Food and Nutrition Sciences, 2026, 17(2), 211-226
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

Characterization of the Nutritional Value of Inkorogo (*Brycinus rhodopleura*), Fish Caught in Lake Tanganyika in Burundi

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How to cite this paper: Niyukuri, J., Nininahazwe, E. and Sindayikengera, S. (2026) Characterization of the Nutritional Value of Inkorogo (*Brycinus rhodopleura*), Fish Caught in Lake Tanganyika in Burundi. *Food and Nutrition Sciences*, **17**, 211-226.
https://doi.org/10.4236/fns.2026.172016

Received: January 13, 2026
Accepted: February 21, 2026
Published: February 24, 2026

Abstract

This study aims to analyze the nutritional value of the species *Brycinus rhodopleura* (vernacular name, Inkorogo), a freshwater fish from Lake Tanganyika. Lipid and mineral content were analyzed using official AOAC methods. Saponification and methylation were performed according to the standardized AOAC 996.06 protocol. Fatty acids were identified by gas chromatography-mass spectrometry (GC-MS). The results revealed that the average lipid content of *Brycinus rhodopleura* was 17.05% ± 1.22%, 14.50% ± 1.61%, and 16.80% ± 1.59% for the Magara, Mvugo, and Karonda beaches, respectively, classifying this species as an oily fish. The lipid profile is dominated by monounsaturated fatty acids (53.22% ± 3.27%), followed by saturated fatty acids (37.73% ± 2.9%) and polyunsaturated fatty acids (15.12% ± 1.44%). Oleic acid (35.79% ± 1.46%) is the most abundant, followed by stearic acid (13.7% ± 0.7%). Significant levels of omega-3 and omega-6 fatty acids were observed: arachidonic acid (3.07% ± 1.06%) and eicosapentaenoic acid (0.99% ± 0.17%), respectively. The minerals identified as having significant levels are calcium (59,856 ± 868.74 mg/kg), phosphorus (24,812 ± 322.94 mg/kg), potassium (12,148 ± 244.03 mg/kg), iron (176 ± 8.77 mg/kg), and zinc (57 ± 4.16 mg/kg). The consumption of *Brycinus rhodopleura* could therefore contribute to improving the nutritional status of local populations and combating malnutrition in Burundi and the Great Lakes region.

Keywords

Brycinus rhodopleura, Nutritional Value, Lake Tanganyika, Inkorogo

1. Introduction

In a world where nearly 30% of humanity suffers from malnutrition and more than 70% of the planet is covered by water, aquatic foods represent an essential component of the global food basket for improving the nutrition, health, and well-being of all people [1]. Furthermore, more than two billion people worldwide suffer from specific deficiencies in dietary micronutrients, including iron, iodine, vitamin A, and zinc; the groups most vulnerable to micronutrient deficiencies are pregnant women, breastfeeding women, and young children in low-income countries [2] [3]. Lake Tanganyika is the second-largest freshwater lake by volume and the second deepest in the world [4]. It is very unique from a biogeographical perspective and is home to more than 300 fish species, a large number of which are endemic [5]. Due to the abundance of fish species, Lake Tanganyika is a biodiversity hotspot. This richness is largely due to the lake's isolation and depth, which have favored the evolution of endemic species. Among these species, Sangala (a type of predatory fish), Tilapia (known for its viability in aquaculture), and catfish (prized for its flesh) are particularly valued by local communities and gourmets worldwide [6].

In Burundi, fishing is an essential source of protein and nutrients for many communities, particularly in rural areas where access to other food sources is limited [7]. Among the available fish species, *Brycinus rhodopleura* is often overlooked and underutilized, despite its nutritional potential. This species, which lives primarily in the country's lakes and rivers, could play a significant role in food security and the fight against malnutrition. However, the lack of data on its nutritional value limits its integration into the daily diet of local populations. Fish are known for their richness in omega-3 fatty acids, high-quality protein, and minerals such as phosphorus, iron, and zinc [8]. Among the fish species found in Burundi, *Brycinus rhodopleura* is of nutritional and economic importance to riverside communities [9]. However, the overexploitation of fish stocks and the lack of information on the nutritional value of this species compromise its potential. It is with this in mind that we want to conduct research on this species of *Brycinus rhodopleura* in order to characterize its nutritional composition and better assess its potential as a food source for local communities.

2. Methodology

2.1. Sample Collection

Samples of *Brycinus rhodopleura* were collected directly from the three landing sites mentioned above (Mvugo, Karonda, and Magara), with fifteen samples per site, for a total of forty-five fish analyzed. Particular attention was paid to post-capture storage conditions. The fish were placed in a cooler containing ice to maintain their freshness until they were transferred to the chemistry laboratory of the Faculty of Sciences at the University of Burundi and to the soil and agri-food products laboratory of the Institute of Agricultural Sciences of Burundi (ISABU), where the analyses were carried out.

2.2. Sample Preparation

Upon arrival at the laboratory, the samples underwent manual evisceration, followed by weighing using an analytical balance. The fish were then dried in an oven at a constant temperature of 40˚C for 12 hours. The drying process was monitored every two hours to ensure a consistent weight was reached. Once drying was complete, the samples were ground using a laboratory grinder to obtain a homogeneous meal, the basis for subsequent analyses. The fat content was determined at the chemistry laboratory of the same Faculty. Mineral analyses were carried out at the Soil and Agri-Food Products Laboratory of the ISABU. Finally, to complete the nutritional evaluation, a portion of the samples was sent to the International Livestock Research Institute (ILRI) in Kenya for omega fatty acid profile analysis.

2.3. Analytical Methods

2.3.1. Water Content Assessment

The water content of the fish samples was determined by successive drying, according to a protocol based on mass loss during drying.

Initially, the samples, sorted by species, were weighed after 12 hours of drying using a precision analytical balance to record an initial mass **(m_1)**. Subsequent weighings were then performed every two hours after a further drying period until a constant mass **(m_2)** was obtained, indicating that all moisture had been removed. This method is based on the principle that dry matter (DM) corresponds to the residual fraction of a product after the removal of water by evaporation. DM can be expressed as a percentage of the initial mass of the sample.

The formula for calculating dry matter is as follows:

Dry Matter (%) = [(Weight of dry matter/Total weight of sample)] × 100

To determine the water content of fish, a commonly used method relies on drying and weighing.

The calculation formula is as follows:

$$\text{TE}\left(\text{g/100g}\right)=\frac{100\times\left(W_1-W_2\right)}{W_1-W_s}$$

where:

W_1 = Weight of the sample and containers before drying (in grams).

W_2 = Weight of the sample and containers after drying (in grams).

W_s = Weight of the tared containers (in grams).

2.3.2. Total Lipid Extraction

The fat content was determined using the continuous Soxhlet extraction method, with hexane as the solvent. This method involves solubilizing lipids in a hot solvent, followed by their recovery after evaporation of the solvent. The analysis was performed at the chemistry laboratory of the Faculty of Sciences at the University of Burundi. The total lipid content was calculated using the following formula:

$$\text{MG}=100\times\frac{\left(M_2-M_1\right)}{X}$$

where:

M_1 = mass of the empty flask (before extraction) in grams;

M_2 = mass of the flask containing the extracted lipids (after extraction) in grams;

X = mass of the analyzed sample in grams.

2.3.3. Determination of Fatty Acid Methyl Esters

Fatty acid analysis was performed at the International Livestock Research Institute (ILRI) laboratory, following the standardized protocol AOAC 996.06 [10]. This method is based on a series of steps, including saponification and methylation, followed by gas chromatography-mass spectrometry (GC-MS) analysis, allowing for the identification and quantification of fatty acids. The results are then expressed as relative or absolute percentages, depending on the needs of the study.

1) Saponification and Methylation

Using a pipette, introduce 0.25 ml of the solutions to be tested into a 15 ml screw-top centrifuge tube, add 3 ml of 0.5 N NaOH in methanol, recap the tube, and shake. 3 ml of 0.5 N sodium hydroxide (NaOH) in methanol are added, and the tube is shaken to promote saponification. The mixture is then heated in a water bath at 85˚C - 100˚C for 5 to 10 minutes before being cooled to room temperature. Under a fume hood, 0.3 ml of boron trifluoride (BF_3) is added, and the mixture is heated again at 85˚C - 100˚C for 10 to 15 minutes to allow fatty acid methylation. After cooling, 4 ml of hexane is added to extract the methyl esters formed. Next, 2 ml of saturated sodium chloride (NaCl) solution is added to the tube. The contents are vigorously shaken and then centrifuged at 2500 rpm for 5 minutes or allowed to stand until clear phase separation occurs. The upper organic (hexane) phase is carefully collected in a new container. A small amount of anhydrous sodium sulfate (Na_2SO_4) is added to remove residual moisture. Finally, 0.7 ml of this solution is transferred to a specific gas chromatography flask (**Table 1**) for final analysis.

2) Calculation and expression of results

The analysis of fatty acid methyl esters required both chromatographic interpretation and spectral comparison to identify and quantify the compounds present. Determination of linear retention indices (LRI) according to Kovats:

For each detected FAME, a linear retention index was calculated from the retention times observed during temperature-controlled chromatography, using the following formula:

$$I = 100 \times \left(n + \frac{t_{r(unknown)} - t_{r(n)}}{t_{r(N)} - t_{r(n)}} \right)$$

where:

I = Kovats retention index.

N = number of carbon atoms in the smallest n-alkane.

N = number of carbon atoms in the largest n-alkane.

T_r = retention time.

Table 1. Chromatographic conditions.

Instrument	Agilent GC			
Software	Workstation			
Sample introduction	Manual-Syringe (10 µl)			
Injection port temperature	280˚C			
Colonne	VF5-MS (5% Phenyl methylpolysiloxane), 30 m × 0.25 mm ID, 0.25 µm film			
GC oven temperature program	Increase	Temperature	Holding time	
		50	0	
	4	180	0	
	3	250	0	
	56 min			
Total analysis time	1 ml/min			
Carrier gas flow rate	1 µl			
Sample injection volume				
Ion trap mass spectrometer parameters	50 - 450	Transfer line temperature		250
Scan range (m/z)	EI	Manifold temperature		100
Transfer line temperature	3	Trap temperature		150

The percentage surface area of fatty acid methyl esters can be determined using the formula below:

$$\%\ \text{surface area of each fatty acid} = \frac{A_x \times 100}{A_T}$$

where:

A_x = surface area of each fatty acid methyl ester.

A_T = total surface area of all fatty acid methyl esters.

100: conversion factor for presenting results as a percentage.

The identification of the peaks corresponding to a fatty acid was done by referring to the standards.

2.3.4. Determination of Mineral Content in Oilcake

Specific analyses of the minerals Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na), Iron (Fe), Phosphorus (P), Copper (Cu), Zinc (Zn), and Manganese (Mn) were performed according to the official AOAC method [11]. These minerals are analyzed in Oilcake obtained from fish removed of water (72, 31%) and oil (16, 11%). Thus, minerals are calculated compared to oilcake, which represents 11% of fresh fish. The dry digestion method was used, where 10 g of each sample was weighed, dried, ground, and used in the analysis for each element. The element content was determined by atomic absorption spectrophotometry (AAS). The results are expressed in mg per 1000 g of sample (mg/1000g). The formula is as follows:

$$\text{Mineral element content} = \left(\frac{\text{Measured concentration}\left(\frac{\text{mg}}{\text{g}}\right) \times \text{Solution volume}(\text{L})}{\text{Sample mass}(\text{g})} \right) \times 1000$$

The concentrations of calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), manganese (Mn), and iron (Fe) were determined by atomic absorption spectrophotometry (AAS) after acid digestion of the samples, in accordance with the official AOAC methods (2019). Sodium (Na) and potassium (K) concentrations were measured by flame spectrometry. Phosphorus (P) was analyzed by colorimetric spectrophotometry after the formation of a colored compound.

2.4. Statistical Data Analysis

Data analysis was performed using IBM SPSS Statistics software, version 26. An analysis of variance (ANOVA) was conducted to detect significant differences between groups, with a significance level set at $\alpha = 0.05$. To further identify these differences, Duncan's multiple comparison test was applied. The results are presented as means, along with their standard deviations.

3. Presentation and Discussion of Results

As part of this study, morphometric measurements were taken, and the *Brycinus rhodopleura* samples analyzed were collected from the beaches of Karonda, Magara, and Mvugo. Physicochemical analyses were performed in the physicochemical laboratories of the East African Nutritional Sciences Institute (EANSI) and the chemistry laboratory of the Faculty of Sciences at the University of Burundi.

3.1. Morphometric Characteristics of *Brycinus rhodopleura*

Morphometric analysis is an important tool for characterizing a species biologically, as it allows for the assessment of structural variability related to the environment, diet, or age. Dimensions such as body length, width, and height are often used to describe the growth and body shape of fish and can vary depending on environmental conditions. Table 2 presents the average morphometric parameters of *Brycinus rhodopleura* from three sampling sites.

Table 2. Morphometric parameters of the studied fish.

Measured parameter	Karonda	Mvugo	Magara	Average
Length (cm)	30 ± 4.56	26 ± 4	28 ± 2.65	28 ± 3.74
Width (cm)	8 ± 2	5 ± 2	7 ± 2.6	6.67 ± 2.2
Height (cm)	5 ± 2	3 ± 1	4 ± 2	4 ± 1.7

The results reveal a significant variation in morphometric dimensions depending on the sampling site. Fish collected at Karonda exhibited larger average sizes in length (30 cm), width (8 cm), and height (5 cm) than those from Mvugo and Magara. This difference could be explained by the quality of the natural food source, the physicochemical characteristics of the water, or the population density [12]. Since Karonda Beach is located near the Kigwena Nature Reserve, a protected area with preserved aquatic biodiversity, the ecological conditions there are likely more favorable. The ecosystem, less disturbed by human activities, offers a more abundant and diverse food source, which could explain the greater growth observed. These results suggest that Karonda provides a more suitable habitat for the development of *Brycinus rhodopleura*. Similar morphometric variations have been reported in other freshwater species [13], thus highlighting the morphological adaptation of fish to their environment.

3.2. Water and Lipid Content of the Fish Species Studied

Determining the water and lipid content is an essential step in assessing the nutritional quality of fish. These two parameters influence the product's energy value, as well as its preservation and stability. **Table 3** presents the results obtained for the *Brycinus rhodopleura* samples.

Table 3. Water and lipid content (relative to dry matter) of fish samples.

Studied parameter	Karonda	Mvugo	Magara	Average
Water content (%)	78.35 ± 1.41	71.40 ± 3.69	67.20 ± 1.67	72.31 ± 2.25
Lipid content (%)	17.05 ± 1.22	14.5 ± 1.61	16.8 ± 1.59	16.11 ± 1.47

The results in **Table 3** show that the water content of *Brycinus rhodopleura* varies significantly depending on the sampling site, ranging from 67.20% ± 1.67% to 78.35% ± 1.41% for the Magara and Karonda sites, respectively, with an intermediate value of 71.40% ± 3.69% at Mvugo. This high water content, typical of freshwater fish, is consistent with the observations of Rieu [13], who emphasizes that high water content makes the flesh more perishable and requires appropriate preservation methods.

Regarding lipid content (on a dry matter basis), the values obtained also varied depending on the site: 17.05% ± 1.22% at Karonda; 14.50% ± 1.61% at Mvugo; and 16.80% ± 1.59% at Magara. These values classify *Brycinus rhodopleura* as an oily fish according to the classification of Jabeen and Shakoor [14]: lean fish (less than 5%), moderately fatty fish (between 5% and 10%), and fatty fish (more than 10%).

This high lipid content could be explained by the accumulation of energy reserves in muscle and visceral tissues, which is influenced by the species' physiology, food availability, and the specific environmental conditions of each site [15]. These results are also comparable to those reported by Mamun *et al.* and Rieu [13] [16], who determined lipid levels ranging from 12.81% to 15.31% in certain tropical species, thus confirming the high nutritional potential of *Brycinus rhodopleura*.

3.3. Mineral Content of *Brycinus rhodopleura*

The mineral content of fish is a key indicator of their nutritional value, particularly for assessing their contribution of micronutrients essential for human health.

Table 4 presents the concentrations of major minerals (P, Mg, K, Na, Ca) and trace elements (Fe, Zn, Cu, Mn) measured in *Brycinus rhodopleura* collected from three locations on the Burundian shoreline of Lake Tanganyika: Karonda, Mvugo, and Magara.

Table 4. Mineral content (mg/kg) of *Brycinus rhodopleura* (Different letters (a, b, c) on the same line indicate a significant difference between sampling sites).

Mineral elements	Karonda	Mvugo	Magara	Average
Major minerals, mg/kg				
Phosphorus (P)	37,328 ± 535.61^{a}	34,250 ± 406.17^{b}	35,150 ± 208.42^{c}	**35,576 ± 383.4**
Magnesium (Mg)	1879 ± 54.06^{b}	1692 ± 57.97^{a}	1754 ± 96.81^{ab}	**1775 ± 69.61**
Potassium (K)	5290 ± 224.85^{b}	5432 ± 69.40^{b}	4827 ± 40.93^{a}	**5183 ± 111.73**
Sodium (Na)	2714 ± 96.02^{a}	2818 ± 81.22^{ab}	2967 ± 80.67^{b}	**2833 ± 257.91**
Calcium (Ca)	59,856 ± 868.74^{b}	58,307 ± 635.58^{a}	57,925 ± 695.10^{a}	**58,696 ± 733.14**
Trace elements, mg/kg				
Iron (Fe)	83.4 ± 1.21^{b}	78.2 ± 1.61^{a}	82.9 ± 2.98^{b}	**81.5 ± 1.93**
Zinc (Zn)	122 ± 17.35^{ab}	148 ± 10.15^{b}	108 ± 14^{a}	**126 ± 13.83**
Copper (Cu)	2.21 ± 0.39^{a}	1.97 ± 0.74^{a}	2.9 ± 0.80^{a}	**2.36 ± 0.64**
Manganese (Mn)	8.5 ± 0.53^{a}	11.4 ± 0.70^{b}	10.7 ± 0.95^{b}	**10.2 ± 0.72**

Phosphorus (P)

Phosphorus levels in *Brycinus rhodopleura* varied significantly between sites ($p < 0.05$), with a maximum observed at Karonda (37,328 ± 535.61 mg/kg), followed by Magara (35,150 ± 208.42 mg/kg) and Mvugo (34,250 ± 406.17 mg/kg). This difference can be explained by the trophic richness and phosphorus availability in the Karonda ecosystem, which are key factors in bone formation and energy metabolism in fish [17]. These results are consistent with those of Kouadio *et al.* [18] (30,000 and 38,000 mg/kg) in Ivorian freshwater fish, who emphasized that phosphorus content is highly dependent on the quality of the natural diet and environmental characteristics. Sufficient phosphorus intake is also an indicator of a healthy ecosystem, promoting optimal growth in aquatic species [19] [20].

Magnesium (Mg) and Potassium (K)

Magnesium showed significant variation between sites ($p > 0.05$), with a maximum concentration observed at Karonda (1879 ± 54.06 mg/kg) and a minimum concentration at Mvugo (1692 ± 57.97 mg/kg). This difference could be linked to the physicochemical characteristics of the water, particularly its salinity, pH, and abundance of aquatic vegetation, which influence its bioavailability [21] [22]. As an essential enzymatic cofactor, magnesium plays a key role in nerve regulation and various metabolic processes [23]

As for potassium, concentrations differ significantly depending on the sampling site, with a maximum of 5432 ± 69.40 mg/kg observed at Mvugo and a minimum of 4827 ± 40.93 mg/kg at Magara. This variation could be explained by differences in the ionic composition of the water, salinity, or temperature, factors that strongly influence potassium uptake and retention in fish. It could also reflect the diversity of diets specific to each site. Potassium plays a fundamental role in maintaining water balance, nerve transmission, and muscle activity [24]. Several authors, including Effiong and Fakunle, and Ding *et al.* [25] [26] have emphasized that the potassium content of fish tissues is closely dependent on the physicochemical characteristics of the aquatic environment, which explains the differences observed between the sites in this study.

Sodium (Na) and Calcium (Ca)

Concentrations of sodium and calcium varied significantly between sampling sites. Sodium levels ranged from 2714 ± 96.02 mg/kg at Karonda to 2967 ± 80.67 mg/kg at Magara. It participates in osmotic regulation and nerve function, and its variability reflects differences in salinity and ionic composition in aquatic environments [27]. As for calcium, the highest values were observed at Karonda (59,856 ± 868.74 mg/kg), slightly higher than those recorded at Mvugo and Magara ($p = 0.041$). This mineral is essential for skeletal formation and muscle activity [28]. Its concentration is thought to depend on local geology and the presence of calcium-rich organisms, such as mollusks and crustaceans [29]. These results are consistent with the physiological needs of fish and their nutritional value for human consumption.

Iron (Fe) and Zinc (Zn)

Iron levels are significantly higher at Karonda (83.4 ± 1.21 mg/kg) and Magara (82.9 ± 2.98 mg/kg) than at Mvugo. Iron plays a central role in hemoglobin synthesis and energy metabolism, as highlighted by Watanabe *et al.* [30]. However, while high iron levels indicate good nutritional availability, they can pose toxic risks if they exceed physiological thresholds [31] [32]. According to Martínez-Alvarez *et al.* [33], iron concentration is strongly influenced by environmental quality, suggesting that the Karonda and Magara sites offer conditions conducive to optimal accumulation of this mineral.

Regarding zinc, its content varied significantly between sites, with a peak recorded at Mvugo (148 ± 10.15 mg/kg). Zinc is essential for numerous enzymatic and immune functions, as also reported by Watanabe *et al.* [30]**.** Its availability can be modulated by environmental factors such as pollution, the quality of natural diets, and anthropogenic intake [34], which explains the differences observed between sites.

Copper (Cu) and Manganese (Mn)

Copper showed no significant difference between sites ($p = 0.283$), with low concentrations ranging from 1.97 to 2.9 mg/kg. Although this trace element is essential in small doses for various physiological functions, it remains within acceptable levels for human consumption, according to Watanabe *et al.* [30] and the **EFSA food safety standards l'EFSA** [35]. However, as Rainbow [36] points out, regular monitoring is recommended to prevent any toxic accumulation.

Regarding manganese, concentrations are significantly higher at Mvugo (11.4 ± 0.70 mg/kg) and Magara (10.7 ± 0.95 mg/kg), compared to 8.5 ± 0.53 mg/kg at Karonda. This mineral plays a crucial role in enzyme systems [37], and the variations in its concentrations between sites could be attributed to geochemical differences in the waters, according to Oymak *et al.* [38]. Furthermore, Yilmaz emphasizes that manganese levels can also reflect local pollution sources [39], highlighting the importance of enhanced environmental monitoring.

3.4. Fatty Acid Composition of *Brycinus rhodopleura*

The fatty acid profile is an important indicator of the nutritional quality of fish. The fatty acid composition of *Brycinus rhodopleura* was analyzed to highlight variations between sampling sites. Fatty acids were classified into three categories: saturated, monounsaturated, and polyunsaturated. **Table 5** presents the average fatty acid content (as a percentage of total fat) of samples collected on the beaches of Karonda, Mvugo, and Magara.

In total, twenty-one fatty acids were identified and quantified in the *Brycinus rhodopleura* samples, distributed into three major nutritional classes.

- **Saturated fatty acids (SFA):** dodecanoic acid (C12:0), trideconoic acid (C13:0), tridecanoic acid (C13:0), tetradecanoic acid (C14:0), pentadecanoic acid (C15:0), and hexadecanoic acid (C16:0), heptadecanoic acid (C17:0), stearic acid (C18:0), eicosanoic acid (C20:0), heneicosanoic acid (C21:0), docosanoic acid (C22:0), and tricosanoic acid (C23:0).
- **Monounsaturated fatty acids (MUFA):** oleic acid (C18:1), elaidic acid (C18:1 *ω*-9), vaccenic acid (C18:1), eicosenoic acid (C20:1) and erucic acid (C22:1).
- **Polyunsaturated fatty acids (PUFA):** linoleic acid (C18:2 *ω*-6), eicosapentaenoic acid or EPA (C20:5 *ω*-3) and arachidonic or eicosatetraenoic acid (C20:4 *ω*-6).

The results obtained show that monounsaturated fatty acids (MUFA) dominate the lipid profile of *Brycinus rhodopleura* overall in all three sampling sites, followed by saturated fatty acids (SFA) and then polyunsaturated fatty acids (PUFA).

The total mean levels observed in the three sampling sites (Karonda, Mvugo, and Magara) are 53.22% ± 3.27%, 50.39% ± 2.97%, and 46.91% ± 3.06% for MUFA; 36.93% ± 4.52%, 34.93% ± 3.18%, and 37.73% ± 2.90% for SFA; and 15.12% ± 1.44%, 12.18% ± 1.32% and 12.48% ± 1.44% for PUFA.

This predominance of MUFA over SFA and PUFA in *Brycinus rhodopleura* is consistent with observations reported by Castro *et al.* [40] and [14], which indicate that oleic acid (C18:1), the main MUFA, is generally one of the most abundant fatty acids in the lipids of many fish species. In this study, oleic acid also had the highest content among all the identified acids, with 35.79% ± 1.46% in Karonda, 33.4% ± 0.78% in Mvugo, and 31.22% ± 1.04% in Magara. These results reinforce the idea of its importance in the lipid fraction of the species.

Table 5. Fatty acid content (%) of *Brycinus rhodopleura* according to sampling sites (saturated fatty acids: SFA; monounsaturated fatty acids: MUFA; polyunsaturated fatty acids: PUFA (Different letters (a, b, c) on the same line indicate a significant difference between sampling sites).

	Karonda	Mvugo	Magara	Average
SFA	**36.93 ± 4.52**	**34.93 ± 3.18**	**37.73 ± 2.9**	**36.53 ± 3.53**
Stearic acid	10.55 ± 0.64^{a}	11.9 ± 1.3^{ab}	13.7 ± 0.7^{b}	12.05 ± 0.88
Dodecanoic acid	0.13 ± 0.26^{a}	0.12 ± 0.01^{a}	0.17 ± 0.02^{b}	0.14 ± 0.09
Trideconoic acid	0.03 ± 0.01^{b}	0.01 ± 0^{a}	0.02 ± 0.01^{ab}	0.02 ± 0.007
Tridecanoic acid	0.03 ± 0.01^{a}	0.04 ± 0.01^{a}	0.02 ± 0.01^{a}	0.03 ± 0.01
Tetradecenoic acid	1.5 ± 0.31^{ab}	1.32 ± 0.21^{a}	1.82 ± 0.16^{b}	1.54 ± 0.22
Pentadecanoic acid	0.38 ± 0.05^{a}	0.36 ± 0.08^{a}	0.49 ± 0.16^{a}	0.41 ± 0.09
Hexadeconoic acid	4 ± 1^{a}	3.1 ± 0.36^{a}	2.8 ± 0.62^{a}	3.3 ± 0.66
Hexadecanoic acid	16.94 ± 0.67^{b}	14.82 ± 0.42^{a}	14.56 ± 0.49^{a}	15.44 ± 0.52
Heptadecanoic acid	0.62 ± 0.72^{a}	0.67 ± 0.26^{a}	0.84 ± 0.19^{a}	0.71 ± 0.39
Eicosanoic acid	1.79 ± 0.57^{a}	1.65 ± 0.28^{a}	2.32 ± 0.23^{a}	1.92 ± 0.36
Heneicosanoic acid	0.48 ± 0.14^{a}	0.62 ± 0.14^{a}	0.58 ± 0.2^{a}	1.92 ± 0.16
Docosanoic acid	0.4 ± 0.1^{a}	0.2 ± 0.1^{a}	0.3 ± 0.1^{a}	0.03 ± 0.1
Tricosanoic acid	0.8 ± 0.04^{a}	0.12 ± 0.01^{a}	0.13 ± 0.01^{a}	0.35 ± 0.02
MUFA	**53.22 ± 3.27**	**50.39 ± 2.97**	**46.91 ± 3.06**	**50.52 ± 3.1**
Oleic acid	35.79 ± 1.46^{b}	33.4 ± 0.78^{a}	31.22 ± 1.04^{a}	33.47 ± 1.09
Eicosenoic acid	2.78 ± 0.56^{a}	2.68 ± 0.32^{a}	2.91 ± 0.71^{a}	2.79 ± 0.53
Elaidic acid	13 ± 1^{a}	12 ± 1.72^{a}	11 ± 1^{a}	12 ± 1.24
Vaccenic acid	1.48 ± 0.2^{a}	2.2 ± 0.1^{b}	1.6 ± 0.26^{a}	1.76 ± 0.18
Erucic acid	0.17 ± 0.05^{a}	0.11 ± 0.05^{a}	0.18 ± 0.05^{b}	0.15 ± 0.05
PUFA	**15.12 ± 1.44**	**12.18 ± 1.32**	**12.48 ± 1.44**	
Linoleic acid	11.06 ± 0.21^{a}	9.7 ± 1.05^{a}	10.2 ± 0.89^{a}	10.32 ± 0.71
Eicosapentaenoic acid	0.99 ± 0.17^{b}	0.32 ± 0.04^{a}	0.76 ± 0.22^{b}	0.69 ± 0.14
Eicosatetraenoic acid (arachidonic acid)	3.07 ± 1.06^{b}	2.16 ± 0.23^{ab}	1.52 ± 0.33^{a}	2.25 ± 0.54
PUFA/ MUFA	**0.28 ± 0.02**	**0.24 ± 0.03**	**0.27 ± 0.00**	**0.28 ± 0.01**

The variation in proportions between sites could reflect differences in natural diet, water temperature, or the composition of phytoplankton and sediments, which influence the biosynthesis or accumulation of different types of fatty acids gras [41] [42]. Overall, this profile, rich in MUFA and moderately rich in PUFA, can be considered nutritionally favorable, particularly for the prevention of cardiovascular disease [43].

1) Saturated fatty acids (SFA)

SFA plays an important role in the energy metabolism of fish [44]. In this study, total saturated fatty acid (SFA) content ranged from 34.93% ± 3.18% in Mvugo to 37.73% ± 2.90% in Magara, with an intermediate value in Karonda (36.93% ± 4.52%). These levels indicate a significant contribution of SFA to the overall lipid composition of *Brycinus rhodopleura*.

Among the identified saturated fatty acids (SFA), hexadecanoic acid (or palmitic acid, C16:0) and stearic acid (C18:0) are the most abundant, representing a large proportion of the total SFA. Hexadecanoic acid reaches 16.94% ± 0.67% in Karonda, compared to 14.82% ± 0.42% and 14.56% ± 0.49% in Mvugo and Magara, respectively, while stearic acid varies between 10.55% ± 0.64% and 13.7% ± 0.7%. These results are consistent with those reported by Prato and Biandolino, and Hossain *et al.* [45] [46], who highlight the high content of these two acids in the muscle lipids of freshwater fish. This high proportion could be explained by their role in energy storage, which is often influenced by water temperature and food availability.

2) Monounsaturated fatty acids (MUFA)

Of endogenous or dietary origin, they play a role in the regulation of lipid metabolism [44]. In *Brycinus rhodopleura*, MUFA are the dominant fatty acids, with levels ranging from 46.91% ± 3.06% in Magara to 53.22% ± 3.27% in Karonda. Oleic acid (C18:1) is by far the main monounsaturated fatty acid (MUFA) identified in all localities, reaching up to 35.79% ± 1.46% at Karonda. It is followed by elaidic acid (C18:1 trans), whose levels are relatively constant, between 11% and 13%, and then by vaccenic, eicosenoic, and erucic acids, in smaller quantities. The predominance of oleic acid was also observed by Castro *et al.* [47] [48], confirming its importance in the lipid fraction of fish. This distribution could result from a diet rich in phytoplankton and microalgae, which would contribute to the biosynthesis or accumulation of these MUFA.

3) Polyunsaturated fatty acids (PUFA)

PUFA, and more specifically long-chain omega-3 PUFA, are essential for growth, brain development, and cardiovascular health [49]. The total PUFA content of *Brycinus rhodopleura* is generally lower than that of MUFA and SFA, at 15.12% ± 1.44% in Karonda, 12.48% ± 1.44% in Magara, and 12.18% ± 1.32% in Mvugo.

Among the PUFA identified, linoleic acid (C18:2 ω-6) is the most abundant, followed by eicosatetraenoic acid (C20:4 ω-6 or arachidonic acid) and eicosapentaenoic acid (EPA, C20:5 ω-3). These three PUFAs are known for their role in regulating cellular functions, immunity, and inflammation [15] [50]. The highest EPA levels were recorded at Karonda (0.99% ± 0.17%), and the lowest at Mvugo (0.32% ± 0.04%), which could reflect differences in trophic origin or physiology between the populations at the different sites.

4. Conclusion

This study has highlighted that *Brycinus rhodopleura* has a very high nutritional value, and its lipid content of 16.12% ± 1.47% (dry matter) allows it to be classified among oily fish. Its lipid composition is characterized by a dominance of monounsaturated fatty acids (50.52% ± 3.1%), of which only oleic acid accounts for 35.79% ± 1.46%, followed by saturated fatty acids (36.93%), with stearic acid totaling 10.55% ± 0.64% to 13.7% ± 0.7%. The latter are polyunsaturated fatty acids (15.12%), including arachidonic acid (omega-6) at 3.07% ± 1.06% and eicosapentaenoic acid (EPA) (0.99% ± 0.17%), an omega-3 fatty acid well-known for its beneficial effects on cardiovascular health. Regarding minerals, the observed levels reflect the nutritional richness of the species: phosphorus: 37,328 ± 535.61 mg/kg; calcium: 59,856 ± 868.74 mg/kg; potassium: 5432 ± 69.40 mg/kg; iron: 83.4 ± 1.21 mg/kg; zinc: 148 ± 10.15 mg/kg. Thus, *Brycinus rhodopleura* appears to be a local food source rich in essential nutrients, with promising potential to contribute to improving the nutrition of populations living around Lake Tanganyika and to combating malnutrition.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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