International Journal of Environmental Studies

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/genv20

Assessing the effects of geographical origin and production practices on the levels of heavy metals in honey from three regions in Ghana

Charles K. Klutse, Dennis K. Adotey, Yaw Serfor-Armah, Randy Y. Boateng, Amos Forson & Christian K. Nuveadenu

To cite this article: Charles K. Klutse, Dennis K. Adotey, Yaw Serfor-Armah, Randy Y. Boateng, Amos Forson & Christian K. Nuveadenu (2024) Assessing the effects of geographical origin and production practices on the levels of heavy metals in honey from three regions in Ghana, International Journal of Environmental Studies, 81:4, 1783-1796, DOI: 10.1080/00207233.2024.2360368

To link to this article: https://doi.org/10.1080/00207233.2024.2360368

INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
2024, VOL. 81, NO. 4, 1783–1796
https://doi.org/10.1080/00207233.2024.2360368

Routledge
Taylor & Francis Group

ARTICLE

Assessing the effects of geographical origin and production practices on the levels of heavy metals in honey from three regions in Ghana

Charles K. Klutse[a,b], Dennis K. Adotey[a], Yaw Serfor-Armah[a], Randy Y. Boateng[a], Amos Forson[a,c] and Christian K. Nuveadenu[a,c]

[a]School of Nuclear and Allied Sciences, College of Basic and Applied Sciences, University of Ghana-Atomic, Accra, Ghana; [b]Nuclear Power Institute, Ghana Atomic Energy Commission, Accra, Ghana; [c]Accelerator Research Centre, National Nuclear Research Institute, Ghana Atomic Energy Commission, Accra, Ghana

ABSTRACT

To evaluate the impact of production methods and geographical origin on honey quality, honey from three regions in Ghana was analysed using INAA and FAAS for the presence of some selected metals. Five metals were found in all the ninety samples as Mg (321.1 mg/kg), Cu (56.2 mg/kg), V (8.18 mg/kg), Fe (3.28 mg/kg), and Pb (0.0400 mg/kg). Co and Cr were detected in 12% and 45% of the samples respectively but As, Cd, and Hg were not detected. The concentrations of Pb varied significantly based on production practices. Cu, Mg, and V showed differences based on geographical sources, according to the Kruskal Wallis test at $p < 0.05$. Co was below the WHO levels for drinking water and Cr, Cu, Fe, Mg and V were above the WHO levels. Ultimately, the honey source, as opposed to production practices, affected the metal content and potentially, honey consumption can have health risks.

KEYWORDS

Honey; metals; production; stage; hunters; regions

Introduction

Honey is an essential substance with many useful applications, including health, food, and cosmetics [1–3]. This is because honey is composed of nutritionally valuable, anti-oxidative, and anti-bacterial chemicals, and can impact both healing and prophylactic properties [4–6]. The general composition of honey includes sugars, moisture, acids, minerals, enzymes and other components like proteins, pollen, colloids of metals and heavy metals [5,7–9]. Although it has been argued that the metals exist in honey at safe levels [10,11], it has also been demonstrated that honey bees and their products can be used for biomonitoring of metal pollution. This indicates that honey can accumulate pollutants (e.g. microbes, metals, heavy metals, and pesticides) at a level indicating the general pollution of the environment [11–14]. Another major concern is the potential contamination of honey from the point of harvest along the processing routes till it reaches the consumer [11,15,16].

CONTACT Charles K. Klutse cklutse@gmail.com Nuclear Power Institute, Ghana Atomic Energy Commission, P. O. Box LG80, Legon, Accra, Ghana

Published online 31 May 2024

Globally, contaminants in honey have been studied extensively. Some of these contaminants include inorganic substances, agrochemicals, microorganisms, and other environmental pollutants [17–21]. Honey is an export commodity in Ghana. Therefore, regular assessment of honey and current information about its quality can help boost its global appeal and premium price. Additionally, the use of honey in infants' food and medication as a sugar substitute calls for investigation to establish honey's health and safety requirements. Thus, there is a research focus on honey, especially on how the activities of honey producers and retailers impact the quality of honey that reaches the consumer [14,15].

This work is part of the effort to investigate how the post-harvest activities and the state of the environment around honey production affect the level of metals in honey from three honey-producing regions in Ghana. The hypothesis underlying this work is that in terms of elemental contaminants, the environment around production sites and production and handling practices does not significantly affect honey quality. The work will enhance our understanding of the quality of honey produced in Ghana and help identify sources of any contamination and how they can be addressed.

Materials and methods

Samples sites

This work was done in 2015 and 2016. The sampling area shown in Figure 1 was described in an earlier work [15]. The map was generated using ArcGIS software version 10.2 [15,22]. As shown in the map the area covered three regions. Ashanti Region with coordinates (6.7470° N, 1.5209° W) has forest vegetation. Brong Ahafo region with coordinates (7.9559° N, 1.6761° W) has mainly forest vegetation with few pockets of northern savannah. The Greater Accra region with coordinates (5.8143° N, 0.0747° W) has mainly coastal savannah vegetation.

Sample collection

Honey was sampled systematically along the production route (i.e. from the farmer to the retailer) for the analyses of some selected metals. Fresh honey samples were collected from honeycomb with plastic spoons from each farm in all three regions and referred to as production stage one (1). Most of the stage one samples contained honey that had already been harvested but was awaiting squeezing and clarification. The samples were stored in amber plastic bottles previously washed with aqua regia. For each producer, the honey was processed according to each farmer's routine practices (i.e. squeezed, filtered, clarified, etc.) and packaged for sale. Samples taken at this stage were designated as production stage two (2). Honey was also sampled from retailers and designated as production stage three (3).

The samples were systematically taken after interviews with both the producers and the honey retailers to ensure that each sample taken followed the defined production route. Thus, the sampling followed the route designated as the unprocessed (1), after processing (2), and the retailing (3). In practice, retailers often mix honey collected from various sources. For each region, three blanks were prepared at three randomly selected

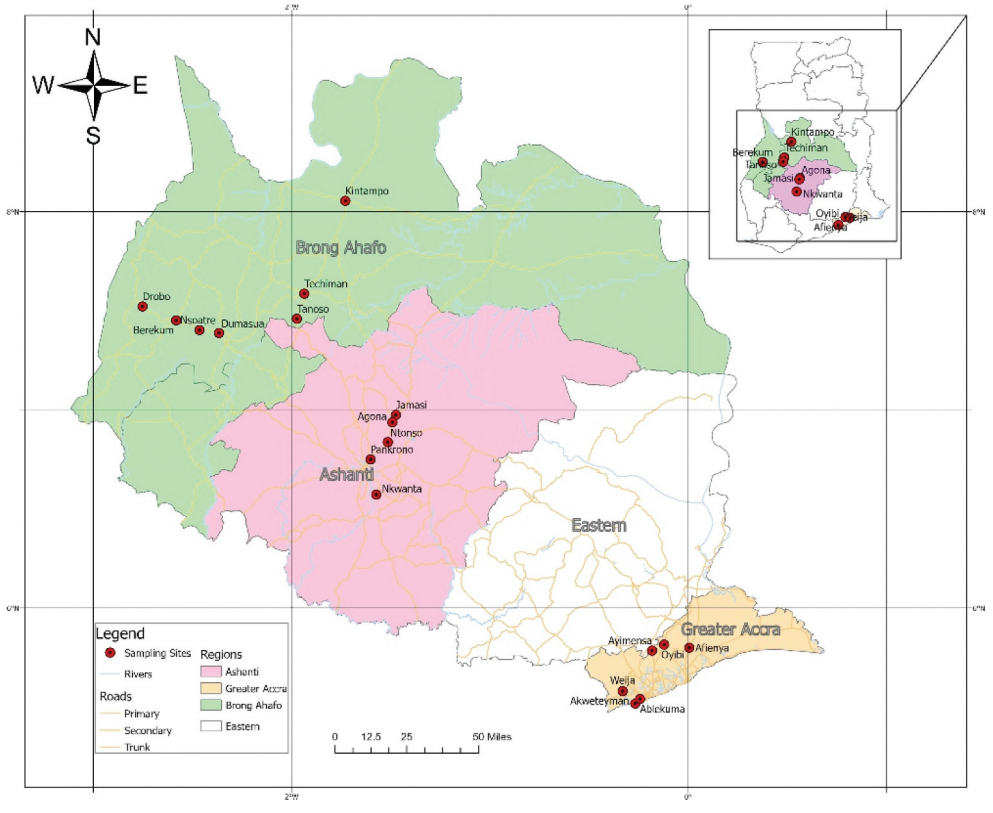

Figure 1. A map of three of the three sample collection regions: Ashanti region, A; Brong Ahafo region, B; and Greater Accra region, C. Some of the ten locations in each region where the honey samples were collected are indicated by the name of the towns.

sites and added to the samples. The metals analysed were mercury (Hg), cobalt (Co), lead (Pb), cadmium (Cd), vanadium (V), and arsenic (As) which are heavy metals and iron (Fe), chromium (Cr), copper (Cu), and Magnesium (Mg) which are essential metals.

Reagents

All chemicals used in this study were of analytical grade. Solutions of 65% v/v Nitric Acid (HNO_3) and 30% v/v Hydrogen Peroxide (H_2O_2) (BDH, Poole, United Kingdom) were used for the digestion of the honey samples. Working standards of Pb, Cr, Co and Fe were prepared by diluting a concentrated stock solution (Merck, Darmstadt, Germany) of 1000 ± 4 mgL^{-1} with 0.25 mol/L nitric acid. For calibration analyses, the working standards were used for serial dilutions.

Analytical methods

The determination of the selected metals was done using Flame Atomic Absorption Spectrometry (FAAS, VARIAN, AA 240 FS, Australia) at Ghana Atomic Energy

Commission, Accra for the elements Pb, Cr, Co and Fe. The FAAS has a deuterium background corrector. All vessels and glassware used were washed with aqua regia, rinsed thoroughly with deionised water, and oven-dried at a temperature of 40°C. Using a 500 mg portion of the sample, honey was digested as described in an earlier work [23].

The FAAS was systematically optimised for the target analytes using flow rates of 13.5 $L.min^{-1}$ and 2.0 $L.min^{-1}$ for oxygen (oxidant) and acetylene gas (fuel) respectively. The operating slit width and lamp current for analytes with the quoted wavelengths Cr (357.9 nm), Co (240.7 nm) and Fe (248.3 nm) were 0.2 nm and 7.0 mA respectively and that of Pb (217.0 nm) was 1.0 nm and 5.0 mA. The instrument was calibrated using the appropriate solution standards. The absorbances of the various analytes were then measured. The absorbances of reagents and procedural blanks were measured before and after the calibration.

For the determination of Cd, Cu, As, Hg, Mg, and V using Instrumental Neutron Activation Analysis (INAA), honey samples were irradiated using a 30-kW miniature neutron source reactor at the Reactor Centre of Ghana Atomic Energy Commission, Accra. The irradiation was done at a thermal neutron flux of 5×10^{11} $ncm^{-2}s^{-1}$. National Institute of Standards and Technology (USA) single standard reference materials with reference number NIST SRM 1643E (estuarine sediment) was used as a standard and treated the same way as the samples.

About 500 mg aliquot of the homogenised samples were measured into a labelled 1.2-mL polyethylene vial and sealed thermally with a soldering rod. The sealed vials were placed in another 7-mL vial and plugged with cotton wool. For the irradiation process, the reactor is equipped with a pneumatic system that operates at a pressure of 25.0 atm. This was used to deposit samples (quadruplicates), blanks, and standards into an irradiation vessel. The short-lived radionuclides (i.e. Mg, Cu, and V) were analysed by irradiating the samples for 2 minutes followed immediately by counting for 10 minutes. To analyse medium-lived radionuclides (i.e. Hg, As, and Cd), the irradiation of the samples was done for an hour, followed by a 24-hour delay before counting for 10 minutes.

The γ-irradiation intensities of the induced radionuclides were measured with a coaxial high-purity germanium detector (ORTEC). Relative to the 1332.5 keV γ-line of ^{60}Co, the detector efficiency was 25%, the resolution was 1.8 keV and the peak-to-Compton ratio was 55:1.

The metal analytes in the samples were identified based on the γ-ray energies of the induced radionuclides. Using the relative comparator method, the concentrations of the analytes in the samples were quantified by analysing the measured intensities of the induced radionuclides with ORTEC MEASTRO-32 γ-ray spectrum analysis software. WinSPAN-2010 version 2.10, a multipurpose γ-ray spectrum analysis-93 software, was used for the peak area determination, processing, and concentration calculation.

Quality control

Validation of the INAA technique

INAA technique was validated using NIST SRM 1643E 10 and 20 mg/kg concentrations. Both the standards and samples were given the same pre-irradiation treatment and irradiated at the same time. The comparator method was used for quantifying

Table 1. Validation of the INAA technique based on measurement of (NIST SRM 1643E reference material (estuarine sediment)). The measurement was done for 10 and 20 mg/kg concentrations and the relative standard deviations are shown.

	Concentration: 10.0 mg/kg		Concentration: 20.0 mg/kg	
Element	Measured	Recovery (%)	Measured	Recovery (%)
Mg	9.37	93.7	18.84	94.2
V	9.76	97.6	19.66	98.3
Cu	10.06	100.6	20.04	100.2
As	9.94	99.4	19.91	99.55
Hg	10.16	101.6	20.38	101.9
Cd	9.81	98.1	19.68	98.4

concentrations of the analytes, so spike recovery and procedural blanks were not required. To determine the accuracy of the system, percentage recovery was calculated by comparing the concentration measured to the certified concentration for each element. Table 1 shows certified and measured concentrations and the percentage recoveries. The relative deviations for both concentrations ranged from 0.2 to 6.3%.

To determine the precision of the INAA used, five measurements of the NIST SRM 1643E were taken and the coefficient of variation among the five measurements was determined for some selected analytes. In all cases, the coefficient of variation was below 7% (i.e. it ranged from 0.5 to 6.7%).

For the elements analysed with FAAS, procedural blanks were used to account for procedural errors and possible contaminations from the reagents used. The average blank readings of the procedural blanks were used for the background corrections. The procedural blanks were prepared the same way as the samples. Each region had at least 9 procedural blanks, which were the three blanks from each of the three production stages. Sample duplications and spikes and recovery methods were used as additional quality control measures. The spike and recovery analyses were done after the analysis of the sample for each region by adding working solutions of the standards to fresh portions of three randomly chosen samples and a blank from each region. The digestion and AAS analysis procedures were repeated. The percentage recovery was determined using the differences in sample concentration before and after spiking relative to the concentration of the standard. The percentage recoveries of the spiked metals were 97.8%, 99.2%, 101.3%, and 98.9% for the metals Pb, Cr, Co, and Fe respectively. The coefficient of variation for the percentage recoveries ranged from 4.2 to 9.8%. Analyses of both the reagent and procedural controls indicated that no significant contamination was introduced.

Detection limits for various metals corresponded to the concentration associated with three times higher than the standard deviation of the background noise recorded in 27 (i.e. 9 for each of the three sites) readings of the procedural blanks. The limits of detection (LOD) for each of the metals were Pb 0.001 mg/kg, Fe 0.24 mg/kg, Co 0.005 mg/kg, Cr 0.006 mg/kg, Mg 0.1 mg/kg, V 0.005 mg/kg, Cu 0.01 mg/kg, Cd 0.001 mg/kg, As 0.01 mg/kg, and Hg 0.001 mg/kg. The limits of quantification (LOQ) were calculated as Pb 0.03 mg/kg, Fe 0.80 mg/kg, Co 0.017 mg/kg, and Cr 0.020 mg/kg, Mg 0.33 mg/kg, V 0.017 mg/kg, Cu 0.033 mg/kg, Cd 0.003 mg/kg, As 0.033 mg/kg, and Hg 0.003 mg/kg.

Data analysis

Microsoft Excel and Python 3 were used for all data and statistical analysis. From the initial descriptive statistics of the data, the comparison of values of mean and median indicated a lack of normal distribution. Histograms and Kolmogorov-Smirnov tests were used to further confirm whether the data were normally distributed. Based on the test for normal distribution, non-parametric statistics were used. Kruskal Wallis test was used to test for variation in the central tendencies.

Results and discussion

Honey samples were collected from three regions represented by A (Ashanti region), B (Brong Ahafo region), and C (Greater Accra region). From each region, ten honey producers were selected and samples were taken from the three production stages, that is before processing, after processing, and at the retailing points for metal analyses. The Concentrations of the following metals As, Cd, and Hg were below the detection limit in all the honey samples. For that matter, they were not included in the results and discussions. Co was detected in 11 out of 90 samples representing 12% with a concentration range just above the detection limit (0.009–0.013 mg/kg). Even though Cr was found in 41 samples representing 45%, all the samples were within a narrow concentration range (i.e. 0.042–0.078 mg/kg). Therefore, both metals were discussed minimally in this work.

Table 2 is a descriptive statistic of the selected analytes detected in the various honey samples. Apart from Pb and Fe, the values for the mean and median were different indicating that skewness exists in the data. This was confirmed by the p-values (all were less than 0.05) for the Kolmogorov-Smirnov tests and the histograms (not shown). These observations indicated that the non-parametric statistical comparisons among groups were adequate. Therefore, median values were considered as a measure of central tendency and the statistical test of variation was based on Kruskal-Wallis tests.

Figure 2 represents the result of the data collected based on interviews and observations to determine the impact of the activities in the environment in which the bees foraged and the beehive was located as well as the honey production practices on the level of metals detected in the honey samples. The responses to the interview questions led to the determination of the following: 1) the nearness of the beehive to specific activities, 2) the types of materials used during honey harvesting and processing, and 3) whether adulteration occurred. The distance bees forage from

Table 2. Descriptive statistics of all the honey samples ($n = 90$), concentrations are in (mg/kg). *$n = 41$, n/a =was not considered due to narrow concentration range, KS = Kolmogorov-Smirnov, std = standard deviation.

Metals	KS test	Median	Min	Max	Mean	Std
Pb(mg/kg)	7.1e–24	0.40	0.03	0.828	0.4	0.2
Fe(mg/kg)	1.4e–110	3.267	1.548	11.052	4.0	1.0
Mg(mg/kg)	0.0	321.1415	75.697	681.236	310	150
V(mg/kg)	3.9e-80	8.1765	0.49	34.565	12	10
Cu(mg/kg)	0.0	56.235	4.524	288.298	73	70
*Cr (mg/kg)	n/a	0.048	0.042	0.078	0.047	0.007

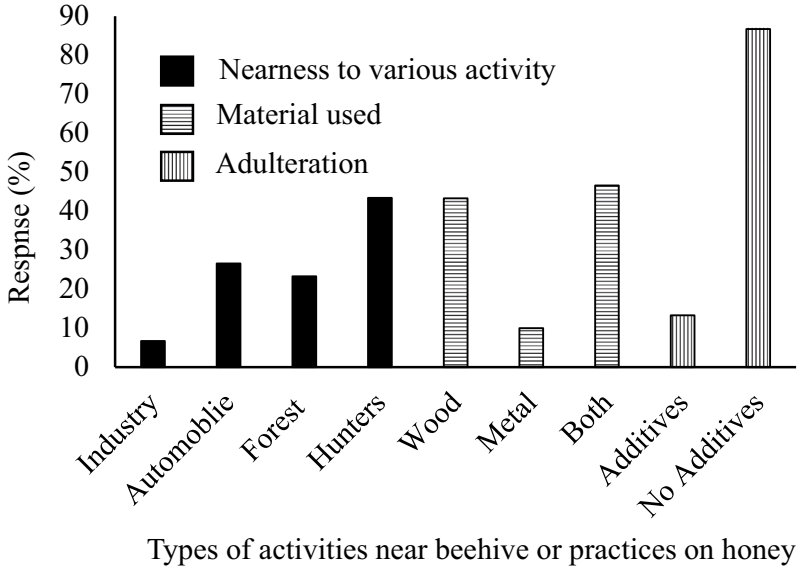

Figure 2. The distribution of the responses of the interview conducted to determine honey production practices and conditions of the beehive environment. Types of activities close to honey production locations are depicted by solid black bars; the materials used for processing are depicted with horizontal line bars; and Occurrence of honey adulteration is depicted by vertical line bars. (Figure size: 1.5 column fitting).

the hive is known to be dependent on the time of the year and forage type and availability [24]. For this work, the nearness of the farm to a designated place was considered to be less than 1 km. Observations and the responses indicated that beehives located near industries, cities, commercial areas, and construction sites (designated as industry) made up 6.7% of the total samples collected. Samples collected from sources located near roads, filling stations, and auto-mechanic shops (designated as automobiles) are about 26.6%, and those far away from human settlements (designated as a forest) formed (23.3%).

Most samples collected (i.e. 43.4%) are from producers who do not have localised beehives because they are either honey hunters or off-takers from different farmers (designated as hunters). The materials commonly used for the extraction and processing of honey were wood and metals. About 49.7% of the respondents indicated they used both wood and metal whereas those who used wood or metal only were 43.4% and 10.0% respectively (Figure 2). On measures taken to reduce contamination, the majority of the respondents (not shown in the figure) indicated that they sometimes covered their heads and/or wore gloves during honey extraction. Although there were no data available to show the distribution of the respondents according to the various processing methods they used to extract and clarify honey, most of them squeezed the honey by hand. Others tended to use multiple methods, which included melting with heat, sieving through nets, decantation, solar and cold extractions, and filtration. Only 13.3% of the participants indicated that they often add water to improve the consistency and increase the volume of honey (Figure 2).

Table 3. The concentrations of selected heavy metals in honey were collected from the three regions. The sample size from each region is 30. A is Ashanti region, B is the Brong Ahafo region and C is the Greater Accra Region, KW = Kruskal Wallis.

Metals	Regions	Median	Min	Max	KW Test
Pb(mg/kg)	A	0.402	0.090	0.828	0.011
	B	0.471	0.096	0.678	
	C	0.276	0.030	0.660	
Fe(mg/kg)	A	3.11	1.55	4.81	0.230
	B	3.68	2.50	6.80	
	C	3.11	1.82	11.1	
Mg(mg/kg)	A	324.3	97.40	681.2	3.7e−9
	B	393.3	302.0	552.4	
	C	164.7	75.70	350.1	
V(mg/kg)	A	6.42	0.490	19.3	6.4e−12
	B	22.9	5.02	34.6	
	C	4.2	0.962	17.2	
Cu(mg/kg)	A	36.7	5.19	193	0.0346
	B	50.1	4.99	203	
	C	65.0	4.52	288	

Regional concentration of metals in honey samples

Table 3 shows the values for the median, minimum, and maximum concentrations of various metals assessed (Pb, Fe, Mg, V, and Cu) in honey samples from the three regions (A, B, and C). Kruskal Wallis test of variation shows that the concentrations of Fe in honey collected from the three regions were not significantly ($p \leq 0.05$) different, indicating that the prevalence of Fe in the honey was not region-specific in this work.

Earlier work done to profile honey based on the level of minerals and trace metals in bee products showed that the level of Fe in honey is not a suitable indicator for geographical discrimination of honey [25–28]. But, the level of the same metal in bees and pollen could be used as a metal pollution indicator [26,29,30]. In contrast, vegetation-based differences in Fe concentration in honey samples have been reported in earlier work [31]. There were significant regional differences in the concentrations of four of the metals (Pb, Mg, V, and Cu) in honey. The concentrations of Pb in honey from Regions A and B were not significantly different from each other, but they were significantly ($p \leq 0.05$) greater than the concentrations of Pb in samples of honey from Region C.

For Cu, the concentrations in honey from regions B and C were not significantly different from each other but both were significantly greater than the concentrations determined in samples from region A. There were regional differences in the concentrations of Mg and V in the samples of honey collected from the three regions. Previous research in this area has shown that levels of Mg, Cu, Pb and V in honey can provide geographical, botanical, and pollution information [25,29,31–34]. Except for Cu most of the metals analysed showed lower median concentrations in samples collected from Region C. Region C which is the capital city has most of its beehives in controlled and secluded environments, unlike regions A and B where most of the samples came from honey hunters whose practices are often not regulated.

There were no data on the levels of the metals in the sampling sites within the period of sampling for comparative analysis. Nevertheless, this work shows that the levels of metals in honey are generally higher in samples collected in forest areas than in the city (i.e. coastal savannah zones). This is in contrast with earlier work done in 1998 [31]. This

can be attributed to current observations indicating that construction work and vehicular activities are becoming prevalent in areas which used to be considered forest areas – a reflection of the general development trend in Ghana.

The effect of after-harvest honey handling on levels of metals

The result was analysed based on the three stages of honey production (1: just after harvest, 2: after extraction and filtering, and 3: at the retail point). For all the metals assessed, there were general increases in the median concentrations as honey moved from the production stage 1 to 3. The median concentrations for all the metals assessed were highest in the honey samples collected from production stage 3 (Table 4).

Except for Pb and Fe, the Kruskal Wallis variation test showed that the increases were not significant at $p \leq 0.05$. This is an indication that for metals (i.e. Mg, V, and Cu) assessed, the honey production regime employed had an insignificant impact on the levels of metals in the honey. The levels of Pb determined in the samples from each of the production stages were significantly different. For Fe, the concentrations in honey samples from production stage 1 were significantly lower than the median concentrations in samples from production stages 2 and 3. But, the median concentrations of honey samples from production stages 2 and 3 were not significantly different at the level of $p \leq 0.05$. The literature reviewed so far did not show any similar work regarding the assessment of the impact of the honey production regime on the prevalence and level of metals in honey. One study remarked that metal levels in honey can be increased by poor harvesting, extraction, and storage conditions [33]. This work did not consider the elemental content of the local equipment used for honey extraction and filtration.

There are no clear guidelines about the maximum permissible limits of metals in honey. Codex Alimentarius Commission states that heavy metals in honey shall be at a level that does not pose a hazard to human health [35]. Accordingly, the levels of metals in this study were compared to the levels normally permitted for natural mineral drinking water in various regulations (Table 5). For the 90 samples of honey analysed in this study, six samples had levels of Cr above the WHO and EU maximum limit. For

Table 4. The concentrations of selected heavy metals in honey collected from the three production stages. The sample size from each stage is 30. Stage 1 is before processing, 2 is after extraction and clarification and 3 is the retail points, KW = Kruskal Wallis.

Metals	Processing Stage	Median	Min	Max	KW Test
Pb(mg/kg)	1	0.249	0.030	0.624	2.7e–5
	2	0.432	0.150	0.678	
	3	0.501	0.186	0.828	
Fe(mg/kg)	1	2.95	1.55	5.44	8.1e–4
	2	3.22	1.67	6.07	
	3	3.79	1.88	11.0	
Mg(mg/kg)	1	314	75.7	659	0.807
	2	320	79.9	674	
	3	338	83.0	681	
V(mg/kg)	1	6.67	0.490	30.03	0.338
	2	7.28	0.498	34.6	
	3	9.62	0.523	34.1	
Cu(mg/kg)	1	52.2	4.52	228	0.767
	2	60.1	5.14	264	
	3	61.2	6.84	271	

Table 5. The comparison of the concentration of metals in honey in this study to the various Guidelines indicated for natural drinking water. ML = minimum limit, b/d = below detection.

	Concentration mg/kg		
Metal	This study mg/kg	ML	Standards
Pb	0.03–0.828	0.01	CXS 103–1995 [36]
Fe	3.267–11.548	0.2/2	WHO [37]
Mg	75.697–681.236	0.5–90	WHO [38]
V	0.49–34.565	0.02	WHO Air Quality Guidelines for Europe [39]
Cu	4.524–288.298	1.0	CXS 108–1995 [36]
As	b/d	0.01	CXS 103–1995 [36]
Cd	b/d	0.003 0.05	CXS 103–1995 [36]
Hg	b/d	0.001	CXS 103–1995 [36]
Co	b/d – 0.013	Not stated	
Cr	0.042–0.078	0.05	WHO [37]

V and Co there are no data about their maximum limit in drinking water. The Pb, Fe, Cu, and Mg concentrations in all the samples were above the various guidelines (i.e. WHO, USEPA, and EU) maximum limits for drinking water [37,40]. The presence of some heavy metals especially Pb in honey samples analysed in this study above allowable limits shed light on the potential health risks associated with the consumption of honey [41–43].

Various research articles discussed levels of heavy metals and other elements in honey using various analytical techniques and samples from various environmental settings [42–44]. It was not possible to have similar studies for comparative discussions of this work. But, a comprehensive review of minerals, trace elements and heavy metals found in honey from different origins was done by Solayman *et al.* in 2016 [45]. There are several research efforts by Di Bella *et al* [25], Tsegay [46] and others that profiled the metal content of honey [31,41,43,47–49]. Our results are within the range of concentrations quoted in these reviews and other works. The current research did not detect in all the honey samples As, Cd, and Hg, which are known potential health concerns. Thus consumers of honey from these three regions of Ghana may be safe from the health risks of these metals.

Conclusion

Honey samples from parts of Ghana were assessed for the potential impact of the environment in which honey is produced and the associated processes on the level of heavy metals in honey. In all, ten metals were analysed, but three of the metals As, Cd, and Hg could not be detected in any of the samples. Two of the metals Co and Cr could only be detected in 12 and 41% of the samples respectively and only 7% of the samples had the Cr concentration levels within WHO and EU recommended levels for drinking water. The rest of the metals Pb, Fe, V, Cu and Mg were detected at concentrations above WHO limits for drinking water and most internationally recommended maximum limits for drinking water. Significant variations were not detected among the concentrations of Fe in honey from the various regional sources or production stages considered.

Concentrations of Pb in honey collected from forest regions were significantly higher than in honey from coastal savannah regions. The concentrations of Cu in honey from the three regional sources considered were significantly different from one another, with

honey from coastal savannah regions having the highest concentration of Cu. The concentrations of Mg and V were significantly different in all regions and the median concentrations were lower in the coastal savannah regions. There was no effect from post-harvest handling on the concentrations of the metals V, Cu, and Mg in the honey collected at the various production stages.

The concentrations of Cu were significantly higher in samples collected at the retail end than the level in the sample collected before processing. The Pb concentrations were significantly different at each production stage. It appears there are differences in the concentrations of metals in honey varying with the location of production. Nevertheless, except for Cu and Pb, it is not possible to conclude that honey production practices significantly impact the concentration of heavy metals in the honey assessed.

The study provides information useful for various stakeholders in the honey industry to take actions that can help protect consumers from harmful metals exposure, enhance honey industry regulations, and improve the quality of honey. Further research is necessary to trace the honey contamination pipeline thereby identifying safe sources of honey and promoting such honey to boost the local beekeeping industry and Ghanaian honey marketability. Assessment of the honey contamination pipeline can help educate the producers about sustainable beekeeping practices to prevent honey contamination. The regulatory authorities can implement stricter safety standards and innovative processes for screening honey production and distribution to reduce the levels of metal contamination. Finally, this study will greatly help honey consumers make informed choices about honey sources to reduce the potential health risks from honey consumption.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors received no financial support in connection with this article.

Data availability statement

All data generated or analysed during this study are included in this paper.

References

[1] Eteraf-Oskouei, T. and Najafi, M., 2022, Uses of natural honey in cancer: An updated review. *Advanced Pharmaceutical Bulletin* **12**(2), 248–261. doi: 10.34172/apb.2022.026

[2] Farooqui, T. and Farooqui, A.A., 2011, Health benefits of honey: Implications for treating cardiovascular diseases. *Current Nutrition & Food Science* **7**(4), 232–252. doi: 10.2174/157340111804586448

[3] Hadi, H., Syed Omar, S.S. and Awadh, A.I., 2016, Honey, a gift from nature to health and beauty: A review. *British Journal of Pharmacy* **1**(1), 46–54. doi: 10.5920/bjpharm.2016.05

[4] Lianda, R.L.P., Sant'ana, L.D., Echevarria, A. and Castro, R.N., 2012, Antioxidant activity and phenolic composition of Brazilian honeys and their extracts. *Journal of Brazilian Chemical Society* **23**(4), 618–627. doi: 10.1590/S0103-50532012000400006
[5] Pătruică, S., Alexa, E., Obiştioiu, D., Cocan, I., Radulov, I., Berbecea, A., Lazăr, R.N., Simiz, E., Vicar, N.M., Hulea, A. and Moraru, D., 2022, Chemical composition, antioxidant and antimicrobial activity of some types of honey from Banat Region, Romania. *Molecules* **27**(13), Article 4179. doi: 10.3390/molecules27134179
[6] Iwegbue, C.M.A., Obi-Iyeke, G.E., Tesi, G.O., Obi, G. and Bassey, F.I., 2015, Concentrations of selected metals in honey consumed in Nigeria. *International Journal of Environmental Studies* **72**(4), 713–722. doi: 10.1080/00207233.2015.1028783
[7] White, J.W., 1967, Honey, its composition and properties. *In: Beekeeping in the United States Handbook, United States Department of Agriculture* **335**(147), 56–64.
[8] Ball, D.W., 2007, The chemical composition of honey. *Journal of Chemical Education* **84** (10), Article 1643. doi: 10.1021/ed084p1643
[9] da Silva, P.M., Gauche, C., Gonzaga, L.V., Costa, A.C.O. and Fett, R., 2016, Honey: Chemical composition, stability and authenticity. *Food Chemistry* **196**, 309–323. doi: 10.1016/j.foodchem.2015.09.051
[10] Hilmi, M., Bradbear, N. and Mejia, D., 2011, Beekeeping and sustainable livelihoods. In: *FAO Diversification Booklet* Vol. 1 (2nd ed). (Rome, Italy: Food and Agriculture Organisation of United Nations), pp. 26–28.
[11] Bogdanov, S., 2006, Contaminants of bee products. *Apidologie* **37**(1), 1–18. doi: 10.1051/apido:2005043
[12] Mukiibi, S.B., Nyanzi, S.A., Kwetegyeka, J., Olisah, C., Taiwo, A.M., Mubiru, E., Tebandeke, E., Matovu, H., Odongo, S. and Abayi, J.J.M., 2021, Organochlorine pesticide residues in Uganda's honey as a bioindicator of environmental contamination and reproductive health implications to consumers. *Ecotoxicology and Environmental Safety* **214**, Article 112094. doi: 10.1016/j.ecoenv.2021.112094
[13] Cunningham, M.M., Tran, L., McKee, C.G., Polo, R.O., Newman, T., Lansing, L., Griffiths, J. S., Bilodeau, G.J., Rott, M. and Guarna, M.M., 2022, Honey bees as biomonitors of environmental contaminants, pathogens, and climate change. *Ecological Indicators* **134**, Article 108457. doi: 10.1016/j.ecolind.2021.108457
[14] Adadi, P. and Obeng, A.K., 2017, Assessment of bacterial quality of honey produced in Tamale metropolis (Ghana). *Journal of Food & Drug Analysis* **25**(2), 369–373. doi: 10.1016/j.jfda.2016.07.005
[15] Klutse, C.K., Larbi, D.A., Adotey, D.K. and Serfor-Armah, Y., 2021, Assessment of effect of post-harvest treatment on microbial quality of honey from parts of Ghana. *Radiation Physics and Chemistry* **182**, Article 109368. doi: 10.1016/j.radphyschem.2021.109368
[16] Kugonza, D.R. and Nabakabya, D., 2008, Honey quality as affected by handling, processing and marketing channels in Uganda. *Tropicultura* **26**(2), 113–118.
[17] Yayinie, M. and Atlabachew, M., 2022, Multi-element analysis of honey from Amhara region-Ethiopia for quality, bioindicator of environmental pollution, and geographical origin discrimination. *Biological Trace Element Research* **200**(12), 1–15. doi: 10.1007/s12011-021-03088-0
[18] Gomes, S., Dias, L.G., Moreira, L.L., Rodrigues, P. and Estevinho, L., 2010, Physicochemical, microbiological and antimicrobial properties of commercial honeys from Portugal. *Food and Chemical Toxicology* **48**(2), 544–548. doi: 10.1016/j.fct.2009.11.029
[19] De Beer, T., Otto, M., Pretoruis, B. and Schönfeldt, H.C., 2021, Monitoring the quality of honey: South African case study. *Food Chemistry* **343**, Article 128527. doi: 10.1016/j.foodchem.2020.128527
[20] Tchoumboue, J., Awah-Ndukum, J., Fonteh, F.A., Dongock, N.D., Pinta, J. and Mvondo, Z. A., 2007, Physico-chemical and microbiological characteristics of honey from the Sudano-Guinean zone of West Cameroon. *African Journal of Biotechnology* **6**(7), 908–913.
[21] Rodrigues, C.D.S., Ferasso, D.C., Prestes, O.D., Zanella, R., Grando, R.C., Treichel, H., Coelho, G.C. and Mossi, A.J., 2018, Quality of Meliponinae honey: Pesticides residues,

pollen identity, and microbiological profiles. *Environmental Quality Management* **27**(4), 39–45. doi: 10.1002/tqem.21547

[22] ESRI, 2013, *ArcGIS Desktop: Release 10.2* (Redlands, CA: Environmental Systems Research Institute).

[23] Tuzen, M. and Soylak, M., 2005, Trace heavy metal levels in microwave digested honey samples from Middle Anatolia, Turkey. *Journal of Food and Drug Analysis* **13**(4), Article 13. doi: 10.38212/2224-6614.2571

[24] Couvillon, M.J., Riddell, P., Accleton, F.C., Fensome, C., Quah, K.A., Taylor, S.K.L., EL and Ratnieks, F.L.W., 2015, Honey bee foraging distance depends on month and forage type. *Apidologie* **46**(1), 61–70. doi: 10.1007/s13592-014-0302-5

[25] Di Bella, G., Potortì, A.G., Beltifa, A., Ben Mansour, H., Nava, V. and Lo Turco, V., 2021, Discrimination of tunisian honey by mineral and trace element chemometrics profiling. *Foods* **10**(4), Article 724. doi: 10.3390/foods10040724

[26] Fakhimzadeh, K. and Lodenius, M., 2000, Honey, pollen and bees as indicator of heavy metal pollution. *Acta Universitas Carolinae Environmentalica* **14**, 13–20.

[27] Oroian, M., Prisacaru, A., Hretcanu, E.C., Stroe, S.-G., Leahu, A. and Buculei, A., 2016, Heavy metals profile in honey as a potential indicator of botanical and geographical origin. *International Journal of Food Properties* **19**(8), 1825–1836. doi: 10.1080/10942912.2015.1107578

[28] Bogdanov, S., Haldimann, M., Luginbuhl, W. and Gallmann, P., 2007, Minerals in honey: Environmental, geographical and botanical aspects. *Journal of Apicultural Research* **46**(4), 269–275. doi: 10.1080/00218839.2007.11101407

[29] Ruschioni, S., Riolo, P., Minuz, R.L., Stefano, M., Cannella, M., Porrini, C. and Isidoro, N., 2013, Biomonitoring with honeybees of heavy metals and pesticides in nature reserves of the Marche Region (Italy). *Biological Trace Element Research* **154**(2), 226–233. doi: 10.1007/s12011-013-9732-6

[30] Costa, A., Veca, M., Barberis, M., Tosti, A., Notaro, G., Nava, S., Lazzari, M., Agazzi, A. and Tangorra, F.M., 2018, Heavy metals on honeybees indicate their concentration in the atmosphere: A proof of concept. *Italian Journal of Animal Science* **18**(1), 309–315. doi: 10.1080/1828051X.2018.1520052

[31] Yeboah-Gyan, K. and Marfo, E.K., 1998, The colour and mineral composition of honeys produced in major vegetation areas of Ghana. *Journal of Apicultural Research* **37**(2), 79–84. doi: 10.1080/00218839.1998.11100958

[32] Santos, J.S.D., Santos, N.S.D., Santos, M.L.P.D., Santos, S.N.D. and Lacerda, J.J.D.J., 2008, Honey classification from semi-arid, Atlantic and transitional forest zones in Bahia, Brazil. *Journal of the Brazilian Chemical Society* **19**(3), 502–508. doi: 10.1590/S0103-50532008000300018

[33] Bartha, S., Taut, I., Goji, G., Vlad, I.A. and Dinulică, F., 2020, Heavy metal content in polyfloralhoney and potential health risk. A case study of Copșa Mică, Romania. *International Journal of Environmental Research and Public Health* **17**(5), Article 1507. doi: 10.3390/ijerph17051507

[34] Conte, P., Del Caro, A., Balestra, F., Piga, A. and Fadda, C., 2018, Bee pollen as a functional ingredient in gluten-free bread: A physical-chemical, technological and sensory approach. *LWT - Food Science & Technology* **90**, 1–7. doi: 10.1016/j.lwt.2017.12.002

[35] Codex Alimentarius Commission, 2001, Revised codex standard for honey. Codex stan 12–1981: Rev. 1 (1987). *Rev* **2** (2001), 1–8.

[36] Joint FAO and WHO Codex Alimentarius Commission, 2019, *Standard for natural mineral water, First edition* (Rome: World Health Organization and Food and Agriculture Organization of the United Nations).

[37] WHO, 2022, Guidelines for drinking-water quality: 4th edition incorporating the first and second addenda. [About 4 screens], Available online at: https://www.who.int/publications/i/item/9789240045064 (accessed 2 May 2023).

[38] Atkinson, S.A., Costello, R. and Donohue, J.M., 2009, Chapter 2-Overview of global dietary calcium and magnesium intakes and allowances. In: J. Cotruvo and J. Bartram (Eds)

Calcium and magnesium in drinking water: Public health significance (Geneva: World Health Organization), pp. 18–36.

[39] WHO, 2000, Chapter 6 - Inorganic pollutants. In: F. Theakston (Ed.) *Air quality guidelines for Europe*, (2nd ed). pp. 170–172. (Copenhagen: World Health Organization, Regional Office for Europe).

[40] European Union, 2020, Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption. *Official Journal of the European Union* **435**, 1–62.

[41] Zergui, A., Boudalia, S. and Joseph, M.L., 2023, Heavy metals in honey and poultry eggs as indicators of environmental pollution and potential risks to human health. *Journal of Food Composition & Analysis* **119**, Article 105255. doi: 10.1016/j.jfca.2023.105255

[42] Ullah, R., Jan, F.A., Gulab, H., Saleem, S., Ullah, N. and Wajidullah, 2022, Metals contents in honey, beeswax and bees and human health risk assessment due to consumption of honey: A case study from selected districts in Khyber Pakhtunkhwa, Pakistan. *Archives of Environmental Contamination and Toxicology* **82**(3), 341–354. doi: 10.1007/s00244-021-00910-7

[43] Scivicco, M., Squillante, J., Velotto, S., Esposito, F., Cirillo, T. and Severino, L., 2022, Dietary exposure to heavy metals through polyfloral honey from Campania region (Italy). *Journal of Food Composition & Analysis* **114**, Article 104748. doi: 10.1016/j.jfca.2022.104748

[44] Ru, Q.-M., Feng, Q. and He, J.-Z., 2013, Risk assessment of heavy metals in honey consumed in Zhejiang province, southeastern China. *Food & Chemical Toxicology* **53**, 256–262. doi: 10.1016/j.fct.2012.12.015

[45] Solayman, M., Islam, M.A., Paul, S., Ali, Y., Khalil, M.I., Alam, N. and Gan, S.H., 2016, Physicochemical properties, minerals, trace elements, and heavy metals in honey of different origins: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety* **15**(1), 219–233. doi: 10.1111/1541-4337.12182

[46] Mesele, T.L., 2021, Review on physico-chemical properties of honey in Eastern Africa. *Journal of Apicultural Research* **60**(1), 33–45. doi: 10.1080/00218839.2020.1754566

[47] Abdulkhaliq, A. and Swaileh, K.M., 2017, Physico-chemical properties of multi-floral honey from the West Bank, Palestine. *International Journal of Food Properties* **20**(2), 447–454. doi: 10.1080/10942912.2016.1166128

[48] Nkansah, M.A., Shamsu–Deen, M. and Opoku, F., 2018, Phytocompounds, heavy metal and mineral contents in honey samples from selected markets in the Kumasi metropolis. *Emerging Science Journal* **2**(5), 287–294. doi: 10.28991/esj-2018-01152

[49] Adugna, E., Hymete, A., Birhanu, G., Ashenef, A., Yildiz, F. and Yildiz, F., 2020, Determination of some heavy metals in honey from different regions of Ethiopia. *Cogent Food & Agriculture* **6**(1), Article 1764182. doi: 10.1080/23311932.2020.1764182