

# Comparative Studies of Proximate and Mineral Composition of Fresh and Smoked *Clarias gariepinus*, *Oreochromis niloticus*, and *Bagrus bayad* from River Rima, Nigeria

I. M. Imam<sup>1\*</sup>, I. N. Giddy<sup>1</sup> and M. Saidu<sup>2</sup>

<sup>1</sup> Department of Fisheries and Aquaculture, Usmanu Danfodiyo University, Sokoto

<sup>2</sup> Department of Fisheries Technology, Federal College of Freshwater Fisheries Technology, Baga, Maiduguri, Borno State, Nigeria

\*Corresponding Author: [ayindeimam46@gmail.com](mailto:ayindeimam46@gmail.com)

## Abstract

This study assessed the proximate and mineral composition of three commercially important freshwater fish species *Clarias gariepinus*, *Oreochromis niloticus*, and *Bagrus bayad* collected from River Rima, Sokoto State, Nigeria. Both fresh and smoked samples were analyzed to determine the effects of processing on their nutritional quality. Proximate analysis included the determination of moisture, crude protein, lipid, ash, and crude fiber contents, while mineral composition (sodium, potassium, calcium, magnesium) was quantified using Atomic Absorption Spectrophotometry. Phosphorus was determined using the procedure of Phosphorus, Inorganic kits “Spectrum- Diagnostics, Germany IFUFCC34”. Results indicated that proximate composition varied significantly among species and between treatments. Moisture content decreased considerably after smoking, while protein levels increased, with smoked *Clarias gariepinus* recording the highest protein value (45.30%). Lipid content was generally higher in *Oreochromis niloticus*, whereas ash was more concentrated in smoked samples. Mineral analysis revealed species-specific differences, with smoked fish exhibiting higher concentrations of calcium and phosphorus, enhancing their dietary value. The increase in nutrient density due to smoking also suggests improved preservation and extended shelf life. These findings underscore the nutritional significance of these freshwater fish species and highlight the role of traditional processing in improving food quality, supporting both dietary needs and policy initiatives for small-scale fisheries and food security in the region.

**Keywords:** Proximate composition; Mineral analysis; Freshwater fish; *Clarias gariepinus*; *Oreochromis niloticus*; *Bagrus bayad*; Smoking; River Rima

## Introduction

The nutritional characteristics of fish and fishery products are of vital interest to consumers. Fishery products are highly nutritious and excellent means of obtaining dietary essentials like protein, minerals and vitamins (FAO, 2020). In recent years, fish has become a favorite foodstuff for the majority of societies because of several health reasons (Ali and Kiumars, 2010). Fish is a cheap source of high-quality protein; thus, there is a need to produce it as an alternative way of fulfilling animal protein requirements, especially for poor rural communities (Sutharshiny and Sivashanthini, 2011). It is also widely accepted because of its high palatability, tender flesh and low cholesterol (FAO, 2016). In Nigeria, fish provides approximately 5.6%

of total protein intake (including both plant- and animal-based sources) and nearly 38.2% of all animal protein consumed (FAO, 2016). Because fish food contains antimicrobial peptides, regular consumption of fish also promotes the defense mechanism against human pathogens (Ravichandra et al., 2011). Lipids in fish are a rich source of omega-3 fatty acids recommended for human health improvement and disease prevention (Calder, 2012). Regular intake of fish has been linked to improved heart and brain function, as well as reduced risk of various diseases including arthritis, Alzheimer’s disease, dementia, diabetes, migraine headaches, inflammatory conditions and certain cancers (Connor et al., 2015). Moreover, fish muscle and bones are good sources of calcium and phosphorus, along with essential minerals such as iron, zinc,

iodine, magnesium, and potassium (Ersoy and Ozeren, 2009). Minerals are vital to human health because they regulate acid–base balance, haemoglobin formation, water balance, bone and teeth formation, and enzymatic reactions (Duran, 2010; Mendil, 2010). About 65% of fish minerals are deposited in bone, which is particularly significant in Nigeria where small fishes are consumed whole, including the bones. The nutritional status of fish varies among different species and also within the same species depending on habitat, feeding habits, diet, and environmental conditions (Yeannes and Almandos, 2003).

Previous studies have documented the general nutritional value of fish, highlighting their role as a source of protein, lipids, minerals, and bioactive compounds important for human health (Connor et al., 2015; Calder, 2012). However, much of the existing research has focused on marine species or cultured freshwater fish, with limited attention given to locally important wild freshwater species in Nigeria. In particular, there is scarcity of data on the proximate and mineral composition of *Clarias gariepinus*, *Oreochromis niloticus*, and *Bagrus bayad*, despite their high consumption and economic significance in the country. Furthermore, although smoking is a widely used preservation technique that can influence nutrient composition, few studies have examined its impact on these species within the Sokoto region.

Addressing this gap is important because fish constitutes a major source of affordable animal protein for rural and urban households in Nigeria, contributing significantly to food security (FAO, 2016). Establishing the nutritional profiles of both fresh and smoked samples of these species will not only provide baseline information for consumers and nutritionists but also support policy initiatives on small-scale fisheries, nutrition labeling, and food safety. Based on these premises, the objective of the study was to investigate the proximate and mineral composition of *Clarias gariepinus*, *Oreochromis niloticus*, and *Bagrus bayad* from River Rima, Sokoto State, Nigeria, with emphasis on the effects of

smoking on their nutritional quality.

## Materials and method

### *Study area*

The Rima River, forms part of the Sokoto Rima Basin in northern Nigeria, drains a sub-basin area of approximately 65,000 km<sup>2</sup> and plays a crucial role in the region's aquatic ecosystem and local economy (Mohammed et al., 2022). The Rima River flows through Wamako in Sokoto State, Nigeria, lying between approximately 13°06'58" and 13°07'24" N latitude and 5°15'03" and 5°15'38" E longitude (Akinbiyi, Sule, Muhammad, & Usman, 2019). Its volume and discharge capacity are significant, making it a vital water resource for the region. The Goronyo Dam on the Rima River contributes approximately 976 million m<sup>3</sup> of storage capacity, with an annual runoff of around 1.7 billion m<sup>3</sup> in the catchment underscoring the river's hydro-irrigation potential (World Bank, 2020; Wikipedia, 2025). The river supports local livelihoods by supplying fish for artisanal fisheries and enables irrigation for rice cultivation, a key agricultural activity in Sokoto State. Sokoto, in Nigeria's northwest. It has a population of about 5,307,154, its semi-arid climate features a wet season which begins from May and ends in September. The State has an annual rainfall ranging from 500 mm to 1300 mm (Ekoh & Alimp, 2020; Nigerian Investment Promotion Commission [NIPC], 2023).

### *Sample collection and preparation*

The fish samples used for the study were 27 in number, with an average weight ranging from 25–250 g. The species included *Oreochromis niloticus*, *Clarias gariepinus*, and *Bagrus bayad*. They were purchased from local fishermen at the landing site of River Rima once a month for a period of three months. The fish samples were immediately transported in good condition, after which they were smoked. The smoking process was carefully prepared. The three fish species were thoroughly cleaned to remove slime, blood, and harmful

bacteria. The fish were eviscerated, leaving the skin intact. Smoking was carried out using a traditional *mud (mould) banda kiln*, a locally fabricated smoking chamber widely used in northwestern Nigeria for fish preservation. After cleaning, the fish were arranged on wire mesh trays inside the *banda kiln*. The experiment design was a completely randomized design, consisting of a 3 × 3 layout, where three experimental treatments were each replicated three times. A controlled fire using hardwood fuel was maintained at the base to ensure slow, uniform smoking. The process lasted for approximately 24 hrs, with the kiln temperature ranging between 60–80 °C. Smoking continued until the fish attained a firm texture and reduced moisture content, indicating complete drying. During and after smoking, hands, utensils, and work surfaces were kept clean, and the fish were cooled on clean trays before packaging to prevent cross-contamination.

#### *Procedure for proximate and minerals*

The dried (smoked) fish were transported to the Soil Chemistry Laboratory, Usmanu Danfodiyo University, Sokoto, for analysis. On arrival, samples were kept at ≤4 °C and processed within 24 h. Whole fish were rinsed with deionized water, blotted dry, and homogenized by species to obtain composite samples. Aliquots for drying were spread in thin layers (<5 mm) on pre-weighed, clean stainless or aluminum trays.

Drying was performed in a forced-air convection oven set at 70–80 °C. Trays were loaded so that air could circulate freely, and the oven temperature was verified with an in-oven thermometer. Samples were first dried for 12 hr, cooled in a desiccator (silica gel, 20–25 min), and weighed on an analytical balance (readability 0.1 mg). The constant-weight criterion was defined as two consecutive weights differing by ≤0.1% (or ≤0.001 g, whichever was greater) after an additional 1–2 hr drying interval. This dry–cool–weigh cycle was repeated until the criterion was met (total drying time typically 18–24 h, depending on sample thickness). Dried material was stored in airtight bags with desiccant until analysis. From each composite, 2.00 g of the dried,

homogenized sample was taken for proximate analysis and 0.50–1.00 g for mineral analysis. Proximate composition (moisture, crude protein, crude lipid, ash, crude fibre) was determined by AOAC methods (AOAC, 2000). Energy was calculated from proximate data using Atwater factors (protein = 4 kcal/g, lipid = 9 kcal/g, carbohydrate by difference = 4 kcal/g), where applicable. Mineral elements such as Na, K, Ca, Mg, Fe and Zn were analyzed using flame AAS after HNO<sub>3</sub>–H<sub>2</sub>O<sub>2</sub> digestion. Initial calibration of the AAS was through multi-element standards traceable to certified stock solutions; a reagent blank. Continuing calibration checks were run after every 10 samples. Results are reported as ppm (µg/g, dry weight). Each determination was performed in duplicate/triplicate; data quality was accepted when recoveries were 95–105% and calibration R<sup>2</sup> ≥ 0.995. Phosphorus was determined using Inorganic kits “Spectrum-Diagnostics, Germany IFUFCC34”.

**Safety and quality assurance.** Acid digestion and solvent handling were all performed in a certified fume hood with PPE (lab coat, nitrile gloves, eye protection). Hot-work precautions were followed when operating ovens and hotplates (heat-resistant gloves; “hot” labels on trays). Material Safety Data Sheets (MSDS) for nitric acid, hydrogen peroxide, and solvents were consulted; acid wastes were collected in labeled containers for institutional hazardous-waste disposal. Glassware was acid-washed (10% HNO<sub>3</sub>) and rinsed with deionized water to minimize contamination. Balances and oven thermometers were checked/calibrated per laboratory schedule.

#### *Moisture content determination (AOAC, 2000):*

A 10 g sample of the prepared wet sample was dried at 65°C for 24 hours and subsequently at 105°C for 6 hours in a hot air oven (Fine Tech, Shinsaeng, Korea).

$$\text{Moisture percentage} = (W_1 - W_2) / W_1 \times 100 \quad [1]$$

W<sub>1</sub> = The sample's weight before drying

W<sub>2</sub> = The sample's weight following drying

Note: The dry matter percentage was determined using the following method:

$$\text{Moist\%} - \text{dry matter\%} = 100$$

*Calculating the proportion of fat using "ether extract" (AOAC, 2000):*

After weighing one gram of the dried sample, it was placed in the thimble of the Soxhlet apparatus and wrapped in filter paper with a given weight. Petroleum ether (60/80) was used for the extraction, which lasted for 17 hours. The following formula was used to get the fat percentage:

$$\text{fat percentage: } (W1-W2)/A \times 100 = \text{Fat\%} \quad [2]$$

W1 = Weight prior to extraction

W2 is the weight following extraction.

A = Sample weight

*Ashes content determination AOAC, 2010):*

Porcelain crucibles that had been previously cleaned and weighed were used to weigh one gram of the dry material. The crucibles were placed in a Muffle Furnace (Thermolyne, 6000 Furnace) and burned for six hours at 550°C, producing a grayish-white ash:

$$\text{Ash\% equals to } (\text{ash weight}) / (\text{sample weight}) \times 100 \quad [3]$$

*Determination of element composition*

Mineralization of sample (incineration method):

One gram of the dry sample was put in a crucible and was ashed at 500-550°C for 6 hrs. After cooling, a 1:2 (v/v) of 10 ml of 65% Nitric acid and 20 ml of double distilled water was added and then thoroughly mixed. The solution was covered with watch glass and heated in a boiling water bath for 30 minutes and then cooled. The content was transferred to a 100 ml volumetric flask and diluted to the mark with deionized water and then mixed well. The suspension was filtered through Whatman no. 45 filter paper and the first 5-10 ml of the filtrate was discarded. The rest of the filtrate was collected into a brown glass bottle ready for the estimation of minerals.

*Estimation of macro-elements*

Calcium content:

According to procedures of Calcium OCPC kits "Spectrum-diagnostics, Germany

IFUFCC07

$$\text{Calcium conc. (mg/dl)} = \frac{A_{\text{sample}}}{A_{\text{standard}}} \times 10 \times \text{dilution} \quad [4]$$

Phosphorus content.

According to procedures of Phosphorus, Inorganic kits "Spectrum- Diagnostics, Germany IFUFCC34".

$$\text{Phosphorus conc. (mg/dl)} = \frac{A_{\text{sample}}}{A_{\text{standard}}} \times 5 \times \text{dilution} \quad [5]$$

Magnesium content:

According to procedures of Magnesium kits "Spectrum-diagnostics, Germany IFUFCC94".

$$\text{Magnesium conc. (mg/dl)} = \frac{A_{\text{sample}}}{A_{\text{standard}}} \times 2.5 \times \text{dilution} \quad [6]$$

Sodium content:

According to procedures of Sodium kits "Spectrum-diagnostics, Germany IFUFCC94".

$$\text{sodium conc. (mg/dl)} = \left( \frac{A_{\text{sample}}}{A_{\text{standard}}} \times 150 \right) \times \frac{\text{dilution} \times 23 *}{10 ** \times 1 ***} \quad [7]$$

Where: \*23 = atomic weight of sodium.

10 = conversion factor (L to dl)

1 = the valence of sodium

Potassium content:

According to procedures of potassium kits "Spectrum-diagnostics, Germany IFUFCC53".

$$\text{Potassium conc. (mg/dl)} = \frac{A_{\text{sample}}}{A_{\text{standard}}} \times 5 \times \frac{\text{dilution} \times 39.098 *}{10 **} \quad [8]$$

Where: 39.098 = conversion factor, which relates to the molecular weight of Potassium, 10 = conversion factor (L to dl).

*Statistical analysis*

The data collected were subjected to determine variations in parameters among the species using ANOVA in SPSS Version 2023.

## Results

Mean proximate composition in Smoked fish species from River Rima.

The results in Tables 3.1 and 3.2 depict there is significant difference ( $p < 0.05$ ) in the proximate composition of smoked and fresh *Bagrus bayad* and *clarias gariepinus* except in the composition of *Oreochromis niloticus* which shows no significant difference ( $p > 0.05$ ) in all their mean value (19.72-3.0).

*Mean concentration of mineral elements in fresh fish species from River Rima*

The result in Table 3.3 depicts that there is significant difference ( $p < 0.05$ ) in the mineral composition of fresh *Bagrus bayad* and *clarias gariepinus* except in the composition of *Oreochromis niloticus* which shows no significant difference ( $p > 0.05$ ) in all their mean value (12.00-0.30).

*Mean concentration of mineral elements in smoked fish products from River Rima*

Table 3.4 shows that there is a significant difference ( $p < 0.05$ ) in the mineral composition of smoked *Bagrus bayad* and *Clarias gariepinus* except in the composition of *Oreochromis niloticus* which shows no significant difference ( $p > 0.05$ ) in all the mean value (15.38-0.05).

**Discussion**

*Crude protein composition in smoked Fish species from River Rima*

The results indicated that, in smoked samples of *Oreochromis niloticus*, there was no significant difference ( $p > 0.05$ ) in crude

**TABLE 3.1**

Mean proximate composition of Smoke fish from River Rima

Fish species	moisture	Ash	Lipid	Fiber	crude protein	CHO
<i>oreochromis niloticus</i>	5.67±1.37 <sup>a</sup>	13.80±3.29 <sup>a</sup>	9.00±0.95 <sup>a</sup>	3.00±0.63 <sup>a</sup>	14.78±1.32 <sup>a</sup>	19.72±4.49 <sup>a</sup>
<i>Bagrus bayad</i>	6.60±1.56 <sup>a</sup>	12.51±3.00 <sup>a</sup>	6.66±1.44 <sup>a</sup>	3.17±0.59 <sup>a</sup>	51.37±1.88 <sup>ab</sup>	19.58±4.42 <sup>a</sup>
<i>clarias gariepinus</i>	6.50±1.57 <sup>a</sup>	19.30±4.16 <sup>a</sup>	9.50±3.36 <sup>a</sup>	4.17±0.53 <sup>a</sup>	45.30±0.46 <sup>b</sup>	15.33±5.96 <sup>a</sup>

The mean±standard deviation with the same superscript, along the same column show no significant difference ( $p > 0.05$ ).

**TABLE 3.2**

Mean proximate composition of Fresh fish sample from River Rima

Fish species	moisture	Ash	Lipid	Fiber	crude protein	CHO
<i>oreochromis niloticus</i>	77.0±0.29 <sup>a</sup>	31.67±13.3 <sup>a</sup>	5.00±0.02 <sup>a</sup>	2.00±0.1 <sup>a</sup>	13.06±0.0 <sup>a</sup>	2.94±0.0 <sup>a</sup>
<i>Bagrus bayad</i>	72.0±0.17 <sup>b</sup>	5.00±0.23 <sup>a</sup>	1.00±0.12 <sup>b</sup>	2.00±0.0 <sup>b</sup>	16.19±0.0 <sup>b</sup>	3.31±0.0 <sup>b</sup>
<i>clarias gariepinus</i>	64.50±0.11 <sup>c</sup>	6.00±0.29 <sup>a</sup>	1.33±0.28 <sup>b</sup>	2.50±0.0 <sup>b</sup>	11.81±0.0 <sup>c</sup>	14.19±0.2 <sup>c</sup>

The mean±standard deviation with the same superscript along the same column show no significant difference ( $p > 0.05$ )

**TABLE 3.3**

Mean proximate composition of Fresh fish sample from River Rima

Fish species	Na	Ca	Mg	P	K
<i>oreochromis niloticus</i>	6.00±0.17 <sup>a</sup>	0.30±0.01 <sup>a</sup>	1.80±0.06 <sup>a</sup>	0.06±0.002 <sup>a</sup>	12.00±0.29 <sup>a</sup>
<i>Bagrus bayad</i>	4.00±0.29 <sup>a</sup>	0.30±0.01 <sup>a</sup>	0.80±0.02 <sup>ab</sup>	0.04±0.002 <sup>a</sup>	11.00±0.17 <sup>b</sup>
<i>clarias gariepinus</i>	5.00±0.23 <sup>b</sup>	0.40±0.01 <sup>b</sup>	0.90±0.03 <sup>b</sup>	0.40±0.01 <sup>b</sup>	10.00±0.23 <sup>c</sup>

The means ±standard deviation in the same column show no significant differences ( $P > 0.05$ ) with the same superscript

**TABLE 3.4**

Mean mineral composition of Fresh fish species from River Rima

Fish species	Na	Ca	Mg	P	K
<i>oreochromis niloticus</i>	13.33±2.67 <sup>a</sup>	0.53±1.39 <sup>a</sup>	1.60±0.05 <sup>a</sup>	0.05±0.003 <sup>a</sup>	15.38±3.65 <sup>a</sup>
<i>Bagrus bayad</i>	14.67±2.59 <sup>a</sup>	0.70±0.08 <sup>a</sup>	1.52±0.25 <sup>a</sup>	0.05±0.003 <sup>ab</sup>	18.33±5.57 <sup>a</sup>
<i>clarias gariepinus</i>	14.33±2.24 <sup>a</sup>	0.67±0.09 <sup>a</sup>	1.57±0.15 <sup>a</sup>	0.06±0.003 <sup>b</sup>	18.02±4.25 <sup>a</sup>

The mean ±standard deviation with the same superscript, along the same column show no significant difference ( $p > 0.054.0$ )

protein content compared with fresh samples, indicating that smoking did not markedly alter its protein composition. However, for smoked *Bagrus bayad* and *Clarias gariepinus*, there was a significant difference ( $p < 0.05$ ) in crude protein levels. This suggested that smoking had a measurable effect on their protein composition, likely due to moisture loss and concentration effects.

These results are similar to the work of Alaa et al. (2024); in which the mean value for crude protein of 73.26,  $81.22 \pm 0.24$  in *Clarias gariepinus* and *Bagrus bayad* respectively shows significant difference. The significant difference in their crude protein composition can be influenced by various factors. According to Ogata and Shearer (2020), the protein content in fish varies depending on species, habitat, diet, and processing methods, environmental conditions, fish size, amount of protein in the diet, and feeding rate.

#### *Mean proximate composition of Fresh fish sample from River Rima*

The results showed that in fresh *Oreochromis niloticus*, there was no significant difference ( $p > 0.05$ ) in ash content compared with the other fresh species, indicating that mineral content was relatively stable across these samples. However, in *Bagrus bayad* and *Clarias gariepinus*, a significant difference ( $p < 0.05$ ) was observed in their ash contents. This suggests that these species inherently possess different levels of mineral deposition in their tissues, which may be attributed to species-specific feeding habits, ecological niches, and biochemical composition. The significant variation reflects genuine biological differences rather than random variation. This explanation aligns with findings from several studies including those of Effiong and Fakunle, (2011) that the ash content “5.50” for *Bagrus bayad* shows significant difference and of “ $1.10 \pm 0.12$ ”, for *Clarias gariepinus* by Anarado et al. (2023), who emphasized the impact of species-specific characteristics and habitat on proximate and mineral composition. The significant differences in the ash content of two fish species can result from factors

like variations in diet and feeding habits, habitat and water chemistry, physiological and genetic differences, seasonal and growth variations, sample composition (bone-to-flesh ratio), processing methods (e.g., smoking), and potential exposure to pollution or contamination.

#### *Mean mineral composition of Fresh fish species from River Rima*

The results indicate that the mineral compositions in fresh *Oreochromis niloticus* have no significant difference ( $p > 0.05$ ), while in *Bagrus Bayad* and *Clarias gariepinus*, there are significant differences in their Mg and K contents ( $p < 0.05$ ). The pattern of mineral concentrations in the sample of each species is in the order  $K > Na > Mg > Ca > P$ . These results are similar to those of Alaa et al. (2024) in which the mean value for magnesium content is  $15.12 \pm 0.68$  for *Bagrus bayad* and potassium  $347.72 \pm 37.34$  for *Clarias gariepinus* shows significant difference in their mineral contents. The differences in Mg and K content between *Bagrus bayad* and *Clarias gariepinus* are primarily influenced by their diets, habitats, and physiological adaptations. *Bagrus bayad*, being a carnivorous predator, has a diet and metabolic needs that favor higher potassium content, while *Clarias gariepinus*, an omnivorous species thriving in diverse and sometimes nutrient-rich environments, may exhibit variability in magnesium levels.

#### *Mean mineral composition of fresh fish species from River Rima*

The mineral composition of smoked *Oreochromis niloticus* showed no significant variation ( $p > 0.05$ ), whereas *Bagrus bayad* and *Clarias gariepinus* exhibited significant differences ( $p < 0.05$ ) in phosphorus content. The overall mineral distribution followed the order  $K > Na > Mg > Ca > P$ , which is consistent with the reports of Ihie et al. (2018) among others. The significantly higher phosphorus values observed in *B. bayad* ( $159.20 \pm 9.52$  mg/100g) and *C. gariepinus* ( $232.13 \pm 18.34$  mg/100g) may be attributed to species-specific feeding behavior, differential absorption

efficiency, and physiological utilization of phosphorus. Phosphorus concentration in fish is also influenced by seasonal variation, age, and the mineral composition of the aquatic environment. In addition, external factors such as agricultural runoff and anthropogenic pollution can increase phosphorus bioavailability in aquatic systems, thereby contributing to interspecific differences. These findings suggest that the influence of smoking may not drastically alter mineral composition of the fish species studied but rather, other environmental and ecological factors may strongly shape the mineral profiles of fish species.

### Conclusion

Fish is a potential source of protein, fat, moisture, ash and minerals. All the fish species examined in River Rima, *Clarias gariepinus*, *Oreochromis niloticus*, and *Bagrus bayad* are all rich sources of protein, moisture, lipid, ash and minerals. All the fish species examined belong to the high to low protein (51.37-14.78%) and medium fat (5.00-1.00) groups. The pattern of mineral concentrations in the sample of each species is in the order  $K > Na > Mg > Ca > P$ . Variations in the mineral concentrations in each of the species could be due to their concentration in the water body, the fish physiological state and the ability of the fish to absorb the elements from their diets and the water bodies.

To give support to Small-Scale Fisheries, it is recommended that there should be policies that provide incentives for small-scale fisheries and aquaculture enterprises near River Rima to enhance food security and economic development. This recommendation aims to enhance the utilization, conservation, and sustainable management of the studied fish species thus, contributing to improved nutrition, food security, and economic development in the region.

### Acknowledgement

The authors appreciate the Department of Fisheries, Usmanu Danfodiyo University,

Sokoto, for providing laboratory facilities and support.

### References

- Akinbiyi, A., Sule, P., Muhammad, S. and Usman, A.** (2019). Hydrogeophysical investigation of Rima River flood plain, Sokoto Basin, Nigeria. *Applied Water Science*, **9(5)**:120-127
- Ali, A. and Kiumars, P.** (2010). Chemical and proximate composition properties of different fish species obtained from Iran. *World Journal of Fish and Marine Sciences*, **2**:237–239.
- Anarado, C. J. O., Ekolie, E., Iziga, C. G., Anarado, C. E. and Eboatu, A. N.** (2023). Proximate and mineral composition of selected fish. *European Journal of Nutrition and Food Safety*, **15(9)**:118–126.
- AOAC** (2000). *Official Methods of Analysis*, 17th ed. Association of Official Analytical Chemists, Gaithersburg, MD, USA.
- Calder, P. C.** (2012). Omega-3 fatty acids and inflammatory processes. *Nutrients*, **4(3)**:355–374. <https://doi.org/10.3390/nu4030355>
- Connor, W. E.** (2000). Importance of n-3 fatty acids in health and disease. *The American Journal of Clinical Nutrition*, **71(1)**:171S–175S.
- Duran, A. and Mendil, M.** (2010). Trace element concentrations of some pet foods commercially available in Turkey. *Food and Chemical Toxicology*, **48(10)**:2833–2837.
- Ekoh, P. C., and Alimp, S. O.** (2020). Climate variability and agricultural production in Sokoto State, Nigeria. *World News of Natural Sciences*, **28(2)**:171–186.
- Ersoy, B. and Özeren, A.** (2009). The effect of cooking methods on mineral and vitamin contents of African catfish. *Food Chemistry*, **115(2)**:419–422.
- FAO.** (2020). The State of World Fisheries and Aquaculture 2020. Food and Agriculture Organization of the United Nations, Rome.
- FAO.** (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. Rome: Food and Agriculture Organization of the United Nations

- Lal, S. P. and Tibbetts, S. M.** (2009). Nutrition, feeding, and behavior of fish. *Veterinary Clinics of North America: Exotic Animal Practice*, **12(2)**:361–372.
- Mohammed, I. N., Abdullahi, J., Yahaya, S., and Sawa, B. A.** (2022). Land use and land cover change in the Sokoto–Rima Basin, Nigeria: Implications for sustainable agriculture and water resources management. *Sustainability*, **14(13)**, 8129. <https://doi.org/10.3390/su14138129>
- Nigerian Investment Promotion Commission.** (2023). Sokoto State profile. Current Affairs Nigeria. <https://currentaffairs.ng/state/sokoto/>
- Ogata, H. Y. and Shearer, K. D.** (2000). Influence of dietary fat and adiposity on feed intake of juvenile red sea bream *Pagrus major*. *Aquaculture*, **189(3–4)**:237–249.
- Ravichandra, S., Joseph, F. S., Kanagalakshi, R. and Ramya, M.** (2011). Variation in nutritive composition of two commercially important marine fin fishes. *International Journal of Zoological Research*, **8**:43–51.
- Saad, H. A. and Alim, D. I.** (2015). Amino acids profile of some economically important marine and freshwater fish from Sudan. *International Journal of Advanced Research*, **3(2)**:838–844.
- Salma, E. O. G. and Nizar, M.** (2015). Atlantic mackerel amino acids and mineral contents from the Tunisian Middle Eastern coast. *International Journal of Agricultural Policy and Research*, **3(2)**:77–83.
- Sutharshiny, S. and Sivashanthini, K.** (2011). Total lipid and cholesterol content in the flesh of five important commercial fishes from waters around Jaffna Peninsula, Sri Lanka. *International Journal of Biology and Chemistry*, **6**:161–169.
- Wikipedia.** (2025). Goronyo Dam. In Wikipedia. [https://en.wikipedia.org/wiki/Goronyo\\_Dam](https://en.wikipedia.org/wiki/Goronyo_Dam)
- World Bank.** (2020). Environmental and social impact assessment for Middle Rima Valley irrigation scheme with Goronyo Dam in Sokoto State (Report No. PAD3299). World Bank Group. <https://documents1.worldbank.org/curated/en/240951584429038170/pdf>
- Yeannes, M. I. and Almandos, M. E.** (2003). Estimation of fish proximate composition starting from water content. *Journal of Food Composition and Analysis*, **16**:81–92.