Journal of Science Research and Reviews
PRINT ISSN: 1595-9074
E-ISSN: 1595-8329
DOI: https://doi.org/10.70882/josrar.2026.v3i4.253
Homepage: https://josrar.esrgngr.org
Original Research Article

Comparative Assessment of the Nutritional Quality of Selected Cultured Fish Species in Argungu, Kebbi State, Nigeria: A Multivariate Statistical Approach

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KEYWORDS
Cultured Fish,
Nutritional Quality,
Proximate Composition,
Mineral Composition,
Principal Component Analysis.

ABSTRACT
Fish is an important source of high-quality protein and essential nutrients that contribute to food security and human health. This study comparatively assessed the nutritional quality of selected cultured fish species in Argungu, Kebbi State, Nigeria, using proximate composition, mineral analysis, and multivariate statistical techniques. A comparative laboratory-based design was adopted, and 45 fish samples comprising Clarias gariepinus, Oreochromis niloticus, and Heterobranchus spp. were collected from commercial fish farms. Proximate and mineral compositions were determined using standard AOAC procedures, while data were analysed using descriptive statistics, Pearson correlation, Principal Component Analysis (PCA), and Hierarchical Cluster Analysis (HCA). Results showed considerable variations in nutritional composition among the fish species. Clarias gariepinus recorded the highest crude protein (20.84 ± 0.62%) and energy value (121.68 ± 2.34 kcal/100 g), whereas Heterobranchus spp. exhibited the highest lipid (3.84 ± 0.21%) and ash (2.18 ± 0.10%) contents. Heterobranchus spp. also recorded higher calcium, phosphorus, magnesium, and zinc concentrations, while Clarias gariepinus had the highest iron content. Significant correlations were observed between protein and energy ($r = 0.84$, $p < 0.001$), protein and phosphorus ($r = 0.71$, $p = 0.003$), and moisture and energy ($r = -0.82$, $p < 0.001$). PCA extracted three components explaining 82.6% of total nutritional variation, while HCA classified Clarias gariepinus and Heterobranchus spp. as nutritionally similar. The study concludes that cultured fish species in Argungu possess considerable nutritional value, although their contributions vary by species. Multivariate techniques effectively identified nutritional patterns and species similarities. It is recommended that fish farmers, consumers, and relevant stakeholders consider species-specific nutritional characteristics in fish production, dietary selection, and aquaculture management to promote improved nutrition and sustainable aquaculture development.

CITATION
Rdoruwa, I. A., Augie, B. H., & Augie, M. H. (2026). Comparative Assessment of the Nutritional Quality of Selected Cultured Fish Species in Argungu, Kebbi State, Nigeria: A Multivariate Statistical Approach. *Journal of Science Research and Reviews*, *3*(4), 219-228. https://doi.org/10.70882/josrar.2026.v3i4.253

INTRODUCTION

Fish is one of the most important sources of high-quality animal protein and an essential component of human nutrition. It supplies highly digestible protein, essential amino acids, omega-3 polyunsaturated fatty acids, vitamins, and minerals that promote growth, cognitive development, immune function, and overall health. Beyond its nutritional value, fisheries and aquaculture contribute significantly to food security, employment, poverty reduction, and economic development worldwide (FAO, 2024; WHO, 2024).

The increasing global demand for fish, coupled with declining productivity of capture fisheries due to overexploitation and environmental degradation, has accelerated the expansion of aquaculture as the major source of aquatic food production. Consequently, cultured fish have become increasingly important in meeting global nutritional needs. A systematic review of 41 studies involving 27 fish species revealed that both cultured and wild fish possess valuable nutritional characteristics, although their quality varies depending on species, diet, farming practices, and environmental conditions (Hoa et al., 2025).

Nigeria has experienced considerable growth in aquaculture over the past two decades, with *Clarias gariepinus*, *Oreochromis niloticus*, and *Heterobranchus* species dominating commercial production. While increased production has improved fish availability and rural livelihoods, emphasis has gradually shifted toward improving the nutritional quality of cultured fish to satisfy consumer expectations and public health needs. Comparative investigations have shown that cultured fish species are important sources of dietary protein and essential nutrients, although their nutritional composition differs among species and production systems (Anarado et al., 2023; Imam et al., 2025).

The nutritional quality of fish is commonly evaluated through proximate composition and mineral content, which provide information on dietary value, processing quality, and consumer acceptability. Proximate analysis generally includes moisture, crude protein, lipid, ash, crude fibre, carbohydrate, and energy value, while mineral assessment focuses on essential elements such as calcium, phosphorus, iron, magnesium, sodium, potassium, and zinc. Differences in nutritional composition among freshwater fish species have been reported, indicating that nutritional quality is species-dependent and influenced by biological and environmental factors (Mustafa et al., 2023).

Several biological and environmental factors influence the nutritional composition of cultured fish, including species, genetics, feed quality, water quality, culture system, stocking density, and post-harvest handling. Among these factors, feed composition plays a crucial role in determining flesh quality and nutrient retention. Dietary modification studies have demonstrated that appropriate feed formulation can maintain or improve growth performance, nutrient retention, and flesh quality of cultured fish species (Akter et al., 2024; Prakash et al., 2025).

Recent studies have further highlighted variations in proximate and mineral composition among commercially important fish species, emphasizing the need for continuous nutritional evaluation of cultured fish. Differences in nutrient composition may affect the suitability of individual species for specific dietary and nutritional purposes (Oyekanmi et al., 2024; Epinipre et al., 2025; Birie et al., 2025).

Although previous studies have generated valuable information on fish nutritional quality, many investigations have relied mainly on descriptive statistics and univariate analyses to compare individual nutritional parameters. Such approaches provide limited understanding of relationships among multiple nutritional variables measured simultaneously. Multivariate statistical techniques, including Principal Component Analysis (PCA), provide a more comprehensive approach by identifying underlying nutritional patterns, reducing complex datasets into meaningful components, and classifying fish species based on overall nutritional characteristics. Previous nutritional profiling studies have demonstrated the usefulness of PCA in differentiating fish species according to their nutrient composition (Begum et al., 2024).

Despite increasing aquaculture activities in Argungu, Kebbi State, information on the comparative nutritional quality of cultured fish species remains limited. Furthermore, there is limited application of multivariate statistical techniques for evaluating nutritional variability among cultured fish species in the area. This knowledge gap restricts the availability of scientific information required by fish producers, consumers, nutritionists, and policymakers for evidence-based aquaculture development and informed dietary decisions.

Therefore, this study comparatively assesses the nutritional quality of selected cultured fish species in Argungu, Kebbi State, Nigeria, using proximate and mineral composition together with multivariate statistical techniques. The findings are expected to provide baseline nutritional information, enhance understanding of interspecific nutritional variation, and contribute to sustainable aquaculture development and food security in Nigeria.

The aim of the study is to comparatively assess the nutritional quality of selected cultured fish species in Argungu, Kebbi State, Nigeria, using a multivariate statistical approach.

The specific objectives are to:

1. Determine the proximate composition of selected cultured fish species in Argungu, Kebbi State, Nigeria.

2. Determine the mineral composition of the selected cultured fish species
3. Examine the relationships among proximate and mineral composition variables
4. Compare the overall nutritional quality of the selected cultured fish species using multivariate statistical techniques

MATERIALS AND METHODS

Study Area

The study was conducted in Argungu Local Government Area of Kebbi State, Northwestern Nigeria. Argungu is one of the major fisheries and aquaculture centres in the country and is well known for its long-standing fish production activities. The area has experienced increasing aquaculture development, particularly the culture of commercially important freshwater fish species such as African catfish (Clarias gariepinus), Nile tilapia (Oreochromis niloticus), and Heterobranchus species. Fish farming in the area is practiced using earthen ponds, concrete tanks, and other intensive and semi-intensive production systems, making it suitable for comparative nutritional assessment of cultured fish species.

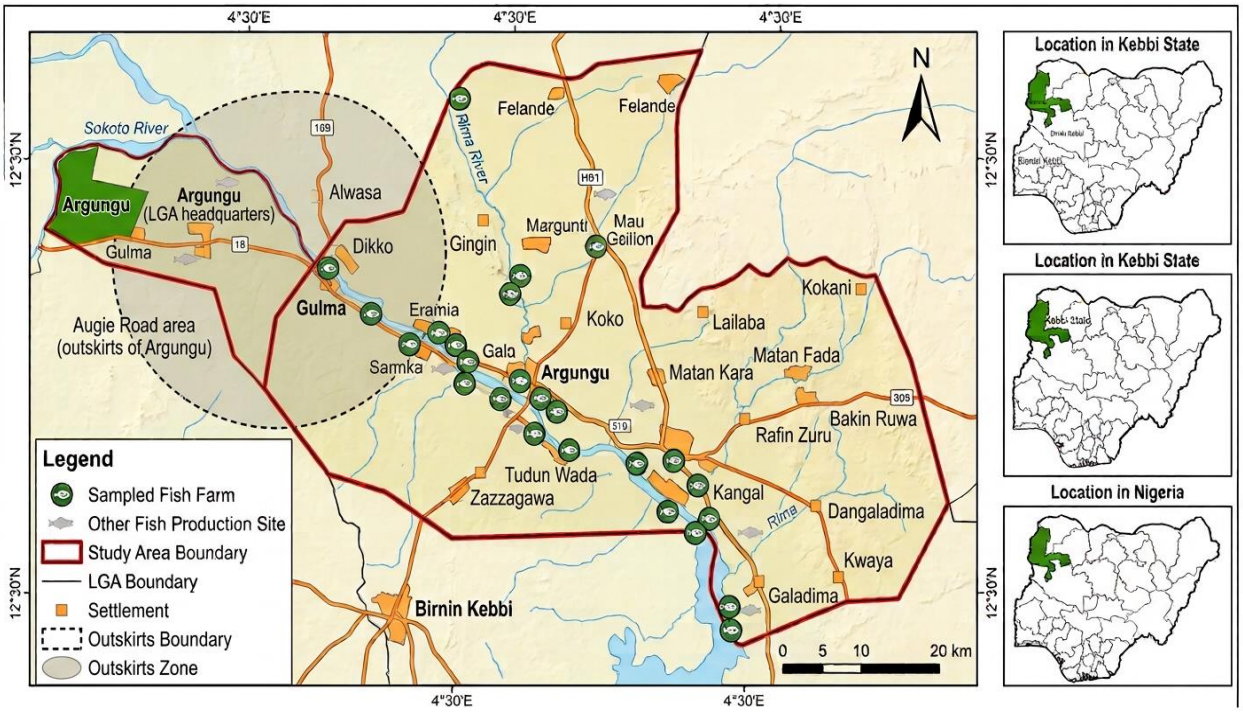

Figure 1: Map of Argungu Local Government Area, Kebbi State, Nigeria, showing the Study Area and Sampled Fish Farms

Research Design

The study adopted a comparative cross-sectional laboratory-based design. Fresh samples of selected cultured fish species were collected from commercial fish farms and analysed for proximate and mineral composition. The resulting data were subjected to descriptive, correlation, and multivariate statistical analyses to evaluate nutritional variability among the selected fish species.

Sample Collection

Three commonly cultured freshwater fish species were purposively selected from registered fish farms in Argungu Local Government Area, Kebbi State, Nigeria. The selected species were African catfish (*Clarias gariepinus*), Nile tilapia (*Oreochromis niloticus*), and *Heterobranchus* species. The fish samples were obtained from registered commercial fish farms located in Argungu, Alwasa, Gulma, Kokani, and Dikko communities, where fish are cultured using earthen ponds and concrete tanks under semi-intensive production systems.

Fresh market-size fish of approximately similar weight and maturity were collected directly from the farms. Only healthy fish specimens were selected in order to minimize variation associated with disease, age, and body size. A total of 45 fish samples were collected, comprising 15 specimens from each species. Each individual fish served as an experimental unit for laboratory analysis.

Table 1: Selected Cultured Fish Species and Sample Size

Fish Species	Scientific Name	Sample Size
African catfish	Clarias gariepinus	15
Nile tilapia	Oreochromis niloticus	15
Heterobranchus	Heterobranchus spp.	15
Total		45

Source: Field data, 2026.

Sample Preparation

Immediately after collection, the fish samples were placed in ice-filled insulated containers and transported to the laboratory. Each specimen was washed with distilled water to remove adhering debris and slime. The edible muscle tissues were carefully dissected, homogenized using a laboratory blender, packaged in sterile polyethylene bags, and stored at −20°C until laboratory analysis.

Determination of Proximate Composition

The proximate composition of the selected cultured fish species was determined following the standard analytical procedures of the Association of Official Analytical Chemists (AOAC, 2023). The parameters analysed included moisture content, crude protein, crude lipid, ash content, crude fibre, carbohydrate, and energy value. Moisture content was determined using the oven-drying method, while crude protein was quantified using the Kjeldahl method based on total nitrogen determination and subsequent conversion to protein content. Crude lipid was determined by Soxhlet solvent extraction, whereas ash content was measured by incineration in a muffle furnace. Crude fibre was estimated using the acid-alkali digestion method, and carbohydrate content was calculated by difference. The energy value of each fish sample was estimated from the proximate composition using the Atwater conversion factors.

Energy (kcal/100g) = (4 × %Protein) + (9 × %Lipid) + (4 × %Carbohydrate)

Determination of Mineral Composition

Mineral analysis was also carried out following AOAC (2023) procedures. The minerals analysed were calcium (Ca), phosphorus (P), iron (Fe), magnesium (Mg), potassium (K), sodium (Na), and zinc (Zn).

Fish samples were subjected to wet-acid digestion prior to mineral determination. Calcium, iron, magnesium, and zinc concentrations were measured using an Atomic Absorption Spectrophotometer (AAS). Sodium and potassium were determined using a flame photometer, while phosphorus was determined colorimetrically using the molybdenum blue method.

Statistical Analysis

The data obtained from the laboratory analyses were entered into Microsoft Excel and analysed using IBM SPSS Statistics version 27 and R statistical software. Descriptive statistics, including mean and standard deviation, were used to summarize the proximate and mineral composition of the selected cultured fish species in accordance with Objectives 1 and 2. Pearson product-moment correlation analysis was employed to examine the relationships among the proximate and mineral composition variables, addressing Objective 3. To achieve Objective 4, Principal Component Analysis (PCA) was used to identify the major nutritional components explaining variation among the fish species and to determine the variables contributing most to their nutritional quality. Hierarchical Cluster Analysis (HCA), using Ward's linkage method and Euclidean distance, was further performed to classify the fish species based on similarities in their nutritional composition. All statistical analyses were conducted at a significance level of $p < 0.05$.

Ethical Considerations

Fish samples were obtained from commercial fish farms with the consent of the farm owners. Sample collection and laboratory analyses were conducted in accordance with institutional guidelines for the handling of aquatic organisms. Standard laboratory procedures were followed to ensure the reliability, accuracy, and reproducibility of the analytical results.

RESULTS AND DISCUSSION

Proximate Composition of Selected Cultured Fish Species

The proximate composition of the selected cultured fish species is presented in Table 2. The results showed noticeable variations among the three fish species. *Clarias gariepinus* recorded the highest crude protein (20.84 ± 0.62%) and energy value (121.68 ± 2.34 kcal/100 g), whereas *Oreochromis niloticus* had the highest moisture content (77.42 ± 0.85%). *Heterobranchus* spp. exhibited the highest crude lipid (3.84 ± 0.21%) and ash content (2.18 ± 0.10%). The carbohydrate content was generally low in all the fish species.

Table 2: Proximate Composition of Selected Cultured Fish Species (Mean ± SD)

Parameter	*Clarias gariepinus*	*Oreochromis niloticus*	*Heterobranchus* spp.
Moisture (%)	74.63 ± 0.91	77.42 ± 0.85	75.18 ± 0.74
Crude protein (%)	20.84 ± 0.62	18.76 ± 0.54	19.92 ± 0.48
Crude lipid (%)	2.92 ± 0.18	2.11 ± 0.15	3.84 ± 0.21
Ash (%)	1.68 ± 0.09	1.44 ± 0.08	2.18 ± 0.10
Crude fibre (%)	0.32 ± 0.03	0.29 ± 0.02	0.35 ± 0.03
Carbohydrate (%)	0.61 ± 0.04	0.58 ± 0.03	0.53 ± 0.02
Energy (kcal/100 g)	121.68 ± 2.34	97.15 ± 1.96	114.44 ± 2.12

Source: Authors' laboratory analysis, 2026.

Mineral Composition of Selected Cultured Fish Species

Table 3 presents the mineral composition of the fish species. *Heterobranchus* spp. recorded the highest calcium (41.62 ± 1.84 mg/100 g), phosphorus (245.73 ± 8.21 mg/100 g), and magnesium (28.46 ± 1.17 mg/100 g), while *Clarias gariepinus* had the highest iron concentration (2.46 ± 0.15 mg/100 g). The sodium and potassium contents were highest in *Oreochromis niloticus*.

Table 3: Mineral Composition of Selected Cultured Fish Species (Mean ± SD)

Mineral	*Clarias gariepinus*	*Oreochromis niloticus*	*Heterobranchus* spp.
Calcium (mg/100 g)	38.42 ± 1.64	35.18 ± 1.42	41.62 ± 1.84
Phosphorus (mg/100 g)	232.54 ± 7.42	221.73 ± 6.85	245.73 ± 8.21
Iron (mg/100 g)	2.46 ± 0.15	1.92 ± 0.12	2.28 ± 0.14
Magnesium (mg/100 g)	26.41 ± 1.06	24.62 ± 0.94	28.46 ± 1.17
Sodium (mg/100 g)	58.63 ± 2.21	62.41 ± 2.34	57.82 ± 2.18
Potassium (mg/100 g)	324.85 ± 10.34	336.72 ± 11.05	318.64 ± 9.83
Zinc (mg/100 g)	1.54 ± 0.08	1.32 ± 0.07	1.68 ± 0.09

Source: Authors' laboratory analysis, 2026.

Correlation among Proximate and Mineral Composition Variables

Pearson correlation analysis revealed several significant relationships among the nutritional variables (Table 4). Crude protein showed a strong positive correlation with energy value ($r = 0.84$, $p < 0.001$) and phosphorus ($r = 0.71$, $p < 0.01$), indicating that fish with higher protein content also possessed higher energy and phosphorus levels. Moisture content was negatively correlated with crude lipid ($r = -0.76$, $p < 0.01$) and energy value ($r = -0.82$, $p < 0.001$), suggesting that fish with higher moisture generally had lower lipid content and caloric value. Calcium was positively associated with ash content ($r = 0.79$, $p < 0.01$), reflecting the contribution of minerals to total ash content.

Table 4: Selected Pearson Correlation Coefficients among Nutritional Variables

Variables	r	p-value
Protein vs Energy	0.84	<0.001
Protein vs Phosphorus	0.71	0.003
Moisture vs Lipid	−0.76	0.001
Moisture vs Energy	−0.82	<0.001
Ash vs Calcium	0.79	<0.001
Calcium vs Phosphorus	0.74	0.002
Lipid vs Energy	0.88	<0.001

Source: Authors' computation from laboratory data, 2026.

Principal Component Analysis

The suitability of the data for Principal Component Analysis (PCA) was confirmed by a Kaiser–Meyer–Olkin (KMO) value of 0.79 and a significant Bartlett's Test of Sphericity ($\chi^2 = 286.41$, df = 91, $p < 0.001$), indicating adequate sampling adequacy and sufficient intercorrelation among variables.

The PCA extracted three principal components with eigenvalues greater than one, explaining 82.6% of the total variation in nutritional composition (Table 5). The first principal component (PC1) explained 48.3% of the total variance and was characterized by high positive loadings for crude protein, phosphorus, calcium, and energy value. The second principal component (PC2) accounted for 22.4% of the variance and was mainly associated with moisture and lipid content, while the third component (PC3) explained 11.9% of the total variance and was dominated by sodium and potassium concentrations.

Table 5: Total Variance Explained by Principal Component Analysis

Component	Eigenvalue	Variance (%)	Cumulative (%)
PC1	6.76	48.3	48.3
PC2	3.14	22.4	70.7
PC3	1.67	11.9	82.6

Source: Authors' computation from laboratory data, 2026.

The PCA biplot (Figure 2) showed clear separation among the three fish species based on their nutritional characteristics. *Clarias gariepinus* was associated with higher protein and energy values, *Heterobranchus* spp. clustered with calcium, phosphorus, and ash content, whereas *Oreochromis niloticus* was closely associated with higher moisture content.

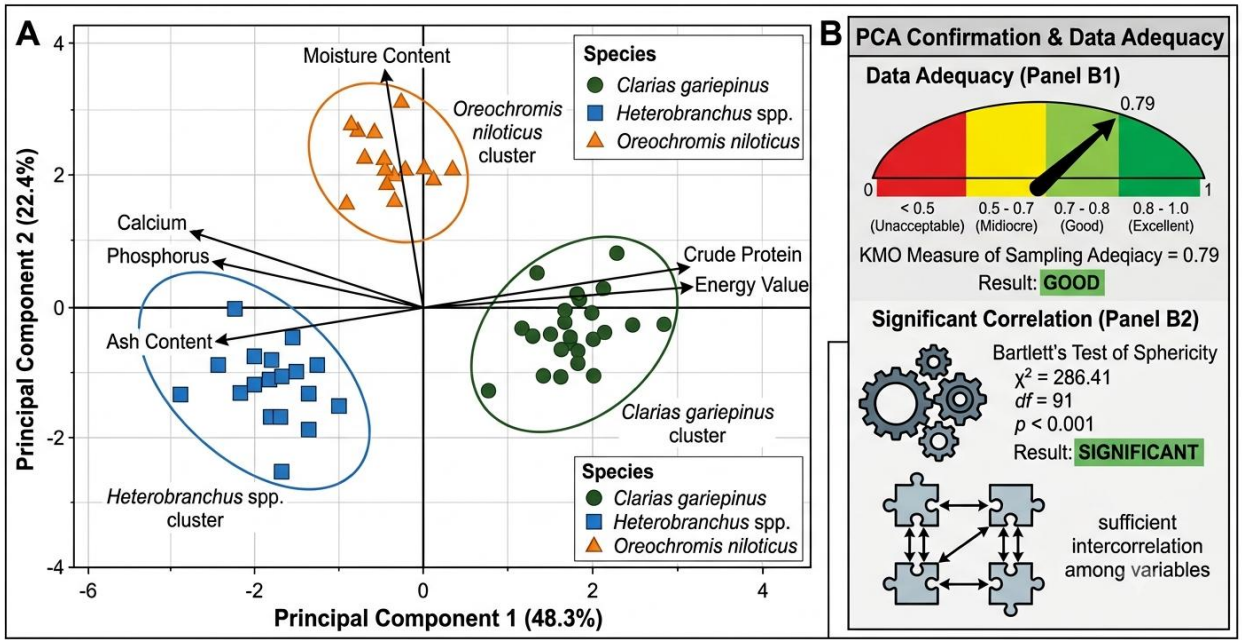

Figure 2: Principal Component Analysis (PCA) Biplot Showing the Distribution of the Selected Cultured Fish Species Based on Proximate and Mineral Composition

Hierarchical Cluster Analysis

Hierarchical Cluster Analysis (HCA) was performed using Ward's linkage method and Euclidean distance to classify the selected cultured fish species according to similarities in their nutritional composition. Figure 3 presents the resulting hierarchical cluster dendrogram.

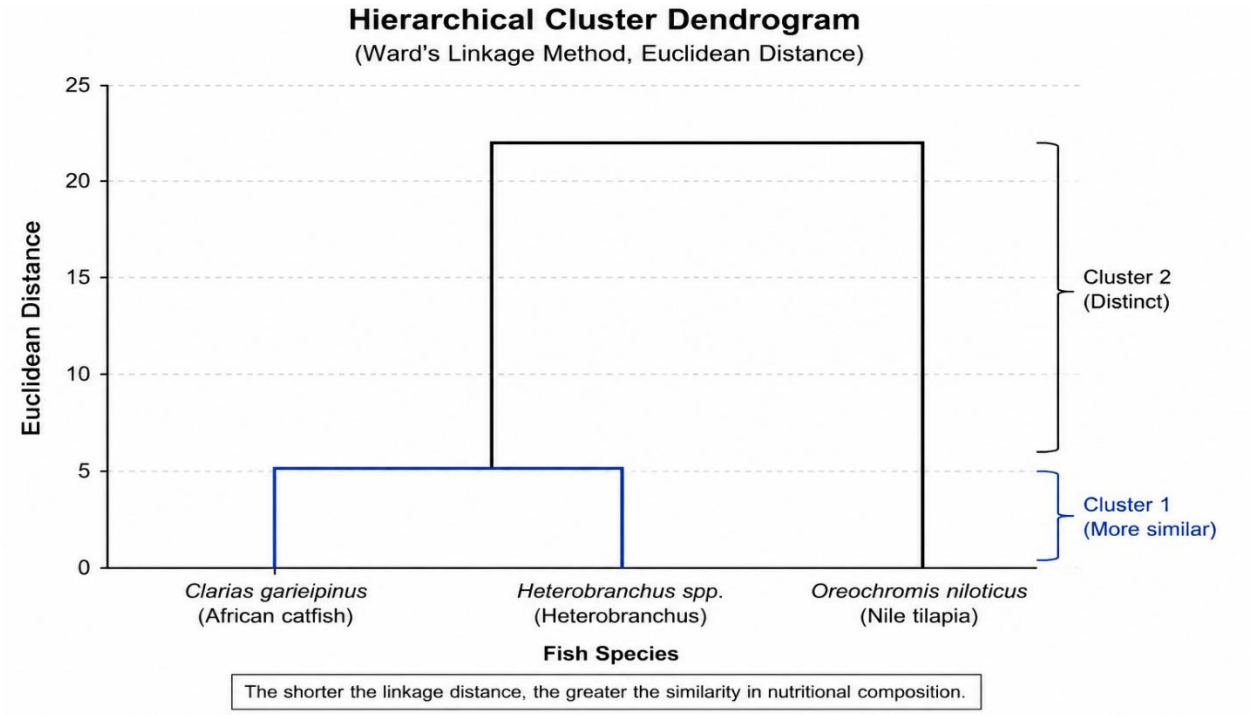

Figure 3: Hierarchical Cluster Dendrogram Showing the Nutritional Similarity among the Selected Cultured Fish Species

The dendrogram revealed two major clusters. The first cluster comprised *Clarias gariepinus* and *Heterobranchus* spp., indicating that the two species shared relatively similar proximate and mineral composition. In contrast, *Oreochromis niloticus* formed a distinct second cluster, reflecting a different nutritional profile characterized by relatively higher moisture content and comparatively lower protein and mineral concentrations. The clustering pattern is consistent with the Principal Component Analysis (Figure 2), which also separated *Oreochromis niloticus* from *Clarias gariepinus* and *Heterobranchus* spp., confirming that the latter two species exhibited greater nutritional similarity.

Discussion

The present study comparatively assessed the nutritional quality of selected cultured fish species in Argungu, Kebbi State, using proximate composition, mineral composition, correlation analysis, and multivariate statistical techniques. The findings demonstrated considerable variation in nutritional composition among the fish species, confirming that the nutritional value of cultured fish is species-dependent and influenced by biological and management factors. This observation agrees with previous reports that nutrient composition differs among freshwater fish species because of variations in genetics, feeding regimes, environmental conditions, and culture practices (Mustafa et al., 2023; Hoa et al., 2025).

The proximate composition results showed that *Clarias gariepinus* contained the highest crude protein and energy value, while *Heterobranchus* spp. recorded the highest crude lipid and ash contents. In contrast, *Oreochromis niloticus* exhibited the highest moisture content. The relatively higher protein content observed in *Clarias gariepinus* suggests that it may provide greater dietary protein than the other species investigated, making it a valuable source of high-quality animal protein. The higher moisture content recorded in *Oreochromis niloticus* is consistent with the inverse relationship commonly observed between moisture and lipid content in fish muscle. These findings are comparable with those reported by Anarado et al. (2023), who observed significant differences in proximate composition between cultured African catfish and Nile tilapia, and by Epinipre et al. (2025), who similarly reported that *Clarias gariepinus* possessed higher protein content than other commonly consumed fish species in Nigeria.

The mineral composition also differed considerably among the fish species. *Heterobranchus* spp. contained the highest concentrations of calcium, phosphorus, magnesium, and zinc, whereas *Clarias gariepinus* recorded the highest iron content. Conversely, *Oreochromis niloticus* contained relatively higher sodium and potassium concentrations. These differences indicate that individual fish species may contribute differently to human micronutrient intake. Calcium and phosphorus are essential for bone development, iron is indispensable for haemoglobin synthesis and oxygen transport, while magnesium, potassium, and sodium play important roles in metabolic regulation and electrolyte balance. Similar

species-related variations in mineral composition have been documented by Mustafa et al. (2023), Imam et al. (2025), and Birie et al. (2025), all of whom reported significant differences in mineral concentrations among freshwater fish species.

The correlation analysis revealed significant relationships among several nutritional variables. The strong positive association between crude protein and energy value indicates that fish with higher protein content generally provide greater caloric value. Likewise, the positive relationship between protein and phosphorus suggests that nutritionally richer fish species tend to accumulate higher levels of essential minerals. In contrast, the significant negative correlations between moisture content and both lipid and energy values demonstrate the well-established dilution effect of moisture on nutrient concentration in fish tissues. The positive association observed between calcium and ash content further confirms that ash largely reflects the total mineral content of fish flesh. These findings are consistent with established principles of fish muscle biochemistry and support previous nutritional studies that reported similar relationships among proximate constituents and mineral elements (Begum et al., 2024; Prakash et al., 2025).

The Principal Component Analysis proved effective in summarizing the multidimensional nutritional dataset into a smaller number of components. The first three principal components explained over 80% of the total variation, indicating that most of the nutritional variability among the fish species could be explained by a limited number of nutritional variables. The first component was primarily associated with crude protein, phosphorus, calcium, and energy value, suggesting that these variables are the major determinants of overall nutritional quality. The PCA biplot clearly distinguished the three fish species according to their nutritional profiles, with *Clarias gariepinus* associated with higher protein and energy values, *Heterobranchus* spp. associated with mineral-rich characteristics, and *Oreochromis niloticus* associated mainly with higher moisture content. This finding demonstrates the usefulness of multivariate statistical techniques for identifying nutritional patterns that may not be evident through conventional descriptive analysis alone. Similar applications of Principal Component Analysis in fish nutritional studies have been reported by Begum et al. (2024), who successfully classified freshwater fish species according to their nutrient composition.

The results of the Hierarchical Cluster Analysis further strengthened the PCA findings by grouping *Clarias gariepinus* and *Heterobranchus* spp. into the same cluster while separating *Oreochromis niloticus* into a distinct cluster. This indicates that the two catfish species possess more similar nutritional characteristics than Nile tilapia. The consistency between the PCA and HCA results demonstrates the robustness of the multivariate analyses and confirms that combining different multivariate techniques provides a more comprehensive assessment of fish nutritional quality than relying solely on descriptive statistics. Similar clustering of nutritionally related fish species has been reported in previous nutritional profiling studies employing multivariate statistical methods (Hoa et al., 2025; Begum et al., 2024).

Overall, the findings of this study demonstrate that significant nutritional differences exist among cultured fish species produced in Argungu, Kebbi State. *Clarias gariepinus* exhibited superior protein and energy content, *Heterobranchus* spp. showed greater mineral richness, while *Oreochromis niloticus* contained comparatively higher moisture content. These findings provide useful information for consumers, fish farmers, nutritionists, and policymakers regarding species selection for dietary purposes and aquaculture production. Furthermore, the successful application of correlation analysis, Principal Component Analysis, and Hierarchical Cluster Analysis confirms the value of multivariate statistical techniques in fisheries and food science research, particularly for evaluating complex nutritional datasets.

CONCLUSION

This study comparatively assessed the nutritional quality of selected cultured fish species in Argungu Local Government Area of Kebbi State, Nigeria, using proximate composition, mineral composition, and multivariate statistical techniques. The findings revealed substantial variations in nutritional characteristics among *Clarias gariepinus*, *Oreochromis niloticus*, and *Heterobranchus* spp., confirming that the nutritional value of cultured fish is species-specific and influenced by biological and production-related factors.

Among the studied species, *Clarias gariepinus* demonstrated the highest crude protein and energy contents, indicating its potential as a superior source of dietary protein and energy. *Heterobranchus* spp. exhibited higher concentrations of essential minerals, particularly calcium, phosphorus, magnesium, and zinc, highlighting its importance as a valuable source of micronutrients. Conversely, *Oreochromis niloticus* recorded higher moisture content and comparatively lower levels of protein and minerals, reflecting differences in its nutritional profile.

The correlation analysis demonstrated significant relationships among nutritional variables, particularly the strong positive associations between protein, energy, and phosphorus, as well as the negative relationship between moisture and nutrient concentration. These relationships emphasize the interconnected nature of proximate and mineral components in determining fish nutritional quality.

The application of Principal Component Analysis and Hierarchical Cluster Analysis provided a comprehensive

understanding of the overall nutritional variation among the selected fish species. The multivariate analyses successfully identified major nutritional factors responsible for species differentiation and revealed clear patterns of similarity and dissimilarity among the fish species. The consistency between PCA and HCA findings confirms the usefulness of multivariate statistical approaches in evaluating complex nutritional datasets in fisheries research.

Overall, the study establishes that cultured fish species in Argungu, Kebbi State, possess considerable nutritional value, although their contributions to human nutrition differ according to species. The findings provide baseline information that can support consumer dietary decisions, aquaculture management strategies, and nutritional planning. Furthermore, the integration of laboratory nutritional analysis with multivariate statistical techniques offers a valuable framework for future studies aimed at improving fish production, quality assessment, and sustainable aquaculture development in Nigeria.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. It is recommended that fish farmers in Argungu and other aquaculture-producing areas should consider the nutritional characteristics of different fish species when selecting species for production, as *Clarias gariepinus* demonstrated higher protein and energy content, while *Heterobranchus* spp. showed superior mineral composition.
2. Routine assessment of the proximate and mineral composition of cultured fish should be encouraged among aquaculture producers, research institutions, and relevant government agencies to ensure continuous monitoring of fish nutritional quality and consumer safety.
3. Fish farmers should adopt improved feeding strategies and quality feed formulations to enhance nutrient retention, flesh quality, and overall nutritional value of cultured fish, considering the important influence of feed composition on fish nutrient accumulation.
4. Researchers in fisheries and food science should incorporate multivariate statistical techniques, such as Principal Component Analysis and Hierarchical Cluster Analysis, into nutritional assessment studies to provide a more comprehensive understanding of complex relationships among multiple nutritional variables.
5. Government agencies, fisheries extension officers, and nutrition professionals should intensify consumer education on the nutritional benefits of different cultured fish species to promote informed dietary choices and contribute to improved food and nutrition security.

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