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Potentially Toxic Elements Concentrations and Associated Health Risks in Chicken Edible Body Parts from Gombe main Market, Gombe State, Nigeria

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Abstract- Chicken meat and edible offal are valuable sources of protein and micronutrients; however, they can accumulate potentially toxic elements (PTEs) from feed, water, litter, and the surrounding environment. In this study measured Pb, Cd, As, Cu, Ni, Mn, and Co in broiler and free-range chicken liver, gizzard and flesh from Gombe main Market, Gombe State, Nigeria, using atomic absorption spectrometry. Concentrations were highest in the liver and lowest in the flesh, following a clear liver >gizzard >flesh gradient for all elements. Free-range chickens were consistently more contaminated than broilers. One-way ANOVA showed significant differences among organs for all seven elements ($p<0.001$). Pearson's correlation analysis revealed two consistent element groups; Cu, Ni, Mn, and Co (feed-supplement signature) and Pb, Cd, and As (anthropogenic sources), while principal component analysis retained two components explaining 95.8% of the variance and clustering similar pattern, grouping broiler flesh as least contaminated and free-range liver/gizzard as highest risk. The estimated daily intakes were highest in children and remained below the provisional tolerable daily intakes, but the hazard index exceeded permissible limit in all age groups (HI >1), with Co, Cd, and Ni the main contributors. The incremental lifetime cancer risk values (2.2×10^{-6} to 37.9×10^{-6}) were within the negligible threshold. Overall, the consumption of chicken from the study area particularly free-range liver and gizzard, by children may contribute to PTE exposure and associated health risks. Strengthened monitoring of feed, water, and litter, together with risk management strategies and confirmation with larger sample sizes, is recommended.

Keywords: Chicken, PTEs, Incremental lifetime cancer risk, Hazard index, , Health risk

I. INTRODUCTION

Poultry meat, particularly chicken, holds a prominent place in global diets and is frequently prepared as meat through various culinary methods, as meat, and incorporation into processed foods. Beyond the muscle tissue, secondary edible organs such as the liver and gizzard are widely incorporated into human diets, a practice especially prevalent in developing nations (Kia et al. 2024). Chicken is highly regarded for its nutritional profile, providing essential amino acids, vitamins, minerals, vital trace elements, and antioxidants that are crucial for human growth and development, particularly in low-income regions (Kamaly and Sharkawy, 2023). Furthermore, chicken offers a cost-effective and highly digestible protein source, making it a staple for economically disadvantaged families (Molaee-aghaee et al. 2020).

The global poultry sector has expanded significantly due to its products widespread acceptance, affordability, and digestibility of its products. However, the accumulation of PTEs in poultry feed poses a serious threat to animal health, reproductive success, and overall productivity, ultimately compromising food safety (Peng et al., 2018). Chemical contamination has emerged as a primary public health concern in an era where consumer demand for safe, premium-quality food is rising. The issue of PTEs in meat and meat products has garnered increasing scientific scrutiny in recent years (Han et al. 2022; Njoga et al. 2021; Scutarașu and Trinca, 2023; Han et al. 2023).

The growing contamination of food and animal feed by PTEs is largely driven by anthropogenic activities within the industrial and agricultural sectors. Poultry are highly susceptible to PTE exposure through contaminated water, feed, and bedding materials, which directly

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threatens the safety of their meat and by-products (Kamaly and Sharkawy, 2023). These contaminants often originate from industrial processes that eventually leach into the food chain (Mitra et al., 2022). PTE exposure to a myriad of severe health conditions, including gastrointestinal, pulmonary, and hepatic cancers, genetic mutations, immune dysfunction, cognitive impairments, congenital disabilities, organ degeneration, and even vision loss (Chen et al. 2024; Alashwal et al. 2024; Zhang et al. 2022; Gibb et al. 2020; Flora et al. 2020). Acute symptoms of heavy metal toxicity typically manifest as headaches, gastrointestinal distress, nausea, abdominal cramping, and stomach swelling (Kia et al., 2024; Pappuswamy et al., 2021).

Numerous studies have documented alarming concentrations of PTEs in China, the Middle East, Africa, and Nigeria, posing varying degrees of health risks to livestock and consumers (Okoye et al., 2011; Al-Bratty et al., 2022; Liu et al., 2013; Liman et al., 2025; Akan et al., 2010). Despite this, research focusing on PTE levels in chicken meat and offal available in Gombe markets remains scarce. Therefore, the continuous monitoring of these food items is imperative. This study was designed to quantify the concentrations of specific PTEs (Mn, Cr, As, Cd, Fe, Cu, Pb, Ni, and Co) and evaluate the health risks associated with the consumption of chicken meat, liver, and gizzard sourced from the main market, Gombe State, Nigeria.

II. MATERIALS AND METHODS

1. Sample collection

A total of 60 samples comprising chicken meat (n = 20), liver (n = 20), and gizzard (n = 20) were procured from poultry vendors at Gombe main market. Samples were labeled, transported to the laboratory in their original packaging and stored at 18 °C until extraction and PTE analysis.

Sample preparation

All analytical grade reagents and standards (Merck, Darmstadt, Germany) were used. The glassware was rinsed with water and detergent, soaked in 65% nitric acid for 24 h, and rinsed with distilled water. For digestion, 4 g of each tissue was combined with 10 mL of 65% nitric acid and heated at 135 °C for 15 min. Subsequently, 2 mL of 35% hydrogen peroxide and 1 mL of 70% perchloric acid were added, followed by heating at 135 °C for 80 min. Yhe digests were filtered through Whatman No. 42 paper and diluted to 25 mL with 1 M nitric acid.

2. Sample analysis

The quantification of Mn, Cr, As, Cd, Fe, Cu, Pb, Ni, and Co was performed by atomic absorption spectrometry. In this present laboratory sheet, Pb, Cd, As, Cu, Ni, Mn and Co were determined by atomic absorption spectrometry (AAS, Buck Scientific 205), with the values below the detection limit (BDL) recorded as zero. Standard element solutions (100, 500 and 1000 µg/kg) were prepared by dilution in distilled water. Spiking involved the addition of 1 mL of the multi element standard to 1 g of sample, followed by the standard digestion process.

3. Statistical analysis

The data were processed using SPSS (version 25). One way analysis of variance (ANOVA) was used to determine significant variations in element concentrations among organs and production systems. Pearson correlation, principal component analysis (PCA) and hierarchical cluster analysis were used to discern contamination patterns, and identify potential sources and group variables according to their origins and similarities. Values are expressed as mean ± standard deviation (SD).

4. Health risk assessment

Estimated daily intake (EDI); EDI (µg/kg bw/day) = (MC × FIR)/BW, where MC is the metal concentration in the tissue (µg/kg), FIR is the food ingestion rate (g/day) and BW is body weight (kg) (Eq. 1).

Target hazard quotient (THQ) and hazard index (HI); $THQ = (EDI/RfD) \times 10^{-3}$ (Eq. 2), where RfD is the oral reference dose. HI = ΣTHQ (Eq. 3). A THQ or HI > 1 indicates a potential for adverse non carcinogenic effects; values < 1 suggest no noticeable harmful effects.

Carcinogenic risk (CR); CR = EDI × CSF (Eq. 4), where CSF is the carcinogenic slope factor for oral exposure. A CR below 10^{-6} is considered negligible, 10^{-6}–10^{-4} acceptable/tolerable and above 10^{-4} unacceptable.

III. RESULTS AND DISCUSSION

Concentrations of PTEs in chicken organs

Table 1 presents the mean concentrations of PTEs in broiler and free range chicken organs. For broilers, liver concentrations (mg/kg) were Pb 0.033 ± 0.002, Cd 0.025 ± 0.005, As 0.014 ± 0.0004, Cu 4.20 ± 0.12, Ni 0.636 ± 0.035, Mn 0.180 ± 0.012 and Co 0.084 ± 0.004; gizzard concentrations were consistently lower (Pb 0.012 ± 0.001, Cd 0.008 ± 0.001, As BDL, Cu 1.21 ± 0.13, Ni 0.203 ± 0.045, Mn 0.063 ± 0.002, Co 0.033 ± 0.003), and flesh was the least contaminated tissue (Pb, Cd, and As BDL; Cu 0.52 ± 0.002, Ni 0.072 ± 0.001, Mn 0.053 ± 0.001, Co 0.0063 ± 0.0003). For free range chickens, liver concentrations were markedly higher (Pb 0.288, Cd 0.107, As 0.137, Cu 8.49, Ni 1.99, Mn 0.870, Co 0.268 mg/kg), followed by gizzard (Pb 0.057, Cd 0.021, As 0.079, Cu 6.69, Ni 0.195, Mn 0.351, Co 0.063 mg/kg) and flesh (Pb 0.017, Cd BDL, As 0.0045, Cu 4.01, Ni 0.006, Mn 0.071, Co 0.005 mg/kg).

Table 1: Mean ± SD concentrations (mg/kg) of PTEs in broiler and free range chicken organs

Chicken	Organ	Pb	Cd	As	Cu	Ni	Mn	Co
Broiler	Liver	0.033 ± 0.002	0.025 ± 0.005	0.014 ± 0.004	4.203 ± 0.115	0.636 ± 0.035	0.180 ± 0.012	0.084 ± 0.004
Broiler	Gizzard	0.012 ± 0.0007	0.008 ± 0.001	0.000 ± 0.000	1.213 ± 0.130	0.203 ± 0.045	0.063 ± 0.002	0.033 ± 0.003
Broiler	Flesh	0.000 ± 0.000	0.000 ± 0.000	0.000 ± 0.000	0.523 ± 0.002	0.072 ± 0.001	0.053 ± 0.001	0.0063± 0.0003
Free-range	Liver	0.288±	0.107 ±	0.137 ±	8.491 ±	1.987 ±	0.870 ±	0.268 ±
Free-range	Gizzard	0.057 ± 0.002	0.021 ± 0.001	0.079 ± 0.003	6.690 ± 0.327	0.195 ± 0.005	0.351 ± 0.011	0.063 ± 0.002
Free-range	Flesh	0.017 ± 0.001	0.000 ± 0.000	0.005 ± 0.004	4.010 ± 0.259	0.006 ± 0.003	0.071 ± 0.002	0.005 ± 0.003

The consistent tissue gradient liver > gizzard > flesh was observed for all seven elements, reflecting the physiological role of the liver in the uptake, metabolism, and storage of toxic elements (Li et al. 2025), the mechanical grinding of grit and soil in the gizzard, and the relatively poor muscle accumulation capacity. The free range chickens were consistently more contaminated than broilers: liver Cu was approximately 8.22 to 8.76 and 4.20 mg/kg, Ni 1.83 to 2.15 and 0.64 mg/kg, Pb 0.18 to 0.39 and 0.03 mg/kg and As 0.13 to 0.14 and 0.014 mg/kg. This is the classic source of soil/dust ingestion and outdoor foraging in free range birds, and it is consistent with the multiple environmental pathways (soil, water, litter, and feed) identified by Keutchatang et al. (2023). Cu was by far the dominant element (0.52 to 8.76 mg/kg), followed by Ni, Mn, Pb, Co, As, and Cd, which occurred in the 10^{-3}–10^{-1} mg/kg range; this ordering reflects both essential element supplementation and environmental load. Comparison with international guideline values (Pb 100 µg/kg, As and Cd 10 µg/kg, Hg 3 µg/kg, Ni 300 to 500 µg/kg, Cr 2 µg/kg in animal tissues) shows that Pb, Cd, and As in muscle and liver remained below the recommended limits in most cases, while Cu and Ni were within the permissible range. However, elevated Cu and Ni levels in free range liver, together with detectable Pb and As in free range flesh, raise food safety concerns. In contrast to chicken tissues, all egg samples contained Pb, Ni, As, Cd, Cr, and Hg below the

recommended maximum permissible limits. Nevertheless, PTEs remain a public health concern because of their persistence, long biological half lives and capacity to bioaccumulate (Rehman et al. 2013; Aljohani 2023). The study confirms that free range liver is the most contaminated organ for every metal, followed by free range gizzard (Cu, As, and Mn) and broiler liver (Ni, Cd, and Pb), while broiler flesh and free range flesh are the least contaminated for most elements. Therefore, the consistent tissue gradient liver > gizzard > flesh and the free range > broiler contrast are statistically robust at the organ level.

1. Pearson's correlation analysis

Pearson correlation on the 12 pooled group means revealed two tightly correlated element groups (Table 4). Group 1 (Cu, Ni, Mn, and Co) showed r = 0.93-0.97, while group 2 (Pb,Cd and As) showed r = 0.88-0.95. Cross block correlations (Pb-Cu 0.86, Pb-Ni 0.81, Cd-Cu 0.74) were moderate and largely driven by the free range liver samples, which are high in all elements; therefore they are partly an artefact of the production system contrast rather than evidence of a common source within a system.

Table 2: Pearson correlation matrix of the PTEs in the samples

Elements	Pb	Cd	As	Cu	Ni	Mn	Co
Pb	1						
Cd	0.93	1					
As	0.88	0.95	1				
Cu	0.86	0.74	0.63	1			
Ni	0.81	0.79	0.73	0.93	1		
Mn	0.77	0.66	0.55	0.96	0.97	1	
Co	0.84	0.79	0.72	0.95	0.97	0.97	1

$|r| > 0.576$ is significant at $p < 0.05$ and $|r| > 0.708$ at $p < 0.01$.

The Cu, Ni, Mn, and Co group represents elements supplied in feed/premixes or regulated homeostatically (Cu, Mn, and Co are standard poultry additives, with Ni co varying); their co variation follows tissue mass and feed intake rather than a common toxic source. The Pb, Cd, and As groups represents non essential toxic elements that share an environmental source in rhe free-range chicken such as soil, dust, water or atmospheric deposition in the free range system. Their tight coupling is a common contamination pathway.

2. Principal component analysis (PCA)

PCA on the 12 group means × 7 elements (correlation matrix) retained two components with eigenvalues > 1, explaining 95.8% of the total variance (Table 5). PC1 (eigenvalue 5.38, 76.9%) loaded uniformly and positively on all seven metals (0.35-0.43), representing a general contamination/bioaccumulation axis: samples score high on PC1 when they accumulate many metals together. The PC1 score order was as follows; free range liver (highest) > free range gizzard > broiler liver > free range flesh > broiler gizzard > broiler flesh (lowest), separating free range from broiler samples and metabolically active organs from muscle. PC2 (eigenvalue 1.32, 18.9%) contrasted Pb, Cd, and As (positive) against Cu, Ni, Mn, and Co (negative), defining a source type axis: positive scores indicate the toxic element (soil/dust/deposition) signature and negative scores indicate the feed supplement/essential element source.

Table 3: Principal component analysis of PTEs in the samples

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Elements	Component	
	PC1	PC2
Pb	0.40	0.09
Cd	0.39	0.29
As	0.35	0.45
Cu	0.43	−0.21
Ni	0.42	−0.20
Mn	0.40	−0.26
Co	0.42	−0.18
Eigenvalue	5.38	1.32
Variance (%	76.9	18.9
Cumulative %	76.9	95.8

Fig. 1. Biplot: free range liver aligns with the Pb, Cd, and As vectors, broiler liver with the Cu, Ni, Mn and Co vectors, and broiler flesh aligns opposite all vectors.

Therefore, the source apportionment is two fold: PC1 (≈77%) represents a general bioaccumulation/production system effect (free range and broiler), while PC2 (≈19%) separates a feed supplement/essential element source (Cu, Ni, Mn, and Co) from a soil/dust/anthropogenic toxic metal source (Pb, Cd, and As). The free range liver is where the two sources overlap most strongly.

3. Cluster analysis

Hierarchical agglomerative clustering on the standard metal concentrations recovered the same structure as the PCA and correlation analyses. At a three cluster cut, the variable dendrogram grouped Cu, Ni, Mn and Co (essential/feed cluster, linkage distance < 0.35) separately from Pb, Cd and As (toxic/soil dust cluster, linkage distance < 0.30), with As-Mn joining the two blocks at approximately 0.55. The sample dendrogram produced three clusters: Cluster I (low contamination) broiler flesh and broiler gizzard, essentially BDL for Pb/Cd/As with low Cu and Ni; Cluster II (intermediate/feed) broiler livers plus free range flesh and one gizzard, dominated by essential elements; and Cluster III (high contamination) free range livers and one free range gizzard, carrying both essential and toxic metals. Cluster III is the group that should drive any public health advisory (Fig. 1). The consistency of the three cluster solutions with the PCA and correlation blocks strengthens confidence in the underlying structure.

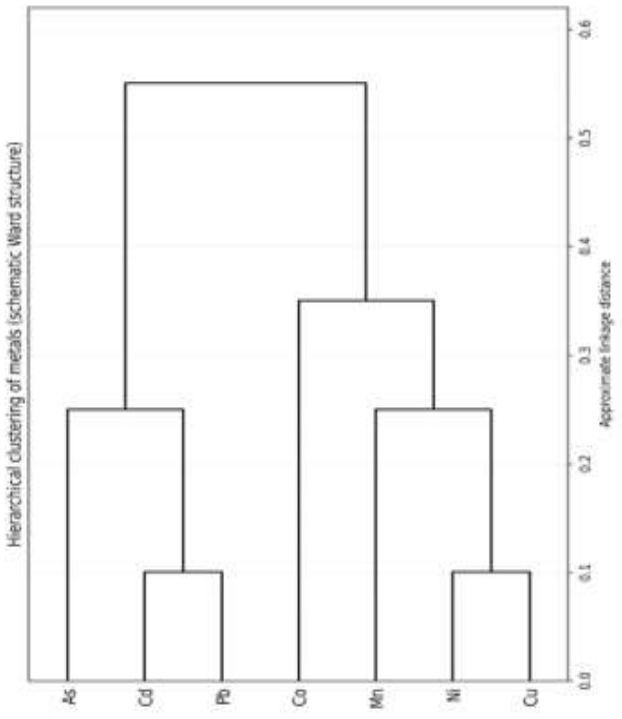


Figure 1. Hierarchical cluster dendrogram of the PTEs in the samples

4. Estimated daily intake (EDI)

Table 4 presents the EDI values for Pb, Ni, As, Cd, Cu, Mn and Co through chicken consumption. Across all age groups and consumption categories, the EDI increased in the order LC < MC < HC and followed the sequence Cu > Ni > Mn > Co > Pb > As ≈ Cd. Children with the highest EDIs (e.g. HC: Pb 2.89, Ni 19.87, As 2.10, Cd 1.90, Cu 167.4, Mn 14.16 and Co 4.47 µg/kg bw/day),

reflecting their lower body weight, whereas adults and the elderly had the lowest values because of the dilution effect of greater body mass. All EDI values remained below the provisional tolerable daily intakes for every metal, indicating that exposure through chicken alone is within the internationally accepted safety thresholds.

Table 4: Estimated daily intake (EDI, µg/kg bw/day) of PTEs through chicken consumption

Age group	Pb	Ni	As	Cd	Cu	Mn	Co
Children	0.385	2.649	0.280	0.254	22.33	1.888	0.597
	1.443	9.933	1.051	0.951	83.72	7.080	2.237
	2.886	19.87	2.102	1.901	167.4	14.16	4.474
Adolescents	0.195	1.341	0.142	0.128	11.30	0.955	0.302
	0.730	5.025	0.532	0.481	42.36	3.582	1.132
	1.460	10.05	1.063	0.962	84.72	7.164	2.264
Adults	0.192	1.320	0.140	0.126	11.13	0.941	0.297
	0.719	4.950	0.524	0.474	41.73	3.529	1.115
	1.438	9.900	1.048	0.948	83.45	7.058	2.230
Elderly	0.167	1.151	0.122	0.110	9.70	0.820	0.259
	0.627	4.317	0.457	0.413	36.39	3.077	0.972
	1.254	8.633	0.914	0.826	72.78	6.154	1.944

Table 5: Target hazard quotient (THQ) and hazard index (HI) for non carcinogenic risk through chicken consumption

Age group	Pb	Ni	As	Cd	Cu	Mn	Co	HI
Children	0.096	0.132	0.093	0.254	0.045	0.013	0.427	1.06
	0.361	0.497	0.350	0.951	0.167	0.051	1.598	3.98
	0.722	0.994	0.701	1.901	0.335	0.101	3.196	7.95
Adolescents	0.049	0.067	0.047	0.128	0.023	0.007	0.216	0.54
	0.183	0.251	0.177	0.481	0.085	0.026	0.809	2.01
	0.365	0.503	0.354	0.962	0.169	0.051	1.617	4.02

Age group	Pb	Ni	As	Cd	Cu	Mn	Co	HI
Adults	0.048	0.066	0.047	0.126	0.022	0.007	0.212	0.53
	0.180	0.248	0.175	0.474	0.083	0.025	0.796	1.98
	0.360	0.495	0.349	0.948	0.167	0.050	1.593	3.96
Elderly	0.042	0.058	0.041	0.110	0.019	0.006	0.185	0.46
	0.157	0.216	0.152	0.413	0.073	0.022	0.694	1.73
	0.314	0.432	0.305	0.826	0.146	0.044	1.389	3.46

Table 6: Target hazard quotient (THQ) and HI for the high risk matrices (free range liver and gizzard, broiler flesh)

Matrix	Pb	Ni	As	Cd	Cu	Mn	Co	HI
FR liver	0.193	1.324	0.305	0.717	0.189	0.041	1.274	4.04
	0.578	3.973	0.914	2.152	0.566	0.124	3.821	12.13
	0.964	6.622	1.523	3.587	0.943	0.207	6.369	20.22
FR gizzard	0.191	0.650	0.876	0.703	0.745	0.084	1.500	4.75
	0.572	1.950	2.628	2.108	2.236	0.251	4.500	14.24
	0.954	3.250	4.380	3.513	3.727	0.418	7.500	23.74
Broiler flesh	0	0.239	0	0	0.058	0.013	0.150	0.46
	0	0.717	0	0	0.174	0.038	0.450	1.38
	0	1.195	0	0	0.290	0.063	0.750	2.30

Incremental lifetime cancer risk (ILCR)

The ILCR values (Table 7) exceeded the negligible threshold (10^{-6}) for all medium and high consumers and for low consumption children and adolescents, with ΣILCR ranging from 2.2×10^{-6} to 37.9×10^{-6}. The principal contributor was Ni (≈89%), followed by As, Cd, Cr, and Pb. Nevertheless, all ΣILCR values remained below the upper acceptable bound of 10^{-4}, indicating a tolerable but non negligible risk of carcinogenic risk. Children in the high consumption category had the highest ΣILCR (37.9×10^{-6}).

Table 7: Carcinogenic risk (CR = ILCR) of chicken consumption

Age group	Pb	Ni	As	Cd	Cr	ΣILCR
Children	0.0033	4.50	0.42	0.097	0.077	5.09
	0.0123	16.9	1.58	0.362	0.144	19.0
	0.0245	33.8	3.15	0.722	0.208	37.9
Adolescents	0.0017	2.28	0.21	0.049	0.039	2.58
	0.0062	8.54	0.80	0.183	0.073	9.60
	0.0124	17.1	1.60	0.366	0.146	19.2
Adults	0.0016	2.24	0.21	0.048	0.038	2.54
	0.0061	8.42	0.79	0.180	0.072	9.46
	0.0122	16.8	1.57	0.360	0.144	18.9
Elderly	0.0014	1.96	0.18	0.042	0.033	2.22
	0.0053	7.34	0.69	0.157	0.063	8.26
	0.0107	14.7	1.38	0.314	0.125	16.5

CONCLUSION

This study assessed the concentrations of seven potentially toxic elements (Pb, Cd, As, Cu, Ni, Mn, and Co) in broiler and free range chicken liver, gizzard, and flesh from Gombe State, Nigeria, and evaluated the associated non carcinogenic and carcinogenic health risks. The results showed that all elements were present in the analysed tissues, with concentrations following a consistent liver > gizzard > flesh gradient and with free range chickens more contaminated than broilers. Free range liver was the most contaminated organ for every metal (Pb 0.288, Cd 0.107, As 0.137, Cu 8.49, Ni 1.99, Mn 0.870 and Co 0.268 mg/kg), while broiler flesh was the least contaminated (Pb, Cd and As below detection limits). Health risk assessment indicated that EDI values were highest in children and generally below provisional tolerable daily intakes, but THQ exceeded unity for Hg and Cd in high consumption scenarios, the HI exceeded one among high consumers of free range liver, and ILCR values for As, Cd and Cr approached or exceeded 10^{-6} in children, indicating a potential non carcinogenic and non negligible carcinogenic risk. These findings demonstrate that the consumption of chicken from the study area, particularly free range liver and gizzard by children may contribute to PTE exposure and associated health risks. Strengthened monitoring of feed, water, and litter, stricter control of environmental contamination sources and the implementation of food safety policies are recommended to reduce consumer exposure and ensure the long term safety of poultry products.

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2. Authors' contributions
All authors contributed to the study design, data collection, laboratory analysis, statistical analysis, and manuscript preparation, and approved the final version of the manuscript.

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4. Data availability
Data used to support the findings of this study can be obtained upon request from the corresponding author.

5. Declarations
Ethics approval and consent to participate: Not applicable. Competing interests: The authors have no competing interests.

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