Muñoz and Palmero, 2006; Escuredo et al., 2013; Karabagias et al., 2014). Potassium is the most abundant element in honey, with chlorine, sulphur, sodium, phosphorus, magnesium, silicon, iron, and copper following closely after (Devillers et al., 2002; Sajtos et al., 2019). In biological systems, macromineral elements like potassium, calcium, and sodium, as well as trace or micro minerals like iron, copper, zinc, and manganese, play an important role, which include induction of general metabolism, stimulation of the circulatory and reproductive systems, and catalysis of numerous biochemical events (Alqarni et al., 2014).

The purpose of this study was to investigate the concentrations of macro and micro minerals in honeys from various types of honey and geographical locations in Kosovo.

Materials and Methods

Honey sampling

In this research was involved in a total of 60 honey samples from different rural (n = 28), suburban (n = 9), urban (n = 23), from six main regions (Prishtina, Prizren, Gjilan, Ferizaj, Peja and Mitrovica) of Kosovo (Figure 1). As per botanical origin of the involved samples, there were 19 mountains, 26 meadow and 15 acacia honey samples. The samples were collected in glass jars, directly from the beekeepers' apiaries, and were kept in cool dark place until analysis was performed.

Sample digestion

An amount of 500 mg of each honey sample was added in Teflon tube, then was added 3 ml deionized water and digested with 5 ml HNO₃ (65 %) and 3 ml of H₂O₂ (35 %), using Microwave digestion system. After digestion all samples were diluted with deionized water in a 50 ml volumetric flask and stored in the refrigerator on 4 °C, until measured. The contents of metals in extracts were measured with a flame atomic absorption spectrometer (AAS) (M Series, Thermo, UK).

Statistical analysis

The experimental data analysis was carried out using IBM SPSS 27 software (Version 27.0, Armonk, NY, 2020). One-way ANOVA models were performed for macro-minerals (Na, Ca, K, Mg) and micro-minerals (Mn, Ni, Cu, Fe, Zn). The factors analyzed were the type of honey (Mountain honey, Meadow honey, and Acacia honey) and the geographical origin (rural, suburban and urban). Normality of the residuals was checked by Kolmogorov-Smirnov test ($p > 0.05$). Homogeneity of error variances was accepted by Levene's test ($p > 0.05$) except in the case of Na ($p < 0.05$). In case of significant results by Levene's test, Games-Howell's post hoc tests were used to separate significant groups. In other cases, homogeneous groups were separated by Tukey's post hoc tests. The relationship between the concentrations of minerals in the nectar honeys was assessed using Spearman's rank correlation coefficients.

Results and Discussions

Our study quantified the macro- and micro-mineral content in honey samples, categorized by their botanical (mountain, meadow, acacia) and geographical (rural, suburban, urban) origins. The employment of flame atomic absorption spectrometry facilitated precise mineral analysis, revealing significant variations influenced by both botanical and geographical factors.

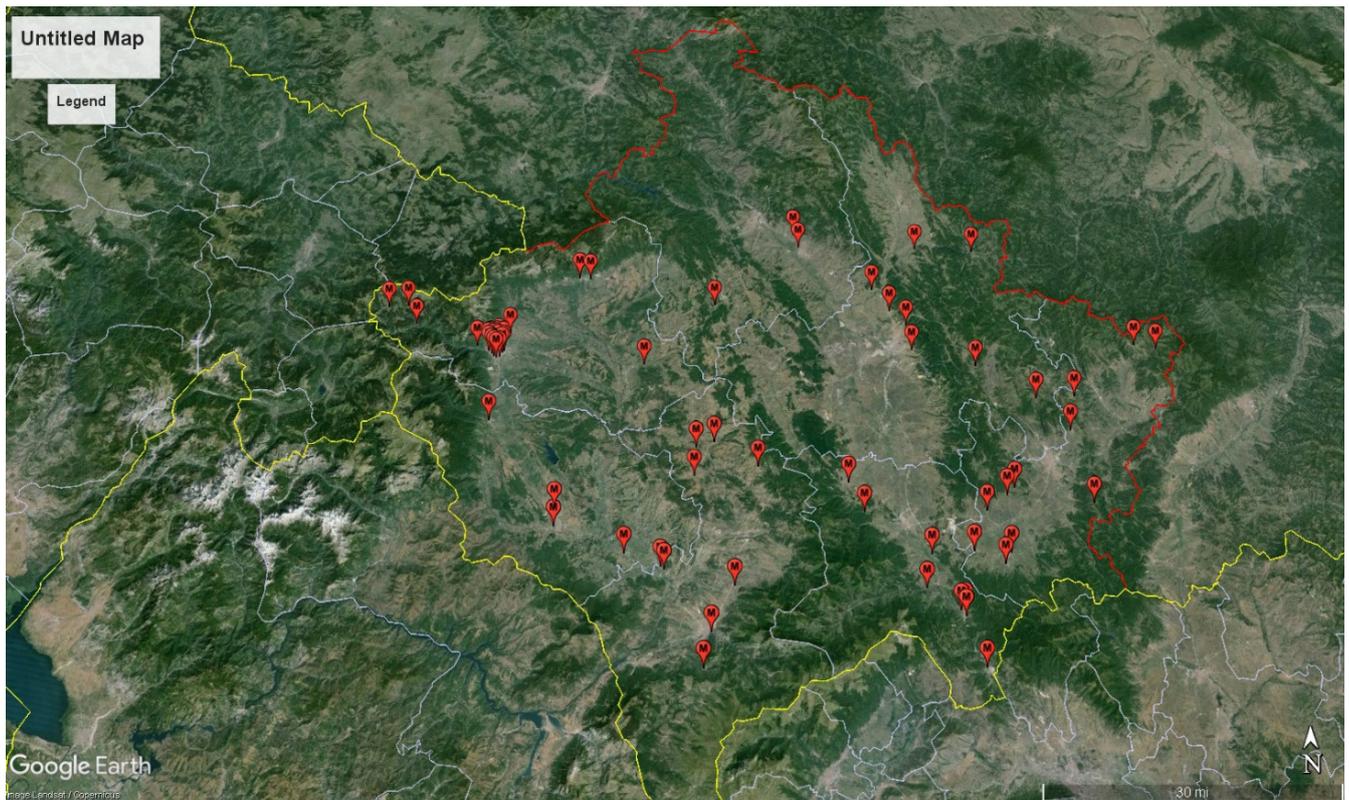


Fig. 1. Honey bee sampling sites

Source: Authors' own elaboration

The mean values of macro- and micro-minerals concentrations (in mg.kg^{-1} of honey) in different types of honey of different geographical areas of Kosovo are presented in Table 1 and Table 2. Minerals were significantly different depending on the botanic origin and geographical origin of the honey. There was high variability among the mineral concentrations in the analyzed honey samples. The highest variability among micro-minerals was observed for Fe, followed by Ni, Zn, Mn and Cu. The average concentrations of micro-minerals (Mn, Ni, Cu, Fe, Zn) were between $0.07\text{--}30.96 \text{ mg.kg}^{-1}$ of honey. Mountain honey had significantly higher concentrations of Mn ($P \leq 0.01$) and Cu ($P \leq 0.001$), and significantly lower concentrations of Ni ($P \leq 0.001$) and Zn ($P \leq 0.001$) than acacia honey. No significant differences were observed between mountain and meadow honeys in all the studied micro-minerals ($P > 0.05$), except for Ni ($P \leq 0.001$). Meanwhile, Fe concentrations were not significantly different among nectar honeys of different botanical origin ($P > 0.05$).

The highest variability among macro-minerals was observed for K, followed by Mg, Ca and Na. The mean concentrations of macro-minerals (Na, Ca, K, Mg) were between $10.71\text{--}1142.21 \text{ mg.kg}^{-1}$ of honey. Mountain honey obtained

significantly more K ($P \leq 0.001$) and Mg ($P \leq 0.01$) than meadow and acacia honey (Table 1). Meanwhile, Na and Ca concentrations were not significantly different among honey samples of different botanical origin ($P > 0.05$). No significant differences were observed between meadow and acacia honeys in all the studied macro-minerals ($P > 0.05$).

It should be emphasized that mountain nectar honeys had 3 times more K and 1.5 more Cu and Mn than acacia nectar honeys. Meanwhile, acacia nectar honeys had 3 times more Zn and 2 times more Ni than mountain nectar honeys. Meadow nectar honeys had 2 times more K and 2 times less Zn than acacia nectar honeys. The difference was even lower (with only 1.5 less K and 1.5 more Zn) of meadow nectar honeys compared with mountain nectar honeys.

The results indicated that mountain honeys were particularly rich in K and Mg, essential minerals that play critical roles in human health, including nerve function and muscle health. This could be attributed to the diverse flora in mountain regions, which is likely richer in these minerals. Conversely, acacia honey stood out for its higher Na and Fe content, possibly reflecting the specific mineral uptake of acacia plants. These findings align with previous studies

Table 1. Comparison of macro- and microminerals (in mg.kg⁻¹ of honey) between different types of nectar honeys

	Type of honey	Mountain honey (n = 19)	Meadow honey (n = 26)	Acacia honey (n = 15)	SEM (n = 60)	P value
Na	Mean	34.35 ^a	38.2 ^a	39.46 ^a	0.93	NS
	Range	18.18-50.19	28.79-53.41	27.72-49.6		
K	Mean	700.83 ^a	420.52 ^b	207.28 ^b	44.74	***
	Range	69.47-1142.21	35.00-1031.49	28.1-991.4		
Ni	Mean	5.35 ^c	8.78 ^b	11.44 ^a	0.46	***
	Range	0.37-11.47	4.51-15.7	7.42-15.29		
Cu	Mean	1.50 ^a	1.24 ^a	0.85 ^b	0.07	***
	Range	0.79-2.28	0.07-2.25	0.34-1.93		
Fe	Mean	9.73 ^a	9.87 ^a	11.83 ^a	0.73	NS
	Range	5.23-16.68	3.76-30.96	4.96-26.14		
Ca	Mean	18.68 ^a	19.19 ^a	20.91 ^a	0.93	NS
	Range	10.83-29.04	10.95-41.27	12.52-36.2		
Mn	Mean	4.10 ^a	2.99 ^{ab}	2.29 ^b	0.21	**
	Range	1.86-7.94	1.15-8.21	0.33-4.35		
Mg	Mean	30.5 ^a	23.49 ^b	22.9 ^b	1.09	**
	Range	16.71-49.69	13.03-41.26	10.7-37.98		
Zn	Mean	2.48 ^b	4.12 ^b	8.03 ^a	0.42	***
	Range	0.48-7.64	0.93-9.09	4.82-14.12		

Mean values with different letters (a-c) in the same row are significantly different. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; NS – Not significant; SEM – Standard error of mean.

Source: Authors' own elaboration

highlighting the influence of floral sources on honey's mineral composition.

A novel aspect of our research was the examination of honey's mineral content based on its geographical origins. Rural and suburban honeys exhibited higher levels of Cu and Mn, suggesting that less industrialized areas might provide a cleaner environment for bees, leading to the production of mineral-rich honey. Urban honey samples, while slightly lower in certain minerals, underscore the resilience of honeybees in adapting to various environments, although they may reflect the impact of pollution on mineral uptake.

In comparison to other studies, Meadow honey from Kosovo has demonstrated low levels of Ca, while exhibiting similar levels of Na and Mg. Additionally, the honey has shown high levels of Mn, Zn, Fe, Cu, and K, with the exception of K, where the highest content was found in honey from Hungary by (Bodó et al., 2021).

Acacia honey has been found to have similar levels of Zn, Mn, Mg, Na and Ca compared to other authors. However, a study by (Alqarni et al., 2014) found that honey from Saudi Arabia had higher levels of Na, Fe, and Ca. The high-

est levels of Ca were found in samples from Malaysia (Muhammad and Sarbon., 2023) and Romania (Pătruică et al., 2022). Acacia honey from Kosovo was found to have high levels of minerals such as K, Ni, and Cu. The honey from the Mountains has been found to have low levels of Ca, Mg, and Mn, while Zn, Ni, and K levels are higher. However, it should be noted that the potassium levels in honey from Croatia, as reported by (Bilandžić et al., 2019), show the highest value. Additionally, the Ni levels in honey from Malaysia, as reported by (Cheng et al., 2019), are higher. On the other hand, other authors have reported similar contents for elements such as Cu, Na, and Fe. However, the values of Na in honey from Kosovo exceed those reported by (Kováčik et al., 2016) for Slovakian honey and by (Bilandžić et al., 2019) for Croatian honey.

Geographical origin of nectar honeys had a higher effect on micro-minerals than on macro-minerals concentrations. Except for Fe, significant differences were observed between all the studied microminerals concentrations (Ni, Cu, Mn, Zn) on nectar honeys of different geographical origin (Table 2). Rural nectar honeys had significantly more Cu (1.37

Table 2. Comparison of macro- and microminerals (in mg.kg⁻¹ of honey) between different types of nectar honeys

	Country	Macro- and microminerals (mg.kg ⁻¹)									Authors
		Na	K	Ni	Cu	Fe	Ca	Mn	Mg	Zn	
Acacia honey	Poland	1.30	16.6	0.03	0.01	0.12	4.88	0.05	1.01	0.41	Grembecka & Szefer., (2012)
	Malaysia	42.72	466.5	nd	0.41	12.83	40.6	nd	6.34	1.17	Muhammad and Sarbon., (2023)
	Saudi Arabia	15.94	428.5	0.52	nd	92.56	96.7	5.25	188.7	4.36	Alqarni et al., (2014)
	Hungary	5.99	226.5	nd	<0.1	<0.05	12.4	0.12	5.24	0.15	Bodó et al., (2021)
	Romania	13.02	56.74	0.24	6.98	7.284	37.4	0.90	35.17	4.55	Pătruică et al., (2022)
Mountain honey	Slovakia	9.67	37.1	1.35	2.01	5.14	24.1	15.1	65.0	1.30	Kováčik et al., (2016)
	Malaysia	nd	667.3	523.	nd	6.96	177.	nd	34.41	1.57	Cheng et al., (2019)
	Croatia	9.6	2120	nd	0.72	2.3	162	13	73	1.3	Bilandžić et al., (2019)
	S. Arabia	20.84	384.2	0.39	nd	84.84	91.8	4.98	68.6	4.16	Alqarni et al., (2014)
Meadow honey	Hunagry	25.08	2523.	nd	1.67	2.35	135.	0.56	167.12	2.63	Bodó et al., (2021)
	Mediterrane	nd	nd	nd	0.35	1.82	61.9	0.47	15.49	1.85	Karabagias et al., (2019)
	Italy	28.83	731	nd	0.84	7.19	146.	0.48	26.58	nd	Conti et al., (2007)
	Poland	nd	233	nd	0.04	1.9	58.4	0.37	11.6	2.26	Wiczorek et al., (2014)

nd – not detected

Source: Authors' own elaboration

mg.kg⁻¹, $P \leq 0.01$) and significantly less Zn (3.56 mg.kg⁻¹), than the urban nectar honeys. Sub-urban nectar honeys contained the lowest concentrations of Ni, Fe and Zn (8.21, 9.86, and 3.56 mg.kg⁻¹, respectively), and the highest concentration of Cu and Mn (1.37, and 3.39 mg.kg⁻¹, respectively), then the rural and urban nectar honeys. No significant differences were observed between all micro-minerals concentrations of sub-urban and rural nectar honeys, except for Ni ($P \leq 0.001$). Sub-urban nectar honeys had significantly less Ni and Zn ($P \leq 0.01$) and significantly more Cu and Mn, ($P \leq 0.001$) than the urban nectar honeys. It can be concluded that in terms of micro-mineral concentrations, sub-urban nectar honeys were closer to the rural than the urban nectar honeys.

For macro-minerals, geographical origin of nectar honeys had a significant effect on K and Mg, while it had no effect on Na and Ca concentrations. Significantly ($P \leq 0.001$) higher content of K was found on the rural and the sub-urban nectar honeys compared to the urban nectar honeys. Similarly, significantly ($P \leq 0.05$) higher content of Mg was observed in the sub-urban nectar honeys compared to urban nectar honeys. The statistical analysis highlighted significant differences among the honey types, with botanical origin having a profound effect on macro-minerals like K and Mg and micro-minerals such as Mn, Ni, Cu, Fe, and Zn. These differences could be instrumental in developing honey as a dietary supplement, tailored to specific nutritional needs based on its mineral content. Moreover, the geographical classification revealed that environmental factors play a significant role in shaping honey's mineral profile. The higher mineral content in rural and suburban honeys points to the potential negative impact of urbanization on the nutritional

quality of honey, emphasizing the need for environmental stewardship.

No significant differences ($P > 0.05$) were observed between the rural and the sub-urban honeys on all studied macro-minerals concentrations. Rural nectar honeys had 2 times more K and 1.5 times less Zn than urban nectar honeys. Rural nectar honeys had 1.5 times more Ni than sub-urban nectar honeys. Sub-urban nectar honeys had 2.5 times more K, 1.5 times more Mn, 2 times less Zn and Ni than urban nectar honeys. It should be emphasized that both botanical and geographical origin did not have a significant effect on Na, Fe, and Ca concentrations of nectar honeys ($P > 0.05$).

Comparison of results from various authors have shown that honey from rural areas in Kosovo has high levels of elements potassium (K), nickel (Ni), and copper (Cu). Additionally, the content of iron (Fe) and zinc (Zn) is higher in Kosovo honey, with similar values to honey from Australia reported by (Hungerford et al., 2020). In terms of sodium (Na) and calcium (Ca) content, Kosovo honey exceeds that of Malaysian honey reported by (Cheng et al., 2019), while the magnesium (Mg) content is similar to honey from Malaysia. The Na content in honey from urban areas exceeds that of honey from Australia reported by (Hungerford et al., 2021). The honey from Poland, as reported by (Gałczyńska et al., 2021), has the highest potassium (K) content. Additionally, our country's honey has higher nickel (Ni), copper (Cu) and iron (Fe) content compared to other authors, while the calcium (Ca) content shows the opposite trend. Furthermore, from (Liberato et al., 2013) we observed that elements such as manganese (Mn), magnesium (Mg), and copper (Cu), had approximately similar values in Brazilian honey,

while from (Perna et al., 2021) we found zinc (Zn) content of Italian honey.

Our study also explored the correlations between different minerals within honey, revealing significant positive and negative relationships that suggest a complex interplay affecting honey's overall nutritional value. For example, the strong positive correlation between potassium and magnesium across all honey samples indicates a consistent

pattern that might be used to predict the nutritional quality of honey.

In most cases (58%) the Spearman's correlation coefficients (r_s) were found to be positive between the concentrations of minerals in nectar honeys (Table 5). The highest correlation between minerals was found to be for K and Mg ($r_s = 0.700$, $P \leq 0.01$), followed by K and Mn ($r_s = 0.682$, $P \leq 0.01$) and Mn and Mg ($r_s = 0.657$, $P \leq 0.01$). Kędzier-

Table 3. Comparison of macro- and microminerals (in mg kg⁻¹ of honey) between nectar honeys of different geographical origin

	Geographical origin	Rural (n = 28)	Sub-urban (n = 9)	Urban (n = 23)	SEM (n = 60)	P value
Na	Mean	37.23 ^a	36.04 ^a	38.47 ^a	0.93	NS
	Range	18.18–50.19	25.95–52.7	27.72–53.4		
K	Mean	540.61 ^a	698.22 ^a	258.15 ^b	44.7	***
	Range	31.9–1138.05	381–1092.8	28.1–1142		
Ni	Mean	8.21 ^a	4.54 ^b	10.03 ^a	0.46	***
	Range	3.88–15.7	0.37–8.81	3.32–15.29		
Cu	Mean	1.37 ^a	1.46 ^a	0.95 ^b	0.07	**
	Range	0.07–2.28	0.58–1.94	0.34–2.25		
Fe	Mean	9.86 ^a	7.67 ^a	11.9 ^a	0.7	NS
	Range	4.46–23.07	3.76–14.17	4.29–30.96		
Ca	Mean	18.51 ^a	20.63 ^a	21.08 ^a	0.9	NS
	Range	10.83–36.23	14.1–29.04	12.5–41.27		
Mn	Mean	3.39 ^{ab}	4.4 ^a	2.4 ^b	0.2	**
	Range	1.72–8.21	2.46–7.94	0.33–8.21		
Mg	Mean	25.68 ^{ab}	31.80 ^a	22.98 ^b	1.09	*
	Range	14.18–41.26	20.05–49.7	10.7–40.95		
Zn	Mean	3.56 ^b	2.88 ^b	6.47 ^a	0.42	***
	Range	0.48–9.09	1.43–8.09	1.47–14.12		

Mean values with different letters (a-b) in the same row are significantly different. SEM – Standard error of mean; *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; NS – Not significant.

Source: Authors' own elaboration

Table 4. Comparison of macro- and microminerals (in mg.kg⁻¹ of honey) between different types of nectar honeys

	Country	Macro- and microminerals (mg.kg ⁻¹)									Authors
		Na	K	Ni	Cu	Fe	Ca	Mn	Mg	Zn	
Rural honey	Italy	39.7	nd	0.028	0.274	1.458	37.54	0.237	18.45	0.866	Perna et al., (2021)
	Malaysia	589.46± 26.48	698.20± 30.04	nd	nd	7.05± 0.68	191.9± 12.40	nd	41.06± 7.85	2.09± 0.24	Cheng et al., (2019)
	Switzerland	nd	nd	0.056	0.18	0.278	nd	0.453	nd	0.217	Bogdanov et al., (2007)
	Australia	68.91	990.3	0.058	0.3104	4.012	77.37	4.48	29.29	10.9	Hungerford et al., (2020)
	Brasil	6.6	302.9	nd	0.44	1.1	14.58	0.61	7.71	1.14	Liberato et al., (2013)
Urban honey	Australia	99.7 ± 82.5	965 ± 651	0.033 ± 0.107	0.2 ± 0.4	3.1 ± 8.0	85.2 ± 39.9	3.8 ± 4.1	28.7 ± 19.6	6.0 ± 16.6	Hungerford et al., (2021)
	Poland	15.3	1411	0.03	0.29	2.5	74.6	0.45	21.6	3.47	Galczyńska et al., (2021)
	Italy	62.94	nd	0.041	0.198	nd	54.58	4.321	23.91	1.137	Perna et al., (2021)
	Brasil	2.1	103.4	nd	0.36	0.32	30.59	0.43	11.74	0.26	Liberato et al., (2013)

nd – not determined

Source: Authors' own elaboration

Table 5. Spearman's rank correlation coefficients between the micro- and macro-minerals in nectar honeys

Mineral	Na	K	Ni	Cu	Fe	Ca	Mn	Mg	Zn
Na	–	0.092	0.220	0.109	-0.078	0.148	-0.047	0.099	0.193
K	0.092	–	-0.562**	.534**	-0.251	0.026	0.682**	0.700**	-0.546**
Ni	0.220	-.562**	–	-0.477**	0.387**	-0.110	-0.319*	-0.266*	.644**
Cu	0.109	0.534**	-0.477**	–	-.283*	0.021	.448**	0.212	-0.501**
Fe	-0.078	-0.251	0.387**	-0.283*	–	0.101	-0.090	-0.002	0.492**
Ca	0.148	0.026	-0.110	0.021	0.101	–	0.057	.264*	0.107
Mn	-0.047	0.682**	-0.319*	0.448**	-0.090	0.057	–	.657**	-0.389**
Mg	0.099	0.700**	-.266*	0.212	-0.002	.264*	0.657**	–	-0.148
Zn	0.193	-0.546**	0.644**	-0.501**	0.492**	0.107	-0.389**	-0.148	–

**p < 0.01; *p < 0.05

Source: Authors' own elaboration

ska-Matysek et al., (2018) reported similar relationships between the mentioned minerals concentrations in Polish nectar honeys. Significant negative correlation coefficients were found between K and Ni ($r_s = -0.562$, $P \leq 0.01$), K and Zn ($r_s = -0.546$, $P \leq 0.01$) and Cu and Zn ($r_s = -0.501$, $P \leq 0.01$). The lowest positive correlation coefficients between minerals were found to be for Ca and Cu ($r_s = 0.021$), followed by Ca and K ($r_s = 0.026$). Meanwhile the lowest negative correlation coefficients were found to be between Mg and Fe ($r_s = -0.002$), followed by Mn and Na ($r_s = -0.047$).

In conclusion, our integrated results and discussion underscore the intricate relationship between honey's mineral content and its botanical and geographical origins. This research not only adds to the body of knowledge on honey's nutritional properties but also provides practical insights for beekeepers, consumers, and policymakers on the importance of preserving natural habitats and promoting sustainable beekeeping practices to enhance the health benefits of honey.

Conclusions

The findings demonstrate that honey's botanical origin significantly impacts its macro-minerals (K, Mg) and micro-minerals (Ni, Cu, Mn, Zn) content. Specifically, mountain honey was found to be rich in K, Cu, Mn, and Mg, while acacia honey exhibited higher levels of Na, Ni, Ca, Fe, and Zn. This suggests that the type of flora available to honeybees plays a crucial role in the mineral enrichment of honey. Moreover, the geographical classification of honey into rural, suburban, and urban origins revealed distinct differences in mineral profiles, particularly in micro-minerals. No significant differences were observed between rural and sub-urban nectar honeys on all the studied minerals, except for Ni. Rural and sub-urban nectar honeys contained higher

amounts of K, Cu, Mg, and Mn than urban honeys. Meanwhile, the urban nectar honeys contained higher amounts of Na, Ni, Fe, Ca and Zn than sub-urban and rural nectar honeys. Rural and suburban honeys were found to contain higher quantities of beneficial minerals compared to their urban counterparts, highlighting the impact of environmental factors and industrial activities on the mineral content of honey. The interplay between macro- and micro-minerals in honey also reveals significant correlations, suggesting complex interactions within the honey matrix that contribute to its overall nutritional value. These findings provide a deeper understanding of how natural and anthropogenic factors influence the health-promoting properties of honey. In conclusion, this study not only sheds light on the nutritional variability of honey based on its botanical and geographical origins, but also emphasizes the importance of preserving natural habitats and promoting sustainable beekeeping practices to maintain the high nutritional value of honey. For consumers, producers, and researchers, these insights underscore the need to consider origin in selecting and producing honey with optimal health benefits.

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