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Comparative evaluation of heavy metal contamination, nutritional quality, and associated health risks of selected imported and locally produced fish feeds in Ijebu-Ode, Ogun State, Nigeria

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Abstract
The quality and safety of aquaculture feeds are essential for sustainable fish production and public health due to their nutritional and contaminant profiles. This study comparatively assessed proximate composition, heavy metal contamination, and associated health risks of imported floating and locally produced sinking fish feeds in Ijebu-Ode, Ogun State, Nigeria. Proximate analysis showed higher crude protein in sinking feeds (41.50–47.50%) than floating feeds (33.48–46.02%). Heavy metal concentrations in floating feeds ranged from BDL–0.15 mg/kg (Pb), 0.01–0.30 mg/kg (Cd), 10.50–25.00 mg/kg (Zn), and 16.00–25.00 mg/kg (Cu), while sinking feeds contained 0.10–1.30 mg/kg (Pb), 0.23–1.30 mg/kg (Cd), 17.00–40.00 mg/kg (Zn), and 9.82–20.42 mg/kg (Cu). Mean Pb (0.57 mg/kg) and Cd (0.50 mg/kg) in sinking feeds exceeded the WHO limit of 0.30 mg/kg. Health risk assessment showed higher exposure in sinking feeds. For children, THQ values reached 3.925 (Cu) in floating feeds and 1.243 (Pb), 3.840 (Cd), and 2.975 (Cu) in sinking feeds, indicating significant non-carcinogenic risk. The hazard index ranged from 1.224–1.979 for adults and 5.366–8.675 for children, indicating cumulative risk, especially among children. Carcinogenic risk (CR) for Cd ranged from 1.37×10^{-3} –5.34×10^{-3} (adults) and 6.02×10^{-3}–2.34×10^{-2} (children), exceeding acceptable limits (10^{-6}–10^{-4}), suggesting possible long-term health effects. Relative risk values were highest for Pb (19.49) and Cd (3.89), suggesting higher exposure from sinking feeds. These findings highlight the need for stricter quality control of locally produced feeds to ensure aquaculture safety.

Keywords: Fish feeds, proximate composition, Heavy metals, Health risk assessment, Bioaccumulation, Non-carcinogenic risk

1. Introduction

The aquaculture industry is one of the world's fastest growing food producing sectors, offering an important source of food security and high-quality protein. Aquaculture productivity and sustainability rely heavily on the quality of fish feed, which should deliver essential nutrients and be contaminants-free (Food and Agriculture Organization, 2022). Insufficient feed quality not only impacts fish productivity and well-being, but also human health via the food chain.

Recently, the contamination of aquaculture by heavy metals has received great attention due to their persistence, bioaccumulation and non-biodegradability (Ali et al., 2019; Tchounwou et al., 2012). Metals such as lead (Pb), cadmium (Cd), zinc (Zn), and copper (Cu) may enter fish feeds through contaminated feed ingredients, environmental pollution, and inadequate feed manufacturing and handling practices. These metals were selected for this study because of their widespread occurrence in aquaculture feeds, potential for bioaccumulation, and significant implications for environmental and public health. While Zn and Cu are essential trace elements required for normal physiological functions, excessive concentrations may induce toxic effects. In contrast, Pb and Cd are non-essential toxic metals that can accumulate in aquatic organisms and pose serious health risks to humans, including neurotoxicity, renal dysfunction, and carcinogenic effects following prolonged exposure (Briffa et al., 2020).

There have been recent reports of high concentrations of heavy metals in aquatic mediums and food in Nigeria, as well as other developing regions, which are of environmental concern as well as posing a public health risk (Awe et al., 2025; Popoola et al., 2026). For example, levels of Pb and Cd higher than the maximum allowable levels were found in fish and other food products through atomic absorption spectrophotometry (AAS) analysis, potentially posing dietary risks (Njoga et al., 2021). In a like vein, studies on aquatic ecosystems in Southwest Nigeria have shown remarkable spatial and bioaccumulation effects on metals like Cu, Cr, Pb, and Cd, implying a rise in anthropogenic activities in aquatic environments (Adesakin et al., 2026).

Beyond contamination concerns, the nutritional composition of fish feed is a critical determinant of

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aquaculture performance. Proximate components such as crude protein, lipids, ash, and moisture content directly influence fish growth, feed conversion efficiency, and overall production outcomes (Jobling, 2012). Protein, in particular, is essential for tissue development and metabolic processes, making it a key indicator of feed quality. However, variations in feed formulation, ingredient sourcing, and processing technologies often result in differences in the nutritional quality of fish feeds, especially between imported and locally manufactured products (Gabriel et al., 2007).

Previous studies in Nigeria have largely targeted heavy metal contamination in aquatic organisms, water bodies, and sediments, with relatively limited attention given to fish feed as a primary exposure pathway. For example, studies in Bauchi State assessed heavy metals in fish, water, and synthetic feeds, reporting the presence of multiple trace metals in aquaculture systems (Suleiman et al., 2022). Other studies have examined proximate composition alongside heavy metals in aquatic organisms such as crabs and fish, demonstrating variability in both nutritional content and contaminant levels (Ayanda et al., 2019). While these studies provide important information on food safety and environmental contamination, they are often limited in scope, focusing either on aquatic organisms or environmental matrices rather than on fish feeds themselves.

More importantly, there is a paucity of comprehensive studies that simultaneously evaluate both heavy metal contamination, nutritional composition of fish feeds, and as well as associated health risks particularly in a comparative framework involving imported and locally produced feeds in Southwest Nigeria. Given the increasing reliance on aquaculture in Ogun State and the widespread use of commercial feeds from diverse sources, there is a critical need to assess not only the safety but also the nutritional adequacy of these feeds. Therefore, the present study aims to investigate a comparative evaluation of heavy metal (Pb, Cd, Cu, and Zn) contamination and nutritional quality of imported floating and locally produced sinking fish feeds in Ijebu-Ode, Ogun State, Southwest, Nigeria, with particular emphasis on assessing the associated health risks. By integrating chemical analysis with risk-based interpretation, this study seeks to offer valuable insights into the safety, improve feed quality control, and promote sustainable aquaculture practices.

2. Materials and Methods

2.1 Study Area

This study was carried out in Ijebu-Ode, Ogun State, located in Southwest Nigeria. The region is characterized by increasing aquaculture activities and widespread use of both imported and locally produced fish feeds. The selection of this study area was based on its growing importance in fish farming and the potential risks associated with feed quality and safety.

2.2 Sample Collection

A total of 20 commercially available fish feed samples were collected, comprising two categories: 10 imported floating feeds and 10 locally produced sinking feeds. Samples were randomly purchased from major aquaculture feed distributors and markets across Ogun State to represent commonly used feed products. All sample containers were pre-cleaned and handled according to standard protocols for trace metal analysis to prevent contamination (Vasileski, 2000).

2.3 Sample Preparation and Digestion

Basic sample preparation involved homogenizing the fish feed samples using a pestle and mortar. The ground samples were dried in an oven at 105°C to remove moisture and then weighed to a constant weight. The samples were acid-digested using the wet digestion method that have been known to result in high recovery of heavy metals in food materials (Akilu & Lawal, 2025). A 1.0 g of each of the dried samples was placed in a digestion flask and 20 mL of acid mixture containing concentrated HNO_3 and $HClO_4$ (2:1:1, v/v) was added. The sample was then boiled on a hot plate until a clear solution was achieved. The solution was cooled and filtered and made upto a known volume with distilled water (Omeje et al., 2021). All the 20 samples were similarly processed.

2.4 Determination of Heavy Metals

Pb, Cd, Zn and Cu were measured, using Atomic Absorption Spectrophotometry (AAS) (Buck Scientific 210VGP, East Norwalk, CT, USA). The machine was calibrated with standards for the metals. Blanks were also included in the analysis. All analyses were repeated three times and the results expressed in mg/kg.

2.4.1 Quality Assurance and Control

Quality assurance and quality control (QA/QC) of the analytical procedure were assessed through recovery studies to evaluate the accuracy and reliability of the digestion and analytical methods. Recovery experiments were performed in triplicate using one representative fish feed sample. The sample was divided into two portions: one portion was spiked with a known concentration of a standard solution containing Pb, Cd, Zn, and Cu, while the second portion remained unspiked. Specifically, One gram (1.0 g) of fish feed sample was weighed into a digestion flask and fortified with 20 mL of a mixed standard solution containing Pb, Cd, Cu, and Zn at a concentration of 5 mg /L and subsequently subjected to the same digestion procedure as the unspiked sample. The concentrations of Pb, Cd, Zn, and Cu in both spiked and unspiked samples were determined using AAS. The percentage recovery (R%) for each metal was calculated using Equation (1):

$$\boldsymbol{R}(\%) = \frac{\boldsymbol{C_s - C_0}}{\boldsymbol{C}} \times \frac{\boldsymbol{100\%}}{\boldsymbol{1}} \qquad (1)$$

where $\boldsymbol{C_s}$ is the concentration of the metal in the spiked sample, $\boldsymbol{C_0}$ is the concentration of the metal in the unspiked sample, and C is the amount of metal added during spiking. Analytical precision was evaluated through triplicate measurements, and the results were expressed as relative standard deviation (RSD).

2.5 Proximate Composition Analysis

Proximate analysis of the fish feed samples was conducted following methods of the Association of Official Analytical Chemists (AOAC, 2019). Moisture was measured by drying the sample to a constant weight at 105°C. Crude protein was determined using the Kjeldahl method and calculated as total Kjeldahl nitrogen multiplied by a conversion factor of 6.25. Crude fat was determined by Soxhlet extraction using petroleum ether as the extraction solvent. Ash content was measured by incineration in a muffle furnace at 550°C until constant weight was obtained. Crude fibre was determined by sequential acid–alkaline digestion using 1.25% H_2SO_4 followed by 1.25% NaOH, with refluxing for 30 min at each stage. Carbohydrate content was estimated by difference. The analysis of these 20 samples allowed a comparison to be made between imports (floating) and inland feeds (sinking).

2.6 Health Risk Assessment

The health risks of contaminated fish feeds with heavy metals were assessed using the conventional risk indices, such as Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), Cancer Risk (CR) and Relative Risk (RR)

2.6.1 The EDI

The EDI of heavy metals was evaluated using the Equation (2)

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

But,

$$AT = 365 \times ED$$

Therefore,

$$EDI = \frac{C \times IR \times EF}{BW \times 365} \qquad (2)$$

In the absence of experimentally determined bioaccumulation or biotransfer factors linking metal concentrations in fish feeds to edible fish tissues, the health-risk assessment was conducted using a conservative worst-case approach, assuming complete transfer (100%) of metals from feed to fish flesh. Therefore, the estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), and carcinogenic risk (CR) values represent upper-bound estimates of potential human exposure. Exposure frequency (EF) was set at 360 days year^{-1}, exposure duration (ED) at 70 years for adults, ingestion rate (IR) at 0.125 kg person^{-1} day^{-1} based on average fish consumption rates reported in the literature, body weight (BW) at 70 kg for adults and 16 kg for children, and averaging time (AT) as recommended for non-carcinogenic risk assessment (Oguguah et al., 2017; Adebiyi et al., 2022).

2.6.2 The THQ

The following Equation (3) was used to determine the non-carcinogenic health risk (known as the target hazard quotient (THQ)). The THQ is the ratio of the EDI to the reference dose (RfD).

A target hazard quotient (THQ) value less than 1 indicates that the estimated daily exposure is below the reference dose (RfD), suggesting that non-carcinogenic adverse health effects are unlikely to occur over a lifetime of exposure. Conversely, a THQ value equal to or greater than 1 indicates that the exposure level exceeds the reference dose, implying a potential risk of noncarcinogenic health effects, particularly with prolonged exposure.

$$THQ = \frac{EDI}{RFD} \qquad (3)$$

where, EDI = estimated daily intake and RfD = reference dose (mg/kg/day). The RfD for Pb, Cd, Zn and Cu are 0.0035, 0.001, 0.300 and 0.040 mg/kg/day respectively, followed from guidelines set by the United States Environmental Protection Agency (USEPA, 2015).

2.6.3 HI

The overall non-carcinogenic risk was evaluated using the HI, defined as the sum of individual target hazard quotients (THQs), as presented in Equation (4) and adopted from Chien et al. (2002) and Aendo et al. (2022).

$$HI = \sum THQ$$

$$HI = THQ_{(Pb)} + THQ_{(Cd)} + THQ_{(Cu)} + THQ_{(Zn)} \qquad (4)$$

where, HI < 1 is acceptable risk and HI ≥ 1 indicates Potential health concern.

2.6.4 CR

Equation 5 was used to calculate the CR over a lifetime of Pb and Cd exposure using the cancer slope factor (Zhang et al., 2023; Zhou et al., 2024). However, Zn and Cu are non-carcinogenic**,** therefore, no CR

$$CR = EDI \times CSF \quad (5)$$

Where CSF is the cancer slope factor measured mg/kg/day. According to US Environmental Protection Agency, the acceptable lifetime carcinogenic risk (CSF) for Pb and Cd are 0.0085 and 6.1 (mg/kg/day)$^{-1}$ respectively (Oyasowo et al., 2021).

2.6.5 Relative risk (RR)

Relative exposure (RR), also referred to as the exposure ratio, was used to compare exposure levels between feed types and to identify the most significant contributors to contamination i.e. harmful contaminants (Alexander et al., 2012). It was estimated as the ratio of estimated daily intake (EDI) between sinking and floating feeds to evaluate differences in contamination levels, as presented in Equation (6).

$$RR = \frac{EDI_{sinking}}{EDI_{floating}} \qquad (6)$$

where all parameters have been previously defined in the present study.

2.7 Statistical Analysis

The results from the 20 samples were presented as the mean ± standard deviation (SD) of three replicates. Data were analysed using IBM SPSS Statistics (version 26). To compare the groups, we applied one-way analysis of variance (ANOVA), with $p < 0.05$ considered significant.

3. Results and Discussion

3.1. Validation of Analytical Procedure

The analytical result for the sensitivity, calibration curve and percentage recovery for the analysed metals in the feed samples is presented in Table 1. The analytical method demonstrated excellent performance for the determination of Pb, Cd, Cu, and Zn in fish feed samples. Calibration curves showed strong linearity, with R^2 values ranging from 0.9897 to 0.9997. Spike-recovery tests yielded recoveries between 98.00 ± 1.42% and 98.50 ± 2.46%, indicating high analytical accuracy and negligible matrix interference. The low limit of detection (LOD) (0.0014–0.0049 mg/kg) and limit of quantification (LOQ) (0.0080–0.018 mg/kg) values demonstrate the sensitivity of the method for trace metal determination. Furthermore, the low relative standard deviations (RSD<5) associated with the recovery values confirm good precision and reproducibility. Overall, the validation results indicate that the method was accurate, precise, and suitable for the determination of heavy metals in fish feed samples.

3.2. Proximate Composition of Fish Feeds

The proximate composition of imported floating feeds and locally produced sinking feeds are presented in Tables 2 (a) and (b). The results reveal significant variations in nutrient composition across feed types, particularly in crude protein content, which is a key determinant of feed quality. Crude protein (CP) had the highest mean concentration of 37.32±0.92 and 44.35±1.22% in both floating and sinking fish feeds with sinking feeds having the highest percentage of protein even more than carbohydrate while crude ash had the lowest mean concentration of 2.66±0.090 and 5.01±0.12% respectively. The coefficient of variation was seen to be overall quite low for the various proximate constituents in fish feed samples (RSD < 6%). This showed no high variability in the results of the proximate analysis for all the samples.

Crude protein content is the most critical nutritional parameter influencing fish growth and feed efficiency. The floating feeds exhibited protein values range from 33.48% to 46.02% with an average of 37.32±0.92%, while locally produced sinking feeds showed consistently higher protein content ranging from 41.50% to 47.50% with an average of 44.35±1.22%. This finding agrees with the report by Magna et al. (2025) on the proximate composition and heavy metal concentration of commercial tilapia starter feeds Sold in Asuogyaman Municipality, Ghana. The range of percent crude protein obtained in this work is more than that reported by the Sarkar et al. (2022) and Bhowmik et al. (2023). They demonstrated that the protein content of commercial feeds are low. In current work, the high protein level in the sinking feeds depicts better quality. However, this does not necessarily translate to better performance in aquaculture systems. The physical nature of sinking feeds leads to rapid disintegration and nutrient leaching in water, thereby reducing the effective protein available for fish consumption. In contrast, floating feeds remain stable on the water surface, allowing for controlled feeding and higher nutrient retention. Recent studies have emphasized that feed efficiency depends not only on nutrient composition but also on feed stability and ingestion dynamics (Gaillard et al., 2020; Wu et al., 2020). Consequently, despite their lower protein content, floating feeds may result in better growth performance due to improved nutrient utilization.

Moisture content was observed to be higher in sinking feeds (10.40–11.46%) compared to floating feeds (8.28–10.00%). Elevated moisture levels are undesirable as they reduce shelf life and promote microbial growth, leading to feed spoilage. High moisture content also contributes to poor pellet integrity, making sinking feeds more susceptible to disintegration in water. This accelerates nutrient leaching, particularly of soluble components such as proteins and lipids. In contrast, lower moisture content in floating feeds enhances structural stability and prolongs storage life. These findings align with recent reports indicating that moisture content is a key determinant of feed durability and storage quality, with values above 10% increasing the risk of microbial contamination and nutrient degradation (Rathod et al., 2024). Similarly, Sarkar et al. (2022) tested a commercially available fish feeds in Bangladesh and reported that moisture content ranged between 10-12%. , which is in tandem with the values reported in this study.

Ash content, which reflects the total mineral composition of the feed, was higher in sinking feeds (4.20–5.80%) compared to floating feeds (about 1.20–5.40%). Elevated ash content may indicate higher inclusion of inorganic materials or low-quality ingredients. Recent studies have highlighted that excessive mineral content in feeds can negatively influence nutrient absorption and feed conversion efficiency (Lall & Kaushik, 2021; Mmanda, 2025). Therefore, the relatively lower ash content in floating feeds suggests better formulation balance and higher digestibility. The values of crude ash content reported

Table 1: Analytical performance characteristics of the AAS method for the determination of Pb, Cd, Cu, and Zn in fish feed samples.

Metal	Co (mg/kg)	Spike Added (mg/kg)	Cs (mg/kg)	Recovery (%) ±RSD	Calibration Curve (R^2)	LOD (mg/kg)	LOQ (mg/kg)
Pb	15.00	100.00	113.50	98.50±2.46	0.9897	0.0014	0.018
Cd	2.00	100.00	100.00	98.00±3.42	0.9996	0.0030	0.0080
Cu	45.00	100.00	143.00	98.00±4.26	0.9997	0.0049	0.013
Zn	120.00	100.00	218.00	98.00±1.42	0.9994	0.004	0.013

LOD = limit of detection, LOQ = limit of quantification

Table 2(a): Results of proximate composition of floating fish feeds analysed

Samples	**MC**	**Ash**	**CP**	**CF**	**CFA**	**CHO**
F 1	9.00±0.12	2.00±0.08	42.42±0.91	2.80±0.13	11.00±0.42	33±0.49
F 2	10.00±0.14	1.20±0.09	46.02±0.92	3.00±0.14	7.98±0.41	32.00±0.51
F 3	10.00±0.16	5.40±0.088	42.22±0.93	3.00±0.14	5.14±0.43	34.26±0.52
F 4	9.00±0.15	2.30±0.092	34.52±0.94	3.20±0.16	8.00±0.41	43.74±0.51
F 5	9.50±0.14	3.50±0.091	33.48±0.93	3.50±0.15	7.00±0.43	44.76±0.52
F 6	10.00±0.13	2.20±0.09	34.92±0.91	2.54±0.17	6.24±0.41	45.64±0.53
F 7	10.00±0.16	2.50±0.092	34.82±0.90	3.50±0.16	12.00±0.43	38.00±0.49
F 8	8.28±0.14	3.50±0.093	34.95±0.90	3.00±0.15	6.20±0.42	45.42±0.50
F 9	10.00±0.15	1.50±0.095	35.97±0.92	3.00±0.16	5.60±0.41	46.42±0.51
F 10	10.00±0.15	2.50±0.092	33.87±0.90	3.52±0.14	5.82±0.43	47±0.52
Range	8.28-10.00	1.20-5.40	33.48-46.02	2.54-3.52	5.14-11	32-46.42
Mean	9.58±0.14	2.66±0.090	37.32±0.92	3.11±0.15	7.50±0.42	41.02±0.51
RSD (%)	1.50	3.38	2.45	4.83	5.60	1.24

RSD = relative standard deviation (Coefficient of variation)

Table 2(b): Results of proximate composition of sinking fish feeds analysed

Samples	**MC**	**Ash**	**CP**	**CF**	**CFA**	**CHO**
S 1	11.00±0.31	4.20±0.11	45.00±1.23	5.50±0.24	9.00±0.24	25.00±1.02
S 2	11.20±0.35	4.80±0.14	47.50±1.19	5.80±0.29	8.50±0.39	21.90±1.00
S 3	11.20±0.32	5.00±0.10	43.00±1.11	6.00±0.30	8.00±0.40	26.80±0.99
S 4	11.40±0.29	5.20±0.20	42.00±1.25	6.20±0.24	7.50±0.42	27.30±1.20
S 5	11.00±0.34	5.50±0.13	44.50±1.20	6.00±0.32	8.20±0.39	24.80±1.10
S 6	12.00±0.32	5.80±0.12	41.5±1.23	6.50±0.29	7.80±0.41	26.40±1.01
S 7	10.40±0.29	4.60±0.11	48.00±1.20	5.60±0.24	9.20±0.43	21.80±1.00
S 8	11.30±0.41	5.00±0.10	43.50±1.24	6.10±0.22	8.30±0.41	25.80±0.98
S 9	11.00±0.29	4.70±0.12	42.50±1.32	6.30±0.22	8.00±0.42	27.40±0.99
S 10	11.46±0.31	5.30±0.10	46.00±1.24	5.90±0.23	8.70±0.45	22.50±1.02
Range	10.40-11.46	4.20-5.80	41.50-47.50	5.50-6.50	7.50-9.00	21.80-27.40
Mean	11.20±0.32	5.01±0.12	44.35±1.22	5.99±0.26	8.32±0.41	24.97±1.03
RSD (%)	2.86	2.45	2.75	4.32	4.98	4.13

in this study are a little bit higher those reported by Sarkar et al. (2022), this may be due to source of materials used in the production of the feeds.

Crude fibre content was significantly higher in sinking feeds (5.50-6.50%) compared to floating feeds (2.54-3.52%). High fibre content is generally undesirable in fish feeds, as most fish species have limited ability to digest fibre efficiently. The lower fibre content observed in floating feeds indicates better formulation using more digestible ingredients, which enhances nutrient absorption and feed efficiency. Similar findings have been reported in recent aquaculture nutrition studies, where low-fibre diets were associated with improved growth and feed utilization (Liu et al., 2022; Bhowmik et al., 2023).

Floating feeds had a slightly higher crude fat (lipid) content (5.14-11.00%) than sinking feeds (7.50-9.00) based on range. Lipids also are a critical energy source in fish diets (triglycerides) and helps in enhancing feed efficiency by allowing spare protein for growth (Bhowmik et al., 2023). Lipids also supply fish with essential lipids that fish may not be able to synthesise (Janbakhsh, et al., 2018). Sinking feeds have lower lipid levels, which may lower energy levels of feeds, thus, restricted growth performance although they have higher protein levels. Further, the level of lipids in the feed contributes to the pellet structure and water absorption, therefore, lower levels of lipids in sinking feeds may also contribute to their poor stability. Lipid content has been highlighted in recent studies to be important for improving feed conversion ratio and hence growth in aquaculture species (Bhowmik, et al., 2023). But in our study lipid content for both the floating and sinking fish feeds is equal or higher than those recommended for cat fish feed based on other studies (Wilson., 2017; Sarkar et al., 2022).

Carbohydrate content was generally higher in floating feeds (41.02±0.51%) compared to sinking feeds (24.97±1.03%). This is likely due to the use of carbohydrate-rich binders (e.g., starch) in floating feed production to enhance pellet expansion and buoyancy. Although fish have limited capacity to utilize carbohydrates compared to proteins and lipids, moderate carbohydrate levels are beneficial as they provide an economical energy source and improve pellet stability (Kamalam & Panserat, 2016; Annamalai et al., 2021). Conversely, the lower carbohydrate content in sinking feeds may reduce pellet cohesion, leading to faster breakdown in water. This observation is consistent with recent findings that carbohydrate-based binders play a critical role in feed stability and water durability (Mustafa & Al-Faragi, 2021).

As show in Table 3. A one way analysis of variance (ANOVA) was used to compare the proximate composition of sinking and floating fish feeds. The results revealed statistically significant differences ($p < 0.05$) in moisture content ($F = 33.52$, $p < 0.001$), crude ash ($F = 39.84$, $p < 0.001$), crude protein ($F = 20.67$, $p < 0.001$), crude fibre ($F = 89.15$, $p < 0.001$, and carbohydrate ($F = 64.72$, $p < 0.001$) levels between the two feed types. Floating feeds had significantly lower moisture, ash and higher carbohydrate levels than sinking feeds. On the other hand, sinking feeds had significantly higher crude protein and crude fibre values. But there was no significant difference ($p > 0.05$) in the crude fat ($F = 0.32$, $p = 0.219$) levels between the two types of feeds, suggesting similar fat content. The significant difference in most of the proximate parameters illustrates the differences in nutritional content, which may be due to different processing methods, formulations or ingredients.

3.3. Elemental Levels of Floating and Sinking Fish Feed Samples

The levels of lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) in imported floating and local sinking fish feeds are showed in Table 4. This showed a variation in contamination between the two types of feeds, higher values were also observed in the local sinking feeds. The highest mean concentration (24.06±0.38 mg/kg) in sinking fish feeds was noted to be zinc (Zn) while the lowest mean concentration (0.029±0.0011 mg/kg) in floating fish feeds was also for lead (Pb). The relative standard deviation (RSD) was found to be relatively low for all the metals in the samples (RSD < 6.00%). This indicated that there was low variability of the metals in the samples.

The levels of lead (Pb) in imported floating feeds varied from 0.00 to 0.15 mg/kg, while those in local sinking feeds varied from 0.10 to 1.30 mg/kg. The maximum permissible level prescribed by World Health Organization (WHO, 2010) is 0.30mg/kg. Most of the sinking feed samples exceeded this limit, with particularly high values observed in Samples 1 (0.90±0.025mg/kg), 2 (1.30±0.022 mg/kg), 8 (0.84±0.022 mg/kg), and 10 (0.87±0.021 mg/kg). However, in floating feed samples, Pb was absent in samples F3 to F8 (BDL) and the rest of the floating feed samples were below than the WHO permissible levels. This suggests high accumulation of Pb in locally produced feeds probably due to Use of contaminated ingredients, improper processing and quality control, and/or environmental exposure during the production. This finding is similar with Sarkar et al., 2022 and Magna et al., 2025. Nevertheless, Rakib et al., 2024 found high Pb levels in aquaculture, which could be caused by contaminated feed and exposure. The findings of their study agree with the present study's data for sinking feeds. Pb is a non-essential and toxic element, which causes neurological and developmental problems (Gudadhe et al, 2024; Leal et al., 2023). Its high level in fish feeds is a cause for concern in terms of bioaccumulation and human health.

The concentration of cadmium in floating feeds range from 0.01 to 0.16 mg/kg while that in sinking feed range from 0.23 to 1.30 mg/kg. The global permissible level is 0.50 mg/kg. All the samples in floating feed samples were below the permissible limit recommended by World Health Organisation (WHO, 2010) while a significant percentage of sinking feeds had higher Cd concentration (especially Samples 3 (0.80±0.027 mg/kg) and 8 (1.30±0.027 mg/kg). The elevated Cd concentrations in sinking feeds indicate greater contamination from the raw materials like farm waste, industrial waste and contaminated water. Cadmium concentrations in the present study (up to 1.30 mg/kg in sinking feeds) are higher than those reported in recent study. For instance, Cd levels as low as 0.027 mg/kg have been reported in commercial feeds (Sarkar et al., 2022) which are similar to the values reported for floating fish feeds in this study. Cd is highly toxic and accumulates in biological tissues, posing risks such as kidney damage and carcinogenic effects. The elevated levels observed in sinking feeds indicate a potential long-term health risk**.** Although, recent research has shown that Cd can exceed safety limits in aquaculture systems, especially where environmental contamination is high (Hasan et al.,

Table 3: One-way analysis of variance (ANOVA) showing differences in proximate composition between sinking and floating fish feeds

Parameter	**F-value**	**p-value**	**Significance**
Moisture Content (MC)	33.52	< 0.001	Significant
Crude Ash	39.84	< 0.001	Significant
Crude Protein (CP)	20.67	< 0.001	Significant
Crude Fibre (CF)	89.15	< 0.001	Significant
Crude Fat (CFA)	0.32	> 0.05	Not Significant
Carbohydrate (CHO)	64.72	< 0.001	Significant

Table 4: Concentrations of heavy metals (Pb, Cd, Zn, and Cu) in floating and sinking fish feed samples and comparison with permissible limits

Fish Feeds									
	Floating					**Sinking**			
Samples	**Pb**	**Cd**	**Zn**	**Cu**	**Samples**	**Pb**	**Cd**	**Zn**	**Cu**
F 1	0.020±0.0010	0.020±0.0020	10.50±0.82	17.50±0.54	S 1	0.90±0.025	0.40±0.023	20.00±0.37	10.42±0.42
F 2	0.070±0.0011	0.030±0.0021	12.50±0.80	23.50±0.52	S 2	1.30±0.022	0.56±0.025	25.00±0.39	17.82±0.41
F 3	BDL	0.15±0.0022	11.00±0.81	21.50±0.53	S 3	0.30±0.021	0.80±0.027	40.00±0.38	19.32±0.40
F 4	BDL	0.16±0.0021	15.00±0.79	23.00±0.52	S 4	0.19±0.022	0.24±0.029	35.00±0.40	19.21±0.42
F 5	BDL	0.070±0.0019	19.00±0.84	16.00±0.51	S 5	0.10±0.023	0.46±0.027	17.00±0.37	20.42±0.43
F 6	BDL	0.010±0.0020	15.00±0.78	25.00±0.52	S 6	0.25±0.025	0.23±0.029	21.00±0.39	15.46±0.42
F7	BDL	0.040±0.0021	25.00±0.72	17.00±0.51	S 7	0.40±0.024	0.47±0.027	19.00±0.38	10.22±0.42
F 8	BDL	0.30±0.0020	17.50±0.71	22.50±0.53	S 8	0.84±0.022	1.30±0.027	24.00±0.37	9.82±0.42
F 9	0.15±0.0011	0.20±0.0021	15.50±0.83	16.00±0.52	S 9	0.50±0.022	0.24±0.026	20.34±0.36	11.57±0.40
F 10	0.050±0.0013	0.30±0.0021	11.00±0.92	21.50±0.52	S 10	0.87±0.021	0.28±0.027	19.25±0.37	19.82±0.39
Range	0.020-0.15	0.01-0.16	10.50-25.00	16.00-25.00		0.10-1.30	0.23-1.30	17.00-40.00	9.82-20.42
Mean	0.029±0.0011	0.13±0.0021	15.20±0.80	20.35±0.52		0.57±0.023	0.50±0.027	24.06±0.38	15.41±0.41
RSD	3.88	1.61	5.28	2.57		4.02	5.36	1.57	2.67
WHO (2010) Limit	0.30	0.50	50.00	30.00		0.30	0.50	50.00	30.00

2025).

Zinc (Zn) concentrations ranged from 10.5 to 25.0 mg/kg with average of 15.20±0.80 mg/kg in floating feeds and 17.0 to 40.0 mg/kg with mean of 24.06±0.38 mg/kg in sinking feeds. These levels are below World Health Organization (WHO) permissible limit of 50 mg/kg. While zinc concentration was higher in sinking feeds, it did not cross the permissible level. Zinc is a trace element essential for fish's metabolic and enzymatic processes. But can be toxic in high levels. Zinc concentrations in this study (10.5-40 mg/kg) are in line with recent research, with Zn being the most prevalent metal in fish feeds (Bhowmik et al., 2023). The elevated Zn levels in sinking feeds may be attributed to the deliberate supplementation of feed formulations with inorganic zinc sources such as zinc sulphate ($ZnSO_4 \cdot 7H_2O$) or zinc oxide (ZnO), as well as the inclusion of trace mineral premixes and/or fish meal and animal by-products, which are naturally rich in zinc.

Copper (Cu) concentrations in floating feeds were 16.0-25.0 mg/kg and in sinking feeds 9.82-20.42 mg/kg, which are below the upper permissible level by WHO (30 mg/kg). Higher levels of Cu were noted in floating feeds when compared to sinking feeds. The present Cu levels (9.82-25.0 mg/kg) are also within the safe limits and are consistent with other studies having moderate Cu levels in aquafeeds (Rind et al., 2025). Copper is an essential micronutrient involved in enzyme activity and iron metabolism. But high doses can be toxic (Sarkar et al., 2022). The current concentrations indicate that both the feeds are safe but the greater Cu concentration in floating feeds could be due to better mineral supplementation and formulation of feeds.

The high concentrations of Pb and Cd in locally sourced sinking feeds are concerning. They can accumulate in fish tissues and become part of the human diet, with potential consequences for human health (Saha et al., 2021; Emenike et al., 2022). Further, heavy metals can decrease fish growth and survival, disrupt physiological processes and deteriorate water quality (Abbas et al., 2021). Recent research has highlighted that feeds are an important source of heavy metal contamination in aquaculture systems, especially in developing countries where regulation is weak (Emenike et al., 2022; Baeelashaki et al., 2025).

One-way analysis of variance (ANOVA) was used to compare the concentrations of heavy metals in floating

Table 5: ANOVA comparing heavy metal concentrations in floating and sinking fish feed samples

Metal	F-value	p-value	Significance
Pb	18.92	< 0.001	Significant
Cd	7.84	< 0.05	Significant
Zn	6.55	< 0.05	Significant
Cu	4.12	< 0.05	Significant

Table 6: Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ) of Potentially Toxic Elements in Fish Feeds Consumed by Adults and Children

		Floating		Sinking	
Element (mg/kg)	Population	EDI	THQ	EDI	THQ
Pb	Adults	5.10×10^{-5}	0.015	9.94×10^{-4}	0.284
	Children	2.24×10^{-4}	0.064	4.35×10^{-3}	1.243
Cd	Adults	2.25×10^{-4}	0.225	8.76×10^{-4}	0.876
	Children	9.87×10^{-4}	0.987	3.84×10^{-3}	3.84
Zn	Adults	0.0268	0.089	0.0423	0.141
	Children	0.117	0.39	0.185	0.617
Cu	Adults	0.0358	0.895	0.0271	0.678
	Children	0.157	3.925	0.119	2.975
TTHQ (HI)	Adults		1.224		1.979
	Children		5.366		8.675

Table 7: CR and RR of heavy metals in floating and sinking fish feed samples

		Fish feeds		
		Floating	Sinking	
Element (mg/kg)	Population	CR	CR	RR
Pb	Adults	4.34×10^{-7}	8.45×10^{-6}	19.49
	Children	1.90×10^{-6}	3.70×10^{-5}	19.42
Cd	Adults	1.37×10^{-3}	5.34×10^{-3}	3.89
	Children	6.02×10^{-3}	2.34×10^{-2}	3.89
Zn	Adults	NA	NA	1.58
	Children	NA	NA	1.58
Cu	Adults	NA	NA	0.76
	Children	NA	NA	0.76

NA = not applicable. Carcinogenic risk (CR) was not evaluated for Zn and Cu because these elements are not classified as carcinogenic under the USEPA Integrated Risk Information System (IRIS) framework; therefore, no carcinogenic slope factors are available for their risk quantification.

and sinking fish feeds as presented in Table 5. This showed statistically significant variation ($p < 0.05$) in the concentrations of Pb, Cd, Zn and Cu between floating and sinking feeds, highlighting that feed composition and ingredient sources play an important role in metal incorporation in feed. Lead (Pb) levels were significantly higher in sinking feeds than in floating feeds, with some feeds surpassing the recommended maximum level (0.3 mg/kg) set by international authorities. Similarly, the levels of essential trace elements zinc (Zn) and copper (Cu) were significantly different between the two feed types, with higher concentrations typically found in sinking feeds. But they remained below the safety limits, indicating that they pose little immediate threat. These variations in trace element concentrations could be due to differences in feed formulation, processing techniques and additive inclusion during feed preparation. The results underline the importance of ongoing quality control of fish feeds to avoid potential health issues from heavy metal exposure.

3.4. Potential Health Risk Assessments

The calculated EDIs of the elements were used for the risk assessment in order to estimate both non-carcinogenic and carcinogenic risks of consumption of fish fed with the samples. The calculated target hazard quotients (THQs) of fish consumption for adults and children are shown in Table 6. It was shown that the calculated EDI values for both adults and children of the metals Pb, Cd and Zn are lower than their respective RfDs (Rfd values are: Pb is 0.0035 mg/kg/day, Cd is 0.001 mg/kg/day, Zn is 0.300 mg/kg/day, and Cu, 0.040 mg/kg/day) for floating feeds, and hence, non-carcinogenic risk from ingestion of fish feed is unlikely. The estimated daily intake

(EDI) of Cu for children in floating feeds (0.157 mg kg^{-1} day^{-1}) exceeded the oral reference dose (RfD = 0.040 mg kg^{-1} day^{-1}), indicating a potential concern for copper exposure under a direct ingestion scenario. This is reflected in the corresponding target hazard quotient (THQ) value, which was 3.925 for Cu in children consuming floating feeds, representing a significant non-carcinogenic risk and a key finding of this study. A similar trend was observed in sinking feeds, where Pb, Cd, and Cu contributed to elevated exposure levels in children. In floating feeds, THQ values for Pb, Cd, and Zn remained below 1 for both adults and children, indicating negligible non-carcinogenic risk for these metals, whereas Cu was the only metal exceeding the safety threshold in children. The generally higher THQ values observed in children compared to adults are attributed to lower body weight, which increases exposure per unit body mass. Similarly, for sinking feeds, the THQs of Pb, Cd and Cu were higher than 1 in children while in adults, it was less than 1. If the THQ value of foods is greater than 1, it is regarded as unsafe for human consumption (Adebiyi et al., 2022). Besides, locally made sinking feeds showed higher TTHQ (HI) values than imported floating feeds possibly because of differences in raw material and manufacturing processes used in feed production and regulation.

The cancer risk (CR) and relative risk (RR) of heavy metals exposure through consumption of fish fed with the samples by adults and children is illustrated in Table 7. The highest RR found was for Pb of 19.49 and the lowest for Cu of 0.76 for the floating and sinking fish feeds respectively. The RR order of the fish feeds analysed are: Pb, Cd, Zn and Cu. This study has concluded that the greatest risks of consumption of the fish fed with the samples analysed are Pb and Cd respectively similar result is seen in Channa et al (2024). The acceptable value for carcinogenic risk (CR) as stated by USEPA is 10^{-6}-10^{-4} (Oni et al., 2022). This connotes cancer risk of 1 in 1,000,000 to 1 in 10,000 humans. USEPA (2004) and Zhang et al. (2015) also suggests the risk ranges from negligible to high level if the value of CR is less than 10^{-6} to greater than 10^{-4} respectively. In freshwater fish feeds, the CR of Cd from floating fish feeds fed by the samples are higher than the risk level in both adults and children (suggesting a lifetime cancer risk) while Pb is lower than the risk level in both age groups. This was also the case with sinking feeds. Similar findings are found in recent studies where the highest carcinogenic risk of various metals were observed with Cd due to its persistence and bioaccumulative property (Younis et al., 2024). In contrast, Pb had lower CRs which are mostly at acceptable levels or just greater than the acceptable level, but still might be dangerous with long term exposure. The high CR values than the acceptable level indicate the potential carcinogenic risk of fish that were fed with the samples.

While the concentrations of other important metals such as Zn and Cu were below the threshold limits set by international bodies, such as the World Health Organization and the Food and Agriculture Organization, exposure to multiple metals should not be ignored in cumulative risk assessment (Bahiru & Teju, 2019). There have been numerous reports that adherence to individual metals limits does not guarantee freedom from potential health risks associated with a mixture of contaminants (Hasanein et al., 2022)

In summary, results of this study suggest that while some of the heavy metal levels in fish feeds may be within permissible limits, the cumulative lifetime risk (particularly the risks associated with Cd and Pb) can result in high non-carcinogenic risks and carcinogenic risks, especially in sensitive subpopulations such as children These findings are consistent with recent global studies that have raised concerns about the contamination of aquaculture products by heavy metals and its impacts on food security and human health (Yin et al., 2024). Hence, regular monitoring, enhanced enforcement and better feed practices are crucial to control contamination and ensure aquaculture safety.

4. Conclusion

In this study, proximate composition and level of contamination by heavy metals in some imported floating and indigenous produced sinking fish feeds were compared, and the attendant health risk was assessed in aquaculture in Ijebu-Ode, Ogun State, Nigeria. The results revealed clear differences in both nutritional quality and contamination profiles between the two feed categories. The imported floating feeds generally had better matches to proximate diet stated by manufacturers and lower levels of toxic metals compared to the local produced sinking feeds which had relatively high crude protein but also lead and cadmium. The results of the heavy metal analysis showed the levels of Pb, Cd, Zn and Cu in sinking feeds to be much higher than that found in floating feeds. While most of these were within acceptable limits of the World Health Organization (WHO) and Food and Agriculture Organization (FAO), higher Pb and Cd are of potential concern. Risk assessment revealed that although human adults are unlikely to be affected, kids may be more sensitive, with the THQ and HI values higher than the level permitted for sinking feeds. Carcinogenic risk assessment also showed that cadmium has a significant impact on potential carcinogenic risk. Therefore, these results suggest that monitoring fish feed quality needs to be conducted on a regular basis and regulatory control of locally produced feeds should be stringent to reduce contaminations by heavy metals and protect fish products as part of the food chain.

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