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Evaluation of Heavy Metal Concentrations and Pesticide Residues of Honey Harvested by Beekeepers from Selected Towns in South East Nigeria

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ABSTRACT: This study evaluated heavy metal concentrations and pesticide residues of honey harvested by beekeepers from selected towns in South east Nigeria. Four samples of natural honey harvested by beekeepers in Onitsha, Amizi, Enugu and Awka were used for this study. The Atomic Absorption Spectrophotometer and High Performance Liquid Chromatography were used to determine the levels of heavy metals and pesticide residues respectively. The results showed that Cadmium levels were lowest in Enugu (0.157 mg/kg) and highest in Awka (3.124 mg/kg). The concentration of Zinc was highest in Awka (4.327 mg/kg) and lowest in Enugu (0.151 mg/kg). Iron was not detected in the locations except in Awka (0.065 mg/kg). Awka also recorded the highest concentration of nickel (0.266 mg/kg) while Onitsha had the least (0.014 mg/kg). Chromium level was highest in Onitsha (0.019 mg/kg) while the least in Enugu (0.015 mg/kg). No significant difference was found in all heavy metal concentrations among the four locations, except in zinc and cadmium. Although cadmium and nickel exceeded the permissible limits, zinc, iron, and chromium did not. Significant differences were found in pesticide residue concentrations of honey samples among locations. However, with the exception of 2_4 DDT, aldrin, diazinon, dicophol, g-chlordane, and heptachlor, all concentrations were below the FAO-recommended limit. The areas with the highest densities were Amizi, Onitsha, and Awka. There is need to regularly monitor heavy metal and pesticide residue levels and to raise public awareness about the risks associated with high concentrations of contaminants in honey was highlighted.

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Honeybees can produce honey from plant nectar and serve as agricultural pollinators hence are crucial to ecology and the economy (Cesar, 2017; Khan *et al*., 2017; Cianciosi *et al*., 2018). Honey is the most popular product produced by honeybees because it is a naturally occurring sweetener with nutritional value. (Mejias and Garrido, 2022). The type of plant that honeybees pollinate, together with the climate,

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geography, and species of honeybees affects its quality, composition, flavor, aroma, and color (Oroian *et al*., 2018). Honey's chemical makeup accounts for its many nutritional, therapeutic, and prophylactic qualities (Chandrama *et al.*, 2014). It is made up of several carbohydrates, primarily fructose and glucose, which account for 85–95% of its total sugars. Glucose is less soluble than fructose, and thus, the ratio of glucose to fructose determines whether honey is liquid or not (da Silva *et al*., 2016). When two or more molecules of glucose binds, they form polysaccharides, creating other kinds of sugar. Additionally, honey contains organic acids, amino acids, vitamins, proteins, flavonoid, enzymes and lipids (da Silva *et al*., 2016). According to early Greek, Roman, Vedic, and Islamic literature, honey has long been thought to have positive health effects (Hossen *et al*., 2017). Due to its complex makeup, honey has been effective in treating burns, wounds, skin ulcers, conditions affecting the eyes, and as an antimicrobial agent (Chandrama *et al*., 2014). The chemicals in honey and their quantities determine its purity and origin as well as play a significant role in its medicinal characteristics (Solayman *et al*., 2016; Lekduhur *et al*., 2021). There are two main sources of heavy metals: anthropogenic and natural. Agrochemicals and mineral fertilizers, industrial wastes, sewage sludge, vehicle exhaust, and the mining and metalliferous industries are examples of anthropogenic sources (Jiao *et al*., 2015). Pesticides, which are widely used in agriculture to combat crop diseases and pests, are often dispersed across farming areas before or during cultivation (Tudi *et al*., 2021; Rajveer *et al*., 2019). The excessive use of pesticides and environmental degradation result in pesticide residues frequently contaminating various ecosystems (Barganska *et al*., 2014). Pollutants that honeybees are exposed to can have prolonged effects on their health and potentially impact human health (Zhu *et al*., 2014). A few pesticide residues may find their way into honey when honeybees feed on the nectar of affected plants, thereby lowering the honey's quality (Barganska *et al*., 2014). Variety of detrimental health impacts, ranging from sublethal ones that impair honeybee productivity to major ones that raise colony death, can result from this exposure (Dively *et al.*, 2015).

Agrochemicals have the potential to interfere with honeybee colony coordination and communication, reducing pollination and honey production (Kairo *et al*., 2016). Agrochemicals can also lower the number of live sperm in honeybee drones and disrupts growth, longevity and immune system (Wu-Smart and Spivak, 2016; Kairo *et al*., 2016). Moreover, honey containing pesticide residues reveals a human exposure pathway (Onuwa *et al*., 2017). Heavy metal and pesticide contaminants originating from agricultural sources are extremely difficult issues that need immediate response (Onuwa *et al*., 2017). The heavy metals are absorbed by the honeybee plants through their root systems, travel through their nectar, and then end up in the honey produced by the honeybees (Toma *et al*., 2020). Pollen can carry heavy metals from the atmosphere back to the hive, where they are deposited on the hairy bodies of honeybees (Chandrama *et al*., 2014). Although heavy metals could cause poisoning in the bodies of honeybees, they can still fly great distances in search of food, therefore poisoning may not necessarily result in death except in very high levels (Aljedani, 2017). High concentrations of metals are undesirable and may be harmful to human health due to their known or suspected toxicity (Singh *et al*., 2014). Food contamination is a result of the widespread use of agricultural chemicals like pesticides for disease and pest control (Onuwa *et al*., 2017). If beehives are treated with pesticides before establishing colonies, this could potentially serve as an additional source of contamination and contaminate the honey (Lekduhur *et al*., 2021). Many people utilise honey for several reasons, as food, nutrient needs, and therapeutic purposes therefore, honey contamination may pose serious health risks (Lozowicka, 2013).

Honey is widely consumed and highly valued for its purported health advantages (da Silva *et al*., 2016). On the other hand, worries about heavy metals and pesticide residues in honey have grown. When these pollutants are present in large amounts, consumers will be at risk of some health problems. In order to protect the health of those who consume this natural food, determining the safety of honey is crucial. Pesticide usage in agriculture has risen significantly in recent decades, and can contaminate honey by getting into the nectar and pollen that honeybees gather. Similarly, heavy metals from various environmental sources can accumulate in honeybee colonies (Mullin *et al*. 2010).The aim of this paper was therefore to evaluate the heavy metal concentrations and pesticide residues of honey harvested by beekeepers from selected towns in South East Nigeria.

MATERIALS AND METHODS

Study Area: This study was carried out at the Springboard Research Laboratory in Awka, Anambra State, which is located between 6.2222° N and 7.0818° E in terms of longitude and latitude. It is an east west direction, roughly 5 kilometres north of the equator along the Enugu-Onitsha expressway (Onah *et al*., 2019). Awka serves as the capital of Anambra

State in Nigeria. From an ecological perspective, Awka is located 333 meters above sea level in a valley on the plains of the Mamu River, encircled by tropical rainforest (Ogbuchukwu *et al*., 2019). Awka spans 8 km east-west along the Enugu-Onitsha expressway and roughly 5 km north-south (Abajue and Ewuim, 2020).

Collection of Samples: Four samples of freshly harvested natural honey from beekeepers in Enugu, Onitsha, Amizi, and Awka were collected. The samples were delivered to the Springboard Research Laboratory in Awka for analysis after being kept in clean labeled jars.

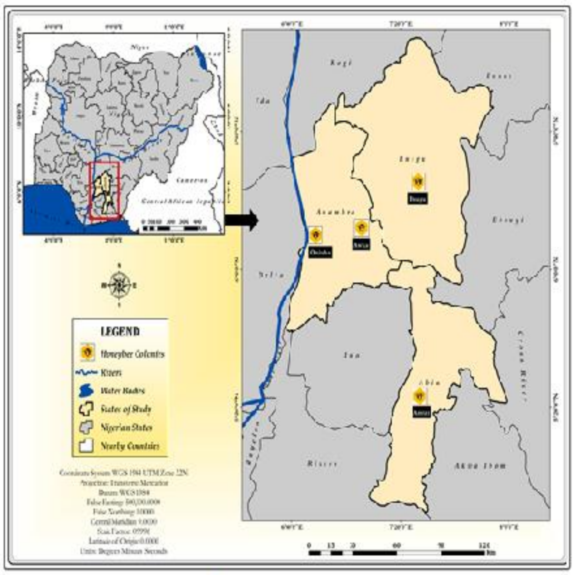

Fig 1. Map of Nigeria showing the Honeybee Colonies
Source: Researcher's Field Work and GIS Mapping, 2024

Procedure for Heavy Metal Analysis

Atomic Absorption Spectrophotometer (AAS) Analysis of Honey for Heavy Metal Content: Using an analytical balance, two grams (2g) each of the honey samples were weighed. The samples were then put into a beaker and mixed with 20ml of aqua regia acid combination (65ml conc. HNO_3, 8ml perchloric acid, and 2ml conc. H_2SO_4). Heat was applied to the flask until a clear digest was obtained. After filtering, the digest was diluted to a 100-milliliter level with distilled water. A reliable company provided a set of standard solutions that were used to calibrate the device. Additionally, five replications of each metal content measurement were carried out. Using an atomic absorption spectrophotometer, the digested honey samples were examined for the presence of heavy metals (Cd, Fe, Ni, Cr, and Zn) (Ševičienė *et al*., 2022; Birhanu, 2015).

The Atomic Absorption Spectrophotometer's (AAS) operating principle: The basic idea behind a spectrophotometer is that when a sample is aspirated into a flame and atomized, the AAS light beam from the monochromator is directed through the flame and onto a detector, which measures the amount of light absorbed by the atomized element in the flame when it is lit. Each metal element has a unique wavelength on the hollow cathode lamp that contains the element or elements that need to be studied. The energy of the characteristic wavelength on the element or metals to be analyzed composed hollow cathode lamp source. The concentration of the element in the tested sample is directly correlated with the amount of energy of the characteristic wavelength absorbed in the flame. The sample is injected into an air-acetylene flame that is oxidizing. The aspiration of the aqueous sample revealed the sensitivity for 1% absorbed.

Pesticides Residue Analysis

Soxhlet extraction of oil from the honey samples: A 250 milliliter (250 ml) round-bottom flask was dried in an oven for 15 minutes at 105 to 110 degrees Celsius. It was then placed in a desiccator and left to cool. The solvent n-hexane was poured into the 240 ml flask. With cotton wool acting as a filter underneath, the weighed sample (20g) was placed into the soxhlet apparatus's thimble. The apparatus was put together on the Soxhlet apparatus's boiling flask, allowed to stand on an electric hot plate set at a temperature between 60 and 75 degrees Celsius, and allowed to reflux roughly four times for five extractions in a row. To extract the extracted oil and separate the n-hexane solvent, the extract from the flask was collected and poured onto a rotatory evaporator set to run between 40 and 60 degrees Celsius. For analysis, the extracted oil was gathered and kept in a container (Toma *et al*., 2020).

Preparation of sample for pesticide residue analysis: After carefully shaking a beaker filled with 20 milliliters of N-hexane and pipetting five millimeters of the oil sample, the mixture was put into a separating funnel and left to stand for thirty minutes. In order to analyze pesticide residue using gas chromatography with flame ionization detection (GC-FID) and store it in a sample vial, the N-hexane layer was gathered (Chai *et al*., 2014).

Quantification with GC-FID: A flame ionization detector-equipped BUCK M910 gas chromatography system was used to analyze the amino acid profile. Utilized was a 15-meter RESTEK MXT-1 column (15 m * 250 u * 0.15 u). With a linear velocity of 30 cm/s and an injector temperature of 280 °C, 2 ul of sample were splitlessly injected at a rate of 40 ml/min using helium as the carrier gas at 5.0 pa.s. After operating at 200 degrees Celsius for five minutes, the temperature of the oven was raised to 330 degrees Celsius at a rate of 3 degrees Celsius per minute. At 320 °C, the detector was in operation. The ratio between the area and mass of the internal standard and the area of the compounds that were identified was used to estimate the components of amino acids. The various amino acid concentrations were given in milligrams per kilogram. When the device is prepared, the appropriate injection technique was used to inject 1 microliter of sample onto column A (Schoňtt *et al*., 2021).

Statistical Analysis: The data on the mean concentration of heavy metals and pesticide residues in the honey collected from different locations was subjected to descriptive statistics and One-way Analysis of Variance (ANOVA) at $p<0.05$ using SPSS version 25 software. The sample means were separated using the Tukey Honestly Significant Difference (HSD) test.

RESULTS AND DISCUSSION

Table 1 revealed the mean concentrations of heavy metals in four samples of honey that were collected from selected towns in South east Nigeria. The result showed that the concentration of cadmium was lowest in Enugu (0.157 mg/kg) and highest in Awka (3.124 mg/kg). Enugu had the lowest zinc concentration (0.151 mg/kg), whereas Awka had the highest (1.611 mg/kg). Iron was not detected in all the locations except in Awka (0.065 mg/kg). Onitsha had the greatest concentration of chromium (0.019 mg/kg), while Enugu had the lowest (0.015 mg/kg). There was no significant variation in the concentrations of iron, nickel, and chromium (P>0.05), however there was a significant difference in the concentrations of zinc and cadmium (P<0.05) among the four locations. Although zinc, iron, and chromium concentrations were significantly (P<0.05) below the recommended limit, the overall mean concentrations of cadmium and nickel were above the FAO/WHO permissible limit.

Table 1: Mean concentrations of heavy metal in honey sampled from four locations

	Mean concentrations of heavy metal in honey (mg/kg)				
Locations	**Cadmium**	**Zinc**	**Iron**	**Nickel**	**Chromium**
Onitsha	$1.336^{a}\pm0.560$	$1.547^{a}\pm0.701$	$0.000^{a}\pm0.000$	$0.014^{a}\pm0.015$	$0.019^{a}\pm0.004$
Amizi	$0.358^{a}\pm0.109$	$0.419^{a}\pm0.122$	$0.000^{a}\pm0.000$	$0.024^{a}\pm0.017$	$0.017^{a}\pm0.023$
Enugu	$0.157^{a}\pm0.035$	$0.151^{a}\pm0.028$	$0.000^{a}\pm0.000$	$0.245^{a}\pm0.298$	$0.015^{a}\pm0.001$
Awka	$3.124^{b}\pm0.648$	$4.327^{b}\pm0.641$e	$0.065^{a}\pm0.048$	$0.266^{a}\pm0.361$	$0.018^{a}\pm0.003$
Total	1.244 ± 1.297	1.611 ± 1.804	0.016 ± 0.035	$0.137^{a}\pm0.218$	$0.017^{a}\pm0.009$
FAO/WHO Limit	0.20	5.0	0.30	0.10	0.10
Remark	Unsatisfactory	Satisfactory	Satisfactory	Unsatisfactory	Satisfactory

Columns sharing similar superscripts are not significantly difference at P>0.05

The result in Figure 2 revealed that the cadmium concentrations in the locations were above the recommended standard by FAO/WHO except in Enugu. Figures 3, 4 and 6 revealed that the concentrations of zinc, iron and chromium respectively were below the recommended standard by FAO/WHO. Figure 5 revealed that the nickel concentrations in the locations were below the recommended standard by FAO/WHO except in Enugu and Awka

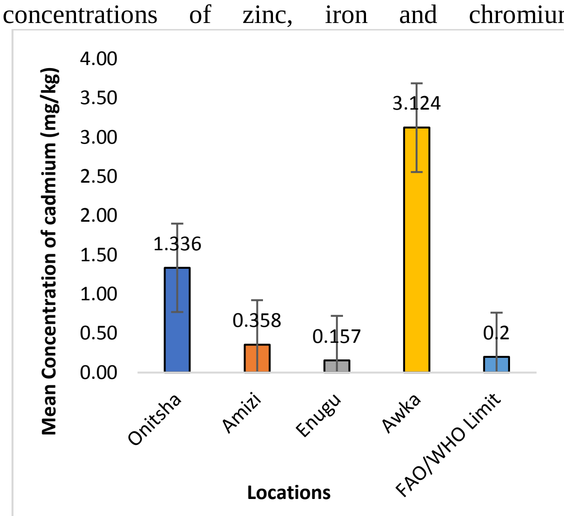

Fig 2: Comparison between mean concentrations of cadmium in the four locations and the FAO/WHO limit

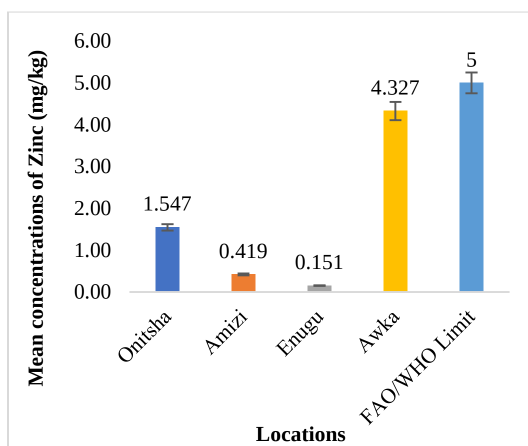

Fig 3: Comparison between mean concentrations of zinc in the four locations and the FAO/WHO limit

Table 2 showed the mean concentrations of pesticide residues in four honey samples collected from selected towns in South east Nigeria. Table 2 revealed that Awka had the highest concentrations of 2_4 DDT (2.455 mg/kg), Aldrin (1.978 mg/kg), Chloropyrifos (1.892 mg/kg), Diazinon (2.241 mg/kg), Dichlorovos (1.386 mg/kg), Endosulfan (2.511 mg/kg), and g-chlordane (0.405 mg/kg), whereas Onitsha had the highest concentrations of Carbaryl (0.138 mg/kg) and Carbofuran (0.116 mg/kg). Dieldrin (0.112 mg/kg) and Heptachlor (0.214 mg/kg) had the highest concentrations in Amizi, whereas Dicophol (0.077 mg/kg) and T-nonachlor (0.044 mg/kg) had the highest concentrations in Enugu and Onitsha, respectively.

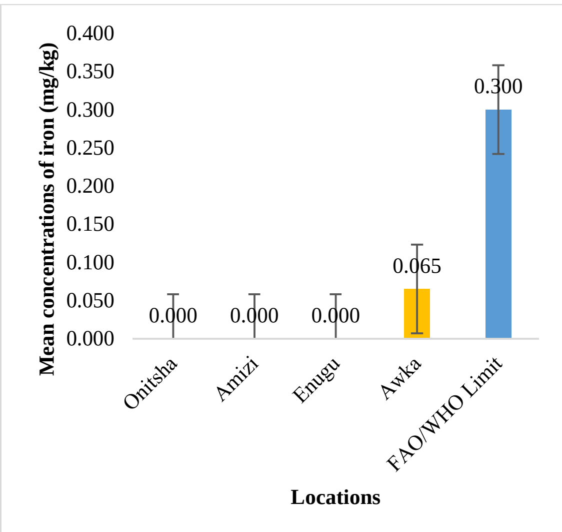

Fig 4: Comparison between mean concentrations of iron in the four locations and the FAO/WHO limit

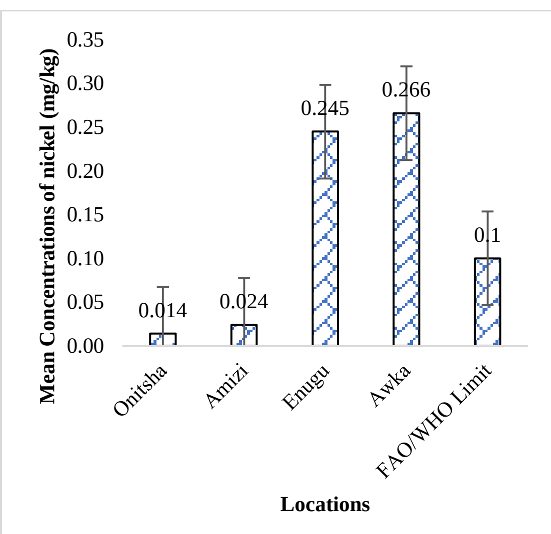

Fig 5: Comparison between mean concentrations of nickel in the four locations and the FAO/WHO limit

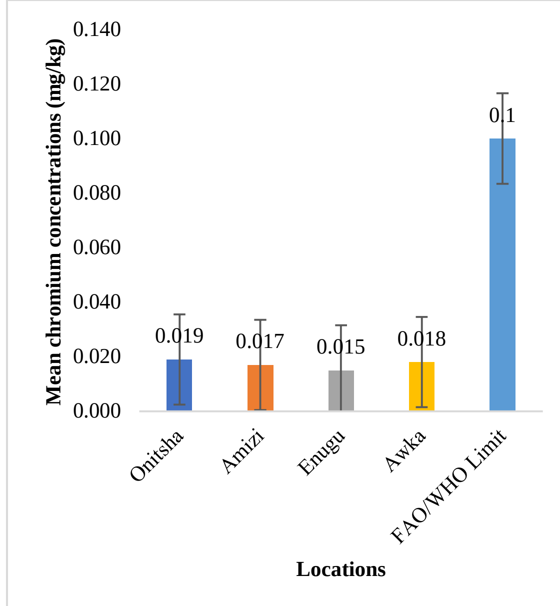

Fig 6: Comparison between mean concentrations of chromium in the four locations and the FAO/WHO limit

With the exception of carbaryl, dicophol, and diedrin (P>0.05), there was statistically a significant difference in the concentrations of the pesticide residue components recovered from the honey samples in the different sites. Table 2 also demonstrated that, with the exception of 2_4 DDT, aldrin, diazinon, dicophol, g-chlordane, and heptachlor, all concentrations of the different pesticide residual components were below the FAO-recommended limit. The result of this study revealed that iron was not detected in all locations except Awka (0.065 mg/kg). This could be attributed to the fact that Awka might have an underlying geology rich in iron-bearing rocks that releases iron into the soil and water through weathering. This could be the cause of the high mean concentration of iron in the area. The large concentration of manufacturing, mining, and other related businesses in Awka may be linked to the city's high mean concentration of iron. These industries may raise iron levels through runoff, waste disposal, and emissions. Awka's high iron concentration may be explained by human activities like construction and trash disposal, which can destabilize the soil and release iron into the environment. Nimyel *et al.* (2015) earlier stated that iron is one of the common elements on Earth which can be obtained by burning or disposing of garbage. The iron concentration (136 to 407 mg/kg) reported in the work by Adebiyi *et al.* (2004) was significantly higher than the values obtained in this study indicating that the honey sampled in Awka was not very rich in iron. On the other hand, Kebebe *et al.* (2019) also reported that higher mean concentration of iron (4.87 to 11.79 µg/g) than those obtained from this study. The outcomes of this investigation, however, disagreed with those of Kebebe *et al.* (2019), who found a statistically significant variation in the iron levels in honey.

Table 2: Pesticide residue in honey samples collected from four locations in Southeastern Nigeria

Pesticide Residues	**Mean Concentration (in mg/kg) of Pesticide residues per locations ±SD**				**Total**	**FAO limit**	**Remark**
	Onitsha	**Amizi**	**Enugu**	**Awka**			
2_4 DDT	$0.003^{a}\pm0.002$	$0.534^{a}\pm0.004$	$0.491^{a}\pm0.061$	$2.455^{b}\pm0.599$	0.871±1.028	0.01	Unsatisfactory
Aldrin	$0.023^{a}\pm0.004$	$0.024^{a}\pm0.001$	$0.023^{a}\pm0.004$	$1.978^{b}\pm0.077$	0.512±0.905	0.20	Unsatisfactory
Carbaryl	$0.138^{a}\pm0.001$	$0.000^{a}\pm0.000$	$0.000^{a}\pm0.000$	$0.000^{a}\pm0.000$	0.034±0.064	0.05	Satisfactory
Carbofuran	$0.116^{b}\pm0.001$	$0.003^{a}\pm0.002$	$0.003^{a}\pm0.003$	$0.000^{a}\pm0.000$	0.03±0.053	0.05	Satisfactory
Chloropyrifos	$0.000^{a}\pm0.000$	$0.204^{a}\pm0.002$	$0.322^{a}\pm0.002$	$1.892^{b}\pm0.262$	0.605±0.81	1.0	Satisfactory
Diazinon	$0.000^{a}\pm0.000$	$0.031^{a}\pm0.000$	$0.000^{a}\pm0.000$	$2.241^{b}\pm0.296$	0.568±1.039	0.02	Unsatisfactory
Dichlorovos	$0.128^{a}\pm0.001$	$0.331^{b}\pm0.000$	$0.363^{c}\pm0.002$	$1.386^{d}\pm0.003$	0.552±0.524	0.10	Unsatisfactory
Dicophol	$0.000^{a}\pm0.000$	$0.000^{a}\pm0.000$	$0.077^{a}\pm0.048$	$0.000^{a}\pm0.000$	0.019±0.04	0.01	Unsatisfactory
Dieldrin	$0.02^{a}\pm0.001$	$0.112^{a}\pm0.001$	$0.057^{a}\pm0.075$	$0.000^{a}\pm0.000$	0.047±0.054	0.2	Satisfactory
Endosulfan	$0.021^{a}\pm0.001$	$0.11^{a}\pm0.003$	$0.216^{a}\pm0.002$	$2.511^{b}\pm0.679$	0.714±1.141	5.0	Satisfactory
g-chlordane	$0.206^{b}\pm0.001$	$0.000^{a}\pm0.000$	$0.000^{a}\pm0.000$	$0.405^{c}\pm0.09$	0.153±0.183	0.1	Unsatisfactory
Heptachlor	$0.000^{a}\pm0.000$	$0.214^{b}\pm0.001$	$0.000^{a}\pm0.000$	$0.000^{a}\pm0.000$	0.053±0.099	0.01	Unsatisfactory
T-nonachlor	$0.011^{b}\pm0.001$	$0.000^{a}\pm0.000$	$0.044^{c}\pm0.002$	$0.000^{a}\pm0.000$	0.014±0.019	0.04	Satisfactory

Rows sharing similar superscripts are not significantly different at P>0.05

In every location sampled, the chromium level in honey was below the permissible limit. This might be because the honeybees' feeding sites have little sources of the metal. In small levels, chromium is a necessary dietary requirement, and a lack of it can cause problems with the metabolism of glucose. On the other hand, chromium is said to cause cancer. As a result, consuming too much of this metal is harmful to human health (Shekhawat *et al.*, 2015). The amounts of chromium found in this study were reported to be 0.015-0.019 mg/kg. Honey analyzed in a few Indian study locations where greater levels of chromium pollution than those reported in this study were noted are as follows: Belgaum (0.14 ppm), Ajjampura (0.14 mg/kg), and Devanahalli (0.12 mg/kg) (Gunat *et al.*, 2021). The findings of this study are consistent with those of Singh *et al.* (2014), who stated that the concentration (mg/kg) was within the range of 0.11-0.09. There were also no significant differences in the results obtained and the mean concentration of chromium in this study was also lower than that of Kebebe *et al.* (2019), who reported a high mean concentration of chromium ranging from 0.16 to 0.50 mg/kg in samples of honey examined in Walmara, where its concentrations in the samples were also not statistically significant (P>0.05).

The nickel mean concentrations in this study varied from 0.014 to 0.266 mg/kg. This finding was different from that of Dalal *et al.* (2017), who reported that almost all samples collected in Saudi Arabia's regions had no nickel at all. The exception to this was the Al-Baha area, where nickel was found at a very little concentration (0.037 ± 0.001 mg/kg), which was lower than that of this study. The study's highest Ni content was discovered in Awka. This may be related to the city's use of diesel and gasoline as well as trash from both industrial and municipal sources. Zinc values varied from 0.151 mg/kg to 4.327 mg/kg for all honey samples. The lowest in Amizi was 0.419 mg/kg, whilst the maximum value recorded in Awka was 4.327 mg/kg. It's interesting to notice that the amount of this metal decreased significantly in other locations. It is worthy to note that industry and agriculture are the main causes of harmful metal contamination in honey (Kędzierska-Matysek *et al.,* 2022). The findings of this investigation were different from those of Kędzierska-Matysek *et al.* (2022), who stated that the mean zinc concentration ranged from (2.694 mg/kg - 0.65 mg/kg) and that the honey variety had no effect on the Zn level.

Cadmium concentrations ranged from 0.157 mg/kg in Enugu to 3.124 mg/kg in Awka. The reason why cadmium levels were highest in Awka may be related to the presence of several major roads, which are homes to piles of rusted metal from wrecked cars and may have contaminated the honey with this element. In comparison to Singh *et al.* (2014), who found cadmium in honey within the same range (0.76 - 0.005 mg·kg−1), the results of this study were higher. The results of this study were also less than those of Ahmida *et al.* (2013), who reported values of 0.02 to 0.06 mg/kg of cadmium. The mean concentration of cadmium obtained in this study was higher than that of Kebebe *et al.* (2019) who reported that there was no significant difference from all the sites and the mean content of cadmium in honey samples from Ethiopia range from 0.04 to 0.70 mg/kg. Cadmium does not naturally occur in the ecosystem in such large quantities, thus the fact that honey had incredibly high levels of the metal is a proof that there is a real pollution problem. Renal and hepatic failure, lung cancer, testicular damage, pulmonary edoema, and bone demineralization can be triggered by high levels of cadmium. It enters the food chain when plants absorb it from contaminated soil or water, and it is discharged into the environment through its use in a variety of industrial activities (Tinkov *et al.,* 2018). Awka had the highest levels of dichlorovos (1.386 mg/kg), 2_4 DDT (2.455 mg/kg), g-chlordane (0.405 mg/kg), aldrin (1.978 mg/kg), chloropyrifos (1.892 mg/kg), diazinon (2.241 mg/kg), and endosulfan (2.511 mg/kg). The primary cause of the dichlorvos-methyl chlorpyrifos that was found was agricultural application. This chemical may be present in Awka since apiaries are situated close to farms that use a lot of these pesticides. The amount of Aldrin found in this investigation was more than that found by Toma *et al.* (2020), who reported Aldrin in all the villages (Dulwarchira, Gada, Gurum, Kwaja, and Muva), with Gurum recording the highest value (0.021 ± 0.03). Nazia *et al.* (2018) also reported dichlorvos levels in Pakistan ranging from 7.0 to 9.40 mg/kg, which was higher than that detected in this study. The average concentrations of chlorpyrifos (17.8 mg kg^{-1}) and dieldrin (12.7 mg kg^{-1}) which were above Codex Alimentarius permissible limits as reported by Nazia *et al.* (2018) was higher than the results obtained from this study.

Conclusion: The findings of this study showed that zinc, iron and chromium were within the FAO/WHO permitted level but cadmium and nickel reported high concentrations that were above the maximum permissible limits. The study also showed that the concentration of the heavy metals followed the decreasing order: Zn > Cd > Ni > Cr > Fe. Pesticide residues such as chlorpyrifos, endosulfan, carbaryl, carbofuran, dieldrin and t-nonachlor were below permissible limit while diazinon, 2_4 DDT, aldrin, dicophol, g-chlordane heptachlor, and dichlorvos were above the permissible limit. Based on the presence of heavy metal and pesticide residues in honey noted in this study, there is need to regularly monitor environmental contamination in the study locations and also enlighten honey consumers and beekeepers on the possible risks associated with such pollutants.

Declaration of Conflict of Interest: The authors declare no conflict of interest.

Data Availability: Data are available upon request from the corresponding author.

REFERENCES

Abajue, MC; Ewuim, SC (2020). Evaluation of Activities of Dipteran Maggots on a Poisoned Pig Cadaver at Nnamdi Azikiwe University Awka Nigeria. *Egypt J. Forensic Sci.* 10, 33 (2020). DOI: https://doi.org/10.1186/s41935-020-00208-0

Adebiyi, FM; Akpan, I; Obiajunwa, EI; Olaniyi, HB (2004). Chemical/Physical Characterization of Nigerian Honey. *Pak. J. Nutr.* 3:278-281. DOI: 10.3923/pjn.2004.278.281

Ahmida, MHS; Elwefali, S, Agba, A, Elagori, M and Ahmida, NHS (2013). Physiochemical, Honey Metals and Phenolic Compounds Analysis of Libyan Honey Samples Collected from Benghazi during 2009-2010. *Food Nutr. Sci.*, 4:33-40. DOI: http://dx.doi.org/10.4236/fns.2013.41006

Aljedani, DM (2017). Effects of Abamectin and Deltamethrin to the Forager's Honeybee Workers of *Apis mellifera jemenatica* (Hymenoptera: Apidae) Under Laboratory Conditions. *Saudi J. Biol. Sci.,* 24(5): 1007–1015. DOI: https://doi.org/10.1016/j.sjbs.2016.12.007

Barganska, Z; Slebioda, M; Namiesnik, J (2014). Pesticides residues level in honey from apiaries located off Northern Poland. *Food Control,* 31: 196-201. DOI: doi.org/10.1016/j.foodcont.2012.09.049

Cesar, V, Vıctor, MA, Octavio, G, Luz, MS and Jose,́ AD (2017). Agricultural pesticide residues in honey and wax combs from Southeastern, Central and Northeastern Mexico. *J. Apic. Res.,* 56(5): 667–679. DOI: https://doi.org/10.1080/00218839.2017.1340798

Chai, LK, Elie, F; Jinang, C. (2014). Determination of 24 pesticides residues in mineral and peat soils by modified QuEChERS method and gas chromatography. *Int. J. Environ. Anal. Chem*, 94(5): 519-530. DOI: https://doi.org/10.1080/03067319.2013.871713

Chandrama, S, Shabiana, K, Bharathi, A, Hemant, L, Min, HY, Mahmoud, AE; Ikhlas, AK (2014). Assessment of Total Phenolic and Flavonoid Content, Antioxidant Properties, and Yield of Aeroponically and Conventionally Grown Leafy Vegetables and Fruit Crops: A Comparative Study. *eCAM,* (4):253875. DOI: https://doi.org/10.1155/2014/253875

Singh, C, Shubharani, R and Sivaram, V (2014) Assessment of Heavy Metals in Honey by Atomic Absorption Spectrometer. *WJPPS.* 3(8): 509-515. https://core.ac.uk/download/pdf/72803874.pdf

Cianciosi, D, Forbes-Hernández, TY, Afrin, S, Gasparrini, M, Reboredo-Rodriguez, P, Manna, P P, Zhang, J, Lamas, LB, Flórez, SM; Toyos, PA (2018). Phenolic Compounds in Honey and Their Associated Health Benefits: A Review. *Molecules,* 23: 23-22. https://doi.org/10.3390/molecules23092322

Dalal, MA (2017). Determination of Some Heavy Metals and Elements in Honeybee and Honey Samples from Saudi Arabia. *Entomol. Appl. Sci. Lett*., 4 (3):1-11. https://easletters.com/article/1ina-determination-of-some-heavy-metals-and-elements-in-honeybee-and-honey-samples-from-saudi-arabia

Dively, GP, Embrey, MS, Kamel, A; Hawthorne, DJ; Pettis, JS. (2015). Assessment of chronic sublethal effects of imidacloprid on honey bee colony health. *PloS One,* 10(3): e0118748. DOI: https://doi.org/10.1371/journal.pone.0118748

Gunat, JL, Peter, OO, Ishaq, SE; Sha'Ato, R (2021). Analysis of Selected Pesticide Residues and Heavy Metals in Honey Obtained from Plateau State, Nigeria. *JASMI* 11:1-13. https://doi.org/10.1371/journal.pone.0118748

Hossen, MS; Ali, MY; Jahurul, MHA, Abdel-Daim, MM, Gan, SH; Khalil, MI (2017). Beneficial roles of honey polyphenols against some human degenerative diseases: A review. *Pharm. Rep.* 69: 1194–1205. https://doi.org/10.1016/j.pharep.2017.07.002

Jiao, L; Liu, X (2015). Structural Basis of Histone H3k27 Trimethylation by An Active Polycomb Repressive Complex 2, *Science,* 350(6258):aac4383. DOI: https://doi.org/10.1126/science.aac4383

Kairo, G, Provost, B, Tchamitchian, S, Ben Abdelkader, F, Bonnet, M, Cousin, M., Sénéchal, J., Benet, P., Kretzschmar, A., Belzunces, L. P. and Brunet, J. (2016). Drone exposure to the systemic insecticide Fipronil indirectly impairs queen reproductive potential. *Sci. Rep., 6*: e1400253. DOI: https://doi.org/10.1038/srep31904

Kebebe, D, Paulos, A; Haile, E (2019). Determination of Physicochemical Properties, Heavy Metals and Pesticide Residues of Honey Samples Collected from Walmara, Ethiopia. *IJARCS*, 6: 23-33. DOI: http://dx.doi.org/10.20431/2349-0403.0607004

Kędzierska-Matysek, M; Teter, A; Skałecki, P; Topyła, B; Domaradzki, P; Poleszak, E; Florek, M. (2022). Residues of Pesticides and Heavy Metals in Polish Varietal Honey. *Foods (Basel, Switzerland)*, 11(15):2362. DOI: https://doi.org/10.3390/foods11152362

Khan, RU; Naz, S; Abudabos, AM (2017). Towards a Better Understanding of the Therapeutic Applications and Corresponding Mechanisms of Action of Honey. *Environ. Sci. Pollut. Res, 24*: 27755–27766. DOI: https://doi.org/10.1007/s11356-017-0567-0

Lekduhur, GJ; Onuwa, PO; Eneji, IS; Rufus, S (2021). Analysis of Selected Pesticide Residues and Heavy Metals in Honey Obtained from Plateau State, Nigeria. *JASMI,* 11: 1-13. DOI: 10.4236/jasmi.2021.111001

Lozowicka, B (2013). The Development, Validation and Application of a GC-Dual Detector (NPD-ECD) Multi-Pesticide Residue Method for Monitoring Bee Poisoning Incidents. *Ecotoxicol. Environ. Saf.,* 97: 210-222. DOI: https://doi.org/10.1016/j.ecoenv.2013.07.010

Mejias, E; Garrido, T (2022). Determination of Pesticides Residues in Bee Products: An Overview of the Current Analytical Methods. *IntechOpen*. DOI: 10.5772/intechopen.102541

da Silva, PM; Gauche, C; Gonzaga, LV; Oliveira-Costa, AC (2016). Honey: Chemical composition, stability and authenticity. *Food Chem.,* 196: 309-323. DOI: https://doi.org/10.1016/j.foodchem.2015.09.051

Mullin, CA; Frazier, M; Frazier, JL; Ashcraft, S, Simonds, R; VanEngelsdorp, D; Pettis, JS. (2010). High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health. *PloS one*, 5(3):e9754. DOI: https://doi.org/10.1371/journal.pone.0009754

Nazia, R; Sehrish, N; Sumaira, A; Karam, A; Afshan, G; Surriya, T; Abbasi, I; Ahmed, KR (2018). Screening of Multiclass Pesticide Residues in

Honey by SPE-GC/MSD: a pilot study. *EMA,* 190:666. DOI: 10.1007/s10661-018-7041-4

Nega, A; Mulugeta, E; Abebaw, A (2020). Physicochemical Analysis and Determination of the Levels of Some Heavy Metals in Honey Samples Collected from Three District Area of East Gojjam Zone of Amhara Region, Ethiopia. *J. Agric. Food Res.*, 11: 260-279. DOI: 10.35248/2593-9173.20.11.279

Nimyel, ND; Egila, JN; Lohdip, YN (2015). The Seasonal Variation of Heavy Metals at Three Dumpsites in Plateau State, Nigeria. *Afr. J. Biol. Sci.*, 18:57-67. DOI: 10.9734/IRJPAC/2015/14179

Ogbuchukwu, PO; Okeke, OC; Ahiarakwem, CA; Ozotta, OO (2019). Geotechnical properties of expansive soils in Awka and environs, Southeastern Nigeria, in relation to engineering problems. *International J. Appl. Sci. Res.*, 2(4): 79-94.

Onah, JC; Obasi, BMP; Ebubechukwu, MS; Onyema, IE (2019). Determination of heavy metals in palmwine from Nsude in Udi Local Government Area, Enugu State, Nigeria. *J. Biol. Chem. Pharm.*, 3(1): 1-4.

Onuwa, PO; Eneji, IS; Itodo, AU; Sha'Ato, R (2017). Determination of Pesticide Residues in Edible Crops and Soil from University of Agriculture Makurdi Farm Nigeria. *Asian J. Phy Chem. Sci.,* 3: 1-17. DOI: 10.9734/AJOPACS/2017/35001

Oroian, M; Ropciuc, S; Paduret, S (2018). Honey authentication using rheological and physicochemical properties. *J. Food Sci. Tech.,* 55(12): 4711-4718. DOI: https://doi.org/10.1007/s13197-018-3415-4

Rajveer, K; Gurjot, KM; Shweta, R; Injeela, K (2019). Pesticides Classification and its Impact on Environment. *Intl. J Curr. Microb. Appl. Sci.,* 8(3):1889-1897. DOI: https://doi.org/10.20546/ijcmas.2019.803.224

Šerevičienė, V; Zigmontienė, A; Paliulis, D (2022). Heavy metals in honey collected from contaminated locations: a case of Lithuania. *Sustainability*, 14(15): 9196. DOI: https://doi.org/10.3390/su14159196

Shekhawat, K; Chatterjee, S; Joshi, B (2015). Chromium Toxicity and Its Health Hazards. *Intl. J. Adv. Res.*, 3:167-172.

Singh, C; Shubharani, R; Sivaram, V (2014). Assessment of Heavy Metals in Honey by Atomic Absorption Spectrometer. *WJPSS*, 3:509-515.

Solayman, MD; Asiful Islam, MD; Paul, S; YousufAli, MD; Khalil, I; Alam, N; Hua Gan, S (2016) Physicochemical Properties, Minerals, Trace Elements, and Heavy Metals in Honey of Different Origins: A Comprehensive Review. *Compr. Rev. Food Sci. Food Saf.,* 15: 219-233. DOI: https://doi.org/10.1111/1541-4337.12182

Tinkov, AA; Filippini, T; Ajsuvakovae, OP; Skalnaya, MG; Aasethf, J; Bjørklundh, G; Gatiatulinai, ER, Popova, EV; Nemereshinai, ON; Huangk, PT; Vinceti, M; Skalny, AV (2018). Cadmium and atherosclerosis: A review of toxicological mechanisms and a meta-analysis of epidemiologic studies. *Environ. Res.,* 162: 240–260. DOI: https://doi.org/10.1016/j.envres.2018.01.008

Toma, I; Jefferson, JN; Clifford, LB; Mofio, BM (2020). Assessment of Heavy Metals and Pesticide Residues in Honey Samples Collected from Selected Villages in Five Local Government Areas of Adamawa State, Nigeria. *IJSRP*, 10:9. DOI: http://dx.doi.org/10.29322/IJSRP.10.09.2020.p10547

Tudi, M; DanielRuan, H; Wang, L; Lyu, J; Sadler, R; Connell, D; Chu, C; Phung, DT; (2021). Agriculture development, pesticide application and its impact on the environment. *Int. J. Environ. Res. Public Health,* 18(3): 1-23. DOI: https://doi.org/10.3390/ijerph18031112

Wu-Smart, J; Spivak, M (2016). Sub-lethal effects of dietary neonicotinoid insecticide exposure on honey bee queen fecundity and colony development. *Sci. Rep.,* 6: 1-1. DOI: https://doi.org/10.1038/srep32108

Zhu, W; Schmehl, DR; Mullin, CA; Frazier, JL (2014). Four common pesticides, their mixtures and a formulation solvent in the hive environment have high oral toxicity to honey bee larvae. *PLoS ONE,* 9: e77547. DOI: https://doi.org/10.1371/journal.pone.0077547