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Nutritional Composition of Value-added Fish Products from Selected Fish Species in Kenya

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Abstract

Fish is an important seafood that provides quality nutrients to human beings which is vital for health and development. This is especially critical in the diets of children under two years old and reproductive women (pregnant and lactating). Selected fish species were sampled from both Lake Victoria and fish farms, and their weight was determined using a sensitive weighing balance and fish-based products (powder and gelatin) developed to food-grade standards. The proximate composition of minerals, amino acid, and fatty acid profile were assessed in the laboratory, and data were analyzed using R statistic tool version 4.2.2 to understand the differences between the variables at a significance level of $p < 0.05$. Results indicated that crude fat ranged from 3-23%, crude protein was highest in Nile perch gelatin at 81.22±1.43 while *omena* and *haplochromine spp.* had the highest concentration of calcium at 6347.1±428.5 and 4522.0±233.3 mg/Kg respectively. The highest concentration of essential amino acids was found in *omena* and Nile perch powder. Among the fatty acids; oleic and palmitic were the dominant fatty acid in the fish products at 25.12±0.56% - 45.12±0.65% and 20.52±0.69% - 44.23±0.74% respectively. The moisture content of the final products was between 4.64 ±0.08% - 8.82±0.35%, which was within limits ensuring little microbial activity thus enhancing the shelf-life of the final products. The developed products had nutrients that are beneficial to human health at desirable concentrations and are recommended for inclusion in the diet of vulnerable groups for a prosperous community free from hunger and malnutrition.

Keywords: proximate composition, minerals, amino acid, fatty acids profile

1. Introduction

Fish is vital for proper human nutrition providing approximately 17% of the global animal protein intake (FAO, 2020). Fish is rich in important micronutrients, minerals, vitamins, amino acids, and essential fatty acids which are often lacking in the diets of poor and vulnerable populations (Thilsted et al., 2016) especially children below 2 years of age, and reproductive women (pregnant and lactating). In addition, this vulnerable population rarely consume fish mainly due to affordability and availability of convenient products. Therefore, the development of nutrient-rich products from fisheries and aquaculture contributes to food and nutrition security for many households thereby meeting the nutrient requirements for optimal growth and development (Gibson et al., 2020). This is mostly important for pregnant and lactating mothers, and infants as the first 1000 days are the most critical days of their life (Longley et al., 2014; WorldFish, 2017). Poor nutrition emanating from chronic malnutrition and micronutrient deficiency during these days can result in permanent and irreversible effects (Victora et al., 2008) with a cost on the health and performance of affected individuals (Grantham-McGregor et al., 2007).

Undernutrition which is evidenced in stunting, wasting and underweight can result to disability or even death. Forty-five percent of mortality in children under five is attributable to under-nutrition; nutritional deficiencies are

responsible for 50% of years lived with disability in children aged four and below (Golden et al., 2016). This condition is evident in many regions in the globe and has continued to rise in Africa from 50 million people in 2000 to 59 million people in 2018 (UNICEF, 2019). In Kenya, 18% of children below 5 years are stunted, 5% are wasted while 10% are underweight (KNBS and ICF, 2023). It is therefore important to feed this vulnerable population with the right diet because the nutrition of the mother and the child significantly affects the child's future well-being and development which further affects educational and economic achievements. (SSentongo, 2021).

Fish are an important source of essential amino acids, long-chain polyunsaturated fatty acids, micronutrients such as vitamins A, B12, and D, and minerals essential for the cognitive development of children and for adult health (Golden et al., 2016; FAO, 2018). In addition, fish is recognized for its importance in enhancing the bioavailability of nonheme iron and zinc from plant-based calorie-dense foods such as rice consumed in the same meal (Beveridge et al., 2013). However, many Kenyans especially pregnant, lactating mothers and children below 2 years old consume lower fish servings than recommended levels by the World Health Organization (WHO) depriving them of vital benefits important for proper growth and development (WorldFish, 2017). In addition, during pregnancy and lactation, women have a higher demand for essential nutrients present in fish products. Poor fetal growth and development resulting from micronutrient inadequacy make children susceptible to opportunistic infections.

Despite the rich nutritional value of fish, intake by this vulnerable age group remains low, especially among the poor due to challenges with the availability and accessibility of convenient products, especially for children. This coupled with an increase in population (KNBS, 2020), has caused a general reduction in the frequency of fish consumption within households further reducing the national fish intake levels when compared to the rest of the World (FAO, 2020). Fish consumed in Kenya is predominantly provided by capture fisheries sourced from rivers, large inland lakes, coastal systems, and aquaculture (Munguti et al., 2021). The major fish species cultured in Kenya are Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarias gariepinus)* while the main source of capture fisheries is Lake Victoria with three major species being Nile perch (*Lates niloticus*), Nile tilapia and silver cyprinid/*omena (Rastrineobola argentea)*. Other species such as Lung fish (*Protopterus aethiopicus*), African catfish, and *Haplochromines spp.* form an important component of the local diet among the riparian communities.

This study sought to develop and assess the nutritional composition of value-added fish products, namely fish powder and fish gelatin for children below 1000 days old and reproductive women throughout the year for food and nutritional security.

2. Materials and Methods

2.1 Sample Collection and Processing of the Value-added Fish Products

A total of six different fish species were collected for the preparation of value-added fish-based products, two species (silver cyprinid/*omena* and *haplochromine spp*) constituted the small fish food that is eaten whole. The big fish collected were Nile tilapia (500-800g), Nile perch (2000-3500g), African catfish (1000-3000g), and Lung fish (1500-3000g). *Omena*, haplochromine, Nile perch and Lung fish were collected from Lake Victoria, Dunga beach in Kisumu County while Nile tilapia and African catfish were collected from a fish farm in Kakamega County.

Gelatin was extracted through heat hydrolysis from Nile perch and Nile tilapia skin. The skin was cut into small pieces to increase the surface area-to-volume ratio for maximum extraction and to improve the efficiency of the extraction process. The resulting sap was then concentrated at 60^0 C before molding into sheets and milling into gelatin powder.

To prepare fish powder from the big fish, the fish were descaled, gutted, washed to food grade standards, and cut into desirable small pieces. Deboning was done to separate the fillet from the adhering bone and partial boiling was done for five minutes at 60^0 C. The separated fillet was used to make fish powder. The moisture content was reduced to below 10% and milling was done to produce the final product.

2.2 Laboratory Analysis

The samples were packed into labeled sterilized air-tight containers and stored in the freezer at -20° C for laboratory analysis. All samples were analyzed in triplicate.

2.3 Proximate Analysis

The moisture content was determined by evaluating the loss of weight after drying the sample in a hot air oven at 105° C for 3 hours until the samples achieved a constant weight as per the (AOAC, 2005) method. Crude lipid was determined by extracting fat using the Soxhlet method (AOAC, 1990). Ash content was determined in moisture-free dry samples in a muffle furnace at 550° C for 20 hours until all organic components of the sample were

incinerated completely (AOAC, 1990). The crude protein content of samples was determined by multiplying the nitrogen content obtained by Kjeldahl's method by the conversion factor of 6.25 (AOAC, 1990). The crude fiber content of the sample was determined according to (AOAC, 1980); whereby 2 grams fat-free sample was digested with 1.25% (0.26 N) H_2SO_4 and 1.25% (0.23 N) NaOH and followed by drying in an oven at 105° C and then for 3 hours in a muffle furnace at 550° C. The energy value was determined by multiplying the crude protein, carbohydrate, and crude lipid content of the sample as per the method described by Jabeen and Chaudhry (2011). Total carbohydrates or nitrogen-free extract (NFE) of the sample were calculated by subtracting the sum of percentages of moisture, crude protein, ash, crude lipid, and crude fiber in the sample from 100% (Castell and Tiews, 1980).

2.4 Mineral Analysis

Mineral content was determined using 5 grams of the sample according to AOAC (2005). Samples were dissolved and digested in 15 ml HNO_3 which was topped up to 50 ml with distilled water after digestion. The aliquot was filtered using Whatman paper (0.45µm thickness) after which the samples were injected and determined using the atomic absorption spectroscopy method (Model AA-7000, Shimadzu, Corp., Kyoto, Japan) (Gokoglu et al., 2004). Potassium and phosphorus contents were analyzed by using the flame photometry method (Junsomboon and Jakmunee, 2011). Iodine was analyzed using the titrimetric/iodometry method.

2.5 Amino Acid Profile

The profiling of amino acids was conducted using the high-performance thin-layer chromatographic (HPTLC) method (Nilima and Kunda, 2014). Samples were hydrolyzed in an acidic solution of HCl at 110° C for 24 hours. The samples were then evaporated in a water bath to remove the trace acid content completely. The individual amino acids were quantified and identified based on the retention time and peak area of the amino acid's standards in HPTLC (Vijayan et al., 2016).

2.6 Fatty Acid Determination

The fatty acid profile was determined by gas chromatography. The extraction of lipids was done by modification of the Bligh and Dyer method (1959). 2 ml of water and 7.5 ml of methanol-chloroform (2:1 v/v) were added and the mixture was shaken overnight at room temperature. The supernatant was separated from the residue. The fatty acids were then obtained and converted into fatty acid methyl esters (FAMEs) by methylation using HCl and methanol mixture. The composition and quantification of individual fatty acids were then determined by comparison of the retention times and peak areas with the respective peak areas of the relevant fatty acids' standards (Mohanty et al., 2019).

3. Statistical Analysis

Descriptive statistics were performed and results were presented as mean ± standard deviation (SD). Statistical analyses were conducted by using the r statistic tool version 4.2.2 to understand the differences between the variables at significance level of $p < 0.05$.

4. Results and Discussion

4.1 Proximate Composition

The moisture content of the prepared fish powder and fish gelatin was below 10% for all the products. This was important in reducing the microbial activities since most microbial activities are inhibited at moisture content below this level (Gram and Dalgaard, 2002) thus increasing the shelf-life of the final product (Dalgaard, 2000). The low moisture content observed in the final product was due to the processing technology which employed programmed drying of the samples that was preceded by milling to make the fish powder. Basiouny (2014) recorded a moisture content of between 9.2-11.9% in Nile tilapia when drying using the oven method (AOAC, 2005). Oduor-Odote et al. (2010) observed slightly higher values of final moisture in *omena* and *kimarawali* (*Stolephorus delicatulus)* at 12.1 and 14.0% respectively.

The crude fat content varied from 3.0 - 23.0%. The amount of fat in fish may be below 1% and may exceed 30% depending on the species and biological status (Cakli et al., 2007). Ash content varied from 1.7-16.7% with the highest value recorded on small fish food (silver cyprinid*/omena* and *haplochromine spp*). The high variation observed was due to the contribution of bones and scales since the small fish whole body was used in the preparation of the final product. Bille and Shemkai (2006) recorded ash content of 15.7% and 17.3% for spiced-smoked *omena* and sun-dried *omena* respectively. Bogard et al. (2015) reported 1.8% ash in Nile tilapia. Biswas et al. (2018) observed similar results at 1.83% ash in Nile tilapia collected from Dekar haor in Bangladesh. Likewise, Jim et al. (2017) found an ash content of 1.76 - 3.30% for Nile tilapia collected from different lakes in

Zimbabwe.

Protein was highest in Nile perch gelatin at 81.22 ± 1.43 while Lung fish and Nile perch values were 77.43 ± 1.21 and 75.53 ± 3.74 respectively. The lowest protein content was recorded in *omena* and *Haplochromines* at 55.1% and 56.2% respectively. Kabahenda et al. (2011) when assessing the protein levels in low-value fish, found a crude protein in the range of 47.9 - 58.8% in *omena.* In other studies, fillets from meager fish *(Argyrosomus regius*), the protein content was 75% of dry matter, the fat content was 19%, and the ash content was 5%. Corresponding values for gilthead sea bream (*Sparus aurata*) fillet were 57% protein, 40% fat, and 4% ash (Yiannopoulos et al., 1999). The value-added products (Nile perch skin and Nile tilapia skin) were also processed with the skin on hence may have contributed further to the protein. A study by Sinanoglou et al. (2014) on the by-products of meager fishes showed that the skin had the highest protein concentration. This explains the contribution of the skin to the protein of the final product.

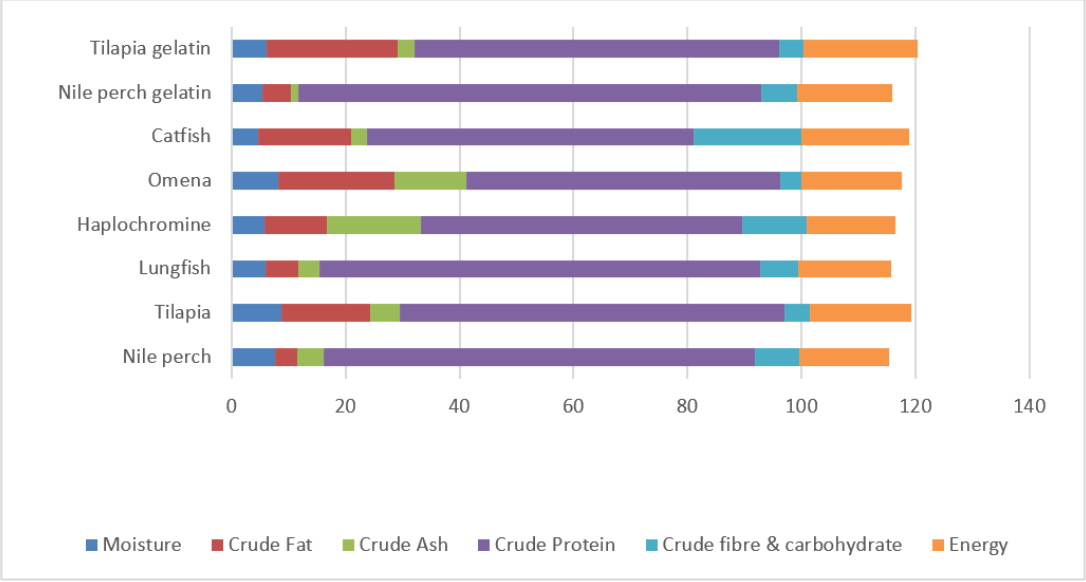

Figure 1. Bar graph showing percentage proximate analysis results of the value-added products from different fish species from Lake Victoria Basin

The high ash content and protein observed in this study could be attributed to the fact that the small fish were processed whole hence the bones and other hard tissues contributed to the high ash content (Usydus et al., 2011). Aquatic organisms take inorganic materials from food and water and store them in skeletal tissue and other membranes (Cakli et al., 2007). Generally, the proximate composition was significantly varied among the studied value-added fish products. This may be due to the absorption capability and conversion potentials of essential nutrients from their diets or their feeding niche (Adewoye and Omotosho, 1997).

4.2 Mineral Composition

Table 1 below shows the mineral composition of the fish powder and gelatin from Nile perch and Nile tilapia skin. All the minerals showed significant differences. *Omena* and *haplochromine spp.* had the highest concentrations of calcium (6347.1±428.5 and 4522.0±222.3 mg/Kg) respectively. The two species comprise the small fish species in Kenya and contribute more micronutrients since they are consumed whole (Thilsted et al., 2016; Roos et al., 2007). Small fish consumed whole are rich in bioavailable micronutrients such as zinc, iron, and calcium (Aakre et al., 2020) and are mostly nutrient dense. This explains why they have more nutrients than fillets. One study found that calcium absorption from the consumption of soft-boned small fish was comparable to that of skimmed milk (Hansen et al., 1998). Potassium levels in the six fish species ranged from 5030.8-9364.7 mg/Kg while phosphorus levels ranged from 1453.8-3163.7 mg/Kg. Jim et al. (2017) found potassium levels in Nile tilapia from three different lakes in Uganda ranging from 3193.3-4293.3 mg/Kg while phosphorus levels were ranging from 1453.8-3163.7 mg/Kg. Another study by Islam et al. (2021) recorded much lower levels of potassium in Nile tilapia in the range of 1096.5-1323.7 mg/Kg.

Trace elements (micro-nutrients) also varied significantly at $p < 0.05$. Zinc levels were highest in *omena* and

haplochromines spp at 67.5 and 69.6 mg/Kg respectively. Kabahenda et al. (2011) assessed micronutrient levels in *omena* from the Lake Victoria region and found zinc in the range of 41-103 mg/Kg on a dry basis. Clarke et al. (2022) found much higher levels of zinc at 170 mg/Kg from *omena* collected from three East African Lakes. The highest manganese content was observed in o*mena* and *haplochromine spp*. at 11.5 and 26.5 mg/Kg respectively. Manganese levels in Nile perch and Nile tilapia was 2.01 and 2.61 mg/Kg respectively while it was not detected in catfish and Nile perch gelatin. Islam et al. (2021) reported that manganese content ranged from 1.02 mg/kg to 4.11 mg/kg in Nile tilapia.

Clarke et al. (2022) concluded that increasing the dietary intake of zinc, iron and calcium is important in curbing micronutrient deficiencies. Worth noting is that it is difficult to meet the Daily Recommended Intake (DRI) of these nutrients from plant-based food sources (Gibson et al., 2020) and therefore animal based protein sources such fish are key for women and children nutrition and wellbeing. Fish obtain minerals from their diet, feeds and also from weathered rocks and soils, and also from minerals present as an electrolyte (Tagliabue et al., 2017). Thus mineral absorption from the environment depends on concentration and species differences which in turn affects homeostasis (Lall, 2021). These variations in factors and conditions may explain the difference in the concentrations of these elements as observed in this study.

Table 1. The table shows the mineral concentrations of fish powder and gelatin processed from different fish species. ND indicates elements not detected

Essential minerals (macro-nutrients expressed in mg/Kg)			
	Calcium	**Potassium**	**Phosphorus**
Nile perch	1842.8±227.4	9093.93±775.9	2584.8±226.3
Nile tilapia	2382.4±151.9	7336.5±578.5	1668.4±77.4
Lungfish	2236.2±278.5	7966.2±498.1	1757.9±44.6
Haplochromines	4522.0±222.3	9364.7±428.3	2916.8±60.1
Omena	6347.1±428.5	7181.3±557.9	3163.7±42.6
Catfish	2447.4±37.7	8361.5±377.8	2157.8±124.1
Nile perch gelatin	3841.5±24.18	5030.8±297.2	1453.8±131.4
Nile tilapia gelatin	3362.1±16.4	6293.8±384.6	1789.8±104.0

Trace elements (micro-nutrients expressed in mg/Kg)				
	Zinc	**Iodine**	**Copper**	**Manganese**
Nile perch	32.2±1.3	1.34±0.02	3.29±0.09	2.01±0.18
Nile tilapia	28.8±2.5	0.98±0.01	4.39±0.30	2.61±0.11
Lungfish	49.43±2.9	0.64±0.01	3.05±0.27	3.16±0.28
Haplochromines	67.5±2.6	0.70±0.02	7.32±0.20	11.48±0.16
Omena	69.6±3.3	0.28±0.01	5.15±0.49	26.54±1.65
Catfish	14.7±0.4	0.34±0.01	3.42±0.13	ND
Nile perch gelatin	7.1±0.5	0.22±0.02	7.45±0.45	ND
Nile tilapia gelatin	10.3±0.7	0.39±0.02	3.12±0.17	4.63±0.31

4.3 Amino Acid Profile

Fish are important sources of amino acids which are the building blocks for protein. Both essential and non essential amino acids were recorded from the samples. The essential amino acids included lysine, leucine, and isoleucine while the non essential amino acids included cysteine, tyrosine, and proline. Similar results were reported by Islam et al. (2021) who found essential amino acids in tilapia to be leucine and lysine while the non-essential were aspartic acid and glutamic acid. Similarly, Moses et al. (2018) reported that leucine, lysine, and aspartic acid to be the major amino acids in tilapia collected from different rivers in Nigeria. Additionally, the findings coincide with Adeyeye et al. (2018) who found aspartic acid and leucine to be the most common amino acids in tilapia. Kim and Lall (2000) investigated the amino acid contents of three kinds of marine flounder fish and found the most abundant amino acids to be aspartic acid, glutamic acid, glycine, leucine, and lysine. In another study, Mohanty et al. (2014) posited that small indigenous fish are rich in histidine while catfishes are rich in glutamic acid and glycine.

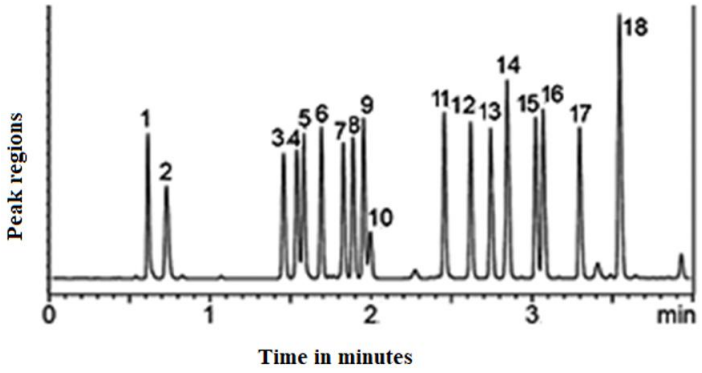

Figure 2. Shows the peak regions for different amino acid concentrations (1. Aspartate, 2. Glutamate, 3. Serine, 4. Glycine, 5. Histidine, 6. Arginine, 7. Threonine, 8. Alanine, 9. Proline, 10. Ammonia, 11. Tyrosine, 12. Valine, 13. Methionine, 14. Cysteine, 15. Isoleucine, 16. Leucine, 17. Phenylalanine, 18. Lysine)

The total essential amino acids (TEAAs) varied significantly at ($p < 0.05$) for all the products. However, there was no significant variation for specific essential amino acids throughout the products as shown in figure 3. Such differences could be attributed to differences in dietary needs of the respective amino acids, type of feed, and niche (Doğan and Ertan, 2017; Kuzu, 2005). It is also a reflection of differences in the protein composition of the product as amino acids are the protein building blocks (Abdullahi, 2002). The amino acid concentration determined in this study were within the standard amino acid values of FAO/WHO (1991) and values of FAO (2013). The products developed can therefore be depended upon for nutritional benefits.

Parameter1	Parameter2	r	95% CI	t(6)	p
Lysine	Threonine	-0.19	[-0.79, 0.60]	-0.47	> .999
Lysine	Histidine	-0.29	[-0.83, 0.52]	-0.74	> .999
Lysine	Isoleucine	0.21	[-0.58, 0.80]	0.53	> .999
Lysine	Leucine	-0.13	[-0.76, 0.63]	-0.31	> .999
Lysine	Methionine	-0.32	[-0.84, 0.49]	-0.84	> .999
Threonine	Histidine	-0.21	[-0.80, 0.58]	-0.52	> .999
Threonine	Isoleucine	-0.22	[-0.80, 0.57]	-0.56	> .999
Threonine	Leucine	-0.46	[-0.88, 0.36]	-1.26	> .999
Threonine	Methionine	-0.30	[-0.83, 0.51]	-0.77	> .999
Histidine	Isoleucine	-0.46	[-0.88, 0.37]	-1.25	> .999
Histidine	Leucine	-0.19	[-0.79, 0.59]	-0.47	> .999
Histidine	Methionine	-0.21	[-0.80, 0.58]	-0.53	> .999
Isoleucine	Leucine	0.63	[-0.13, 0.92]	2.00	> .999
Isoleucine	Methionine	-0.37	[-0.85, 0.45]	-0.99	> .999
Leucine	Methionine	-0.06	[-0.73, 0.67]	-0.15	> .999

p-value adjustment method: Holm (1979)
Observations: 8

Figure 3. Correlation of different essential amino acids showing the differences in their concentrations at $p < 0.05$

Amino acids are important biomolecules that serve as building blocks of proteins and are intermediates in various metabolic pathways (Mohanty et al., 2014). In addition, most of the animal sources are considered high quality protein with maximum indispensable amino acid composition for human needs and high digestibility. They are also precursors for the synthesis of various biologically important substances including nucleotides, peptide hormones, and neurotransmitters. Moreover, amino acids play an important role in regulating gene expression and cell signaling (Mohanty et al, 2014) and act as protein phosphorylation cascade (Wu, 2010), nutrient transport and metabolism in animal cells (Wang et al., 2013), and innate and cell-mediated immune responses.

Leucine, being the only dietary amino acid responsible for stimulating muscle protein synthesis (Etzel, 2004) also has important therapeutic functions in reducing stress conditions associated with burns, trauma, and sepsis (De

Bandt and Cynober, 2006). Arginine plays a critical role in cell division, wound healing, ammonia removal, immune function, and hormone release (Sharma et al., 2013). Methionine is key in improving wound healing, and is also used to treat liver disorders, depression and Parkinson's disease (Mischoulon and Fava, 2002). Amino acids such as glutamic acid, aspartic acid, alanine, and glycine are responsible for flavor and taste (Ruiz-Capillas and Moral, 2004) and therefore play a significant role in determining consumer taste preferences.

4.4 Fatty Acid Composition

The fatty acid profile was dominated by the Monounsaturated Fatty Acids (MUFA), Saturated Fatty acids (SFA), and Polyunsaturated Fatty Acids (PUFA) respectively. The most dominant SFA was palmitic acid. The highest concentration was recorded in *haplochromine spp.* while the lowest concentration was in lung fish. Previous studies also recorded palmitic acid as the highest among the SFA accounting for up to 65% (Huynh and Kitts, 2009; Usydus et al., 2011; Zhang et al., 2020) in fish. Islam et al. (2021) documented SFA, MUFA and PUFA in Nile tilapia. Oleic acid was the highest MUFA in all the samples and the highest levels were recorded in Nile perch gelatin, African catfish powder, and Nile tilapia powder respectively. Mohamed and Al-Sabahi (2011) found palmitic, stearic, oleic and decosahexaenoic fatty acids present in Nile perch fillets. Li et al. (2011) reported a higher content of oleic acid but a lower content of palmitic acid in marine fish species from the East China Sea. Our findings also concur with research by Zhang et al. (2020) who found a similar trend in *Sillago sihama*, *Collichthys lucidus*, *Coilia mystus*, *Harpadon nehereus*, and *Johnius belangerii* while other species in the same study showed elevated SFAs, MUFA and PUFA respectively.

The products prepared in this study had the lowest SFAs and were healthy and potential in preventing malnutrition and cardiovascular diseases (Islam et al., 2021). Among the PUFA, linoleic acid, a metabolic precursor of arachidonic acid was the highest among all the samples followed by linolenic acid, a metabolic precursor of Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA). Saturated fatty acids showed a linear relationship with MUFA and an inverse correlation with PUFA. Figure 4 below shows the relationship between the fatty acids. This inverse relationship was also observed between MUFA and PUFA in the products developed. The high concentration of linoleic acid could be due to the fish diet and the retention of arachidonic acid in the fish tissue. Arachidonic is preferentially retained in the muscle's lipids while EPA is selectively used as a substrate for beta-oxidation hence resulting in low levels. (Suloma et al., 2008; Karapanagiotidis et al., 2010).

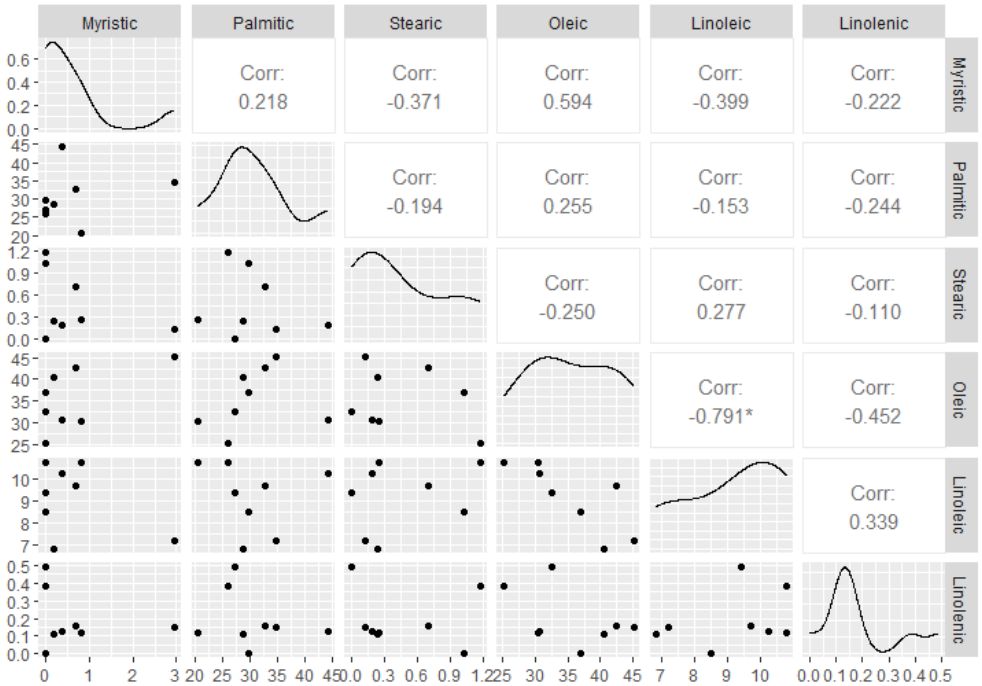

Figure 4. Correlation analysis of different fatty acids and their concentration in fish powder developed from common fish products

5. Conclusion

Value addition of fish through the preparation of fish-based products such as gelatin and fish powder is key in

minimizing post-harvest losses and increasing productivity. In addition, it ensures that fish products are available throughout the year and are easily accessible whenever needed. Considering fish central role in healthy diets, it is important to have nutrition sensitive interventions geared towards alleviating the prevalence of undernutrition such as stunting and wasting in children and micro nutrient deficiencies. Healthy fish diets are key in improving survival, health, physical growth, cognitive development and productivity in children and reproductive women. The fish based products developed were nutrient dense and therefore favourable for good health and development of the targeted vulnerable population. Most importantly, the nutrients were at recommended levels to meet the targeted population's requirements for optimal growth and development to create a healthy society free from hunger and malnutrition. The moisture content of the final product was low enough for minimum microbial activity thus ensuring a longer shelf life.

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Authors contributions

Study Conceptualisation: Cecilia Githukia, Dennis Otieno and Kevin Obiero. Sample preparation: Dennis Otieno, Evans Menach, Cecilia Githukia, Maureen Cheserek and Kevin Obiero. Data Collection: Domitila Kyule-Muendo, Dennis Otieno and Maureen Cheserek. Study design and revision: Jonathan Munguti, Evans Menach and Kevin Obiero. Drafting of the manuscript: Dennis Otieno and Cecilia Githukia. All authors read and approved the final manuscript. In addition, all authors contributed equally to the study.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

The Publication Ethics Committee of the Canadian Center of Science and Education.

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

Provenance and peer review

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Data sharing statement

No additional data are available.

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References

Aakre, I., Bøkevoll, A., Chaira, J., Bouthir, F. Z., Frantzen, S., Kausland, A., & Kjellevold, M. (2020). Variation in nutrient composition of seafood from North West Africa: Implications for food and nutrition security. *Foods, 9*(10), 1516. https://doi.org/10.3390/foods9101516

Abdullahi, S. A. (2002). Seasonal and locational variations in the proximate, amino acid, and mineral contents of *Lates niloticus*, *Heterotis niloticus*, and *Gymnarcus niloticus* in Nigeria. *Journal of Agriculture and Environment, 3*(2), 359-366.

Adewoye, S. O., & Omotosho, J. S. (1997). Nutrient composition of some freshwater fishes in Nigeria. *Bioscience, 11*(4), 333-336.

Adeyeye, S. A. O., Fayemi, O. E., & Adebayo-Oyetoro, A. O. (2018). Amino acid, vitamin, and mineral profiles of smoked fish as affected by smoking methods and fish types. *Journal of Culinary Science and Technology, 17*(3), 195-208. https://doi.org/10.1080/15428052.2017.1418693

AOAC (Association of official analytical chemists) (2005). *Official methods of analysis* (18th ed.). Association of official analytical chemists. Washington DC: 2005.

AOAC (Association of official analytical chemists) (1990). *Official methods of analysis* (15th ed.). Association of official analytical chemists. Washington DC: 1990.

AOAC. (Association of official analytical chemists) (1980). *Official methods of analysis* (13th ed.). Association of official analytical chemists. Washington DC: 1980.

Basiouny, M. A. (2014). Thin layer drying of Nile tilapia fingerlings using mechanical dryer. *Misr Journal of Agricultural Engineering, 31*(2), 599-618. https://doi.org/10.21608/mjae.2014.99631

Beveridge, M. C. M., Thilsted, S. H., Phillips, M. J., Metian, M., Troell, M., & Hall, S. J. (2013). Meeting the food and nutrition needs of the poor: The role of fish and the opportunities and challenges emerging from the rise of aquaculture. *Journal of Fish Biology, 83,* 1067-1084. https://doi.org/10.1111/jfb.12187

Bille, P. G., & Shemkai, R. H (2006). Process development, nutrition and sensory characteristics of spiced-smoked and sun-dried dagaa (*Rastrineobola argentea*) from Lake Victoria, Tanzania. *African Journal of Food Agriculture Nutrition and Development, 6*(2), 1684-5358. https://doi.org/10.4314/ajfand.v6i2.71737

Biswas, M., Islam, M. S., Das, P., Das, P. R., & Akter, M. (2018) Comparative study on proximate composition and amino acids of probiotics treated and nontreated cage reared monosex tilapia *Oreochromis niloticus* in Dekar haor, Sunamganj District, Bangladesh. *International Journal of Fisheries and Aquatic Studies, 6(2),* 431-435.

Bogard, J. R., Thilsted, S. H., Marks, G. C., & Wahab, M. A. (2015). Nutrient composition of important fish species in Bangladesh and potential contribution to recommended nutrient intakes. *Journal of Food Composition and Analysis, 42,* 120-133. https://doi.org/10.1016/j.jfca.2015.03.002

Cakli, S., Kilinc, B., Cadun, A., Dincer, T., & Tolasa, S. (2007). Quality differences of whole ungutted sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) while stored in ice. *Food Control, 18*(5), 391-397. https://doi.org/10.1016/j.foodcont.2005.11.005

Castell, J. D., & Tiews, K. (1980). *Report on the EIFAC, IUNS and ICES working group on the standardization in fish nutrition research*. Hamburg, Federal Republic of Germany, 21- 23 March, 1979. EIFAC Technical Paper. pp. 26.

Clarke, S. B., Nesbitt, W. A., Efitre, J., Masette, M., & Chapman, L. J. (2022). Elemental composition of small pelagic fishes in three East African lakes: Implications for nutritional security. *Fisheries Research, 256,* 106479. https://doi.org/10.1016/j.fishres.2022.106479

Dalgaard, P. (2000). *Fresh and lightly preserved seafood. In shelf-life evaluation of food.* C.M.D. Man & A.A. Jones, editors. Aspen Publisher Inc, London, U.K. pp. 110-139.

De Bandt, J. P., & Cynober, L. (2006). Therapeutic use of branched-chain amino acids in a burn, trauma, and sepsis. *Journal of Nutrition, 185*(1), 308S-313S. https://doi.org/10.1093/jn/136.1.308S

Doğan, G., & Ertan, Ö. O. (2017). Determination of amino acid and fatty acid composition of goldband goatfish [*Upeneus moluccensis* (Bleeker, 1855)] fishing from the Gulf of Antalya (Turkey) *International Aquatic Research, 9*(4), 313-327. https://doi.org/10.1007/s40071-017-0179-9

Etzel, M. R. (2004). Manufacture and use of dairy protein fractions. *Journal of Nutrition, 134*(4), 996S-1002S. https://doi.org/10.1093/jn/134.4.996S

FAO, Food and Agriculture Organization of the United Nations. (2020). *The State of World Fisheries and Aquaculture 2020*. Sustainability in action. Rome, Italy.

FAO, Food and Agriculture Organization of the United Nations. (2018). *The State of World Fisheries and Aquaculture 2018 - Meeting the Sustainable Development Goals*. Rome, Italy.

FAO, Food and Agriculture Organization of the United Nations. (2013). *Dietary protein quality evaluation in human nutrition*. Report of an FAO Expert Consultation. FAO food and nutrition paper 92. Rome, Italy.

FAO/WHO. (1991). *Protein quality evaluation. Report of joint FAO/WHO expert consultation.* FAO food and nutrition paper 51. Rome, Italy.

Gibson, E., Stacey, N., Sunderland, T. C. H., & Adhuri, D. S. (2020). Dietary diversity and fish consumption of mothers and their children in fisher households in Komodo District, Eastern Indonesia. *PLoS ONE, 15*(4), https://doi.org/10.1371/journal.pone.0230777

Gokoglu, N., Yerlikaya, P., & Cengiz, E. (2004). Effects of cooking methods on the proximate composition and mineral contents of rainbow trout (*Oncorhynchus mykiss*). *Food Chemistry, 84*(1), 19-22. https://doi.org/10.1016/S0308-8146(03)00161-4

Golden, C. D., Allison, E. H., Cheung, W. W. L., Dey, M. M., Halpern, B. S., McCauley, D. J., … Myers, S. S. (2016). Nutrition: Fall in fish catch threatens human health. *Nature, 534*, 317-320. https://doi.org/10.1038/534317a

Gram, L., & Dalgaard, P. (2002). Fish spoilage bacteria - Problems and solutions. *Current Opinion in Biotechnology, 13*, 262-266. https://doi.org/10.1016/S0958-1669(02)00309-9

Grantham-McGregor, S., Cheung, Y. B., Cueto, S., Glewwe, P., Richter, L., & Strupp, B. (2007). Developmental potential in the first 5 years for children in developing countries. *Lancet, 369*(9555), 60-70. https://doi.org/10.1016/S0140-6736(07)60032-4

Hansen, M., Thilsted, S.H., Sandström, B., Kongsbak, K., Larsen, T., Jensen, M., & Sørensen, S.S. (1998). Calcium absorption from small soft-boned fish. *Journal of Trace Elements in Medical Biology, 12*(3), 148-54. https://doi.org/10.1016/S0946-672X(98)80003-5

Huynh, M. D., & Kitts, D. D. (2009). Evaluating the nutritional quality of pacific fish species from fatty acid signatures. *Food Chemistry, 114*(3), 912-918. https://doi.org/10.1016/j.foodchem.2008.10.038

Islam, S., Bhowmik, S., Majumdar, P. R., Srzednicki, G., Rahman, M., & Hossain, M. A. (2021). The nutritional profile of wild, pond-, gher- and cage-cultured tilapia in Bangladesh. *Heliyon, 7*(5), e06968. https://doi.org/10.1016/j.heliyon.2021.e06968

Jabeen, F., & Chaudhry, A.S. (2011). Chemical compositions and fatty acid profiles of three freshwater fish species, *Food Chemistry, 125*(3), 991-996. https://doi.org/10.1016/j.foodchem.2010.09.103

Jim, F., Garamumhango, P., & Musara, C. (2017). Comparative analysis of the nutritional value of *Oreochromis niloticus* (Linnaeus), Nile tilapia, and meat from three different ecosystems. *Journal of Food Quality,* 6714347. https://doi.org/10.1155/2017/6714347

Junsomboon, J., & Jakmunee, J. (2011). Determination of Potassium, Sodium, and total alkalies in portland cement, fly ash, admixtures, and water of concrete by a simple flow injection flame photometric system. *Journal of automated methods and management in chemistry, 742656*, 9. https://doi.org/10.1155/2011/742656

Kabahenda, M. K., Amega, R., Okalany, E., Husken., S. M. C., & Heck, S. (2011). Protein and micronutrient composition of low-value fish products commonly marketed in the Lake Victoria region. *World Journal of Agricultural Science, 7*(5), 521-526.

Karapanagiotidis, I. T., Yakupitiyage, A., Little, D. C., Bell, M.V., & Mente, E. (2010). The nutritional value of lipids in various tropical aquatic animals from rice-fish farming systems in Northeast Thailand. *Journal of Food Composition and Analysis, 23*(1), 1-8. https://doi.org/10.1016/j.jfca.2009.08.001

Kim, J. D., & Lall, S. P. (2000) Amino acid composition of whole body tissue of Atlantic halibut (*Hippoglossus hippoglossus*), yellowtail flounder (*Pleuronectes ferruginea*) and Japanese flounder (*Paralichthys olivaceus*). *Aquaculture, 187,* 367-373. https://doi.org/10.1016/S0044-8486(00)00322-7

KNBS and ICF. (2023). *Kenya Demographic and Health Survey 2022.* Key Indicators Report. Nairobi, Kenya, and Rockville, Maryland, USA: KNBS and ICF.

KNBS (2020). *Economic Survey 2020.* Kenya National Bureau of Statistics. Retrieved from https://s3-eu-west-1.amazonaws.com/s3.sourceafrica.net/documents/119905/KNBS-Economic-Survey-

2020.pdf

Kuzu, S. (2005). *The effects of different fishing seasons on the fatty acids composition of red mullet (Mullus barbatus L., 1758) captured from Iskenderun Bay*. MSc Thesis, 39pp Cukurova University, Institute of Applied and Natural Sciences. Adana, Turkey.

Lall, S. P. (2021). The minerals. In R. W. Hardy (Ed.), *fish nutrition.* Elsevier/Academic Press: San Diego, CA, USA.

Li, G., Sinclair, A. J., & Li, D. (2011). Comparison of lipid content and fatty acid composition in the edible meat of wild and cultured freshwater and marine fish and shrimps from China. *Journal of agricultural and food chemistry, 59*(5), 1871-1881. https://doi.org/10.1021/jf104154q

Longley, C., Thilsted, S. H., Beveridge, M., Cole, S., Nyirenda, D. B., Heck, S., & Hother, A. L. (2014). The role of fish in the first 1,000 days in Zambia. IDS special collection. Brighton, UK: Institute of Development. Retrieved from http://opendocs.ids.ac.uk/ opendocs/handle/123456789/4384

Mischoulon, D., & Fava, M. (2002). Role of S-adenosyl-L-methionine in the treatment of depression: a review of the evidence. *American Journal of Clinical Nutrition, 76*(5), 1158S-1161S. https://doi.org/10.1093/ajcn/76.5.1158S

Mohamed, E. H. A., & Al-Sabahi, G. N. (2011). Fatty acids content and profile of common commercial Nile fishes in Sudan. *International Journal of Fisheries and Aquaculture, 3*(6), 99-104.

Mohanty, B. P., Mahanty, A., Ganguly, S., Mitra, T., Karunakaran, D., & Anandan, R. (2019). Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food Chemistry, 293,* 561-570. https://doi.org/10.1016/j.foodchem.2017.11.039

Mohanty, B. P., Mahanty, A., Ganguly, S., Sankar, T. V., Chakraborty, K., Rangasamy, A., & Sharma, A. P. (2014). Amino acid compositions of 27 food fishes and their importance in clinical nutrition. *Journal of Amino Acids,* 269797. https://doi.org/10.1155/2014/269797

Moses, S., Agbaji, E. B., Ajibola, V. O., & Gimba, C. E. (2018). Amino acid composition and proximate analysis in tilapia (*Oreochromis mossambicus*) fish from dams and rivers in Zamfara State, Nigeria. *Journal of Applied Sciences and Environmental Management, 22*(6), 899-905. https://doi.org/10.4314/jasem.v22i6.10

Munguti J., Obiero, K., Orina, P., Mirera D., Kyule D., Mwaluma J., … Hagiwara, A. (Eds) (2021). State of Aquaculture Report 2021: Towards Nutrition Sensitive Fish Food Production Systems. Techplus Media House, Nairobi, Kenya. pp. 190.

Nilima, S. R., & Kunda, N. G. (2014). Identification and quantification of amino acids from medicinally important plants by using high-performance thin-layer chromatography. *Journal of Liquid Chromatography and Related Technologies, 237*(15), 2197-2205. https://doi.org/10.1080/10826076.2013.828306

Oduor-Odote, P. M., Shitanda, D., Obiero, M., & Kituu, G. (2010). Drying characteristics and some quality attributes of *Rastrineobola argentea* (*omena*) and *Stolephorus delicatulus* (kimarawali). *African journal of food agriculture, nutrition and development, 10*(8), 2998-3014. https://doi.org/10.4314/ajfand.v10i8.60887

Roos, N., Thorseng, H., Chamnan, C., Larsen, T, Gondolf, U. H, Bukhave, K., & Thilsted, S. H. (2007). Iron content in common Cambodian fish species: Perspectives for dietary iron intake in poor, rural households. *Food Chemistry, 104*(3), 1226-1235. https://doi.org/10.1016/j.foodchem.2007.01.038

Ruiz-Capillas, C., & Moral, A. (2004) Free amino acids in the muscle of Norway lobster (*Nephrops novergicus, L.*) in controlled and modified atmospheres during chilled storage. *Food Chemistry, 86*(1), 85-91. https://doi.org/10.1016/j.foodchem.2003.08.019

Sharma, S., Shinde, S., & Verslues, P. E. (2013). Functional characterization of an ornithine cyclodeaminase-like protein of *Arabidopsis thaliana*. *BMC Plant Biology, 13,* 182. https://doi.org/10.1186/1471-2229-13-182

Sinanoglou, V. J., Proestos, C., Lantzouraki, D. Z., Calokerinos, A. C., & Miniadis-Meimaroglou, S. (2014). Lipid evaluation of farmed and wild meager (*Argyrosomus regius*). *European Journal of Lipid Science and Technology, 116,* 134-143. https://doi.org/10.1002/ejlt.201300346

Ssentongo, P., Ssentongo, A. E., Ba, D. M., Ericson, J. E., Na, M., Gao, X., … Schiff, S. J. (2021). Global, regional and national epidemiology and prevalence of child stunting, wasting and underweight in low-and middle-income countries, 2006-2018. S*cientific reports 2021, 11*(1), 1-12. https://doi.org/10.1038/s41598-021-84302-w

Suloma, A., Ogata, H. Y., Garibay, E. S., Chavez, D. R., & El-Haroun E. R. (2008). *Fatty acid composition of Nile tilapia Oreochromis niloticus muscles: A comparative study with commercially important Tropical freshwater fish in Philippines*. 8th International Symposium on Tilapia in Aquaculture.

Tagliabue, A., Bowie, A. R., Boyd, P. W., Buck, K. N., Johnson, K. S., & Saito, M. A. (2017). The integral role of iron in ocean biogeochemistry. *Nature, 543*(7643), 51-59. https://doi.org/10.1038/nature21058

Thilsted, S. H., Thorne-Lyman, A., Webb, P., Bogard, J. R., Subasinghe, R., Phillips, M. J., & Allison, E. H. (2016). Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. *Food Policy, 61*, 126-131. https://doi.org/10.1016/j.foodpol.2016.02.005

UNICEF, United Nations Children's Fund. (2019). *WHO. International bank for reconstruction and development/The World Bank*. Levels and trends in child malnutrition: Key findings of the 2019 edition of the joint child malnutrition estimates. Geneva: World Health Organization. Retrieved from https://www.who.int/nutgrowthdb/jme-2019-key-findings.pdf?ua=1

Usydus, Z., Szlinder-Richert, J., Adamczyk, M., & Szatkowska, U. (2011). Marine and farmed fish in the Polish market: Comparison of the nutritional value. *Food Chemistry, 126*(1), 78-84. https://doi.org/10.1016/j.foodchem.2010.10.080

Victora, C. G., Adair, L., Fall, C., Hallal, P. C., Martorell, R., Richter, L., & Sachdev, H. S (2008). Maternal and child undernutrition: Consequences for adult health and human capital. *The Lancet, 371,* 340-357. https://doi.org/10.1016/S0140-6736(07)61692-4

Vijayan, D. K., Jayarani, R., Singh, D. K., Chatterjee, N. S., Mathew, S., Mohanty B. P., & Anandan R. (2016). Comparative studies on nutrient profiling of two deep sea fish (*Neoepinnula orientalis* and *Chlorophthalmus corniger*) and brackish water fish (*Scatophagus argus*). *Journal of Basic Applied Zoology, 77,* 41-48. https://doi.org/10.1016/j.jobaz.2016.08.003

Wang, W., Wu, Z., Dai, Z., Yang, Y., Wang, J., & Wu, G. (2013). Glycine metabolism in animals and humans: Implications for nutrition and health. *Amino Acids, 45*(3), 463-477. https://doi.org/10.1007/s00726-013-1493-1

WorldFish. (2017). *Fish-based recipes.* Penang, Malysia: WorldFish. Booklet. pp. 35.

Wu, G. (2010). Functional amino acids in growth, reproduction, and health. *Advances in nutrition, 1*(1), 31-37. https://doi.org/10.3945/an.110.1008

Yiannopoulos, S., Frenaritou, H., Kokkinofta, R., Argyrides, R., & Akkelidou, D. (1999). *Cyprus food composition tables.* Nicosia: Ministry of Health State General Laboratory.

Zhang, X., Ning, X., He, X., Sun, X., Yu, X., Cheng, Y., ... Wu, Y. (2020). Fatty acid composition analyses of commercially important fish species from the Pearl River Estuary, China. *PLoS One, 15*(1), e0228276. https://doi.org/10.1371/journal.pone.0228276