Proximate Composition and Fatty Acid Content of Commercially Important Fish Species from Ethiopian Lakes: A Review

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Abstract: Fish is an important source of long chain omega-3 polyunsaturated fatty acids (LC n-3 PUFA) and also a good source of protein. Ethiopian lakes harbor a rich fish biodiversity which vary in their nutrient composition. This review will examine published data on the proximate and fatty acid content of six fish species from various Ethiopian Lakes. The fish species include the Nile tilapia (Oreochromis niloticus), African sharp tooth catfish (Clarias gariepinus), Nile perch (Lates niloticus), Barbs (Barbus sp.), Redbelly tilapia (Tilapia zillii) and Common carp (Cyprinus carpio). Species were selected based on their current commercial importance as well as their potential for nutrition. The content of protein, fat, moisture and ash ranged from 13.30 to 18.50%, 0.40 to 2.45%, 77.24 to 80.80% and 0.81 to 1.20%, respectively. The fatty acid content of the fish ranged from 6.42 to 25.01 mg.g⁻¹ dry weight (DW) for saturated fatty acids (SFA), 2.02 to 24.62 mg.g⁻¹ DW for monounsaturated fatty acids (MUFA) and 7.88 to 24.12 mg.g⁻¹ DW for PUFA. Among the SFA, palmitic acid was the main fatty acid while oleic acid and docosahexaenoic acid (DHA) were the main MUFA and PUFA respectively. The highest content of eicosapentaenoic acid (4.74 mg.g⁻¹ DW) was found in Barbs from Lake Langeno while the highest docosapentaenoic acid (3.99 mg.g⁻¹ DW), DHA (11.53 mg.g⁻¹ DW) and total n-3 PUFA (20.61 mg.g⁻¹ DW) were found in Nile tilapia from Lake Haiq. The n-3/n-6 ratios ranged from 1.39 to 5.86 mg.g⁻¹ DW, with the highest ratio coming from Nile tilapia collected from Lake Haiq and the lowest from Redbelly tilapia from Lake Ziway. In conclusion, all the species collected from different Lakes of Ethiopia may be beneficial to human health. However, Nile tilapia from Lake Haiq and Barbs from Lake Langeno are the best for consumption due to higher levels of LC n-3 PUFA.

Keywords: Fatty Acid, Omega-3, Total Lipid, Proximate Composition, Fish Species, Freshwater

1. Introduction

Fish has been recognized as an excellent food source for humans for centuries and is preferred in the diet not only due to its excellent taste and high digestibility but also due to higher proportions of unsaturated fatty acids, essential amino acids and minerals for the formation of functional and structural proteins [1]. Fish meat has been the cheapest source of animal protein and the demand has increased worldwide [2]. Due to a growing human population, aquaculture is expected to fill the gap in supplies of fish as food for humans as demand continues to increase [3]. It is not fully known, however, whether fish and shellfish have consistent nutrient composition in different countries and different ecological environments. Several earlier studies imply that nutrient content of most fish species are more irregular in their fatty acid (FA) profile due to environmental factors, such as feeds, temperature and salinity [4-5]. Moreover, FA present in fish is
subject of a great deal of attention due to its high content of omega-3 polyunsaturated fatty acids (n-3 PUFA) having a positive effect in the prevention of diseases such as hypertension, inflammation, psoriasis, aggression, depression and cancer [6].

The nutritional properties of fish and fish products make them valuable foodstuffs that are beneficial for human health. The nutritional benefits of fish stems for the most part, from its exceptionally advantageous FA profile. In recent years increasing attention has been focused on the significance of n-3 PUFA in human nutrition, particularly eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3). Although PUFA composition varies among different fish species of both freshwater and marine origin, it is important for human health to increase the consumption of fish and its products, which are rich in n-3 PUFA and poor in n-6 PUFA [7]. The composition of fish and fish-derived products is recommended as a means of preventing cardiovascular and other diseases, and these benefits have been considerably promoted over recent decades [8].

The demand for food that promotes health and well-being has increased in recent years. Fish has a particular prominence in this respect, following mounting evidence confirming the health benefits of eating fish. Fish are the main source of n-3 LC PUFA, in particular EPA and DHA, and have been associated with a broad range of health benefits including reducing the risk of cardiovascular diseases (CVD), arthritis and cancers [8]. However, there is concern that there are nutritional differences between the same and different fish species from different freshwater sources. A small group of national studies have focused on the nutritional value of Ethiopian fish species. It has been determined that very little information is available on nutritional content and health benefit of fresh water fish species. n-3 PUFA in particular represent an exciting area of research, with EPA and DHA up and coming as potential mediators in the treatment of different human diseases.

Ethiopian lakes harbor a rich fish biodiversity which vary in their nutrient composition. Nile tilapia (Oreochromis niloticus), African sharp tooth catfish (Clarias gariepinus), Nile perch (Lates niloticus), Barbs (Barbus sp.), Redbelly tilapia (Tilapia zilli), Common carp (Cyprinus carpio) are among the commercially important fish species found in different Ethiopian lakes and widely consumed by the local populace. This review article therefore aimed to present the results of a literature search of the proximate composition and FA contents of these species to justify the consumer’s demands for them in terms of their health benefits. Particular attention has been given to the n-3 PUFA.

2. Materials and Methods

A literature search was conducted through the search engines Scopus, Science Direct and Google Scholar, Addis Ababa University (AAU) library, AAU website data and Internet to gather publicly available information on the lipid/oil, FA content, proximate composition and the nutritional/health benefits of various Ethiopian fish species. In this review, fish species were those collected from various Ethiopian lakes. The fish species included O. niloticus, C. gariepinus, L. niloticus, Barbus sp., C. carpio and Tilapia zilli. Search terms included the scientific name and common name in English of each fish species in conjunction with terms such as “fish”, “FA content”, “total lipid/oil content” and “proximate composition”. Reference lists of scientific articles were cross-checked and only relevant papers were included. The data search was limited to papers presenting results from fish species collected from Ethiopian lakes, but no limitation was set on the date of publications. 11 articles were sourced. From them, 6 articles have been selected and discussed with other necessary references. Data extrapolated from the revised studies were carried out in the form of a narrative review of the reports. This review includes additional references from the relevant articles obtained to include additional material. The data presented in the tables were reproduced from the articles or, if possible, calculated from the data given in the original publications articles.

3. Results and Discussion

3.1. Proximate Composition

Proximate composition of various fish species from different Ethiopian lakes were only analyzed in four studies. Table 1 presents data found in the selected literature for proximate composition. As shown in the table, the reported proximate composition values vary from one fish species to another from the same or different lakes. This variation may be due to many possible factors such as geographical location of catch, the season, environmental conditions, age or sexual maturity, sex, size, feeding habit of the fish, mode of preparation/analysis, and storage that can affect the differences in proximate composition of fish [9-13].

Moisture content in the Ethiopian lakes fish varied, with O. niloticus from Lake Zeway having the highest percentage of moisture (80.80%). content than C. carpio from Lake Hashenge (77.24%). This may show that, C. carpio from Lake Hashenge have concentrated more nutrients than O. niloticus from Lake Zeway and Lake Hashenge. This is in agreement with the report of Ahmed et al. [14] between C. lazeru and O. niloticus. Job et al. [15] and Effiong and Fakunle [16], reported that the moisture contents of O. niloticus was 80.9% & 79.4% respectively which is almost similar with the report 79.50% to 80.80% from Lake Zeway and 77.55% to 77.69% from Lake Hashenge (Table 1). The moisture content of male fishes was higher than the female fishes within the species (Table 1). Different authors have also supported this finding [17-20]. The lower moisture content in female O. niloticus can be attributed to the muscles of female fish containing more organic materials and less water than male fish [17]. Therefore, the percentage range of the moisture content of O. niloticus muscle from Lake Hashenge and Lake Zeway of Ethiopian fish muscle was within the acceptable level (60%-80%) in all the samples; this is most likely due to the stable water levels in
the environmental location where the fish were collected [21].

The content of crude protein of the fish collected from Lake Zeway and Lake Hashenge ranged from 13.30% to 18.50% (Table 1), which was within the range of permissible limits (15% to 28%) for fish and fisheries products. These results were also similar to the 17.4% and 18.4% respectively reported by Job et al. [15] and Effiong and Fakunle [16] in O. niloticus. Lower level of protein content was reported by Alemu et al. [11] in O. niloticus from Lake Zeway compare to Emire and Gebremariam [9] (Table 1). The variation in the protein content of these two studies on the same lake may be the result of seasonal variations and other factors. Various authors have also reported the seasonal variation of protein in fishes [22-23].

The protein content of female and male O. niloticus from Lake Hashenge were higher (16.13% in male and 16.32% in female) than male and female (14.50% and 14.60% respectively) from Lake Zeway (Table 1). It was also reported that average protein decreased with increased age in O. niloticus collected from Lake Zeway (Table 1). Similar results have been reported on O. niloticus and other fish from other regions of the world [18, 24]. The content of crude fat of the fish collected from Lake Zeway and Lake Hashenge ranged from 0.37% to 2.45%. The crude fat content of O. niloticus from Lake Hashenge was higher (2.4%) than the value found from O. niloticus from Lake Zeway (Table 1). This may be due to the water temperature difference between the two lakes and the type of diet of the fish. Supporting this hypothesis, Favalora et al. [25] and Flos et al. [26] reported that the quality of fish is affected by parameters such as feed type, level of dietary intake and growth. The crude fat content values also showed differences within the species, with male O. niloticus from Lake Hashenge had the highest value (2.45%) and male O. niloticus from Lake Zeway had the lowest (0.52%) (Table 1). Additional supporting reports are available from the studies of various researchers. The crude fat content of O. niloticus was reported in the range of 0.7 to 8.5% by Visentainer et al. [27] and the reported value of O. niloticus from Lake Zeway and Lake Hashenge was within this range. A number of factors influence the concentration of fat in fresh water fish such as water temperature, stage of life, environmental salinity, food type and species [10] and diet of the fish [28]. Based on the fat content O. niloticus from Lakes Hashenge and Zeway, and C. carpio from Lake Hashenge were distinguished as lean fish as fat contents of these fishes were lower than 5% by weight [29]. The low concentrations of fat in the muscles of the fresh water species could be due to poor storage mechanisms and the use of fat reserves during spawning activities [30]. The higher fat content in five year fish as compared to four year may be attributed to the diversified feeding habits of the two groups [31-32]. At any stage of fish development, fat content is dependent upon age, the older the fish, the higher the amount of fat. The variations in fat content as fish age may relate to the state of development of gonads and spawning; the fish expends great deal of energy during these developmental stages with fat as its principal source [31-32].

The ash content ranged between 0.81% and 1.20% in the sampled fish from Lake Zeway and Lake Hashenge (Table 1).

### Table 1. Proximal composition of fish species from different Ethiopian lakes.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Lake</th>
<th>Fish species</th>
<th>Moisture (%)</th>
<th>Ash (%)</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>Carbohydrate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emire &amp; Gebremariam [9]</td>
<td>Ziway</td>
<td>O. niloticus</td>
<td>79.90 ± 0.01</td>
<td>0.98 ± 0.01</td>
<td>0.37 ± 0.01</td>
<td>18.50 ± 0.08</td>
<td>0.25 ± 0.01</td>
</tr>
<tr>
<td>Teame et al. [13]</td>
<td>Hashenge</td>
<td>C. carpio</td>
<td>77.24 ± 0.32</td>
<td>0.94 ± 0.09</td>
<td>1.26 ± 0.14</td>
<td>17.25 ± 0.47</td>
<td>3.30 ± 0.37</td>
</tr>
<tr>
<td>Alemu et al. [11]</td>
<td>Ziway</td>
<td>O. niloticus</td>
<td>80.13 ± 0.39</td>
<td>1.13 ± 0.21</td>
<td>0.54 ± 0.02</td>
<td>14.55 ± 0.21</td>
<td>3.66 ± 0.02f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>79.60 ± 0.39</td>
<td>1.17 ± 0.20</td>
<td>0.54 ± 0.02</td>
<td>14.60 ± 0.21</td>
<td>4.09 ± 0.03f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td>80.60 ± 0.39</td>
<td>1.14 ± 0.21</td>
<td>0.52 ± 0.02</td>
<td>14.50 ± 0.21</td>
<td>3.24 ± 0.02f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Four years old</td>
<td>79.50 ± 0.39</td>
<td>1.20 ± 0.21</td>
<td>0.40 ± 0.02</td>
<td>15.80 ± 0.21</td>
<td>3.10 ± 0.02f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Five years old</td>
<td>80.80 ± 0.39</td>
<td>1.00 ± 0.21</td>
<td>0.70 ± 0.02</td>
<td>13.50 ± 0.21</td>
<td>4.20 ± 0.04f</td>
</tr>
<tr>
<td>Tsegay et al. [12]</td>
<td>Hashenge</td>
<td>O. niloticus</td>
<td>77.62 ± 0.30</td>
<td>0.89 ± 0.10</td>
<td>2.40 ± 0.14</td>
<td>16.18 ± 0.29</td>
<td>1.42 ± 0.28f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Female</td>
<td>77.55 ± 0.39</td>
<td>0.97 ± 0.08</td>
<td>2.35 ± 0.18</td>
<td>16.32 ± 0.29</td>
<td>1.22 ± 0.42f</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Male</td>
<td>77.69 ± 0.22</td>
<td>0.81 ± 0.11</td>
<td>2.45 ± 0.09</td>
<td>16.13 ± 0.30</td>
<td>1.61 ± 0.14f</td>
</tr>
</tbody>
</table>

Values are Mean ± Standard deviation of triplicate determinations.

This indicates that O. niloticus and C. carpio from Ethiopian lakes are good source of minerals since ash is a measure of the mineral content of the food component and the inorganic residue that remains after the organic matter has been burnt off. The highest ash content was recorded from O. niloticus collected from Lake Zeway (1.20% in four years old) and lowest value from male O. niloticus from Lake Hashenge (0.81%) (Table 1). The ash content in the two species was less than 2%. Confirming this finding Effiong and Fakunle [16] found 1.12% of content of ash in O. niloticus. But the results of Job et al. [15] are in disagreement with the present report as it relates to the ash content of O. niloticus which was lower (0.57%). Tawfiq [33] reported about 1% value of ash in three fish species in Saudi market. However, Pourshamsian et al. [34] reported a higher range (1.9-2.8%) of ash content in Huso huso (Great Sturgeon) species.

The biochemical composition of freshwater fish varies considerably depending on growing conditions (temperature, dissolved oxygen, pH, salinity, turbidity, altitude, light or luminosity, amongst other factors) and in terms of certain characteristics of the species (age, environment and season) [10].

### 3.2. Fatty Acid Content

Although there is considerable data on FAs content in numerous species of fish from marine and freshwater systems [35], only two published reports are available, to our knowledge, on the FAs content in fish species from different lakes of Ethiopia (Table 2). Zenebe et al. [36] studied O. niloticus, collected from
five Ethiopian lakes and analyzed lipid and FA contents of the dorsal muscle, and Zenebe et al. [37] studied muscle content of different fresh water species collected from five Ethiopian lakes. The aim of the research was to study the variation of FAs both within and between species. Tables 2 present data found in the literature searches on FA contents of five fish species collected from five Ethiopian lakes. A total of 28 FAs from C14:0 to C 22:6 n-3 were identified in the five-commercial species of fish from the five Ethiopian lakes (Table 2). These results are reasonably similar to those obtained by Efeng and Faculce [16], Tenyang et al. [38], Osibona [39], and Mohamed and Al-Sabahi [40]. In their studies, they obtained 23, 24, 22-30 and 33 FAs respectively with different saturation levels which are comparable to the present results. The numbers of different unsaturated FAs were relatively high (20) compared to SFAs (8). Seventeen (14) of the 20 unsaturated FAs were PUFAs and 6 were MUFAs. Among the 14 types of PUFAs, the n-3 PUFAs were relatively more abundant (8), followed by n-6 PUFAs (6). Omega-9 PUFA was recorded only twice. The existence of more unsaturated FAs than saturated FAs in the fish samples is similar to Robert et al. [41] who obtained more categories of unsaturated FAs than saturated FAs in L. niloticus, O. niloticus, T. zillii, and R. argentea. Osibona [39] also found more unsaturated FAs than saturated FAs in C. gariepinus. As shown in tables, the reported FAs levels/contents of the fish varied from one species to another from the same or different lakes. These results agreed well with those presented in studies of freshwater fish [42-43]. Regardless of species, population (site), the most dominant individual FAs were palmitic acid (C16:0), stearic acid (C18:0) and oleic acid (C18:1) and docosahexaenoic acid (22:6n-3; DHA). Reports from other authors on similar studies also indicated the dominance of these FAs in fish species [16, 38-40, 44, 45]. There was a wide variation among the FA contents of fish species in terms of total and individual saturated and unsaturated FAs (Table 2).

### 3.2.1. Saturated Fatty Acids

As shown in Table 2 the saturated fatty acids (SFA) content of the fish varied within and among different fish species from the same or different lakes. The total amount of SFA ranged between 6.42 and 25.01 mg·g⁻¹ DW, and the highest DW was found in O. niloticus from Lake Haiq, whereas the lowest SFA found in O. niloticus caught from Lake Langano.

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#### Table 2. Fatty acid contents (mg/g DW, Mean) of muscle of various fish species from different Ethiopian lakes (Zenebe et al. [36, 37]).

<table>
<thead>
<tr>
<th>Fish species</th>
<th>Fish Source</th>
<th>C14:0</th>
<th>C14:1</th>
<th>C15:0</th>
<th>C16:0</th>
<th>C16:1n7</th>
<th>C17:0</th>
<th>C17:1</th>
<th>C18:0</th>
<th>C18:1n9</th>
<th>C18:1n7</th>
<th>Total SFA</th>
<th>Total MUFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>O. niloticus</td>
<td>Lake Ziway</td>
<td>0.46ab</td>
<td>0.13ab</td>
<td>0.22ab</td>
<td>7.79ab</td>
<td>1.63ab</td>
<td>0.59ab</td>
<td>0.59ab</td>
<td>2.20ab</td>
<td>3.59ab</td>
<td>1.43ab</td>
<td>12.23ab</td>
<td>7.45ab</td>
</tr>
<tr>
<td>Lake Langeno</td>
<td>Lake Langeno</td>
<td>0.13a</td>
<td>0.21b</td>
<td>0.13ab</td>
<td>4.05ab</td>
<td>0.24ab</td>
<td>0.36ab</td>
<td>0.36ab</td>
<td>1.20ab</td>
<td>1.04ab</td>
<td>0.41ab</td>
<td>6.62ab</td>
<td>2.02ab</td>
</tr>
<tr>
<td>Lake Chamo</td>
<td>Lake Chamo</td>
<td>2.18ab</td>
<td>0.21ab</td>
<td>0.32a</td>
<td>14.72ab</td>
<td>4.32ab</td>
<td>0.62ab</td>
<td>0.62ab</td>
<td>3.21ab</td>
<td>7.70ab</td>
<td>1.70ab</td>
<td>22.03ab</td>
<td>14.99ab</td>
</tr>
<tr>
<td>Lake Awassa</td>
<td>Lake Awassa</td>
<td>0.38ab</td>
<td>0.04ab</td>
<td>0.12a</td>
<td>4.46ab</td>
<td>1.10ab</td>
<td>0.31ab</td>
<td>0.31ab</td>
<td>1.25ab</td>
<td>1.70ab</td>
<td>0.85ab</td>
<td>7.09ab</td>
<td>3.90ab</td>
</tr>
<tr>
<td>Lake Haïq</td>
<td>Lake Haïq</td>
<td>4.12c</td>
<td>0.19ab</td>
<td>1.56b</td>
<td>15.40ab</td>
<td>7.65ab</td>
<td>0.34ab</td>
<td>0.34ab</td>
<td>3.61ab</td>
<td>13.53ab</td>
<td>2.16ab</td>
<td>25.01ab</td>
<td>24.62ab</td>
</tr>
<tr>
<td>C. gariepinus</td>
<td>Lake Ziway</td>
<td>0.34a</td>
<td>0.08ab</td>
<td>0.16b</td>
<td>6.39ab</td>
<td>0.87ab</td>
<td>0.36ab</td>
<td>0.36ab</td>
<td>2.13ab</td>
<td>2.70ab</td>
<td>1.62ab</td>
<td>10.4ab</td>
<td>5.58ab</td>
</tr>
<tr>
<td>Lake Langeno</td>
<td>Lake Langeno</td>
<td>0.19ab</td>
<td>0.03ab</td>
<td>0.18a</td>
<td>3.99ab</td>
<td>0.21ab</td>
<td>0.16ab</td>
<td>0.16ab</td>
<td>1.23ab</td>
<td>1.15ab</td>
<td>0.83ab</td>
<td>6.50ab</td>
<td>2.34ab</td>
</tr>
<tr>
<td>Lake Chamo</td>
<td>Lake Chamo</td>
<td>0.84b</td>
<td>0.05ab</td>
<td>0.34a</td>
<td>9.58ab</td>
<td>2.31nc</td>
<td>0.67ab</td>
<td>0.67ab</td>
<td>3.04ab</td>
<td>1.56ab</td>
<td>1.50a</td>
<td>15.77ab</td>
<td>8.52ab</td>
</tr>
<tr>
<td>Lake Awassa</td>
<td>Lake Awassa</td>
<td>0.21bc</td>
<td>0.04ab</td>
<td>0.13b</td>
<td>14.83ab</td>
<td>0.59ab</td>
<td>0.32a</td>
<td>0.32a</td>
<td>1.68ab</td>
<td>4.34ab</td>
<td>1.34ab</td>
<td>7.39ab</td>
<td>3.68ab</td>
</tr>
<tr>
<td>Lake Haïq</td>
<td>Lake Haïq</td>
<td>1.11bc</td>
<td>0.09ab</td>
<td>0.29a</td>
<td>9.48ab</td>
<td>4.40ab</td>
<td>0.22ab</td>
<td>0.22ab</td>
<td>2.62ab</td>
<td>7.29ab</td>
<td>1.74ab</td>
<td>14.82ab</td>
<td>9.43ab</td>
</tr>
<tr>
<td>Barbus sp</td>
<td>Lake Ziway</td>
<td>1.52ab</td>
<td>0.05ab</td>
<td>0.29a</td>
<td>12.31ab</td>
<td>2.57ab</td>
<td>0.77ab</td>
<td>0.77ab</td>
<td>4.52ab</td>
<td>10.07ab</td>
<td>2.40ab</td>
<td>20.55ab</td>
<td>15.87ab</td>
</tr>
<tr>
<td>Lake Chamo</td>
<td>Lake Chamo</td>
<td>0.36b</td>
<td>0.08ab</td>
<td>0.14a</td>
<td>5.11ab</td>
<td>0.91ab</td>
<td>0.53abcd</td>
<td>0.53abcd</td>
<td>2.46ab</td>
<td>3.85ab</td>
<td>1.08a</td>
<td>9.89ab</td>
<td>6.71ab</td>
</tr>
<tr>
<td>Lake Awassa</td>
<td>Lake Awassa</td>
<td>0.52ab</td>
<td>0.06ab</td>
<td>0.17b</td>
<td>6.12ab</td>
<td>0.82ab</td>
<td>0.43acd</td>
<td>0.43ab</td>
<td>2.41ab</td>
<td>2.18ab</td>
<td>0.61a</td>
<td>11.05ab</td>
<td>3.96ab</td>
</tr>
<tr>
<td>L. niloticus</td>
<td>Lake Chamo</td>
<td>1.58ab</td>
<td>0.06ab</td>
<td>0.28b</td>
<td>9.50ab</td>
<td>5.57ab</td>
<td>0.36ab</td>
<td>0.36ab</td>
<td>3.1ab</td>
<td>5.76ab</td>
<td>1.48a</td>
<td>15.69ab</td>
<td>13.48ab</td>
</tr>
<tr>
<td>T. zillii</td>
<td>Lake Ziway</td>
<td>0.48ab</td>
<td>0.60ab</td>
<td>0.15b</td>
<td>6.91ab</td>
<td>1.50ab</td>
<td>0.43abcd</td>
<td>0.43abcd</td>
<td>2.7ab</td>
<td>3.18ab</td>
<td>1.24ab</td>
<td>11.48ab</td>
<td>6.92ab</td>
</tr>
</tbody>
</table>

Mean Value in the same column with different superscript letters are significantly different (p<0.05).

**DW,** dry weight; **mg,** milligram; **g,** gram; **SFA,** saturated fatty acids; **MUFA,** monounsaturated fatty acids; **LA,** linoleic acid; **AA,** arachidonic acid; **ALA,** alpha-Linolenic acid; **EPA,** eicosapentaenoic acid; **DPA,** docosapentaenoic Acid; **DHA,** docosahexaenoic acid; **n-3,** omega-3; **n-6,** omega-6; **PUFA,** polyunsaturated fatty acids.
This is lower than the SFA content (1010.5 mg FAs/g, DW) reported by Mohamed and Al-Sabahi [40] from *O. niloticus* from Nile, Sudan. In all the species, the most abundant SFA was palmitic acid (16:0) which ranged from 3.99 mg·g⁻¹ DW in *C. gariepinus* from Lake Langeno to 15.40 mg·g⁻¹ DW in *O. niloticus* from Lake Haïq. The highest was found in *O. niloticus* from Lake Haïq and the lowest in *C. gariepinus* from Lake Langeno. These results are in agreement with the literature where C16:0 was reported as the most abundant SFA, in *L. niloticus*, *C. gariepinus* and *O. niloticus* from Lake Kainji, Nigeria, in four fish species from Maga Lake in Far North Region of Cameroon, and three freshwater fish species in Malaysia [16, 38, 46]. Likewise, Aggelousis and Lazos [47] showed that in freshwater fish from Greece, the most abundant FAs was palmitic acid. Meanwhile, Osman et al. [48] reported that C16:0 was not the most abundant FA present in some fish from Malaysian waters. The other major SFA found in all fish species was stearic acid (18:0) and it was ranged from 1.20 to 4.52 mg·g⁻¹ DW. The highest (4.52 mg·g⁻¹ DW) stearic acid was found in *Barbus sp* collected from Lake Langeno, while lowest (1.20 mg·g⁻¹ DW) was obtained from *O. niloticus* from Lake Langeno (Table 2). Other authors are also found stearic acid as the second major SFA [16, 38-40, 44, 45].

3.2.2. Monounsaturated Fatty Acids

The total monounsaturated fatty acids (MUFA) varied both within and between fish species collected from the different lakes (Table 2). Total MUFA ranged from 2.02 mg·g⁻¹ DW in *O. niloticus* from Lake Langeno to 24.62 mg·g⁻¹ DW in *O. niloticus* from Lake Haïq. The high content of total MUFA was found in *O. niloticus* from Lake Haïq, whilst the lowest content was obtained in *O. niloticus* from Lake Langeno. Almost all freshwater species, with the exception of *O. niloticus* from Lake Haïq and *L. niloticus* from Lake Chamo, contained lower amounts of MUFA than SFA and PUFA. Supporting results were also reported by other researchers [38, 45]. In all the species, the most abundant MUFA was oleic acid (OA 18:1n-9). Supporting this finding were several other studies [14, 38-39, 44, 45]. Oleic acid ranged from 1.04 to 13.53 mg·g⁻¹ DW and, the highest was found in *O. niloticus* from Lake Haïq and the lowest in *O. niloticus* from Lake Langeno. Palmitoleic acid (C16:1n-7) was the other major MUFA and ranged from 0.21 mg·g⁻¹ DW in *C. gariepinus* from Lake Langeno to 7.65 mg·g⁻¹ DW in *O. niloticus* from Lake Haïq (Table 2). The highest was found in *O. niloticus* from Lake Haïq and the lowest in *O. niloticus* from Lake Langeno. According to Andrade et al. [43] the most dominant MUFAs in freshwater fish from south Brazil were oleic and palmitoleic acids; these studies also are in agreement with the findings on fresh water fish species from Ethiopian lakes (Table 2). Palmitoleic acid was also found as the second major MUFA in many other studies [16, 38-39, 44, 45].

3.2.3. Polyunsaturated Fatty Acids

The total polyunsaturated fatty acids (PUFA) varied within and among the fish species collected from the different lakes. Total PUFA, ranged from 7.88 to 24.12 mg·g⁻¹ DW. The highest content was found in *O. niloticus* from Lake Haïq and the lowest in *O. niloticus* from Lake Langeno (Table 2). Other authors also found LA and AA as the principal n-6 PUFA in fresh water fish collected from different lakes [16, 39, 41, 45]. In contrast Mohamed and Al-Sabahi [40] had not found any AA from *L. niloticus*, *B. bayad*, *O. niloticus*, *S. schall* and *T. lineatus* collected from Nile, Sudan. LA is the precursor of AA, a substrate for eicosanoid production which is also involved in the regulation of gene expression [49]. LA is also found as a structural component of cell membranes and is important in cell signaling. The content of AA ranged between 1.02 and 2.92 mg·g⁻¹ DW. The highest content of AA was found in *Barbus sp* collected from Lake Awassa and the lowest found in *O. niloticus* from Lake Haïq (Table 2). Arachidonic acid present in all the fish species in this work is a precursor for prostaglandin and thromboxane biosynthesis [50]. Arachidonic acid can facilitate the blood clotting process and attach to endothelial cells during wound healing. The inclusion of the fish analyzed in human diets might help in the wound healing process of the consumer.

ii. Omega-3(n-3) Polyunsaturated Fatty Acids

The n-3 polyunsaturated fatty acids (n-3 PUFA) varied both within and between fish species collected from the different Ethiopian lakes. The levels of total n-3 PUFA and EPA, DPA and DHA in the five-commercial species collected from the five lakes are shown in Table 2. The n-3 PUFA are considered to be of major importance in terms of human health. The total number of n-3 PUFAs detected in the fish samples was eight. The total n-3 PUFA ranged from 4.86 to 20.61 mg·g⁻¹ DW. The highest total n-3 PUFA was found in *O. niloticus* collected from Lake Chamo, whereas the lowest found in *O. niloticus* from Lake Awassa. The concentration of PUFA n-3 were higher than n-6 PUFA. This is in agreement with the results presented by de Castro et al. [51] on some freshwater fish in Brazil. The most abundant n-3 PUFA in all the fish examined was DHA, although these four-freshwater fish contained reasonable content of EPA, DPA and ALA. This finding is similar to Efiong and Faculaces [16], Osibona [39], Turon, et al. [44], and Kwetegyeka et al. [45] who described that the most abundant LC n-3 PUFAs in freshwater species is DHA followed by EPA and DPA.

The alpha-linolenic acid (18:3n-3, ALA) ranged from 0.22 to 3.05 mg·g⁻¹ DW. The highest ALA was found in *O. niloticus* collected from Lake Chamo, whereas the lowest found in *O. niloticus* from Lake Langano (Table 2). ALA primarily...
functions as a precursor for the synthesis of EPA which in turn forms DHA but may also have an independent role in protection against CHD via different mechanisms [52]. Conversion of ALA to EPA and DHA is limited and varies according to the intakes of other FAs [53]. Thus, a typical intake of ALA may be less able to satisfy the physiological requirements for LC n-3 PUFAs than LC n-3 FAs.

Eicosapentaenoic acid (20:5n-3, EPA) ranged from 0.48 to 4.74 mg.g⁻¹ DW. The highest (4.74 mg.g⁻¹ DW) level of EPA was found in Barbus sp. collected from Lake Langeno, whereas the lowest (0.48 mg.g⁻¹ DW) found in O. niloticus collected from Lake Awassa (Table 2). Barbus sp is an omnivorous freshwater fish species. According to Barus et al. [54], stream barbell feeds mainly on bottom fauna. It also consumes algae and higher water plants, while plant food predominates in more adult specimens (2-7 years of age). Lenhardt et al. [55] determined that main food in the diet of the stream barbell was Chironomidae although there was also a high quantity of Simulidae and Trichoptera. In other words, LA and OA were found to be higher and DHA and EPA to be lower in diets than tissues. Nevertheless, DHA were 5.7 times higher and EPA 2.8 times higher and n-3/n-6 ratio 4.7 times higher in muscle tissues than diets. These findings may be attributed to high desaturase activity of freshwater fish. Liubojevic et al. [56] analysis FA composition of seven fish species from the Danube River including A. aspia, A. brama, B. barbus, C. carpio, A. ruthenus and E. lucius. The highest EPA was found in B. barbus compared to the other fish species analyzed, whereas the highest DHA was found in E. lucius. Another study by Aras et al. [57] investigated the conversion ratios of stomachs containing FAs to FA profiles of muscle, gonad, gill, liver and adipose tissues and gastric contents in Barbus capito capito. Significant differences were determined between gastric contents and adipose and gonad tissues in terms of total SFA; similar SFAs values were found in all the other tissues. The highest MUFA amounts were found in adipose tissue. n-3 and n-6 levels of muscle, gonad, gill and liver were higher than diet's n-3 and n-6 PUFAs. However, n-3/n-6 PUFA ratio significantly increased in all tissues except adipose tissue. This and the other studies on Barbus sp suggested/indicated that, the Barbus from Lake Langeno Ethiopia had a higher desaturase activity and may have the ability to convert ALA and other short chain PUFA to EPA to a certain extent. Therefore, more detailed studies should be carried out to determine these conditions.

Docosapentaenoic Acid (22:5n-3, DPA) ranged from 0.44 to 3.99 mg.g⁻¹ DW. The highest (3.99 mg.g⁻¹ DW) was found in O. niloticus from Lake Haiq and the lowest (0.44 mg.g⁻¹ DW) in C. gariepinus from Lake Awassa (Table 2). In agreement to this Kwetegyeka et al. [45] found higher DPA in O. niloticus than C. gariepinus collected in selected Ugandan lakes. DHA also varied within and between the fish species collected from the different Ethiopian lakes. DHA ranged 2.69 to 11.55 mg.g⁻¹ DW. The highest (11.55 mg.g⁻¹ DW) content of DHA was found in O. niloticus captured from Lake Haiq and the lowest (2.69 mg.g⁻¹ DW) found in O. niloticus from Lake Awassa (Table 2). Other authors are also reported variations in DHA content of O. niloticus caught from different lakes. For example, Kwetegyeka et al. [45] found the highest content of DHA in O. niloticus from Wampanga Lake Kyoga followed by Napoleon gulf Lake Victoria and the lowest found in O. niloticus from Bukungu Lake Kyoga. As shown in Table 2, O. niloticus from Lake Haiq have relatively higher levels of both EPA and DHA than the other fish species, Barbus sp, C. gariepinus, and L. niloticus. This finding is similar to Efiong and Faculaye [16] and Tenyang et al. [38]. Efiong and Faculaye [16] who fund that both EPA and DHA were higher in O. niloticus than L. niloticus and C. gariepinus collected from Lake Kainji, Nigeria. In a similar study Tenyang et al. [38] found higher content of DHA in O. niloticus compared to the other four fish species collected from Maga Lake, Cameroon.

The higher content of EPA, DHA and total n-3 PUFA in O. niloticus might be attributed to the feeding habits and diverse food items consumed by the fish. O. niloticus feeds lower in the food chain, mainly on microalgae, which are excellent sources of EPA, DPA and DHA. For example, studies by Mfilinge et al. [58] and Meziane et al. [59] reported that diatoms and dinoflagellates contain higher concentrations of EPA and DHA, respectively, and have been used as markers of diatoms and dinoflagellates in the aquatic food web. O. niloticus feed by consuming diverse species of phytoplankton, zooplankton and macrophyte. O. niloticus and T. zillii are the major prey of L. niloticus and C. gariepinus, in the tropical lakes of the Ethiopian Rift Valley. Based on this feeding chain, it is more likely that the EPA, DPA, and DHA contained in the herbivorous fish species were transferred to the carnivorous ones via the food chain. The FAs composition reflects the composition of the diet, because “you are what you eat” [41]. Thus, expansion of diet and diversity of microalgae species contribute to O. niloticus having higher content of EPA, DHA and total n-3 PUFAs which are beneficial for the health of consumers as well as fish. C. gariepinus, and L. niloticus and Barbus sp, have specialized feeding as they increase in size. C. gariepinus and L. niloticus are predators that feed on other fish, crustaceans, and insects [60]. Due to their specialized feeding, they limit the diversity of food and therefore PUFAs compared to O. niloticus. Furthermore, the higher content of EPA, DHA and total n-3 PUFA in O. niloticus collected from Lake Haiq compared to the other Ethiopian lakes, could be related to the O. niloticus diet composition differences between the lakes. It has been established that the composition and proportion of algae that constitute the fish diet varies greatly between lakes. A recent study by Assefa and Getahun [61] reported that O. niloticus from Lake Haiq feeds primarily on blue green algae (Cyanophyta), green algae (Chlorophyta), and diatoms (Bacillariophyta). It has also been found to expand its diet to include Euglenophyta, rotifers, cladocerans, copepods, piscivores, macrophyte shoots, detritus and insects. In Lake Ziway, Tadesse [62] found that fish stomach contents were mainly dominated by blue-green algae, e.g., Microcystis sp. and Lyngbya sp., whereas in Lake Awassa, Getachew and Fernando [63] found that the green algae, Botryococcus spp. along with the blue-green algae, Chroococcc dominated. Based on these studies it is more likely that the diet of the lake could...
affect the LC n-3 PUFAs content of the fish within and among species.

In addition, more types of n-3 PUFA in *O. niloticus* could be as a result of desaturation and elongation of FAs. The ability to elongate and desaturate FAs is not the same in all species of fish. *O. niloticus* have the ability to bio convert stearic acid, OA, and other FAs, which belong to group C: 18 FAs, to highly unsaturated FAs [45]. For example, arachidonic FA is a product of an elongation and desaturation of metabolic precursor of LA, whereas EPA and DHA their metabolic precursor are ALA. Stearic acid, oleic acid, and other C: 18 groups were found to be dominant FAs, contributing to higher composition of FAs in *O. niloticus*. By virtue of this capability, Mwindinga et al. [64] classified *O. niloticus* as an excellent source of n-3 PUFAs and being ideal for production of n-3 supplements.

The presence of EPA and DHA in all the fish species from the different lakes in Ethiopia suggests that consumption of these fish can have a healing effect to alleviate muscle pain and inflammation. EPA and DHA have been reported to reduce the risks of CVD including myocardial infarction, stroke, coronary artery disease and sudden cardiac death. In addition, these FAs play an important role in reduction of cancer risk, Alzheimer’s disease, depression and schizophrenia. Furthermore, EPA and DHA are essential for proper fetal development (particularly neuronal and retinal functions) and healthy aging [65]. Several recent human trials have strengthened the evidence that EPA and DHA can reduce the risk of various chronic diseases, although this has not been a uniform finding. There are many other studies that reported the beneficial effects of n-3 FAs on rheumatoid arthritis [66]. Therefore, fish have been suggested as a key component for a healthy diet in humans [50]. Significant levels of EPA and DHA in fish species of this study indicated that these species can be used to supplement essential FAs in the human diet. Considering the above evidence in total it follows that PUFA are crucial in human physiology and must be included in human diet perhaps in the form of fish as a rich source of these FAs. The potential role of DPA, as a very minor component of fish oil, has been largely ignored, despite the fact that recent research shows DPA contributes almost 30% of total LC n-3 in our diet [67].

### iii. The Omega (n-3) / Omega (n-6) PUFA ratio

In all the species, the n-3/n-6 ratio was higher than 1 and ranged from (1.39 to 5.86 mg·g⁻¹ DW) (Table 2). The highest ratio value (5.86 mg·g⁻¹ DW) was found in *O. niloticus* from Lake Haq, while the lowest (1.39 mg·g⁻¹ DW) n-3/n-6 ratio was observed in *T. zilli* from Lake Ziway. The value reported for *O. niloticus* from Lake Haq was higher than the value (3.7) reported by Kwetegyeka et al. [45] for *O. niloticus* caught from Lake Kyoga, Uganda. The value for *T. zilli* from Lake Ziway is consistent with the value (1.39) given by Kwetegyeka et al. [45] for the same species captured in Lake Victoria. The ratio of n-3/n-6 has been suggested as a useful indicator for comparing relative nutritional value of fish oils. It was suggested that a ratio of 1:1 to 1:5 would constitute a healthy human diet [68].

This research shows that all Ethiopian fresh water fish species are richer in n-3 than n-6 PUFAs (n-3: n-6 = ranged 1.39 to 5.86). The ratio reveals that fresh water fish are a good source of PUFA. All five fresh fish species had the ratio of n-3/n-6 within the recommended ratio. *O. niloticus* contained higher ratio of n-3/n-6, this means that *O. niloticus* has higher nutritional value compared to other fish. These ratio (5.86), from Ethiopian lakes fish (*O. niloticus*) were higher than those obtained by Homayooni et al. [69] for rainbow sardine (3.74) in Iran, Nazemroaya et al. [70] for some marine fish (2.02-4.16) in Iran, Osman et al. [48] for some marine fish (2.16-4.14) in Malaysia, Farhat and Abdul [71] on three freshwater fish species in Pakistan (0.23-0.27), Tenyangi et al. [38] on four fresh water fish from Cameron (0.47- 0.90), and those presented by Kwetegyeka et al. [45] on seven fresh water fish from Lake Victoria, Uganda (0.5-3). All examined species have had n-6/n-3 ratio lower than 1 which are in the prescribed values recommended from WHO/FAO organization. A high n-6/n-3 ratio is problematic because too much AA, an n-6 FA, promotes inflammation, which aggravates heart disease and other illnesses.

Variations, both within and between species have been observed for fresh water fish [42, 45]. Various factors such as diet, genetic variation, temperature, age, size, season, reproductive status, geographic location are responsible for variability in FA composition of the tissues of fresh water fish [4]. Of these factors, diet is suggested to be the dominating factor [72]. Zenebe et al. [36, 37] concluded that the temperature difference (<5°C) measured between the study Ethiopian lakes was not great enough to produce any change in the FA composition of the fish. Fish size does not explain the variations either because the data showed a scattered pattern between fish total length and total lipids. Zenebe et al. [36, 37] added that the reason for the observed results is likely the feeding habits of the fish. The FAs composition reflects the composition of the diet, because “you are what you eat”. Confirming the findings of Zenebe et al. [36, 37], several authors from other parts of the world have also concluded that FA profiles in fish reflect the diets of the animals [14, 38-39, 41, 48, 73]. They also suggested that, in addition to diet composition, the spawning activity of these fish could drain their fat reserves, thereby contributing to the variability of the FAs and low tissue lipids.

### 4. Conclusion and Recommendations

The proximate composition and fatty acid content of fish collected from the different Ethiopian lakes varied both within and between species. Total lipids, SFA, MUFA and PUFA levels varied considerably, both within and between species. *O. niloticus* collected from Lake Haq was found to contain relatively higher levels of DPA, DHA, total n-3 PUFA and n-3/n-6 ratio than the fish from the other lakes. Moreover, *Barbus sp* collected from Lake Langano has a relatively high level of EPA compared to the fish species caught from the other lakes. All the freshwater fish species collected from the different lakes have benefits for human health. Fish from
Ethiopian lakes, as with other tropical freshwater fish, are good sources of LC n-3 PUFA and can prevent CVD, increase learning ability and reducing the risk of certain cancers. However, *O. niloticus* from Lake Haig and *Barbus* sp from Lake Langeno are the best species for consumption due to higher levels of LC n-3 PUFA.

Ethiopia has about 200 fish species, but there are few publications available on specific commercially important fish species and little is known about the FA content of the majority of Ethiopian fish species. Therefore, further large-scale research with large sample size is required to determine the relative fatty acid content of those fish species which have not been assessed before. Furthermore, the analyzed data reported for the fish species from Ethiopian lakes was based on small sample size, and further research with large sample sizes is needed to confirm the results of the fatty acid content of these fish species. It is also recommended that regional and seasonal variation in fatty acid composition of different tissues (such as brain, liver, heart, gills, gonads and adipose) needs to be analyzed for better understanding of the nutritional fatty acid profile of these species. In addition, the fatty acid profile and content of the other fish species from Ethiopian lakes and other water bodies (such as reservoirs and rivers) should be determined. Fish should be assessed for fatty acid variations between different sexes, seasons, sizes, ages, and spawning.

**References**


