Annals of Tropical Research 47 (2):187-200(2025)
https://doi.org/10.32945/atr47213.2025

Original Article

Preliminary assessment of trace elements and toxic heavy metals in poultry feeds and the eco-health implications in Baybay City, Leyte, Philippines

Mary Margaret Daquiado[1] and Lotis M. Balala[1*]

ABSTRACT

There has been a rapid shift in the feeding practices of backyard poultry, with increasing reliance on commercial feeds. Poultry feeds are often supplemented with trace elements to meet nutritional requirements, but can become contaminated with heavy metals during production and handling processes. This study analyzed trace elements, iron (Fe), copper (Cu), zinc (Zn), and heavy metals, lead (Pb) and cadmium (Cd), in feed samples from 10 commercial brands using microwave plasma-atomic emission spectroscopy. Results showed that Fe and Cu levels exceeded the recommended limits in most feeds, as per the Philippine Society for Animal Nutritionists (PhilSAN) and the National Research Council (NRC), with Fe being highest in layer feeds (965.83mg kg^{-1}) and Cu in booster feeds (164.26mg kg^{-1}). Zn levels varied, exceeding limits in most booster, grower, layer, and finisher feeds. Detectable Cd was found in booster, starter, grower, and finisher feeds, while Pb was only present in some brands of booster feeds. These findings underscore the importance of stringent regulatory guidelines for regulating trace element incorporation and ensuring feed quality.

Received: 1 October 2025
Revised: 31 October 2025
Accepted: 31 October 2025
Published: 12 December 2025

Keywords: feeds, heavy metals, poultry, recommended level, trace elements

[1]Faculty of Veterinary Medicine, Visayas State University, Baybay City, Leyte, 6521, Philippines

*Corresponding Author. Address: Faculty of Veterinary Medicine, Visayas State University, Baybay City, Leyte, 6521, Philippines; Email: balalalotis@vsu.edu.ph

INTRODUCTION

The rapid increase in poultry meat and egg production is expected to continue globally, with most of this growth projected to occur in developing countries, driven by rising economies, urbanization, and higher household incomes (Scudiero et al., 2023; Ravindran, 2013). Over recent decades, the poultry industry has undergone significant adjustments to meet the growing demand for a safe and affordable supply of meat and eggs (Xie et al., 2024; Gerber et al., 2008).

Backyard poultry farming in the Philippines is widespread and a substantial source of income and food for small-scale farmers in rural and suburban areas. The lack of natural foraging resources has made farmers rely on commercial feeds locally available from agricultural and veterinary (agrivet) supply outlets. Poultry feeds are designed to provide birds with all the necessary nutrients for their optimal growth as well as egg and meat production (Obi & Ozugbo, 2007).

Feed quality is enhanced by adding trace elements to enhance productivity and improve economic returns (Durso & Cook, 2014). Trace elements are given in small quantities to support animal growth, health, and bird productivity (Leeson & Summers, 2001). Elements such as zinc, copper, iron, manganese, and selenium are often added to poultry and livestock feeds to ensure the animals receive adequate nutrition, especially when the natural sources of these elements may be insufficient or unavailable. Despite the benefits, trace element supplementation is confronted with rising environmental (Finley et al., 2013; Durso & Cook, 2014) and ethical concerns (Littmann et al., 2015). Alternatively, lead, cadmium, mercury, and arsenic are heavy metals that may enter animal feeds through contaminated feedstuffs (Tao et al., 2020). Both trace elements and heavy metals pose a risk of bioaccumulation in poultry tissues, which, when humans regularly consume these products, can lead to neurological impairment, developmental abnormalities, organ dysfunction, and an increased risk of chronic diseases and cancers (Littmann et al., 2015; Wu et al., 2016). Poultry manure loaded with such elements potentially damages the environment through leaching into soil and water systems compromising crop production and food safety in surrounding agricultural areas (Delgado Arroyo et al., 2014).

To address this concern, regulatory agencies in advanced countries, including the European Food Safety Authority, set limits for permissible trace element concentrations in animal feeds to protect both health and the environment (European Union, 2006). However, regulatory guidelines for the use of these elements in feeds in the Philippines require clarification.

This study evaluated the concentration of selected trace elements and heavy metals in commercial poultry feeds commonly sold in Baybay City, Leyte, Philippines to assess if their concentrations are within the safety limits set by the Philippine Society for Animal Nutritionists (PhilSAN, 2010) and the National Research Committee (NRC, 1980). Generated information will be valuable in crafting informed guidelines to ensure human and animal health, food safety, and environmental sustainability. This study has the potential to significantly impact existing relevant laws or shape new policies to regulate and monitor the use of these elements, ensuring the safety and sustainability of poultry production in the country.

MATERIALS AND METHODS

Study Design and Sample Collection

This study employed a cross-sectional design to assess trace element concentrations in commercially available poultry feeds in Baybay City, Leyte. Following the recommendations of VanVoorhis and Morgan (2007), a total of 30 feed samples were collected from nine randomly selected agricultural and veterinary supply (agrivet) stores in the central area of the city. The samples included booster, starter, grower, layer, and finisher feeds, representing 10 different brands. To maintain confidentiality, brand names were anonymized and coded alphabetically (e.g., A, B, C).

A brief survey of the stores identified the ones most frequently visited by poultry farmers and the brands they purchased most commonly. Stores were included if they offered at least two brands of poultry crumble feeds, the preferred feed form among backyard farmers, and provided consent to participate in the study. Feed samples were randomly purchased from multiple stores to capture the variability of brands sold locally. Due to differences in stock availability, some feed types were sampled from a single store.

Sample Processing and Element Analysis

Five elements, copper (Cu), iron (Fe), zinc (Zn), cadmium (Cd), and lead (Pb), were analyzed in the feed samples. Cu, Fe, and Zn were included because they are commonly added as mineral supplements, while Cd and Pb were examined due to their potential occurrence as contaminants in feed ingredients (Domel, et al., 2024; Lee & Kim, 2025). Approximately 250–500g of each sample were purchased from Agrivet stores. Samples were taken from opened or partially filled feed sacks as adulteration or heavy metal contamination may occur during handling. Each sample was placed in a labeled zip-lock plastic bag and transported to the Microbiology Laboratory of the Faculty of Veterinary Medicine, Visayas State University, Baybay City, Leyte, for processing.

The quartering method described by Herrman (2001) was used to reduce the initial feed sample to a few grams for analysis. Approximately 100g of feed were ground in a mortar and pestle and thoroughly mixed. Each sample was poured onto sterile paper, formed into a round shape, and divided into four quadrants. The upper right and lower left portions were removed and then remixed; this process was repeated until a sample weight of 10g was achieved.

The samples were homogenized and submitted to the Central Analytical Services Laboratory at the Philippine Root Crop and Training Center, Visayas State University, for analysis. The feeds were analyzed for trace elements and heavy metals following the procedure illustrated in Figure 1 based on the method of Suleiman et al. (2015). The concentration of elements was determined using microwave plasma atomic emission spectroscopy (MP-AES 4200, Agilent, USA).

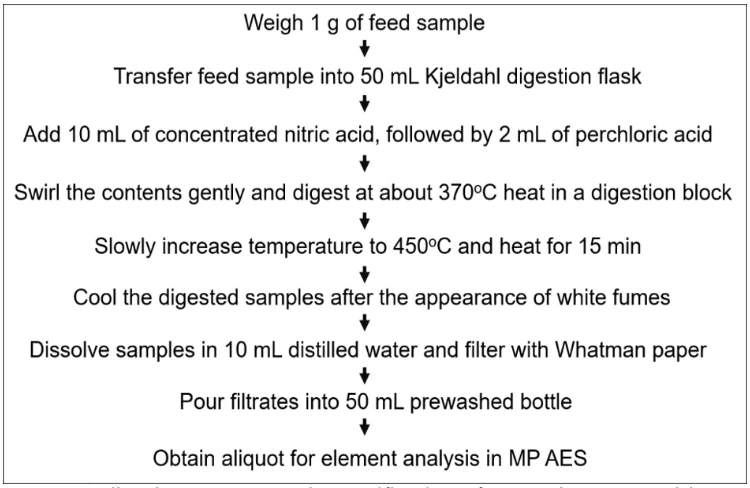

Figure 1. Filtration process and quantification of trace elements and heavy metals in feed samples

Data Analysis

Concentrations of trace elements (Cu, Fe, Zn) and heavy metals (Cd, Pb) in commercial poultry feeds were analyzed by feed type and brand. Each sample was evaluated for conformity to recommended limits (Cu: 4–8mg kg^{-1}; Fe: 50–80mg kg^{-1}; Zn: 40–75mg kg^{-1}; NRC, 1980; PhilSAN, 2010) and classified as "Below," "Acceptable," or "Above" the limit. Data are presented in tabular form, showing feed type, brand, sample size (N), mean ± standard deviation (SD), and conformity classification. Descriptive statistics were used due to the exploratory nature of the study, small sample sizes, and uneven replication across brands. For brands with multiple samples (N > 1), SD was reported to indicate within-brand variability and consistency of elemental concentrations.

RESULTS

Trace Element Concentration in Feed Samples

Levels of trace elements in commercial poultry feed samples were evaluated against the standards set by the National Research Committee (NRC, 1980) and the Philippine Society for Animal Nutritionists (PhilSAN, 2010).

As shown in Table 1, the comparative analysis of Cu, Fe, and Zn across different poultry feed brands revealed elevated concentrations of these trace elements, exceeding the recommended dietary levels.

Table 1. Concentrations of copper (Cu), iron (Fe), and zinc (Zn) in commercial poultry feeds and their conformity to recommended limits.

Feed Type	Brands	N	Cu (mg/kg)	Conformity to Cu limit (4-8 mg/kg)?	Fe (mg/kg)	Conformity to Fe limit (50-80 mg/kg)?	Zn (mg/kg)	Conformity to Zn limit (40-75 mg/kg)?
Booster	A	2	120.00±8.74	Above	151.75±7.23	Above	182.85±3.94	Above
	B	1	164.25	Above	143.59	Above	126.93	Above
	C	2	12.75±1.75	Above	117.82±3.86	Above	45.70±9.40	Acceptable
	E	1	28.29	Above	200.83	Above	119.54	Above
	G	1	10.12	Above	315.82	Above	41.03	Acceptable
	H	1	21.01	Above	224.95	Above	73.62	Acceptable
	I	1	41.64	Above	133.74	Above	85.85	Above
Starter	A	2	149.34±3.65	Above	167.92±14.05	Above	167.94±12.8	Above
	B	3	75.72±55.61	Above	148.60±36.49	Above	127.22±18.88	Above
	C	2	17.48±0.40	Above	326.91	Above	59.26±1.77	Acceptable
	I	1	26.45	Above	218.15	Above	120.13	Above
Grower	F	1	3.89	Acceptable	237.94	Above	9.55	Below
	H	1	25.85	Above	462.36	Above	100.53	Above
	I	1	19.53	Above	186.78	Above	110.00	Above
	J	1	24.90	Above	601.75	Above	100.34	Above

Table 1. continued

Feed Type	Brands	N	Cu (mg/kg)	Conformity to Cu limit (4-8 mg/kg)?	Fe (mg/kg)	Conformity to Fe limit (50-80 mg/kg)?	Zn (mg/kg)	Conformity to Zn limit (40-75 mg/kg)?
Layer	B	2	21.11±2.23	Above	422.65	Above	114.90±14.79	Above
	D	1	8.07	Acceptable	911.22	Above	42.85	Acceptable
	H	1	28.75	Above	965.83	Above	82.97	Above
Finisher	B	2	142.02±15.07	Above	147.08±15.07	Above	124.02±10.80	Above
	C	2	73.73±85.27	Above	328.55±58.63	Above	111.13±81.11	Above
	I	1	1.21	Below	265.97	Above	4.27	Below
Total	10	30						

Note: Conformity to element limits is based on NRC (1980) and PhilSAN (2010) recommended ranges: Cu, 4–8mg kg^{-1}; Fe, 50–80mg kg^{-1}; Zn, 40–75mg kg^{-1}. “Above” indicates concentrations exceeding the upper limit, “Acceptable” indicates concentrations within the recommended range, and “Below” indicates concentrations below the lower limit.

Copper

The National Research Council (1980) recommends a Cu concentration of 6-8mg kg^{-1} for broiler feeds, while PhilSAN (2010) suggests 5-8mg kg^{-1} for breeders and 5-10mg kg^{-1} for egg-type feeds. Results of the study revealed that many commercial feed samples exceeded these recommended levels. Copper concentrations in booster feeds ranged from 10.12 to 164.26mg kg^{-1}, with only brands C and G approximating the recommended levels. Starter feeds exhibited a wide range of Cu concentrations (17.48-149.35mg kg^{-1}), with brand A showing the highest level (149.35mg kg^{-1}). Grower feeds contained Cu concentration between 3.89 and 25.85mg kg^{-1}, with brand F falling below the recommended range at 3.89mg kg^{-1}. Layer feeds had Cu concentration ranging from 8.07 to 28.75mg kg^{-1}, with only brand D having acceptable level. Finisher feeds showed the widest variation in Cu concentration (1.21-142.02mg kg^{-1}), with brand I recording the lowest level (1.21mg kg^{-1}), substantially below the recommended range. Although mean Cu levels varied significantly among booster feed brands, their concentrations were below the maximum tolerable limit of 250mg kg^{-1} for poultry feeds (NRC 2005).

Iron

Iron (Fe) concentrations in commercial poultry feeds varied widely, ranging from 117.82 to 965.83mg kg^{-1}. Layer feeds exhibited the highest Fe levels, while booster feeds had the lowest. These concentrations exceeded the recommended Fe ranges of 50-80mg kg^{-1} for broiler feeds and 25-70mg kg^{-1} for layer feeds, as outlined by NRC (1980) and PhilSAN (2010). Specifically, Fe levels in booster feeds ranged from 117.82-315.82mg kg^{-1}, 148.60-326.91mg kg^{-1} in starter feeds, 186.78-601.75mg kg^{-1} in grower feeds, 422.65-965.83mg kg^{-1} in layer feeds, and 147.08-328.55mg kg^{-1} in finisher feeds. Notably, while many samples were above dietary limits, some samples, particularly among layer feeds, surpassed the maximum tolerable limit of 500mg kg^{-1} (NRC, 2005).

Zinc

The NRC (1980) and PhilSAN (2010) recommend Zn concentration in feeds to be between 40-75mg kg^{-1} and 40-80mg kg^{-1}, respectively. Booster feeds contained Zn levels ranging from 41.03 to 182.85mg kg^{-1}. Only three brands (C, G, H) adhered to the recommended limits. Starter feeds had Zn levels between 59.26 and 167.94mg kg^{-1}, grower feeds between 9.55-110.00mg kg^{-1}, and layer feeds between 42.85-114.90mg kg^{-1}. Finisher feeds contained Zn levels ranging from 4.27-124.02mg kg^{-1}. These measured Zn levels were below the maximum tolerable limit (500mg kg^{-1}).

Heavy Metal Concentration in Feed Samples

Cadmium and lead

According to NRC (1980) and PhilSAN (2010), heavy metals such as cadmium (Cd) and lead (Pb) should be completely absent (0mg kg^{-1}) in commercial feeds. As shown in Figure 2, Cd and Pb concentrations in the analyzed feed samples ranged from trace to detectable levels; however, all values remained below the maximum tolerable limit of 10mg kg^{-1} (NRC, 2005).

Cadmium concentrations reached up to 0.16mg kg^{-1} in booster feeds, 0.10mg kg^{-1} in starter feeds, 0.13mg kg^{-1} in grower feeds, 0.07mg kg^{-1} in layer feeds, and 0.12mg kg^{-1} in finisher feeds. Although Cd was detected in all feed types, its concentrations were within the maximum tolerable limit.

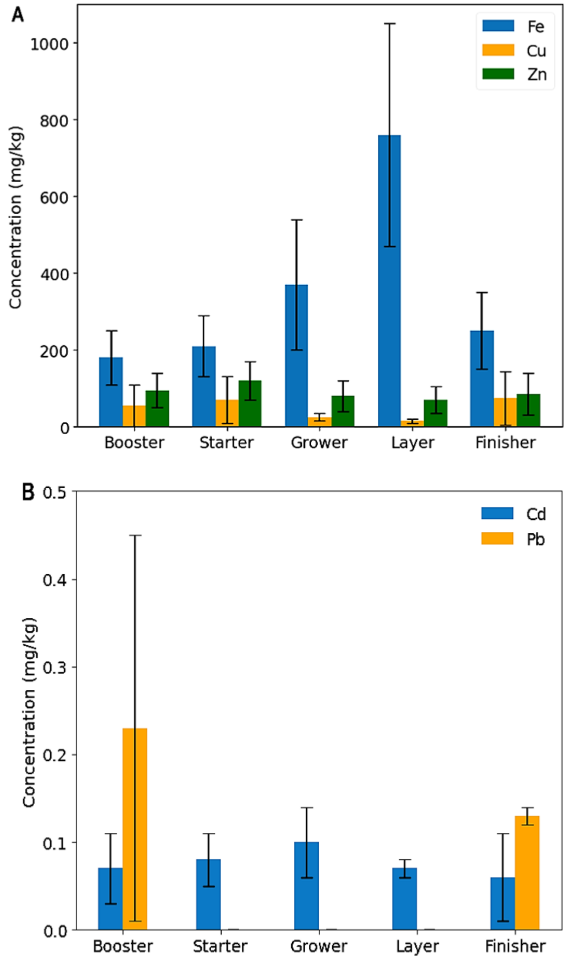

Figure 2. Mean concentrations (mg/kg) of (A) trace elements (Fe, Cu, Zn) and (B) toxic metals (Cd, Pb) in the analyzed samples. Error bars indicate 95% confidence intervals.

Similar to Cd, Pb is not recommended in poultry diets due to its toxicological risks. Pb was detected in trace amounts, with most feeds containing negligible levels. However, notable exceptions included starter feeds from brand I (up to 0.39mg kg^{-1}) and finisher feeds from brand C (up to 0.13mg kg^{-1}). While these Pb levels were below the maximum tolerable limit, their presence could suggest potential contamination of the feed.

DISCUSSION

Commercial feeds are vital components of a healthy diet for backyard poultry. They are convenient to use and contain additives and medications that help prevent common poultry diseases. However, trace elements as additives should be administered at the recommended amount, as excessive manure levels can contaminate soil and water, posing detrimental effects to health and the environment. The increasing reliance of backyard poultry on commercial feeds can exacerbate environmental contamination through improper manure disposal. Frequent exposure of surrounding soil and water to poultry manure can lead to the accumulation of trace elements over time causing mineral imbalances that may adversely affect other organisms relying on these ecosystems.

Findings of this study revealed excessive concentrations of Cu in most of the commercial poultry feeds sold in Baybay City, although all observed levels remained below the maximum tolerable limit (MTL) of 250mg kg^{-1} for poultry (NRC, 2005). The Cu concentrations observed were substantially higher than those reported in poultry feeds from Saudi Arabia (8.94–16.61mg kg^{-1}) and Bangladesh (45.67–98.67mg kg^{-1}) (Korish & Attia, 2020; Rahman et al., 2014). While the levels did not exceed the MTL, the excess Cu above recommended ranges can still lead to unnecessary excretion in manure, which may accumulate in the environment and contribute to soil and water contamination. Cu is essential for bone formation and cardiovascular health (Berger & Cunha, 2006), but excessive intake can interfere with the absorption of other trace elements, such as iron (Fe) and zinc (Zn), potentially causing nutritional deficiencies (Nguyen et al., 2022). Chronic exposure to elevated Cu levels, even below the MTL, may impair liver and kidney function and reduce growth performance in poultry (Richards et al., 2010).

Of particular concern is the potential transfer of Cu residues from feed to poultry tissues, as Cu tends to accumulate in the liver, gizzard, and muscle, which are commonly consumed by people (Korish & Attia, 2020). Regular consumption of such Cu-enriched poultry products such as chicken meat and eggs could increase dietary Cu intake, resulting in oxidative stress, gastrointestinal disturbances, and hepatic toxicity in humans (Gaetke & Chow, 2003). Moreover, Cu-rich manure poses environmental risks, as accumulation in soil can decrease fertility, adversely affect plant growth (Chen et al., 2022), and, through erosion or runoff, contaminate nearby water bodies, contributing to aquatic toxicity and ecosystem degradation (Gupta & Gupta, 1998). Conversely, feed brands with Cu levels below recommended ranges may indicate insufficient supplementation, which can impair hemoglobin synthesis, enzyme function, and overall poultry productivity (NRC, 2005).

The Fe concentrations in the analyzed feeds were considerably higher than the recommended levels and MTL, and also exceeded those reported in Saudi Arabia (Korish & Attia, 2020). While Fe supplementation is essential for various physiological processes in poultry, excessive levels can trigger oxidative stress causing cellular damage and impaired growth and development (Cooper, 2000; Tilman et al., 2002). Fe concentrations reached up to 965.83mg/kg in layer feeds, far exceeding the MTL, which may lead to liver and kidney dysfunction due to Fe toxicity (Han et al., 2022). Additionally, Fe excreted in manure can accumulate in the environment, leading to soil acidification, nutrient imbalances, and leaching into water bodies, with potential long-term contamination and adverse effects on aquatic organisms (Tilman et al., 2002; U.S. EPA, 2024). These findings underscore the need for monitoring of Fe supplementation in commercial poultry feeds to prevent both health risks to poultry and environmental contamination.

As with Cu and Fe, Zn concentrations varied among feed brands, with some exceeding, meeting, or falling below the recommended range of 40–75mg kg^{-1} (NRC, 1980; PhilSAN, 2010). Zinc plays a vital role in growth, reproductive performance, immune response, and antioxidant defense in poultry (Naz et al., 2016). However, feeds with suboptimal Zn levels may lead to impaired growth, reduced hatchability, weakened immunity, and increased susceptibility to infections. Conversely, excessive Zn intake can cause digestive disturbances, kidney dysfunction, and diminished absorption of other trace elements (Dong et al., 2023). Moreover, continuous Zn excretion through manure contributes to soil infertility, altered microbial activity, and water contamination, posing long-term environmental risks (Andresen et al., 2018).

The detection of Cd and Pb in commercial feeds, although within maximum tolerable limits, suggests possible contamination along the feed production chain. Comparable studies reported higher concentrations, with Cd levels ranging from 3.33–16.67mg kg^{-1}, 2.88-98.08mg kg^{-1}, and Pb concentration of up to 5mg kg^{-1} in poultry feeds from Bangladesh, Northeast China, and Saudi Arabia, respectively (Rahman et al., 2014; Zhang et al., 2012; Korish & Attia, 2020). These elevated values are alarming as they exceed the maximum tolerable limits, underscoring the potential health and environmental risks associated with heavy metal contamination. Even low-level exposure is concerning, as prolonged exposure results in bioaccumulation in poultry tissues, potentially exceeding safe limits in edible products such as meat and eggs resulting in health risks to consumers (Korish & Attia, 2020). The presence of heavy metals in feeds often reflects the use of contaminated raw materials such as grains or mineral premixes exposed to pollutants from fertilizers, pesticides, or improper storage conditions (Adekanmi, 2022; Bartkowiak, 2022).

Site observations of feed retail stores in Baybay City, Leyte revealed that poultry feeds were often displayed in semi-open areas exposed to dust and soil, and were frequently handled by multiple personnel with minimal hygiene controls. In several stores, feeds were stacked near corrosive materials such as cleaning agents and disinfectants, while some reused feed sacks or containers that could retain metal residues. A few establishments also stored or sold fertilizers and pesticides alongside feed products, increasing the risk of cross-contamination. Environmental factors—including proximity to roads, small workshops, and other potential sources of airborne pollutants—may further promote the deposition of Cd and Pb on feed surfaces. These inconsistent storage and handling practices heighten the risk of trace heavy metal contamination during retail distribution (Aljohani, 2023; Chen et al., 2022).

The findings of this study provide a valuable baseline for strengthening the monitoring and routine testing of commercial poultry feeds sold in Baybay City, Leyte. The results highlight the need for stricter implementation of local feed quality standards and improved coordination among feed producers, retailers, and regulatory agencies.

CONCLUSION

The study highlights that commercial poultry feeds sold in Baybay City, Leyte contain trace element concentrations exceeding recommended nutritional levels, along with detectable amounts of heavy metals. These results raise significant concerns for animal and public health, as well as for the potential of environmental contamination. Although the measured concentrations remain within maximum tolerable limits, the consistent presence of elevated levels underscores the need for rigorous local monitoring and evaluation of trace element supplementation in feed formulations. Clear regulatory guidelines must be established and strictly enforced to ensure the quality of feed ingredients. Additionally, improving handling, storage, and hygiene practices among feed retailers and distributors are crucial to reduce contamination and safeguard feed safety. Addressing these gaps is vital to maintaining feed quality, protecting consumer health, and promoting sustainable poultry production in Baybay City and nearby areas.

Acknowledgment

The authors express their gratitude to the Microbiology Laboratory of the Faculty of Veterinary Medicine and the Central Analytical Laboratory Services of Visayas State University, Baybay City, Leyte, for their assistance with the sample analysis.

Author Contributions

MMD collected and analyzed data and wrote the first draft; LMB conceptualized the study and wrote the paper.

Funding Source

This research received no external funding and was personally financed by the authors.

Availability of Data and Materials

Data and materials generated in this study are included in this article.

Ethical Considerations

This research required no ethical considerations as it did not involve human or animal subjects.

Competing Interest

The authors declare no conflict of interest to disclose in the conduct of this study. This study is independent and not commissioned by any feed company.

References

Adekanmi, A. T. (2022). *Health hazards of toxic and essential heavy metals from the poultry waste on human and aquatic organisms*. IntechOpen. https://doi.org/10.5772/intechopen.99549

Aljohani, A. S. M. (2023). Heavy metal toxicity in poultry: A comprehensive review. *Frontiers in Veterinary Science, 10*. https://doi.org/10.3389/fvets.2023.1161354

Andresen, E., Peiter, E., & Küpper, H. (2018). Trace metal metabolism in plants. *Journal of Experimental Botany, 69*(5), 909–954. https://doi.org/10.1093/jxb/erx465

Bartkowiak, A. (2022). *Influence of heavy metals on quality of raw materials, animal products, and human and animal health status*. IntechOpen. https://doi.org/10.5772/intechopen.102497

Berger, L. L., & Cunha, T. J. (2006). *Salt and trace minerals for livestock, poultry and other animals* (8th ed.). Salt Institute. https://ftpmirror.your.org/pub/misc/cd3wd/1001/_mc_ag_vet_2006_Dr_Bergers_Main_Book_rd_179840_.pdf?utm_source=chatgpt.com

Chen, G., Li, J., Han, H., Du, R., & Wang, X. (2022). Physiological and molecular mechanisms of plant responses to copper stress. *International Journal of Molecular Science, 23*(21), 12950. https://doi.org/10.3390/ijms232112950

Cooper, G. M. (2000). *The cell: A molecular approach* (2nd ed.). Sinauer Associates. https://www.ncbi.nlm.nih.gov/books/NBK9921/

Delgado Arroyo, M. D. M., Miralles de Imperial Hornedo, R., Alonso Peralta, F., Rodriguez Almestre, C., & Martín Sánchez, J. V. (2014). Heavy metals concentration in soil, plant, earthworm and leachate from poultry manure applied to agricultural land. *Revista internacional de contaminación ambiental*, *30*(1), 43-50.

Domel, J. R., House, G. M., Sobotik, E. B., & Archer, G. S. (2024). Evaluation of egg quality and performance in late-lay hens fed different combinations of copper, manganese, and zinc complexed with sulfate or amino acid ion. *Poultry*, *3*(1), 36-46. https://doi.org/10.3390/poultry3010004

Dong, L., Li, Y., Zhang, Y., Zhang, Y., Ren, J., Zheng, J., Diao, J., Ni, H., Yin, Y., Sun, R., Liang, F., Li, P., Zhou, C., & Yang, Y. (2023). Effects of organic zinc on production performance, meat quality, apparent nutrient digestibility and gut microbiota of broilers fed low-protein diets. *Scientific Reports, 13*, 10803. https://doi.org/10.1038/s41598-023-37867-7

Durso, L. M. & Cook, K. L. (2014). Impacts of antibiotic use in animal agriculture: what are the benefits and risks? Current Opinion in Microbiology, *19*: 37-44. https://doi.org/10.1016/j.mib.2014.05.019.

European Union. (2006). *Regulation (EC) No 1831/2003 on additives for use in animal nutritional* (Official Journal of the European Union).

Finley, R. L., Collignon, P., Larsson, D. G. J., McEwen, S. A., Li, X., Gaze, W.H., Reid-Smith, R., Timinouni, M., Graham, D.W., & Topp, E. (2013). The scourge of antibiotic resistance: the important role of the environment. *Clinical Infectious Diseases, 57*(5), 704-710. https://doi.org/10.1093/cid/cit355

Gaetke, L. M., & Chow, C. K. (2003). Copper toxicity, oxidative stress, and antioxidant nutrients. *Toxicology, 189*(1–2), 147–163. https://doi.org/10.1016/S0300-483X(03)00159-8

Gerber, P., Opio, C., & Steinfeld, H. (2008). *Poultry production and the environment – A review*. Rome, Italy: Animal Production and Health Division, Food and

Organization of the United Nations. https://www.semanticscholar.org/paper/Poultry-production-and-the-environment-%E2%80%93-a-review-Gerber-Opio/11b57f4788910bc6263f7eebbe74c58c3eaff779

Gupta, U. C., & Gupta, S. C. (1998). Trace element toxicity relationships to crop production and livestock and human health: Implications for management. *Communications in Soil Science and Plant Analysis, 29*(11–14), 1491–1522. https://doi.org/10.1080/00103629809370045

Han, M., Fu, X., Xin, X., Dong, Y., Miao, Z., & Li, J. (2022). High dietary organic iron supplementation decreases growth performance and induces oxidative stress in broilers. *Animals, 12*(13), 1604. https://doi.org/10.3390/ani12131604

Herrman, T. (2001). *Sampling: Procedures for feed.* Kansas State University Agricultural Experiment Station and Cooperative Extension Service. https://krex.k-state.edu/bitstream/handle/2097/21600/KSUL0010KSREIGPPUBSMF2036a.pdf?sequence=1

Korish, M. A., & Attia, Y. A. (2020). Evaluation of heavy metal content in feed, litter, meat, meat products, liver, and table eggs of chickens. *Animals (Basel), 10*(4), 727. https://doi.org/10.3390/ani10040727

Lee, J. & Kim, M. (2025). Availability of trace minerals in feed ingredients and supplemental sources (inorganic, organic, and nano) in broiler chickens. Journal of Animal Science and Technology, *67*(4), 805-816. https://doi.org/10.5187/jast.2024.e43

Leeson, S., & Summers, J. D. (2001). *Nutrition of the chicken.* Belgium: University Books. https://books.google.com/books/about/Nutrition_of_the_Chicken.html?id=JlhnQgAACAAJ

Littmann, J. & Viens, A.M. (2015). The ethical significance of antimicrobial resistance. *Public Health Ethics*, *8*(3):209-224. https://doi.org/10.1093/phe/phv025

Naz, S., Idris, M., Khalique, M. A., Ur-Rahman, Z., Alhidary, A. I., Abdelrahman, M. M., Khan, R. U., Chand, N., Farooq, U., & Ahmad, S. (2016). The activity and use of zinc in poultry diets. *World's Poultry Science Journal, 72*(1), 159–167. http://dx.doi.org/10.1017/S0043933915002755

Nguyen, H. T. T., Kheravii, S. K., Wu, S. B., Roberts, J. R., Swick, R. A., & Toghyani, M. (2022). Sources and levels of copper affect liver copper profile, intestinal morphology and cecal microbiota population of broiler chickens fed wheat-soybean meal diets. *Scientific Reports, 12*(1), 2249. https://doi.org/10.1038/s41598-022-06204-9

National Research Council [NRC]. (1980). *Mineral tolerance of domestic animals.* Washington, D.C.: National Academies Press. https://nap.nationalacademies.org/catalog/25/mineral-tolerance-of-domestic-animals

National Research Council. (2005). *Mineral tolerance of animals* (2nd rev. ed.). Washington, D.C.: National Academies Press. https://nap.nationalacademies.org/catalog/11309/mineral-tolerance-of-animals-second-revised-edition-2005

Obi, C. N., & Ozugbo, I. J. (2007). Microbiological analyses of poultry feeds sold in Umuahia main market, Abia State, Nigeria. *Journal of Radiation Research and Applied Sciences, 2*(1), 22–25. https://www.researchgate.net/profile/Clifford-Obi-2/publication/328542710_Microbiological_analyses_of_Poultry_Feeds_sold_in_Umuahia_Main_Market_Abia_State_Nigeria/links/5bd377a5a6fdcc3a8da91ef5/Microbiological-analyses-of-Poultry-Feeds-sold-in-Umuahia-Main-Market-Abia-State-Nigeria.pdf

Philippine Society of Animal Nutritionists [PhilSAN]. (2010). *Feed reference standards* (4th ed.). Laguna, Philippines: University of the Philippines. https://pdfcoffee.com/philsan-feed-reference-standards-4th-ed-edited-pdf-free.html

Rahman, M. A., Kamal, S., Salam, A., & Salam, A. (2014). Assessment of the quality of the poultry feed and its effect in poultry products in Bangladesh. *Journal of Bangladesh Chemical Society, 27*(1&2), 1–9. https://www.researchgate.net/publication/281207190_ASSESSMENT_OF_THE_QUALITY_OF_THE_POULTRY_FEED_AND_ITS_EFFECT_IN_POULTRY_PRODUCTS_IN_BANGLADESH

Ravindran, V. (2013). Poultry feed availability and nutrition in developing countries. *Poultry Development Review*. https://www.fao.org/4/al703e/al703e00.pdf

Richards, J.D., Zhao, J., Harrell, R. J., Atwell, C. A., & Dibner, J. J. (2010). Trace mineral nutrition in poultry and swine. *Animal Bioscience, 23*(11), 1527–1534. https://doi.org/10.5713/ajas.2010.r.07

Scudiero, L., Tak, M., Alarcón, P., & Shankar B. (2023). Understanding household and food system determinants of chicken and egg consumption in India. *Food Security, 15*, 1231–1254. https://doi.org/10.1007/s12571-023-01375-3

Suleiman, N., Ibitoye, E. B., Jimoh, A. A., & Sani, Z. A. (2015). Assessment of heavy metals in chicken feeds available in Sokoto, Nigeria. *Sokoto Journal of Veterinary Sciences, 13*(1), 17-21. https://www.cabidigitallibrary.org/doi/pdf/10.5555/20153393135

Tao, C., Wei, X., Zhang, B., Zhao, M., Wang, S., Sun, Z., Qi, D., Sun, L., Rajput, S.A., & Zhang, N. (2020). Heavy metal content in feedstuffs and feeds in Hubei Province, China. *Journal of Food Protection*, *83*(5), 762-766.https://doi.org/10.4315/0362-028X.JFP-18-539

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*, 671–677. https://doi.org/10.1038/nature01014

US EPA. (2024, October 22). Potential well water contaminants and their impacts. U.S. Environmental Protection Agency. https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts

Wilson VanVoorhis, C. R., & Morgan, B. L. (2007). Understanding power and rules of thumb for determining sample sizes. *Tutorials in Quantitative Methods for Psychology, 3*(2), 43–50. https://doi.org/10.20982/tqmp.03.2.p043

Wu, Y., Zhang, H., Liu, G., Zhang, J., Wang, J., Yu, Y., & Lu, S. (2016). Concentrations and health risk assessment of trace elements in animal-derived food in southern China. *Chemosphere, 144*, 564–570. https://doi.org/10.1016/j.chemosphere.2015.09.005

Xie, N., Zhu, Y., Liu, H., Ye, F., & Liu, X. (2024). Impacts of different epidemic outbreaks on broiler industry chain price fluctuations in China: Implications for sustainable food development. *Sustainability*, *16*(14), 6043. https://doi.org/10.3390/su16146043

Zhang F, Li Y, Yang M, & Li W. (2012). Content of heavy metals in animal feeds and manures from farms of different scales in northeast China. *International Journal of Environmental Research and Public Health, 9*(8), 2658-2668. https://doi.org/10.3390/ijerph9082658