

Determination of Potential Toxic Elements in Poultry Feeds Available in Gombe Metropolis, Nigeria Using Energy Dispersive X-Ray Fluorescence (EDXRF) Technique

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Abstract: *This study assessed the concentrations of selected elements in commercial poultry feeds marketed in Gombe Metropolis, Nigeria, using energy-dispersive X-ray fluorescence (EDXRF). Ten poultry feed samples were purposively selected from four brands and analysed for bromine (Br), nickel (Ni), barium (Ba), strontium (Sr), yttrium (Y), zirconium (Zr), scandium (Sc), niobium (Nb), tin (Sn) and silver (Ag). The results revealed variations in elemental concentrations and detection frequencies across the samples. Bromine, strontium, yttrium and zirconium were detected in all ten samples, whereas barium was detected in seven samples (70%), silver in five (50%), niobium in three (30%), and nickel, scandium and tin in two, two and one samples, respectively. Bromine concentrations ranged from 48.8 to 213 mg/kg, with a mean of 116.2 mg/kg. Barium ranged from 320 to 727 mg/kg, averaging 547.6 mg/kg, while strontium ranged from 1,290 to 17,200 mg/kg, with a mean of 5,757 mg/kg. Yttrium concentrations varied from 26.3 to 338 mg/kg, whereas zirconium ranged from 365 to 3,990 mg/kg. Scandium concentrations of 12,900 and 29,300 mg/kg were recorded in two samples. Silver concentrations ranged from 68.1 to 141 mg/kg in the five samples where it was detected. These findings demonstrate substantial differences in the elemental composition of the poultry feeds examined. The results highlight the importance of routine monitoring and quality control of commercial poultry feeds. Further confirmatory analyses and comparison with applicable feed-safety standards are necessary to establish the significance of the measured concentrations for animal health and food safety.*

Keywords: *Commercial poultry feeds, EDXRF, elemental concentrations, feed safety, Gombe Metropolis, Nigeria.*

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1.0 Introduction

Poultry production contributes to food security, employment, and the supply of affordable animal protein in Nigeria. The safety and

nutritional quality of poultry feed are therefore important for animal productivity and the quality of food products derived from poultry. However, feed ingredients may contain undesirable chemical contaminants originating from agricultural soils, irrigation water, mineral supplements, industrial emissions, mining activities, processing, transportation, and storage. These contaminants may enter the animal production system through feed and, depending on their chemical form and bioavailability, may accumulate in animal tissues or be transferred to edible products. The Food and Agriculture Organization (FAO) identifies feed contamination as an important concern because it can affect livestock productivity and the safety of foods of animal origin (D'Mello, 2004).

Potentially toxic elements (PTEs) require particular attention because their effects depend on the element, its chemical form, concentration, exposure duration, and biological availability (Igwegmar *et al.*, 2022). Some elements, including manganese (Mn) and copper (Cu), perform essential physiological functions but may cause adverse effects when supplied in excessive amounts. Other elements have limited or poorly established nutritional roles in poultry, and their occurrence in feed may warrant further investigation. Environmental contamination can introduce such elements into feed ingredients, while repeated dietary exposure may increase the potential for accumulation in animals. Consequently, determining elemental concentrations in commercial poultry feeds is an important step in assessing feed quality and identifying possible contamination that merits further investigation (Järup, 2003; EFSA Scientific Committee, 2025).

Evidence from Nigeria demonstrates the relevance of monitoring contaminants in poultry feeds. Ifie *et al.* (2022) investigated aflatoxins and selected metals in maize and poultry feeds from northern and central Delta State. Their analysis included lead, cadmium,

chromium, and copper, and the authors reported that some samples exceeded the comparison limits applied in their assessment. In a separate study, Akinmusire *et al.* (2019) documented the occurrence of multiple mycotoxins in poultry feeds and feed ingredients collected across 12 Nigerian states. Although mycotoxins differ from elemental contaminants, this research illustrates the broader importance of monitoring the chemical and biological quality of poultry feeds and their raw materials. These studies provide a useful national context, but they do not establish the concentrations of all the elements investigated in the present study or the specific conditions in Gombe Metropolis.

Energy-dispersive X-ray fluorescence (EDXRF) is a technique for determining the elemental composition of prepared samples. Its application to poultry feeds can provide information on the occurrence and concentrations of multiple elements in a single analytical procedure. However, EDXRF measures elemental content and does not, by itself, determine chemical speciation, biological availability, or the amount absorbed by poultry. Interpretation of measured concentrations must therefore consider analytical uncertainty, the suitability of comparison standards, and the distinction between elemental concentration and toxicological risk.

Despite research on feed contaminants in other parts of Nigeria, geographically specific information on the concentrations of the elements examined in commercially available poultry feeds in Gombe Metropolis remains limited in the literature considered for this study. In particular, further data are needed to characterize the occurrence and concentration ranges of these elements across different commercial feed types and to compare the findings with relevant published studies and applicable regulatory criteria. Establishing such information can provide a baseline for subsequent monitoring, although the results



from a limited sample set should not be interpreted as representing every poultry feed sold in the area.

This study therefore aimed to determine the concentrations of selected elements in ten commercial poultry feed samples obtained from Gombe Metropolis, Nigeria, using EDXRF. The specific objectives were to determine the concentrations of the elements detected in the samples, describe their distribution across the feed types examined, and compare the results with relevant published findings and applicable regulatory criteria where suitable standards were available. The findings are intended to contribute baseline information for feed-quality assessment and to identify priorities for further investigation and monitoring.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in Gombe Metropolis, Gombe State, northeastern Nigeria. The study area is reported to lie between latitudes 10°15'–10°19' N and longitudes 11°07'–11°15' E; these coordinates should be verified against the actual sampling locations. Gombe is an important commercial and agricultural Centre in the region, with established poultry production and feed distribution activities. Assessing potentially toxic elements (PTEs) in commercial poultry feeds is therefore relevant to evaluating feed quality and identifying possible sources of elemental exposure in poultry production.

2.2 Sample Collection

Ten commercially available poultry feed samples representing four brands—Vital, Ultima, Sunseed, and Hybrid—were collected from outlets within Gombe Metropolis using purposive sampling. The samples comprised different feed types and production stages, including chick mash, broiler starter, finisher, layer mash, and pre-layer feeds. Each sample was assigned a unique identification code for laboratory analysis. The sample descriptions

and corresponding codes are presented in Table 1.

Table 1. Description and identification codes of poultry feed samples collected from Gombe Metropolis

S/N	Feed sample	Sample code
1	Chick Mash	CM
2	Broiler Starter Pellet	SP
3	Finisher Vital	FV
4	Finisher Ultima	FU
5	Layer Mash	LM
6	Super Chick	SC
7	Super Starter Ultima	SSU
8	Super Starter Vital	SSV
9	Pre-Layer Ultima	PLU
10	Pre-Layer Vital	PLV

2.3 Sample Preparation

The collected poultry feed samples were air-dried and homogenized before being ground into a fine powder using a mechanical grinder. The powdered samples were sieved to obtain a relatively uniform particle size of approximately 100–200 mesh. Approximately 5 g of each prepared sample was transferred into a 32 mm sample cup covered with a 4 µm polypropylene X-ray film. The samples were then compressed using a hydraulic press to prepare specimens for energy-dispersive X-ray fluorescence (EDXRF) analysis.

2.4 Determination of Potentially Toxic Elements

The elemental composition of the poultry feed samples was determined using a Rigaku NEX DE energy-dispersive X-ray fluorescence (EDXRF) spectrometer equipped with a 15-position automatic sample changer and operated under a helium atmosphere. The instrument used a palladium X-ray tube operated at 60 kV and 10 µA, a 10 mm beam, and a silicon drift detector. Elemental concentrations were quantified using the fundamental parameters (FP) method implemented in the Rigaku RPF-SQX software.



The elements targeted for analysis were manganese (Mn), copper (Cu), nickel (Ni), strontium (Sr), yttrium (Y), zirconium (Zr), scandium (Sc), niobium (Nb), tin (Sn), and silver (Ag).

2.5 Quality Assurance and Quality Control

The analytical procedure included cleaning the sample-preparation equipment and sample holders before use to minimize potential contamination. All samples were analyzed under the same reported instrumental conditions, and elemental concentrations were calculated using the FP method implemented in the instrument software. Instrument operation followed the manufacturer's specifications.

3.0 Results and Discussion

3.1 Concentrations of Selected Elements in Commercial Poultry Feeds

The concentrations of selected elements in the ten commercial poultry feed samples collected from Gombe Metropolis are presented in Table 2. The elements analysed were bromine (Br), nickel (Ni), barium (Ba), strontium (Sr), yttrium (Y), zirconium (Zr), scandium (Sc), niobium (Nb), tin (Sn), and silver (Ag). All concentrations are expressed in milligrams per kilogram (mg/kg), equivalent to parts per million (ppm) on a mass basis.

The results revealed differences in elemental concentrations among the sampled products. Bromine, strontium, yttrium, and zirconium were detected in all ten samples. Barium was detected in seven samples, silver in five, niobium in three, nickel and scandium in two each, and tin in one sample. The distribution indicates that the occurrence and concentration of the measured elements varied among the commercial feed products.

Table 2. Concentrations of selected elements in commercial poultry feed samples determined using EDXRF (mg/kg)

Sample code	Br	Ni	Ba	Sr	Y	Zr	Sc	Nb	Sn	Ag
CM	100	121	682	4,260	212	783	ND	ND	ND	ND
SP	127	ND	ND	5,050	338	466	ND	ND	ND	141
FV	213	ND	644	4,400	209	553	ND	57.7	ND	94.9
FU	132	ND	529	4,870	237	365	ND	ND	ND	124
LM	48.8	124	320	17,200	26.3	737	29,300	ND	ND	ND
SC	118	ND	ND	4,470	145	478	ND	ND	ND	68.1
SSU	110	ND	727	5,580	143	386	ND	ND	ND	ND
SSV	133	ND	447	6,220	233	540	ND	54.4	ND	ND
PLU	77.4	ND	ND	4,230	222	540	ND	ND	ND	125
PLV	103	ND	484	1,290	117	3,990	12,900	62.5	82.4	ND

Note. ND = not detected. Concentrations are expressed in mg/kg (ppm). ND indicates that no numerical concentration was reported for the element in the sample

Contaminants and trace elements can enter animal feeds through raw materials, mineral ingredients, environmental exposure, processing, and storage. D'Mello (2004) described the importance of feed contaminants in animal production, while Järup (2003) discussed the potential health implications of exposure to toxic metals. In Nigeria, Ifie *et al.*

(2022) investigated aflatoxins and selected heavy metals in maize and poultry feeds from Delta State and reported that some samples exceeded the comparison limits used in their study for lead, cadmium, and chromium. Although those elements differ from most of the elements investigated in the present study, the findings demonstrate the relevance of



evaluating elemental contaminants in poultry feeds.

3.2 Descriptive Statistics of Elemental Concentrations

The descriptive statistics for the measured elements are presented in Table 3. The statistics summarize the detection frequency and the range of reported concentrations across the ten

samples. For elements detected in all samples, the mean and median were calculated using all ten values. For elements detected in fewer than ten samples, the mean and median were calculated using detected values only, without assigning zero to non-detects.

Table 3. Descriptive statistics and detection frequencies of selected elements in commercial poultry feed samples

Element	Detection frequency (%)	Number of samples detected	Mean of detected values (mg/kg)	Median of detected values (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Br	100	10	116.2	114.0	48.8	213
Ni	20	2	122.5	122.5	121	124
Ba	70	7	547.6	529.0	320	727
Sr	100	10	5,757.0	4,670.0	1,290	17,200
Y	100	10	188.2	221.5	26.3	338
Zr	100	10	883.8	509.0	365	3,990
Sc	20	2	21,100.0	21,100.0	12,900	29,300
Nb	30	3	58.2	57.7	54.4	62.5
Sn	10	1	82.4	82.4	82.4	82.4
Ag	50	5	110.6	124.0	68.1	141

Strontium had the highest mean concentration among the elements detected in all ten samples, followed by zirconium, bromine, and yttrium. The mean strontium concentration was 5,757 mg/kg, compared with a median of 4,670 mg/kg. This difference was influenced by the high value recorded for Layer Mash (LM). The reported strontium concentration in LM was 17,200 mg/kg, approximately 13.3 times the 1,290 mg/kg recorded in Pre-Layer Vital (PLV).

Zirconium also exhibited considerable variation, ranging from 365 mg/kg in Finisher Ultima (FU) to 3,990 mg/kg in Pre-Layer Vital (PLV). The mean concentration of 883.8 mg/kg was higher than the median of 509 mg/kg, reflecting the influence of the high reported value in PLV. Yttrium concentrations ranged

from 26.3 to 338 mg/kg, while bromine concentrations ranged from 48.8 to 213 mg/kg. Among the detected elements, the mean concentration of nickel was 122.5 mg/kg, based on two detections. Barium had a mean concentration of 547.6 mg/kg among seven detected samples. Niobium had a mean of 58.2 mg/kg, while the only reported tin concentration was 82.4 mg/kg. Silver was detected in five samples, with a mean of 110.6 mg/kg. These descriptive statistics indicate variation in the reported elemental composition of the sampled feeds but do not establish differences across the entire commercial feed market.

3.3 Bromine (Br)

Bromine was detected in all ten poultry feed samples, with concentrations ranging from



48.8 mg/kg in Layer Mash (LM) to 213 mg/kg in Finisher Vital (FV). The mean concentration was 116.2 mg/kg, while the median was 114.0 mg/kg. Finisher Vital had the highest reported bromine concentration, whereas Layer Mash had the lowest.

Orobchenko *et al.* (2022) investigated bromine in chicken eggs, feed, and water from different regions of Ukraine using X-ray fluorescence analysis. Their work provides relevant context for evaluating bromine occurrence in poultry production systems. The bromine concentrations in the present study were also reported in the original manuscript as higher than the range of approximately 0.84–13.49 mg/kg attributed to that study. The difference indicates variation between the reported datasets, although direct comparison depends on the sample matrices, analytical methods, and concentration bases used in the respective studies.

The European Food Safety Authority (EFSA) assessed the risks associated with bromide in food and feed and established maximum safe concentrations for bromide in complete feed, including 4.5 mg/kg for chickens for fattening and 6.6 mg/kg for laying hens (EFSA Scientific Committee, 2025). Bromide exposure is of toxicological interest because of potential effects on the thyroid and nervous system. However, EDXRF measures total elemental bromine and does not distinguish bromide ions from other bromine-containing compounds. The measured bromine concentrations therefore describe total elemental bromine in the samples and are not directly equivalent to the bromide-specific concentrations used in the EFSA assessment.

Differences in bromine concentrations among feed products may be associated with variation in raw materials, mineral ingredients, or environmental inputs. These possible sources were not separately evaluated in the present study. The findings establish the occurrence of measurable bromine in all ten samples and

provide information on its distribution across the products examined.

3.4 Barium (Ba)

Barium was detected in seven of the ten samples, corresponding to a detection frequency of 70%. The concentrations ranged from 320 mg/kg in Layer Mash (LM) to 727 mg/kg in Super Starter Ultima (SSU). The mean concentration among detected samples was 547.6 mg/kg, and the median was 529 mg/kg.

Barium is a naturally occurring element found in mineral deposits and may enter animal feeds through mineral-bearing ingredients and environmental sources. Its toxicological significance depends on the chemical form, concentration, and level of exposure. The National Research Council (NRC, 2005) provides information on mineral tolerances in animal diets, including the importance of considering the dietary basis and the relevant chemical form when interpreting mineral concentrations.

The concentrations reported in the present samples were higher than the 20 mg/kg maximum tolerable level attributed to NRC (2005) in the original manuscript. This comparison should be interpreted in the context of the exact NRC entry and the form of barium to which it applies. Total elemental barium measured by EDXRF is not necessarily equivalent to the concentration of a specific soluble barium compound.

Browning (2017) also worked on barium concentrations and tolerance. The report concerns dietary strontium carbonate and eggshell quality in laying hens, rather than establishing a barium-specific tolerance value. It therefore provides context for strontium research but is not a direct basis for interpreting barium concentrations.

The detection of barium in seven samples indicates that the element was present in a substantial proportion of the sampled products. The observed differences may reflect variation



in feed composition or the mineral content of raw ingredients. The present results describe elemental occurrence and concentration; they do not independently establish adverse effects in poultry.

3.5 Nickel (Ni)

Nickel was detected in Chick Mash (CM) and Layer Mash (LM), at concentrations of 121 and 124 mg/kg, respectively. The mean concentration of the two detected values was 122.5 mg/kg. No numerical nickel concentration was reported for the remaining eight samples.

Nickel can occur in animal feeds through raw materials, mineral ingredients, and environmental inputs. Igwemmar *et al.* (2022), who reportedly measured a concentration of 1.66 ± 0.82 mg/kg, and Islam *et al.* (2017), who reported concentrations ranging from 0.28 to 2.11 mg/kg. These studies provide comparative context for nickel occurrence in feed-related samples, although differences in sample type, analytical procedures, and reporting units influence the interpretation of numerical comparisons.

Järup (2003) reviewed the potential health effects of exposure to toxic metals, including the importance of dose and exposure pathways. The original manuscript also cited Genchi *et al.* (2020) in relation to nickel toxicity. Such literature provides a basis for considering nickel as a potential contaminant, but toxicological effects depend on the chemical form, exposure level, duration, and biological availability of the element.

The reported nickel concentrations were similar in the two samples in which the element was detected. The limited number of detections means that the results describe the two positive samples rather than the overall nickel distribution in all commercial poultry feeds. No animal-feeding experiment or tissue analysis was conducted; consequently, the measurements provide information on feed

composition rather than direct evidence of nickel-related health effects.

3.6 Strontium (Sr)

Strontium was detected in all ten poultry feed samples, with concentrations ranging from 1,290 mg/kg in Pre-Layer Vital (PLV) to 17,200 mg/kg in Layer Mash (LM). The mean concentration was 5,757 mg/kg, and the median was 4,670 mg/kg. Layer Mash recorded the highest reported concentration, while Pre-Layer Vital recorded the lowest. Browing & Cowieson (2013) investigated strontium concentration in animal-feed ingredients and reported concentrations of up to 329 mg/kg in limestone and approximately 159 mg/kg in meat and bone meal.

Navidshad & Mohammadrezaei (2017) also discussed strontium in the context of poultry nutrition and mineral elements. These sources provide background on the occurrence and biological relevance of strontium, although comparisons depend on the original analytical methods, sample types, and reporting basis.

Strontium is a naturally occurring element associated with rocks, soils, and mineral materials. It may enter poultry feed through plant-based ingredients or mineral sources. Because strontium and calcium share some chemical properties, strontium exposure is relevant to the study of mineral metabolism and skeletal tissues. Its biological effects depend on the concentration, chemical form, and bioavailability.

The wide range observed in the present samples indicates differences in the reported strontium concentrations among products. The particularly high value recorded for Layer Mash contributed substantially to the mean. The results provide quantitative information on strontium in the sampled products, but do not independently establish the source of the element or its effects on poultry.

3.7 Yttrium (Y)

Yttrium was detected in all ten samples, with concentrations ranging from 26.3 mg/kg in



Layer Mash (LM) to 338 mg/kg in Broiler Starter Pellet (SP). The mean concentration was 188.2 mg/kg, while the median was 221.5 mg/kg. The highest concentration was recorded in SP and the lowest in LM.

Ramos *et al.* (2016) reviewed rare earth elements in the soil environment, while Lei and Lui (1997) reviewed rare-earth elements as poultry-feed additives. These sources provide background for the occurrence and use of rare-earth elements; however, the specific yttrium concentration range attributed to Ramos *et al.* should be checked against the original paper before it is used for a numerical comparison.

Yttrium is a rare-earth element associated with mineral materials and geological sources. It may enter feed through raw materials or mineral ingredients. Its nutritional role in poultry is not established in the present study, and the measurements do not determine its chemical form or bioavailability. The distribution observed here indicates that yttrium was consistently reported across the ten products, although the concentrations varied considerably.

The results contribute baseline information on yttrium occurrence in commercial poultry feeds sampled in Gombe Metropolis. They do not establish a specific toxicological effect or a regulatory exceedance, as no verified feed-specific criterion was applied in the analysis.

3.8 Zirconium (Zr)

Zirconium was detected in all ten poultry feed samples. Concentrations ranged from 365 mg/kg in Finisher Ultima (FU) to 3,990 mg/kg in Pre-Layer Vital (PLV). The mean was 883.8 mg/kg, and the median was 509 mg/kg. The highest reported value occurred in PLV, while FU had the lowest.

Frommel *et al.* (1993) reported zirconium concentrations of 618 ± 87 ppm in soil from an area of the Ethiopian Rift Valley, with lower concentrations in neighboring areas. Because those measurements were from soil rather than poultry feed, they are not directly comparable

with the concentrations measured in the present study. Beynen (2024) discussed zirconium in pet food, but the relevance of any numerical comparison should be assessed using the original publication and comparable sample matrices.

Zirconium occurs naturally in rocks and minerals and may be present in raw materials used in feed production. The concentrations reported in the sampled products varied widely, with the high value in PLV influencing the mean. The occurrence of zirconium in all ten samples suggests that it was consistently reported by the analytical method used in the study.

The biological role of zirconium in poultry is not established by these results. The measurements describe total elemental concentrations and do not determine chemical form, bioavailability, or potential biological effects. They therefore provide information on elemental occurrence in the sampled products rather than direct evidence of adverse effects.

3.9 Scandium (Sc)

Scandium was reported in two samples: Layer Mash (LM), at 29,300 mg/kg, and Pre-Layer Vital (PLV), at 12,900 mg/kg. The mean of these two values was 21,100 mg/kg. No numerical scandium concentration was reported for the other eight samples.

According to Anas and Abdullahi (2017) scandium concentrations of 0.21–0.81 mg/kg in broiler feeds were reported. The concentrations reported in the present samples are substantially higher than that range. The original manuscript also cites Lei & Lui (1997) in relation to the occurrence of rare-earth elements in animal feeds. These references provide a basis for comparing the reported occurrence of scandium and related elements, subject to the analytical and matrix differences between studies.

Scandium is associated with mineral materials and geological sources. Its occurrence in feed may be related to raw-material composition or mineral inputs. However, the present study did



not determine the source, chemical form, or bioavailability of scandium. The reported concentrations were markedly different between the two samples, with LM having the higher value.

The results show that scandium was reported in two of the ten products analyzed. Its biological significance in poultry cannot be determined from elemental concentration data alone. The findings therefore contribute information on the reported occurrence of scandium in the sampled feed products.

3.10 Niobium (Nb)

Niobium was detected in three samples: Finisher Vital (FV), Super Starter Vital (SSV), and Pre-Layer Vital (PLV), at concentrations of 57.7, 54.4, and 62.5 mg/kg, respectively. The mean concentration among these samples was 58.2 mg/kg, while the median was 57.7 mg/kg. The concentrations varied over a relatively narrow range of 54.4–62.5 mg/kg.

According to Beynen (2023) and Kabata-Pendias (2011) niobium concentrations approaching 11.41 mg/kg were observed some environmental and biological materials. These references provide comparative context for niobium occurrence, although the relevance of the reported 11.41 mg/kg value depends on the original sample matrix and analytical method. Concentrations in animal tissues, soil, and feed are not directly interchangeable.

Niobium occurs naturally in mineral deposits and may enter animal feed through mineral-bearing raw materials. The results indicate that the element was reported in three of the ten products, with the highest concentration in PLV and the lowest in SSV. The current measurements do not establish the source of niobium or its biological availability. They provide a record of its reported occurrence and concentration in the sampled products.

3.11 Tin (Sn)

Tin was detected in one sample, Pre-Layer Vital (PLV), at a concentration of 82.4 mg/kg. The other nine samples had no numerical tin

concentration reported. Consequently, the result characterizes the single detected sample rather than the distribution of tin across the full set of products.

Huang *et al.* (2015) investigated the effects of dietary tin supplementation on broiler chickens using experimental diets containing different concentrations of tin supplied as stannous chloride. Their study examined growth performance, hematological and serum biochemical parameters, antioxidant status, and tin retention. The findings showed that high dietary supplementation affected performance and selected physiological indicators. The experimental results provide context for the biological relevance of dietary tin, although concentrations of an added tin compound in a controlled feeding study are not directly equivalent to total tin measured in commercial feed.

Based on the work of Morshdy *et al.* (2023) tin concentrations were observed to range from 1.14–10.50 mg/kg in chicken meat. The values relate to a different sample matrix from poultry feed, so they should be interpreted as contextual rather than direct feed-to-feed comparisons. Tin concentrations in animal tissues may reflect exposure, absorption, distribution, and elimination rather than the concentration in feed alone.

The reported concentration of 82.4 mg/kg in PLV indicates that tin was measurable in one of the sampled products. As the analysis did not determine the chemical form of tin or measure tin in poultry tissues, the results describe its occurrence in the feed and do not establish the degree of absorption or any resulting biological effect.

3.12 Silver (Ag)

Silver was detected in five of the ten samples, corresponding to a detection frequency of 50%. The concentrations ranged from 68.1 mg/kg in Super Chick (SC) to 141 mg/kg in Broiler Starter Pellet (SP). The mean concentration



among detected samples was 110.6 mg/kg, and the median was 124 mg/kg.

The original manuscript cites Pandey and Madhuri (2014) for a silver concentration of 0.60 mg/kg in animal tissues. It also cites McGillicuddy *et al.* (2017) in relation to the occurrence of silver in environmental and biological materials. The reported concentrations in the present samples are higher than the value attributed to Pandey and Madhuri (2014). However, animal tissue and feed are different matrices, and numerical differences between them do not by themselves establish the degree of exposure or biological accumulation.

Silver is not recognized as an essential nutrient for poultry. Its occurrence in feed may be associated with raw materials, mineral inputs, or environmental sources. The present study did not identify the source of silver, determine its chemical form, or measure its transfer into poultry tissues or eggs.

The results indicate that silver was reported in half of the sampled products, with the highest concentration in SP and the lowest in SC. These findings provide information on the occurrence and distribution of silver in the examined commercial feeds. They do not independently establish a regulatory exceedance or demonstrate adverse effects in poultry or consumers.

3.13 Overall Discussion

The EDXRF results provide a preliminary characterization of ten elements in ten commercial poultry feed samples collected from Gombe Metropolis. Bromine, strontium, yttrium, and zirconium were reported in all samples, while the other elements were detected in between one and seven samples. The descriptive statistics indicate variation in the reported elemental composition of the products, particularly for strontium and zirconium.

The Nigerian study by Ifie *et al.* (2022) provides relevant evidence that elemental contaminants occur in maize and poultry feed

samples in Nigeria. D'Mello (2004) also described the importance of evaluating feed contaminants as part of animal-feed quality and safety assessment. These studies support the broader relevance of feed monitoring, although the elements measured and the concentrations reported in those studies are not identical to those in the present work.

The measured concentrations describe the elemental composition of the sampled products as reported by EDXRF. Elemental analysis does not, on its own, establish chemical speciation, bioavailability, animal exposure, or toxicological effects. The interpretation of any element therefore depends on the applicable evidence for its chemical form, dietary concentration, exposure conditions, and biological effects. This distinction is particularly important when comparing total elemental concentrations with benchmarks developed for specific chemical compounds or ions, as in the case of bromide-specific feed guidance.

The study contributes baseline data on selected elements in commercial poultry feeds available in Gombe Metropolis. The observed differences among products indicate that elemental concentrations were not uniform across the sampled feeds. The results provide a basis for describing elemental occurrence in these products and for comparison with other studies that use compatible sample matrices, analytical methods, and reporting unit

4.0 Conclusion

This study assessed the concentrations of selected elements in ten commercial poultry feed samples marketed in Gombe Metropolis, Nigeria, using energy-dispersive X-ray fluorescence (EDXRF). The results revealed variations in elemental concentrations among the samples, with bromine, strontium, yttrium and zirconium detected in all samples, while nickel, barium, scandium, niobium, tin and silver occurred at varying detection frequencies. Strontium showed particularly high



concentrations in some samples, while elevated values of scandium and zirconium were also recorded in specific feeds. These findings demonstrate differences in the elemental composition of the poultry feeds examined and highlight the importance of monitoring feed quality to support animal health and food safety. However, the measured concentrations alone do not establish toxicity or regulatory non-compliance, which depend on the relevant element-specific standards, chemical forms and exposure conditions.

Routine monitoring of commercial poultry feeds in Gombe Metropolis should be strengthened to assess elemental composition and identify potential contamination. Feed manufacturers should maintain effective quality-control procedures for raw materials, processing equipment and finished products to minimise the introduction of undesirable elements. Regulatory agencies should promote periodic laboratory testing of poultry feeds and compare verified results with applicable national and international standards. Further studies should include a larger number of samples from different manufacturers, production batches and locations to establish a more representative assessment of feed quality. Confirmatory analyses using appropriate validated analytical methods should also be undertaken, particularly for samples with unusually high measured concentrations. Where necessary, additional investigations should examine the chemical forms and bioavailability of the detected elements to improve interpretation of their potential implications for poultry health and human food safety.

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Declarations

Consent for publication

Not Applicable

Data Availability Statement:

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.



Conflict of Interest

The authors have no competing interests to declare that are relevant to the content of this article.

Ethical Considerations

Not applicable

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Usman Muhammad Bakura conceived the study, participated in the methodology, and prepared the initial manuscript. Ishiyaku Ibrahim Babayo contributed to the study design, EDXRF analysis, and interpretation of the results. Hamza Abubakar Hamza contributed to data analysis, interpretation of elemental concentrations, and manuscript review. Hankouraou Seydou contributed to the analytical procedures, data validation, and interpretation of findings. Bala Suleiman Musa contributed to the methodology, scientific review, and critical revision of the manuscript. James Andrews Philip contributed to data interpretation, literature review, and manuscript editing. All authors reviewed and approved the final manuscript.

