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Assessment of heavy metals and proximate composition in poultry feed: a study from Dhaka and Rangpur, Bangladesh

A. Tabassum, M. T. Hassan*, M. M. Hasan, S. M. Islam and M. Begum

Institute of Food Science and Technology (IFST) Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, 1205, Bangladesh

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Abstract

The study investigates the contamination concentrations of heavy metals lead (Pb), cadmium (Cd), and chromium (Cr) in commercial poultry feeds in Bangladesh and evaluates their proximate composition. Using atomic Absorption Spectrophotometry for heavy metal analysis and standard methods for proximate composition, the study analyzed 50 poultry feed samples. Results revealed significant heavy metal contamination in a substantial number of samples, with Pb (≤4.65 mg/kg), Cd (≤0.398 mg/kg), and Cr (≤16.13 mg/kg) levels exceeding permissible limits set by regulatory bodies. This contamination poses serious health risks to poultry and humans, highlighting the potential for bioaccumulation and subsequent entry into the human food chain. Furthermore, the proximate composition analysis showed considerable variability in nutrient profiles among different feed brands, raising concerns about the adequacy of nutritional quality. The findings emphasize the urgent need for firm regional regulation and regular monitoring of poultry feed quality in Bangladesh to ensure public health safety and enhance poultry production sustainability. Implementing comprehensive quality control measures will protect consumer health and support the growth and profitability of the poultry industry in the country.

Keywords: Poultry feed; Heavy metals; Proximate composition; Assessment

Introduction

In Bangladesh, the poultry sector is a crucial sub-sector of livestock production, contributing significantly to economic growth and creating numerous employment opportunities (Islam *et al.* 2014). As the fastest-growing segment of the agricultural sector, the poultry industry provides a cost-effective and nutritious source of animal protein in the form of meat and eggs (Rahman *et al.* 2021). In order to provide a secure and affordable source of animal protein, feed is the most vital component. An IDLC report (2020) stated that the increasing demand for protein-rich diets over the decade has driven nearly a 25% expansion in the commercial poultry feed sector, establishing of many commercial feed mills. However, with the exponential farming activities and feed productivity, numerous environmental challenges also increase, such as pollution with heavy metals (Ullah *et al.* 2017). The raw materials for these poultry feed, like corn, soybean meal, rice bran, and palm oil, originate from various sources and are often exposed to anthropogenic pollutants, including heavy metals (Hossain *et al.* 2007; Imran *et al.* 2014). These metals can enter the food chain through bioaccumulation in feed ingredients, posing significant health risks to consumers. Heavy metals in poultry feed can arise from contaminated fish meal, crops absorbing metals from polluted soil and water, and agricultural inputs like fertilizers and pesticides (Ali and Khan, 2019). Their toxicity and bioaccumulation have been widely studied due to potential health risks.

Studies across South Asia, including Bangladesh, India, and Pakistan, have highlighted the concentrations of toxic metals like lead, cadmium, chromium, mercury, and nickel in poultry feed, frequently associated with anthropogenic activities (Mahmood *et al.* 2004;

*Corresponding author's e-mail: mthassan_bcsir@bcsir.gov.bd

Islam *et al.* 2018). In Bangladesh, industrial operations including tanneries, leather processing, textile dyeing units, sulfuric acid manufacturing, and ceramics production are recognized as major sources of such contamination (Hossain *et al.* 2007; Islam *et al.* 2018; Tabassum *et al.* 2025). These industries release substantial amounts of toxic elements like cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), and so on metals into surrounding ecosystems, including soil, crops, and water bodies, thereby intensifying environmental pollution. This significant presence of heavy metals in food represents a threat to the human body (Wang and Du, 2013; Lyon, 2014; Flora *et al.* 2012). That's why, in recent years, awareness regarding food safety has intensified research efforts focusing on evaluating the potential risks posed by these metals in both animal feed and food products (Monsour *et al.* 2009).

Contamination in poultry feed is an escalating worldwide issue, due to increasing environmental deterioration (Shahriar *et al.* 2025). Even small amounts of pollutants in feed can adversely affect poultry health, causing stunted growth, organ damage, and even death, thereby posing risks to both poultry production and ecological stability (Shahriar *et al.* 2025). Among these metals like cadmium (Cd), lead (Pb), and chromium (Cr) are particularly concerning because of their toxic and potential carcinogenic properties, even found in minimal presence (Muhyaddin *et al.* 2015; Adekoya *et al.* 2018; Duman *et al.* 2019). The United States Environmental Protection Agency identifies these metals as some of the most hazardous environmental contaminants (Lei *et al.* 2010), as they persist in the environment, resist degradation, and accumulate in animal tissues over time, leading to acute and chronic health disorders in humans. The World Health Organization (WHO) has highlighted the health risks associated with heavy metals in broiler meat. Their bioaccumulation can lead to neurotoxicity, nephrotoxicity, and hormonal imbalances, affecting blood, gastrointestinal, and cardiovascular systems of humans (IARC 1993; WHO 1992; WHO 1993; Järup 2003).

Ensuring proper nutrition is essential for a sustainable poultry feed industry, alongside addressing heavy metal contamination. In Bangladesh, feed formulation quality and production efficiency directly impact poultry performance and farm profitability (Ali and Hossain, 2010). However, small and mid-sized feed producers often lack expertise in nutrition, formulation, premixes, additives, enzymes, and proper storage, leading to low-quality feed and suboptimal poultry growth. Limited access to modern equipment further increases production inefficiencies and inconsistencies in feed quality. Farmers typically purchase feed from various markets but often lack the resources to assess its quality. Many rely on secondary information to formulate rations, leading to nutrient imbalances that deviate from optimal standards. Undetected deficiencies in essential nutrients such as protein, fat, energy, minerals, and vitamins can severely impact animal performance (Rahman *et al.* 2014). Therefore, year-round nutrient analysis is crucial to evaluating feeding practices and ensuring high-quality poultry feed across Bangladesh. The Food and Agriculture Organization (FAO) has identified feed quality as a key barrier to sustainable agricultural development, emphasizing its importance in enhancing livestock production and achieving food security (Ravindran, 2013).

Therefore, this study aims to assess the concentrations of heavy metals and evaluate the proximate composition of commercial poultry feeds obtained from different regional markets in Bangladesh. Unlike earlier research that often focused solely on isolated or urban areas, this investigation incorporates samples from both Dhaka—a densely populated urban center—and Rangpur—a representative peri-urban district in the north, offering a more comprehensive understanding of the nationwide variability in feed quality and safety. By generating regionally inclusive data, the study aims to contribute to sustainable agricultural practices, improve poultry productivity, and ensure the safety of poultry products across Bangladesh.

Materials and methods

Sample collection

The research was conducted between December 2023 and June 2024 in two strategically selected districts of Bangladesh—Dhaka and Rangpur—to ensure regional diversity and representativeness of the country's commercial poultry feed market (Fig. 1). Dhaka serves as a major center for industrial feed production and distribution, while Rangpur represents a growing, agriculture-based market with limited industrialization. A total of 50 poultry feed samples were collected, with 25 samples obtained from each district. The study targeted feed types formulated for broiler, layer, and sonali breeds, which are the most widely farmed poultry varieties in the country, including at the household level. Each sample weighing between 0.5 and 1 kg was sealed in labeled resealable bags and conveyed to the Food Toxicology Research Section, IFST, BCSIR. Upon arrival, the samples were kept at −20°C until laboratory analysis.

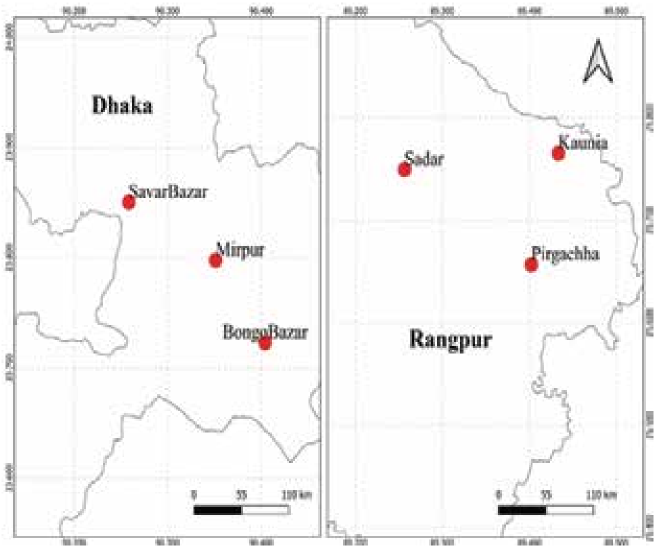

Fig. 1. Map representing poultry feed samples collected from the three locations of Dhaka and Rangpur districts, Bangladesh

Proximate Composition Analysis of Feed Samples

Chemicals

Analytical-grade chemicals were used in the study including anhydrous sodium sulfate (99.0%), concentrated sulfuric acid (98%), selenium dioxide (>96.0%), hydroquinone, and sodium sulfite, all sourced from Merck Co. (Germany). Additional chemicals such as potassium persulfate (>99.0%), boric acid (>99.0%), sodium hydroxide, and ammonium molybdate were obtained from Thermo Fisher Scientific (UK). Standards for calcium, sodium, and potassium were supplied by Inorganic Ventures (Virginia, USA).

Preparation of sample and proximate analysis procedure

For proximate composition analysis, all the feed samples were processed following the standard analytical methods of the Association of Official Analytical Chemists (AOAC, 1995). Before analysis, all samples were set aside at room temperature. To determine moisture content, 7 grams of each sample were taken in a porcelain cup and dried in an oven at 105°C overnight, with moisture percentage calculated based on weight loss before and after drying (AOAC 930.15). The dried samples were then used for ash content analysis by incinerating them in a muffle furnace at 600°C for 20 hours, until only ash remained (AOAC 942.05). The amount of crude protein was obtained using the micro-Kjeldahl method, which estimates protein by measuring nitrogen content. Crude lipid was extracted using the Soxhlet apparatus, per AOAC 2003.05. For crude fiber determination, samples were defatted with petroleum ether and analyzed using the AOAC 925.10 procedure. The content of carbohydrate was estimated by deducting the total percentages of moisture, protein, ash, fat, and fiber from hundred, based on the AOAC (2000) guideline. The total energy level was calculated by standard caloric conversion factors: 4 kcal/g for protein and carbohydrates, and 9 kcal/g for fats, as per the method employed in this study (Vinberg and Duncan, 1971).

Heavy metals determination in feed samples

Samples digestion

A 5 g feed sample was weighed into a crucible, and 5 mL of concentrated nitric acid (69%) was added in a fume hood. The sample was initially incinerated on a hotplate, followed by further ash formation for 6 hours in a muffle furnace at 600°C. After ash formation, the sample was re-digested with 10 ml of hydrochloric acid (37%) under fume hood conditions. The resulting extracts were carefully filtered through filter paper (Whatman No. 1, 12.5-cm) and measured into a 100-mL volumetric flask. Following a brief boiling step, the volume was brought up to 100 ml with deionized water, resulting in a clear or transparent solution. All these analytical grade chemicals were sourced from Merck (USA) (Tabassum *et al.* 2025).

Determination of heavy metals

Heavy metal concentrations were determined following the procedure described in Tabassum *et al.* (2025), with modifications to accommodate the poultry feed sample matrix. The extracted solutions were examined with a Shimadzu AA 7000 Atomic Absorption Spectrophotometer, utilizing argon used for the combustion gas and air as the oxidizing agent. Heavy metal concentrations were quantified based on calibration curves derived from standard solutions (Sigma Aldrich, Switzerland). The analytical procedure was validated using certified reference materials. Calibration standards were established in the range of 0.5–10.0 mg/kg for lead (Pb) and chromium (Cr), and 0.25–4 mg/kg for cadmium (Cd) to assess linearity. The detection limits for Pb, Cd, and Cr were determined to be 0.2 mg/kg, 0.1 mg/kg, and 0.23 mg/kg, respectively, while the quantification limits were 0.6 mg/kg for Pb, 0.33 mg/kg for Cd, and 0.75 mg/kg for Cr (Tabassum *et al.* 2025). Heavy metal concentrations were calculated using the equation:

Metal Concentration in sample = $R \times$ Dilution factor

where R indicates the Atomic Absorption Spectrophotometer (AAS) reading of the digest, and the dilution factor is the ratio of the final digest volume (mL) to the wet weight of the sample (Bhowmik *et al.* 2023). The correlation coefficients (r) for Pb, Cd, and Cr were 0.9999, 0.9998, and 0.9988, respectively, representing high precision. The mean recovery for Pb, Cd, and Cr were 94.8%, 96.1%, and 93.6%, respectively.

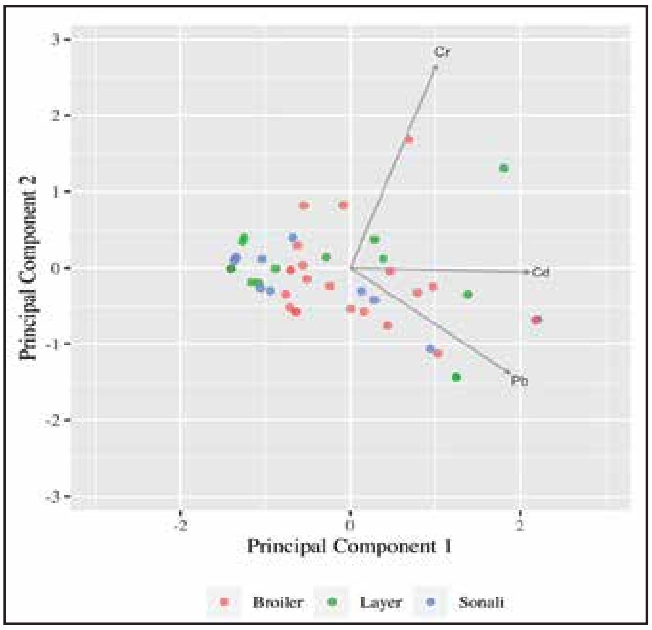

Fig. 2. Biplot representing Heavy Metals (Pb, Cd, Cr) in the three different poultry feeds analyzed

Statistical analysis

Statistical analyses were performed using R Studio version 4.2. The concentrations of heavy metals (Pb, Cr, Cd) and the proximate composition of the feed samples were evaluated by calculating the mean values along with their standard deviations. The non-parametric Kruskal-Wallis H test was done to assess significant differences in heavy metal accumulation among the samples. Principal Component Analysis (PCA) was used to explore the distribution and presence of heavy metals in poultry feed samples (Fig. 2). Additionally, Pearson correlation analysis was conducted to examine potential relationships among the three heavy metals. The geographic coordinates of the sampling locations were processed using the WGS84 geodetic reference system and analyzed with QGIS version 3.16 (Hannover) (Fig. 1).

Results and discussion

Heavy metal analysis

The mean concentration with standard deviation of the heavy metals for three different types of poultry feed was analyzed (Table I). The analysis revealed a significant presence of lead (Pb), cadmium (Cd), and chromium (Cr) in all the feed

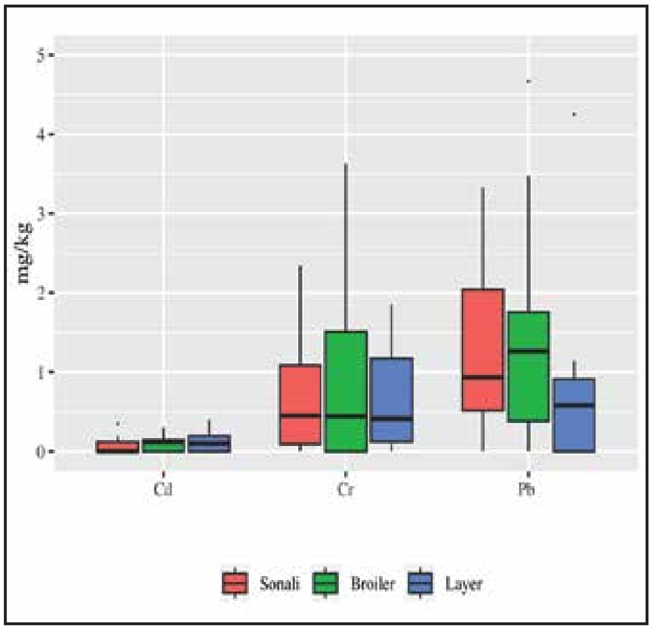

Fig. 3. Boxplot showing the concentration of the heavy metals (Cd, Cr, Pb) different types of poultry feed collected

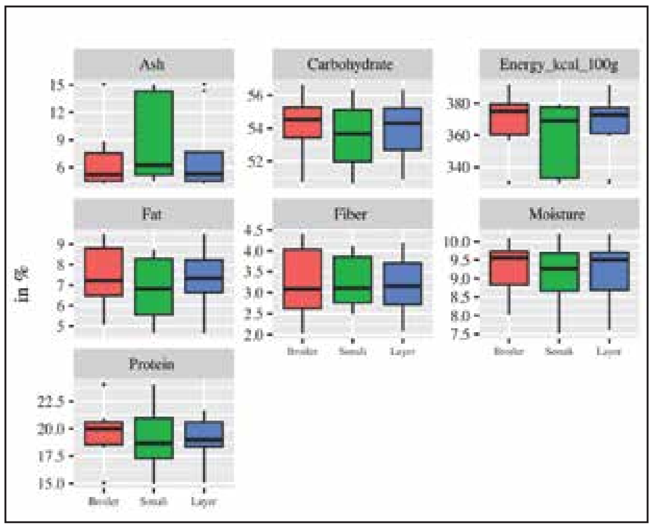

Fig. 4. Boxplot showing the proximate composition in the different types of poultry feed collected

Table I. Mean ± standard deviation of the heavy metal (Pb, Cd, Cr) analyzed on the sampled poultry feed

Feed	Broiler	Layer	Sonali
No. of feed samples	23	14	13
Heavy metals (mg/kg)			
Lead (Pb)	1.45±1.33	0.998±1.44	1.27±1.17
Chromium (Cr)	1.19±1.60	1.71±2.83	1.88±4.34
Cadmium (Cd)	0.10±0.11	0.12±0.13	0.09±0.13

Table II. Pearson Correlation of the heavy metals

	Pb	Cd	Cr
Pb	1	0	0
Cd	0.19	1	0
Cr	0.0063	0.099	1

Table III. Mean ± Standard deviation of the proximate compositions of poultry feed

	Moisture (%)	Ash (%)	Carb (%)	Fat (%)	Fiber (%)	Protein (%)	Energy (Kcal/g)
Broiler	9.26 ± 0.70	6.43 ± 3.11	54.09 ± 1.84	7.43 ± 1.51	3.14 ± 0.76	19.64 ± 2.12	369.98 ± 16.82
Layer	9.19 ± 0.79	7.39 ± 4.19	53.89 ± 1.7	7.39 ± 1.44	3.16 ± 0.68	18.96 ± 2.05	365.99 ± 21.01
Sonali	9.0 ± 0.83	8.44 ± 4.51	53.47 ± 1.89	6.79 ± 1.46	3.24 ± 0.57	19.04 ± 2.65	359.19 ± 20.46

samples. The mean concentrations in total feed samples were 1.682 mg/kg for Pb, 0.193 mg/kg for Cd, and 1.988 mg/kg for Cr. The maximum Pb concentration was found in broiler feed at 4.665 mg/kg, with significant concentrations also present in the feed for layer and sonali breeds at 4.25 mg/kg and 3.324 mg/kg, respectively. Both feed samples of the layer and the Sonali breed had Pb concentrations exceeding permissible limits (Table IV). The highest Cd content was observed in layer feed at 0.398 mg/kg, followed by 0.301 mg/kg in broiler feed and 0.352 mg/kg in sonali breed feed. Cr contamination was highly alarming, with a mean concentration of 1.988 mg/kg. Maximum Cr concentration was detected in Sonali breed feed at 16.133 mg/kg, while layer and broiler feeds contained 10.133 mg/kg and 6.829 mg/kg, respectively. Minimum Cr concentrations were observed at 0.12 mg/kg for broiler feed, 0.11 mg/kg for layer feed, and 0.13 mg/kg for sonali breed feed. Principal Component Analysis (PCA) was utilized to highlight the significant occurrence of heavy metals in the poultry feed samples (Fig. 2). However, the biplot indicated that the associations among the metals were not readily apparent. Each heavy metal can independently exist in a sample without affecting the quantity of other materials. A Kruskal-Wallis H test was conducted to determine the significant differences in the heavy metal (Pb, Cd, Cr) concentrations among the different types of poultry feed.

Proximate analysis

The mean concentration with a standard deviation of moisture, fat, ash, fiber, protein, and carbohydrate of the poultry feeds was analyzed (Table III). Results revealed that moisture content in poultry feed ranged from 7.52% to 10.2%, with broiler, layer, and sonali breed feeds showing ranges of 8.03%-10.09%, 7.61%-10.2%, and 7.52%-10.2%, respectively. Fat percentage, added to improve energy, varied from 5.07% to 9.49% for broiler feed, 4.65% to 9.49% for layer feed, and 4.67% to 8.72% for sonali breed feed. Ash content, reflecting inorganic mineral content, varied widely from 4.85% to 15.09% across all poultry samples. In the case of

Table IV. Standard safety level of the Heavy metals (mg/kg) and standard level of proximate composition (%) in different types poultry feed

Heavy metals (mg/kg)	Bangladesh standard (mg/kg) Fish and Animal Feed Act 2011, Bangladesh	WHO
Cr	0.10	0.05 (CAC, 1995)
Cd	0.05	0.003 (CAC, 1995)
Pb	0.30	0.01 (WHO, 2011)
Proximate Composition (%)	Fish and Animal Feed Act 2011, Bangladesh	
	Broiler Feed	Layer Feed
Protein	>21.20	>17.2
Moisture	10	10
Fat	5.0-7.0	5.0-7.0
Fiber	4.0-6.0	4.0-6.0
Energy	280 Kcal/g	275Kcal/g

Table V. Mean ± Standard deviation of the heavy metal (Cd, Cr, Pb) analyzed on the sampled Poultry feed collected from two districts of Bangladesh. (n= number of samples)

Sampling Location (n)	Cd (mg/kg)	Cr (mg/kg)	Pb (mg/kg)
Dhaka (25)	0.1621 ± 0.12	2.2781 ± 3.77	1.4717 ± 1.415
Rangpur (25)	0.0465 ± 0.089	0.7441 ± 0.926	1.0838 ± 1.184

fiber, the percentage varied between 2.03% and 4.11% in poultry feed. Protein, a critical nutrient affecting costs, ranged from 15.01% to 24.1% in poultry feed, with the highest protein content (21.66%) found in layer feed. Carbohydrates, also known as nitrogen-free extract, consistently showed higher levels, ranging from 50-56% for broiler, layer, and sonali breed feed. Energy content ranged between 329.71 and 392.12 Kcal/g for poultry feed. To assess significant differences in feed compositions, Kruskal-Wallis H tests were conducted.

Heavy metals are a diverse group of elements that play critical roles in biological systems but pose significant health risks when present in excessive amounts. Lead (Pb), chromium (Cr), and cadmium (Cd) are non-essential heavy metals (Olagunju *et al.* 2020) that can accumulate in organisms and cause harmful effects when ingested or absorbed. Studies have shown that chronic exposure to these metals through food, water, or environmental contamination can lead to serious health issues (Kim *et al.* 2019; Kim *et al.* 2020; Balali-Mood *et al.* 2021). WHO (2020) highlights that these metals with other heavy metals, are particularly hazardous substances due to their persistence in the body and ability to cause severe diseases in humans and animals (Järup, 2003; Wu *et al.* 2016). These metals are difficult for organisms to metabolize or excrete efficiently, leading to bioaccumulation and potential toxicity over time.

Lead (Pb) is a pervasive environmental pollutant with widespread industrial use in pesticides, paint pigments, crystal glass manufacturing, and plumbing (WHO, 2023). Despite its industrial utility, Pb poses considerable threats to human and animal health. This study reveals that Pb concentrations in most analyzed feed samples exceed permissible limits (Table IV). According to the Bangladesh Fish and Animal Feed Act of 2011, the allowable Pb limit is 0.30 mg/kg, whereas the WHO recommends a stricter limit of 0.01 mg/kg to mitigate health risks. Research conducted in different regions like Dhaka, Chittagong, Rajshahi, and Mymensingh reveals varying but consistently concerning levels of Pb in

Table VI. Tabulation of Kruskal-Wallis H test of heavy metals (Pb, Cd, Cr) and proximate composition for different feed of fish and shrimp. [$p<0.05$ at 5% level of significance]

Name	statistic	p.value	Alternative
Pb	2.47	0.2909	Reject
Cd	0.3966	0.8201	Reject
Cr	0.1245	0.9396	Reject

Name	statistic	p.value	Alternative
Moisture Percent	1.055	0.59	Reject
Ash Percent	2.684	0.2613	Reject
Protein Percent	0.4538	0.797	Reject
Fat Percent	1.676	0.4326	Reject
Fiber Percent	0.1867	0.9109	Reject
Carbohydrate Percent	1.024	0.5992	Reject
Energy Kcal 100g	1.683	0.431	Reject

poultry feed. For instance, Pb concentrations in broiler feed ranged from 355.46 µg/kg to 759.42 µg/kg in Dhaka, with higher levels reaching 934.60 µg/kg in Chittagong (Hossain *et al.* 2022). In Mymensingh, Pb levels in poultry feed were found to be 0.729 mg/kg (Sarker *et al.* 2017) and 0.16 mg/kg (Tithi *et al.* 2020), whereas recent studies in the Sherpur district reported no detectable Pb (Islam *et al.* 2023). In contrast, the average Pb content in the poultry feed from Rajshahi was 0.68 mg/kg, with a maximum concentration observed at 4.25 mg/kg (Shahriar *et al.* 2025). The contamination of poultry feed ingredients, such as commercial protein fish meal and meat and bone feed meal samples, highlights widespread Pb presence (Glencross *et al.* 2020). Mean concentrations ranged from 7.37-61.42mg/kg significantly (Jothi *et al.* 2016), indicating potential health risks associated with consumption. The impact of Pb contamination extends beyond mere environmental concerns to encompass significant health implications. Research has established a clear link between dietary Pb levels and the accumulation of lead residues in critical organs of laying hens, including the liver, kidneys, eggs, ovaries, and fallopian tubes (Suleman *et al.* 2022). Pb has a pronounced affinity for bone tissue, where it accumulates over time, replacing calcium and potentially leading to skeletal health issues in both animals and humans (Erickson and Kalscheur 2020; NRC 2005). In chicken, Pb accumulation in bones, kidneys, liver, and other tissues disrupts vital systems like the renal, endocrine, cardiovascular, immune, reproductive, and musculoskeletal systems (Bampidis *et al.* 2007).

The study reveals a significant concern regarding cadmium (Cd) contamination in poultry feed, with most samples exceeding the permissible limits (Table IV). The average concentration found was 0.193 mg/kg, far above the legal limit set by the Bangladesh Fish and Animal Feed Act of 2011 (0.05 mg/kg) and the stricter limit by the WHO (0.003 mg/kg) (CAC, 1995). The recent studies reported varying levels of Cd in broiler feed ranging from 3.0 µg/kg to 8.29 µg/kg in Dhaka, while 5.10 µg/kg to 16.75 µg/kg in Chittagong (Hossain *et al.* 2022). The average Cd concentration recorded was 0.21mg/kg in Rajshahi (Shahriar *et al.* 2025). In Mymensingh and surrounding districts, Cd concentrations in poultry feed varied between 1.167 - 2.093 mg/kg (Islam *et al.* 2023; Islam *et al.* 2024) and 0.021 to 0.026 mg/kg (Tithi *et al.* 2020). These findings consistently reveal the presence of Cd in the poultry feed, raising the high risk to poultry health. Chronic or excessive Cd exposure can lead to histopathological damage, kidney and liver impairment, and decreased performance in chickens (Kim, 2023). Cadmium intake negatively affects poultry growth, egg production, and alters tissue structures, increases oxidative stress, disrupts biomolecules, and leads to cell damage and necrosis, which are reflected in blood and biochemical parameters (Kar and Patra, 2021).

Heavy metals, particularly chromium (Cr), pose consequential dangers due to their extensive industrial applications, especially in tanning processes. Chromium can infiltrate poultry products and biomagnify within the food chain, presenting serious health risks (Hossain *et al.* 2009). In this study, Cr levels in most analyzed feed samples significantly surpassed the allowable limits (Table IV). According to the Bangladesh Fish and Animal Feed Act of 2011, the permissible limit for Cr is 0.1 mg/kg, whereas the WHO (2011) sets it at 0.05 mg/kg. Previous studies revealed that the mean concentration of Cr was 21.806 mg/kg in the poultry feed (Islam *et al.* 2024). The studies in Mymensingh and Rajshahi revealed the highest concentration of Cr, 334.82 mg/kg (Tithi *et al.* 2020) and 12.85 mg/kg (Shahriar *et al.* 2025), respectively, in the commercial poultry feed. The raw ingredients, like meat and bone feed meal samples, contained Cr levels between 9.15±1.29 and 40.59±1.54 mg/kg (Jothi *et al.* 2016). Under European Union regulations (EU, 2003), the use of chromium in any amount is prohibited in the raw materials of poultry feed, making its presence in commercial samples a major concern. The presence of chromium in these feed samples raises health concerns due to its ability to bioaccumulate through dietary pathways. For human consumption, acceptable chromium levels are typically between 0.1 and 0.5 mg/kg (Alkhalaf *et al.* 2010). A potential source of chromium contamination in poultry feed is tannery waste, with some effluents reported to contain chromium concentrations as high as 3956 mg/L (Tariq, 2009). Mottalib *et al.* (2018) observed elevated chromium (Cr) levels in chicken meat in Dhaka. The hexavalent form of Cr is particularly hazardous to birds, causing premature aging, impaired hatching ability, and liver damage (Asma *et al.* 1999). It also leads to fetal malformations or death, neural deformities, and DNA mutations. Chronic exposure to high doses of Cr disrupts gastrointestinal microflora (Shrivastava *et al.* 2002). Additionally, Cr is lethal to embryos, causing developmental defects and early chick mortality, negatively impacting chick growth and development (Asma *et al.* 1999). Excessive trace minerals in poultry feed can lead to toxicity, reducing egg production and causing defective embryo development (Miles, 2000).

The correlation analysis among heavy metals (lead, cadmium, and chromium) in poultry feed samples revealed negligible associations between their concentrations (Table II). The observed correlations were not statistically significant, implying that the presence of heavy metals does not predict the presence of others. This suggests that the contamination sources of these metals may differ and may be introduced into the feed through different environmental factors. Furthermore, the KW test was conducted to evaluate whether the concentrations of lead (Pb), cadmium (Cd), and chromium (Cr) differ significantly across various poultry feed types (Table VI). The findings suggest no statistically significant ($p<0.05$) differences, and the concentrations of these metals are relatively consistent across the different feed types analyzed.

A comparison of heavy metal concentrations between Dhaka and Rangpur (Table V) reveals clear regional variation. Cadmium and chromium levels were significantly higher in samples from Dhaka, likely reflecting increased industrial exposure and more complex feed distribution networks in urban settings. While lead was detected in both locations, its marginally higher concentration in Dhaka indicates more contamination sources. These results highlight the importance of regional surveillance, as even peri-urban areas like Rangpur showed measurable contamination. The findings emphasize the need for location-specific regulatory oversight to ensure the safety and quality of poultry feed nationwide.

Proximate composition analysis

Moisture content indicates the amount of water present in feeds. Analysis of poultry feed samples showed that most samples maintained appropriate moisture levels within allowable limits (Table IV). Some studies reported averages exceeding the maximum permissible limit at 11.02% (Hasan *et al.* 2022). This factor is crucial for quality assurance and safe storage (Islam *et al.* 2015; Bala, 2016). Increased moisture content raises the likelihood of fungal and microbial contamination (NRI, 1995). The ash content in feeds pertains to the inorganic mineral content, including essential minerals such as calcium, phosphorus, potassium, and magnesium. Commercial feeds typically have an ash content of around 8.85% (Hasan *et al.* 2022), and the current study found no exceedance of this level. Crude protein is a crucial nutrient in feed due to its cost and significant impact on growth and production (Hasan *et al.* 2022). Most poultry feed samples met the minimum standard values within the Bangladesh standard range, although some fell below these standards. High crude protein levels are vital for poultry growth, while low percentages can hinder the ability of digestive bacteria to maintain adequate levels for feed digestion (Hasan *et al.* 2022). Fats, as concentrated energy sources, influence growth rates, feed efficiency, diet palatability, feed dustiness, and pellet quality. In poultry diets, fats enhance the uptake of fat-soluble vitamins and contribute to feed acceptability (Ravindran, 2012; Baiao and Lara, 2005). The fat content in poultry feed samples adhered to the Bangladesh standard value, contributing to overall energy availability and improved growth performance and feed effectiveness (NRC, 1994). Carbohydrates are a vital energy source for poultry, derived from cereal feed ingredients like maize, rice, and wheat (Ofori *et al.* 2019). The carbohydrate content in the poultry feed samples was within the Bangladesh standard value. Metabolizable energy (ME) measures the feed portion that is available to poultry after digestion and metabolic losses (Ofori *et al.* 2019). In this study, the ME values of analyzed feed samples aligned within the recommended guidelines, averaging approximately 3200 kcal/kg for broiler feed and 2900 kcal/kg for layers feed (NRC, 1994). Statistically, there are no significant ($p<0.05$) differences in the components of proximate compositions of the analyzed feed (Table VI).

Conclusion

This study states significant concerns regarding the heavy metal contamination of commercial poultry feeds in Bangladesh. A substantial number of the samples analyzed were found to contain levels of lead (Pb), cadmium (Cd), and chromium (Cr) that exceeded the permissible limits established by regulatory bodies. The presence of these heavy metals in poultry feed is alarming due to their potential to accumulate in the tissues of poultry, thereby entering the human food chain and posing serious health risks to consumers. These findings emphasize the urgent need for stricter regional regulation and monitoring of feed quality to ensure poultry and public health. Additionally, the proximate composition analysis revealed significant inconsistencies in nutrient content across different feed brands. Such variations can negatively impact poultry health, productivity, and disease resistance, as a balanced diet is essential for optimal growth and performance. In conclusion, there is a clear need for the implementation of comprehensive quality control measures and regular regional monitoring to ensure that poultry feeds are safe and meet nutritional standards. This approach will contribute to the sustainability of agricultural development, improve livestock productivity, and ensure the safety and quality of poultry products in Bangladesh. Ultimately, it will safeguard consumer health while promoting growth and profitability within the poultry industry.

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Author contribution

A.T. designed the study, collected samples, performed the experiments, analyzed the data, and drafted the main manuscript. M.T. H. designed and supervised the study, analyzed the data, and edited the manuscript. S.M.I. and M.M.H. assisted in the experiments. M.B. reviewed the manuscript. All authors read and approved the final manuscript.

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