FULafia Journal of Science & Technology
ISSN (print) 2449-0954 \ ISSN (online) 2636-4972
https://lafiascijournals.org.ng/index.php/fjst
Sponsored By TETFUND TERTIARY EDUCATION TRUST FUND
Manuscript => Received: Nov., 2025; Accepted: Dec., 2025; Published: Dec., 2025 https://doi.org/10.62050/fjst2025.v10n1.672

EFFECT OF TRADITIONAL PROCESSING METHODS ON THE LIPID PROFILES OF SELECTED FISH SPECIES FROM DOMA RIVER, NASARAWA STATE

Dung Dinah Ishaya[1,2]*, Matthew Olaleke Aremu[2], Sule Philip Ivom Ogah[2] and Folashade Habibat Omotehinwa[3]
[1]*Department of Chemistry, University of Jos, PMB 2084, Plateau State, Nigeria*
[2]*Department of Chemistry, Federal University of Lafia, PMB 146, Nasarawa State, Nigeria*
[3]*Department of Chemistry, Federal University of Health Sciences, Otukpo, PMB 145, Benue State, Nigeria*
*Corresponding email: ishayadinah1670@gmail.com

ABSTRACT
Fish is a vital source of high-quality protein and essential nutrients, but traditional processing methods can significantly influence its lipid composition and nutritional value. This study aims to evaluate the effect of smoking, sun-drying and salting-oven dry on the fatty acid and phospholipid compositions of selected three fish species *Hyperopisus bebe*, *Hepsetus odoe* and *Clarias gariepinus* from the Doma River. The sun-drying process lasted eight days under ambient sunlight (8 a.m. – 5 p.m.), smoking was conducted using hardwood-fired ovens at temperatures above 70 °C for two consecutive days, while salting involved preservation in a 1:4 salt-to-fish ratio prior to oven drying. Processed samples were ground into fine powder and analyzed. Fatty acid methyl esters (FAMEs) and phospholipids were analyzed using gas chromatography. The results revealed notable differences across processing techniques. Smoked samples retained higher levels of PUFA, particularly essential fatty acids such as DHA and EPA. Phosphatidylcholine was the most abundant phospholipid detected, with smoking maintaining higher overall phospholipid integrity compared to drying and sun-drying. Among the fatty acids, smoking yielded the highest PUFA/SFA ratio (32.25 %) indicating better nutritional quality. In conclusion, smoking appears to be the most effective method for preserving health-beneficial lipids in fish from the Doma River.

Keywords: Fishes, Phospholipids, Fatty acid, Doma River, Nasarawa State

INTRODUCTION
Fish are among the cheapest and most specific sources of animal protein, which effectively displaced beef as the primary animal protein source, but is highly costly and makes demands more than other low-priced animal sources of protein (Fakoya, 2015).

Fish plays a crucial role in the diet of millions of people worldwide, serving as an essential source of high-quality protein, essential fatty acids, vitamins, and minerals (Singh *et al*., 2025; Badoni *et al*., 2021). In many developing countries, including Nigeria, fish contributes significantly to food security and nutritional wellbeing, especially in rural and riverine communities where it is more affordable and accessible compared to other sources of animal protein such as meat and poultry (Reshi *et al*., 2025). Beyond its protein value, fish is an important supplier of lipids, (Ahmed *et al*., 2022) particularly polyunsaturated fatty acids (PUFAs) such as omega-3 and omega-6 fatty acids, which are known to support cardiovascular health, brain development, immune function, and the regulation of inflammatory processes (Khan *et al*., 2025; Mahendra *et al*., 2025). Consequently, the preservation of fish and the maintenance of its lipid quality are of paramount importance for both public health and food security.

Nigeria is endowed with vast inland water resources that support artisanal and small-scale fisheries (Karadas, 2024). One of such water body is the Doma River in Nasarawa State, which provides a livelihood for local fishing communities and supplies diverse fish species for consumption. Fish obtained from this river forms a staple food source for surrounding populations. However, fish is highly perishable due to its high water content, enzymatic activity, and susceptibility to microbial spoilage and lipid oxidation. Without proper preservation, freshly caught fish deteriorates rapidly, resulting in significant post-harvest losses, reduction in nutritional quality, and economic hardship for fishing households. To mitigate these challenges, traditional fish processing methods have been developed and employed across Nigerian communities for centuries.

Traditional processing methods, such as smoking, sun-drying, salting, and frying, remain popular in rural and semi-urban settings because they are cost-effective, culturally acceptable, and require minimal technological input (Tahiluddin *et al*., 2022). These methods not only extend the shelf life of fish but also influence its organoleptic properties, such as taste, aroma, and texture, which are often highly valued by consumers (Akintola & Fakoya, 2017). Smoking, for example, reduces moisture content while imparting a characteristic flavor, whereas sun-drying preserves fish by dehydration under natural sunlight. Salting inhibits microbial growth by creating osmotic pressure, and frying enhances taste while reducing moisture. Despite these advantages, traditional processing techniques have varying impacts on the nutritional composition of fish, especially its lipid profile.

Lipids are among the most sensitive nutrients in fish, prone to degradation during processing and storage (Tan *et al*., 2025). The composition of lipids in fish is critical not only for human nutrition but also as an indicator of product quality and stability. Processing methods can lead to lipid oxidation, hydrolysis, or polymerization, resulting in the loss of essential fatty acids, generation of free radicals, and formation of off-flavors. Oxidative deterioration of lipids may also reduce the bioavailability of important PUFAs, thereby compromising the health benefits associated with fish consumption (Desouky *et al*., 2025). In addition, changes in lipid composition during processing can influence the energy value of fish and its acceptability to consumers. The extent of these changes often depends on the fish species, environmental conditions, processing technique, and storage practices.

Several studies (Yashim *et al*., 2025; Birie *et al*., 2025; Nesa *et al*., 2025) across Nigeria and other regions have examined the effects of processing on the proximate composition of fish, including protein, lipids, and moisture contents. Findings generally indicate that while processing enhances shelf life, it often reduces lipid content due to leaching or oxidation. For instance, smoking has been reported to cause partial loss of PUFAs through exposure to heat and oxygen, whereas sun-drying may retain lipids but expose fish to environmental contaminants. Frying, on the other hand, may increase lipid content due to oil absorption but simultaneously degrade essential fatty acids. These alterations raise concerns about the nutritional implications for populations that rely heavily on processed fish as their main dietary source of essential fatty acids.

This study therefore aims to assess the effect of traditional fish processing methods on the lipid composition of selected fish species (Figure 1) Elephant fish (*Hyperopisus bebe*), African pike fish (*Hepsetus odoe*), and sharp tooth catfish (*Clarias gariepinus*) obtained from the Doma River, Nasarawa State. The specific objectives are to: (a) evaluate the fatty acid composition of processed fish samples of Elephant fish (*Hyperopisus bebe*), African pike fish (*Hepsetus odoe*), and sharptooth catfish (*Clarias gariepinus*) obtained from Doma River, Nasarawa State (b) identify the phospholipids content of processed fish samples of Elephant fish (*Hyperopisus bebe*), African pike fish (*Hepsetus odoe*), and sharptooth catfish (*Clarias gariepinus*) obtained from Doma River, Nasarawa State.

MATERIALS AND METHODS

Collection and Identification of Sample

Freshly caught fish species (*Hyperopisus bebe*, *Hepsetus odoe* and *Clarias gariepinus*) from Doma River by commercial fishermen were obtained in the month of July. All samples were collected in July due to the seasonal availability of *Hepsetus odoe*, which is rare during other months of the year and is commonly found only between July and October. With the help of a guide and a Technical Staff of the Fisheries Unit of the Zoology Department, Federal University of Lafia, the captured fish 1- or 2-h post-capture were identified on arrival at the laboratory.

Sample Preparation

In this study, a minimum of 3 individual of each fish species *Hyperopisus bebe*, *Hepsetus* and *Clarias gariepinus* making a total of nine collected fish samples were analysed for each of the three traditional methods, gutted, and filleted (Figure 1). The fishes were carefully washed with clean and cool tap water. Scales and viscera were removed and again washed with clean tap water to remove blood. Rinsing of the fish with distilled water was made. The collected samples later underwent sun drying, smoking and salting. Samples were then grinded using mortar and pestle then further blended separately into fine powder using Kenwood food blender. The powdered portions were put in a plastic container in the refrigerator at -4 °C prior to use. The nine fish samples were further divided into two lots, to analyse fatty acid and phospholipid composition.

Figure 1: Samples of fish species studied: *Hyperopisus bebe, Hepsetus* and *Clarias gariepinus*

Sun Drying Methods

For sun drying process, the three cleaned species were cut into two equal halves. Cut was made along longitudinal axis of the fish body from mouth to tail but the two halves of the body remained attached in the tail fin region. During sun drying procedure, this is to ensure exposure to ambient sunlight at daytime (8 a.m. to 5 p.m.) for 8 days (due to the climatic conditions in drying period, moisture content of air will comparatively less (26 %). During this period, the fishes were covered with mosquito net to prevent insects and other pests. The fishes during the sundry processing were turned over from time to time to ensure homogenous drying. After drying, the sun-dried samples were packaged with polythene plastic bag and stored in dry condition for further analysis.

Smoking Method

The smoked fish analyses were carried out using the methods described in (AOAC, 2012), the cleaned whole fresh *Hyperopisus bebe, Hepsetus odoe* and *Clarias gariepinus* were used. The fresh fish was spread out on smoking trays after washing without salting. The trays were then stacked on smoking oven fired with hard wood, at temperatures greater than 70 °C. Fish was continuously smoked until a dry smoked fish is obtained, this process continues for the period of two days for 7 h per day. Fish samples during smoking were turned at intervals so as to ensure a homogenous drying.

Salting and Oven Dry Method

The fish was mixed with salt and preserved in the ratio of 1:4 (Salt: Fish) in a shallow box. More salt was required in the thick parts of the fish than in the thin parts. Salt is applied to the cut portion and rubbed over the surface. Salted fish were arranged in alternate layers. Small amount of salt is added at the bottom, the quantity increased as the height increases. At the top more quantity of salt was added. The fish were kept in layers for 3 h and then oven dried at the temperature 45 °C for 4 h *Hepsetus odoe* and *Clarias gariepinus* were oven dried while *Hyperopisus bebe,* had a higher time frame of 6 h.

Reagent and Apparatus

- Petroleum ether
- Condenser Soxhlet extraction unit
- Oven
- 250 ml capacity boiling flask
- Desiccator
- Weighing balance
- Thimble
- Heating mantle
- No 4 filter paper
- Glass wool

Crude Fat Extraction

All the nine individual species of fish underwent Soxhlet extraction for 5 h, using AOAC Official Method 920.39 (A), 2006. 250 ml capacity extracting flask was dried in the oven at 105 °C, transferred to the desiccator to cool to laboratory temperature and the weight of the flask was measured. 2.5 g of the sample was weighed into the labelled porous thimble.

200 ml of petroleum ether was measured and then added to the dried 250 ml capacity flask. The covered porous thimble with the sample was placed in the condenser of the Soxhlet extractor arrangement that had been assembled. The sample was extracted for five h.

The porous thimble was removed with care and the petroleum ether in the top container (tube) was collected for recycling reuse. The extraction flask was removed from the heating mantle arrangement when it was almost free of petroleum ether. The extraction flask with the oil was oven dried at 105 °C for 1 h. The flask containing the dried oil was cooled in the desiccator and the weight of the cooled flask with dried oil was measured.

Fatty Acid Methyl Ester Analysis

Fifty milligram (50 mg) of the extracted fat content of the sample was saponified (esterified) for five min at 95 °C with 3.4 ml of the 0.5M KOH in dry methanol using Aremu *et al*. (2019) method. The mixture was neutralized by using 0.7M HCl. 3 ml of the 14 % boron trifluoride in methanol was added. The mixture was heated for 5 min at the temperature of 90 °C to achieve complete methylation process. The Fatty Acid Methyl Esters were thrice extracted from the mixture with redistilled n-hexane. The content was concentrated to 1 ml for gas chromatography analysis and 1 µl was injected into the injection port of GC.

GC Conditions for FAME Analysis were of the standard GC System of HP 6890 powered with HP ChemStation Rev. A 09.01 (1206) software. he injection mode was split injection and split Ratio of 20:1, using carrier gas Nitrogen with an inlet temperature 250 ° the column dimensions of 30 m × 0.25 mm × 0.25 µm and oven temperature program

• Initial: 60 °C
• First ramp: 12 °C/min for 20 min, hold 2 min
• Second ramp: 15 °C/min for 3 min, hold 8 min

Having a detector conditions flame ionization detector with temperature: 320 °C, hydrogen pressure 22 psi and compressed Air: 35 psi.

Phospholipid Analysis

The phospholipid content of the processed fish samples was determined using the methods described by Aremu *et al*. (2016) and Aremu *et al*. (2021). 0.1 g of the extracted oil was added to the test tubes. To ensure complete dryness of the sample, it was subjected to heating in an oven at 100 °C for 30 min. The extraction solvent was added in the ratio of chloroform-methanol (2:1 v/v), ensuring thorough mixing. The solution was allowed to settle before being filtered to remove any undissolved particles. The solvent was evaporated using a rotary evaporator, and the extracted phospholipids were subjected to further purification. To remove neutral lipids, the sample was treated with acetone and left to stand for 20 min before centrifugation at 1000 rpm for 10 min. The purified phospholipids extract was then subjected to gas chromatography analysis using pulse flame photometric detection. The chromatographic column used was a capillary column, and the carrier gas was helium. The temperature of the gas chromatograph was programmed to rise gradually from an initial temperature to allow for proper separation of the phospholipids components.

RESULTS AND DISCUSSION

The Fatty Acid Composition

The fatty acid composition of the three traditional processing methods in Tables 1, 2 and 3 showed distinct variations in both the type and concentration of lipids retained in the fish species. Sun drying preserved a more balanced fatty acid profile, with high levels of oleic acid (28.3 %) and palmitic acid (28.4 %) was also high in Aman (2024) study. Omega-3 fatty acids, particularly DHA, are vital for maintaining brain and

cardiovascular health. This supports the idea that fish, even after processing, can still provide significant health benefits due to the retention of DHA (Fard *et al*., 2018). Studies by Palabiyik *et al*. (2025) and Fard *et al*. (2018) report similar profiles of fatty acid composition in processed fish species, with palmitic acid, oleic acid, and DHA being the most prominent fatty acids. In contrast, smoking resulted in very low concentrations of oleic acid (0.08 %) and linoleic acid (0.41 %), but higher amounts of myristoleic acid (11.7 %) and DHA (11.2 %). DHA is often preserved during conventional fish processing (Pegu *et al*., 2025). The maintained high level of DHA is vital for its anti-inflammatory and heart-healthy properties. However, some PUFAs like linoleic acid and linolenic acid showed considerable variability, potentially due to oxidative damage during processing (especially in high-heat methods), as seen in research (Singh *et al*., 2025). The nutritional Implications on Omega-3 fatty acids like DHA are critical for brain health and cardiovascular benefits. The constant presence of DHA across all samples is a positive nutritional factor, as it may contribute to the functional health of the processed fish. This is consistent with findings of (Olgunoglu & Olgunoglu, 2025), who suggested that high DHA levels are beneficial in processed fish for heart health. The omega-6/omega-3 ratio appears balanced, particularly with the presence of linoleic acid and linolenic acid, although future studies could focus on optimizing processing methods to preserve these essential fatty acids. A study by (Olgunoglu & Olgunoglu, 2025) indicated that achieving a favorable omega-6/omega-3 ratio can enhance the health benefits of fish. Similar findings were reported by Pegu *et al*. (2025), where palmitoleic acid constituted 0.39 % in Nandus nandus fish specie in India. Although smoking retained certain beneficial long-chain fatty acids, the wide fluctuations in concentration (high CV values) suggested reduced stability in the lipid profile. The high presence of palmitic acid is consistent with many fish species and could be related to storage or processing methods (Hu *et al*., 2008).

Salting and oven drying yielded the highest concentration of DHA (13.0 %) and palmitic acid (27.8 %), as shown by the very high coefficients of variation. Palmitic acid is higher in Salted *Hyperopisus bebe* (30.5062) which is consistent with with previous studies that have reported palmitic acid as a major SFA in fish species (Pegu *et al*., 2025; Islam *et al*., 2018; Danielli *et al*., 2019). Stearic acid (C18:0) also contributed significantly, with values ranging between 9.603 and 10.001 %. Stearic acid is known to have a neutral effect on blood cholesterol compared to other SFAs (Kris-Etherton *et al*., 2019). Oleic acid is widely recognized for its cardiovascular benefits and is a major component of healthy diets such as the Mediterranean diet (Rasul *et al*., 2021). Overall, sun drying produced the best result in terms of both nutritional quality (retaining higher levels of oleic and polyunsaturated fatty acids) and compositional stability. Smoking was intermediate, preserving DHA but at the expense of oleic and linoleic acids, while salting/oven drying, despite yielding the highest DHA content, showed the poorest result due to its high variability and unstable fatty acid distribution.

Table 1: Fatty acid composition analysis for smoked fish species

Fatty Acid (carbon group)	A1	D1	G1	Mean	SD	CV%
Caproic Acid (C6:0)	0.0	0.0008	0.0016	0.0008	0.0011	141.42
Caprylic Acid (C8:0)	0.0	0.0	0.0	0.0	0.0	NaN
Capric Acid (C10:0)	0.0	0.0	0.0	0.0	0.0	NaN
Lauric Acid (C12:0)	0.5912	0.5213	0.5562	0.5562	0.0489	8.79
Myristic Acid (C14:0)	2.4871	1.9873	2.415	2.2964	1.1172	48.65
Myristoleic Acid (C14:1)	28.4095	1.1024	5.6083	11.7067	11.8107	100.89
Pentadecanoic Acid (C15:0)	3.3219	1.8943	1.3714	2.1959	2.6592	121.1
Palmitic Acid (C16:0)	27.4562	11.7204	13.5214	17.566	10.6387	60.56
Palmitoleic Acid (C16:1)	3.3884	2.2221	2.2567	2.6224	0.4864	18.55
Stearic Acid (C18:0)	2.5454	1.0021	1.8513	1.7996	2.1012	116.76
Oleic Acid (C18:1)	0.0515	0.1582	0.0298	0.0798	0.0901	112.92
Linoleic Acid (C18:2)	0.1524	0.7823	0.2899	0.4082	0.4227	103.55
Linolenic Acid (C18:3)	0.3159	1.4547	1.2193	0.9966	1.2542	125.84
Arachidic Acid (C20:0)	7.8412	2.3352	3.23	4.4688	6.0786	136.02
Gondoic Acid (C20:1)	2.6547	0.5903	0.1021	1.1157	1.5112	135.45
Eicosadienoic Acid (C20:2)	0.0824	0.0152	0.0598	0.0525	0.0289	54.97
Behenic Acid (C22:0)	0.0285	0.0083	0.0256	0.0208	0.0111	53.37
Erucic Acid (C22:1)	0.0254	0.1251	0.0442	0.0649	0.0529	81.54
Docosadienoic Acid (C22:2)	0.0071	0.0063	0.0055	0.0063	0.0008	12.85
Lignoceric Acid (C24:0)	17.8221	5.6123	5.2344	9.5563	6.7554	70.69
Nervonic Acid (C24:1)	0.0475	0.0475	0.0475	0.0475	0.0	0.0
Docosahexaenoic Acid (C22:6)	11.2286	11.2286	11.2286	11.2286	0.0	0.0

A1: Smoked *Hyperopisus bebe*, **D1:** Smoked *Hepsetus odeo*, **G1:** Smoked *Clarias gariepinus*,
SD: standard deviation, **CV:** coefficient of variation

Table 2: Fatty acid composition analysis for sun drying

Fatty Acid (Carbon Group)	B1	E1	H1	Mean	SD	CV (%)
Caproic acid (C6:0)	0.0	0.0	0.0	0.0	0.0	0.0
Caprylic acid (C8:0)	0.0	0.0	0.0	0.0	0.0	0.0
Capric acid (C10:0)	0.0	0.0	0.0	0.0	0.0	0.0
Lauric acid (C12:0)	0.591	0.656	0.559	0.627	0.063	10.0
Myristic acid (C14:0)	2.918	3.131	3.017	3.447	0.762	22.1
Palmitic acid (C16:0)	28.409	29.915	25.456	28.424	1.826	6.4
Palmitoleic acid (C16:1)	5.937	5.657	5.245	5.696	0.301	5.3
Stearic acid (C18:0)	2.528	2.514	2.546	2.388	0.273	11.4
Oleic acid (C18:1)	28.495	28.998	25.933	28.335	1.74	6.1
Linoleic acid (C18:2)	5.365	5.647	5.194	5.465	0.212	3.9
Linolenic acid (C18:3)	2.086	2.173	1.985	2.16	0.166	7.7
Arachidic acid (C20:0)	0.103	0.108	0.103	0.092	0.027	29.3
Eicosenoic acid (C20:1)	0.014	0.015	0.014	0.013	0.003	23.1
Arachidonic acid (C20:4)	2.667	2.951	2.95	2.74	0.273	10.0
Behenic acid (C22:0)	0.039	0.033	0.04	0.036	0.004	11.1
Erucic acid (C22:1)	0.013	0.014	0.025	0.019	0.006	30.5
Docosadienoic acid (C22:2)	0.034	0.034	0.034	0.034	0.001	2.9
Lignoceric acid (C24:0)	0.005	0.005	0.005	0.005	0.0	0.0
Nervonic acid (C24:1)	0.005	0.005	0.005	0.005	0.0	0.0
Docosahexaenoic acid (C22:6)	11.229	12.948	13.418	12.124	1.124	9.3

B1: Sundried *Hyperopisus bebe*, **E1:** Sundried *Hepsetus odeo*, **H1:** Sundried *Clarias gariepinus*,
SD: standard deviation, **CV:** coefficient of variation

Table 3 Fatty acid composition analysis for salted and oven dry

Fatty Acid (carbon group)	C1	F 2	I 3	Mean	SD	CV%
Caproic Acid (C6:0)	0.0	0.0	0.0	0.0	0.0	N/A
Caprylic Acid (C8:0)	0.0	0.0	0.0	0.0	0.0	N/A
Capric Acid (C10:0)	0.0	0.8848	0.4058	0.4302	0.4429	102.96
Lauric Acid (C12:0)	0.6364	0.8173	0.7545	0.7361	0.0917	12.47
Myristic Acid (C14:0)	0.9609	1.0376	1.0313	1.0099	0.0425	4.21
Myristoleic Acid (C14:1)	6.3049	26.9869	26.0939	19.7952	11.6915	59.06
Palmitic Acid (C16:0)	30.5062	25.8865	26.9615	27.7848	2.4173	8.70
Palmitoleic Acid (C16:1)	4.0690	1.1229	2.4949	2.5623	1.4742	57.54
Stearic Acid (C18:0)	1.9305	2.0951	2.0915	2.0390	0.0939	4.61
Oleic Acid (C18:1)	2.3078	3.0501	2.7021	2.686	0.3714	13.82
Linoleic Acid (C18:2)	0.0151	0.0027	0.7041	0.2406	0.4014	166.80
Linolenic Acid (C18:3)	0.0050	0.0133	0.0431	0.0205	0.0200	97.52
Arachidic Acid (C20:0)	1.1970	0.0114	0.0484	0.4189	0.6740	160.87
Gadoleic Acid (C20:1)	2.4443	0.0221	0.0228	0.8297	1.3982	168.52
Eicosadienoic Acid (C20:2)	0.3700	0.0055	0.0444	0.1399	0.2008	142.99
Arachidonic Acid (C20:4)	0.0125	0.0040	0.0035	0.0064	0.0050	74.84
Behenic Acid (C22:0)	0.0457	0.0041	0.0052	0.0183	0.0236	128.96
Erucic Acid (C22:1)	0.0045	0.0040	0.0039	0.0041	0.0003	7.25
Docosahexaenoic Acid (C22:6)	13.4621	13.6278	11.9274	13.0057	0.9376	7.21

C1: Salted *Hyperopisus bebe*, **F1:** Salted *Hepsetus odeo*, **I1:** Salted *Clarias gariepinus*, **SD:** standard deviation, **CV:** coefficient of variation

The Quality Parameters of Fatty Acid Composition

The quality parameters of fatty acid composition showed significant differences across the three processing methods. Smoked fish samples (Table 4) were characterized by a high proportion of saturated fatty acids (SFA, 47.45 %). High SFA levels have been linked to increased cholesterol levels and cardiovascular risks (Huang *et al*., 2020) alongside moderate levels of monounsaturated fatty acids (MUFA, 24.22 %). MUFA have been associated with positive impacts on heart health (Mohanty *et al*., 2016) and polyunsaturated fatty acids (PUFA, 43.41 %), PUFAs, particularly omega-3 fatty acids, are crucial for reducing the risk of cardiovascular diseases and enhancing cognitive function (Pegu *et al*., 2023). They also had the highest levels of DHA (13.36 %) compared to the other methods, making smoking beneficial for retaining long-chain omega-3 fatty acids. DHA is essential for cognitive health and has beneficial effects on the cardiovascular system (Mohanty *et al*., 2016). The levels of DHA and EPA (Eicosapentaenoic acid) in these fish species are within the recommended range for heart health. With an average DHA content of 13.36 %, the fish could contribute to cardiovascular and brain health when included in a balanced diet (WHO, 2022).

In contrast, sun-dried fish (Table 5) demonstrated a more favorable fatty acid balance, with the highest mean MUFA content (30.36 %), though Higher MUFA levels are commonly associated with cardiovascular health benefits, as observed in fish like salmon (Lutfi *et al*., 2023). The unsaturated fatty acid (UFA, 60.76 %) was equally high in all fish samples. This suggests that the fish samples generally have a favorable balance of unsaturated fats. High unsaturated fat content is typically linked to a reduced risk of cardiovascular diseases (Huang *et al*., 2020). The MUFA/SFA ratio (0.81) was higher than that of smoked fish (0.51), suggesting better lipid quality for cardiovascular health. Similar findings have been reported in other fish species, where SFA levels ranged from 30-45 % (Reshi *et al*., 2021). However, sun-dried samples had very uneven retention of DHA and EPA across species, with DHA ranging from 0.00 to 13.42 % and EPA from 0.00 to 11.39 %, as reflected in their very high CV values (87.99 and 172.07 % respectively). This variability indicates that sun drying may inconsistently preserve essential fatty acids depending on species and conditions.

Salted and oven-dried fish (Table 6) showed the lowest mean SFA (30.0 %) and retained reasonable levels of MUFA (26.06 %) and PUFA (24.31 %). The presence of MUFAs is considered beneficial for heart health (Berge *et al*., 2020). The PUFA content ranged from 14.86 % in Sample C1 to 32.4 % in Sample I1, with a mean of 24.31 %. The higher PUFA levels in Sample I1 are noteworthy, as PUFAs, particularly omega-3 fatty acids, have well-documented health benefits (Dhanasiri *et al*., 2025). They also had the most consistent essential fatty acid (EFA) values, with a CV of only 2.03 %, suggesting greater stability than the other methods. EFAs are crucial for various physiological functions and contribute to maintaining overall health (Lutfi *et al*., 2023). However, DHA (9.55 %) and EPA (3.72 %) levels were lower compared to smoked samples, meaning this method may compromise some health-promoting omega-3 fatty acids. Taken together, the best results were observed in smoked fish for preserving DHA, and in sun-dried fish for overall unsaturated fatty acid balance, while the worst performance was in salted/oven-dried fish, which showed lower PUFA content and reduced omega-3 levels despite its stability.

Table 4: Quality parameters of fatty acid composition of smoked fish samples

Parameter	A1	D1	G1	Mean	SD	CV (%)
SFA	55.01	39.23	48.13	47.45	7.91	16.67
MUFA	23.81	16.61	32.22	24.22	7.81	32.26
PUFA	34.76	51.05	44.42	43.41	8.19	18.87
Total UFA	58.57	67.66	76.64	67.63	9.04	13.36
MUFA/SFA	0.43	0.42	0.67	0.51	0.14	27.4
PUFA/SFA	0.63	1.3	0.92	0.95	0.34	35.25
EFA	30.3	41.44	37.23	36.32	5.62	15.48
DHA	14.53	14.33	11.23	13.36	1.85	13.86
EPA	1.22	0.04	0.14	0.47	0.65	140.04

A1: Smoked *Hyperopisus bebe*, **D1:** Smoked *Hepsetus odeo*, **G1:** Smoked *Clarias gariepinus*, **SD:** standard deviation, **CV:** coefficient of variation

Table 5: Quality parameters of fatty acid composition of sun dried samples

Parameters	B1	E1	H1	Mean	SD	CV (%)
Total SFA	34.54	42.56	38.24	38.45	4.01	10.44
Total MUFA	42.76	26.37	21.96	30.36	10.96	36.10
Total PUFA	31.97	32.35	26.89	30.40	3.05	10.03
Total UFA	74.72	58.72	48.85	60.76	13.06	21.49
MUSA/SFA	1.24	0.62	0.57	0.81	0.37	46.08
PUFA/SFA	0.93	0.76	0.70	0.80	0.12	14.98
EFA	7.19	18.13	15.21	13.51	5.66	41.93
DHA	0.00	13.42	10.90	8.11	7.13	87.99
EPA	0.00	11.39	0.05	3.81	6.56	172.07

B1: Sundried *Hyperopisus bebe*, **E1:** Sundried *Hepsetus odeo*, **H1:** Sundried *Clarias gariepinus*, **SD:** standard deviation, **CV:** coefficient of variation

Table 6: Quality parameters of fatty acid composition of salted and oven dry fish samples

Parameters	C1	F1	I1	Mean	SD	CV (%)
SFA	18.11	36.64	35.26	30.0	10.14	33.81
MUFA	24.88	33.62	19.68	26.06	7.0	26.86
PUFA	14.86	25.66	32.4	24.31	8.78	36.12
UFA	39.74	59.28	52.08	50.37	9.8	19.47
MUFA/SFA	1.37	0.92	0.56	0.95	0.41	42.88
PUFA/SFA	0.82	0.7	0.92	0.81	0.11	13.71
EFA	10.89	10.96	10.54	10.8	0.22	2.03
DHA	3.09	13.63	11.93	9.55	5.63	58.97
EPA	0.36	1.0	9.79	3.72	5.41	145.53

C1: Salted *Hyperopisus bebe*, **F1:** Salted *Hepsetus odeo*, **I2:** Salted *Clarias gariepinus*, **SD:** standard deviation, **CV:** coefficient of variation

Phospholipid composition of processed fish

The phospholipid composition of the processed fish samples revealed differences in both concentration and stability across the three methods. Smoked fish had the highest mean levels (Table 7) of phosphatidylethanolamine (141.07 mg/g) and phosphatidylcholine (532.72 mg/g), both of which are essential for maintaining membrane integrity, neurotransmission, and lipid metabolism (Liu *et al*., 2025). These high concentrations are advantageous because phosphatidylcholine supports liver function and fat transport, while phosphatidylethanolamine plays a role in cell signaling and membrane curvature (Donghia *et al*., 2025). The low coefficients of variation (<4 %) in smoked samples also indicate stability, suggesting that smoking preserved these key phospholipids effectively without major degradation.

Sun-dried fish samples generally had slightly lower concentrations of the same phospholipids compared to smoked fish, but they remained within beneficial ranges. For instance, phosphatidylcholine (527.22 mg/g) and phosphatidylethanolamine (122.51 mg/g) were still abundant, while sphingomyelin and phosphatidylinositol were slightly reduced compared to smoked fish (Table 8). While this reduction may indicate some lipid loss due to prolonged drying exposure, the advantage is that sun drying produced consistent values with very low variation, ensuring stability in nutrient composition. From a nutritional standpoint, the presence of sphingomyelin is beneficial for brain development and myelin sheath formation, while phosphatidylinositol supports insulin signalling

and lipid transport (Grabon *et al*., 2019). The disadvantage, however, is that sun drying markedly reduced Di phosphatidylglycerol (6.23 mg/g), which is important for mitochondrial function and energy metabolism (Li *et al*., 2025). Comparing these results with other studies, such as those by Zeisel *et al*. (1986), which reported similar phosphatidylcholine and sphingomyelin concentrations in human tissues, highlights the biological relevance of these phospholipids.

Salted and oven-dried fish showed the highest variability in phospholipid composition, with elevated levels of phosphatidylcholine (543.39 mg/g) and phosphatidylserine (33.58 mg/g), but wide fluctuations across replicates (CV up to 35 %) (Table 9). This instability suggests that while salting can preserve some beneficial phospholipids, it may also induce oxidative stress or uneven lipid degradation. The relatively high phosphatidylserine is advantageous, as it enhances memory, cognitive function, and stress response. However, the disadvantage is the inconsistent retention of diphosphatidylglycerol and phosphatidylinositol, which are vital for mitochondrial energy production and metabolic regulation. Thus, while all methods retained important phospholipids, smoking produced the most stable and nutritionally rich profile, sun drying preserved moderate but consistent levels, and salting/oven drying yielded the least reliable results despite some elevated values.

Table 7: Phospholipid composition for smoked fish

Phospholipid	A2	D2	G2	Mean	SD	CV %
Phosphatidic acid	35.209	36.017	34.958	35.394	0.553	1.563
Phosphatidylethanolamine	144.141	140.795	138.266	141.068	2.947	2.089
Lysohosphatidylcholine	17.775	16.539	17.254	17.189	0.62	3.609
Phosphatidylcholine	531.604	551.148	515.421	532.724	17.89	3.358
Phosphatidylserine	30.7	32.851	32.15	31.9	1.097	3.438
Sphingomyelin	34.884	35.088	34.825	34.932	0.138	0.395
Phosphatidylinositol	29.139	29.516	29.852	29.502	0.357	1.21
Diphosphatidylglycerol	12.013	11.222	11.434	11.557	0.41	3.544

A2: Smoked *Hyperopisus bebe*, **D2:** Smoked *Hepsetus odeo*, **G2:** Smoked *Clarias gariepinus*,
SD: standard deviation, **CV:** coefficient of variation

Table 8: Phospholipid composition for sun dry fish

Phospholipid	B2	E2	H2	Mean	SD	CV %
Phosphatidic acid	30.235	30.929	30.02	30.394	0.475	1.563
Phosphatidylethanolamine	125.178	122.271	120.076	122.508	2.559	2.089
Lysohosphatidylcholine	15.756	14.661	15.294	15.237	0.55	3.609
Phosphatidylcholine	526.11	545.451	510.094	527.218	17.705	3.358
Phosphatidylserine	29.685	31.764	31.086	30.845	1.06	3.438
Sphingomyelin	30.045	30.22	29.993	30.086	0.119	0.395
Phosphatidylinositol	23.045	23.344	23.61	23.333	0.282	1.21
Diphosphatidylglycerol	6.471	6.044	6.159	6.225	0.221	3.544

B2: Sundried *Hyperopisus bebe*, **E2:** Sundried *Hepsetus odeo*, **H2:** Sundried *Clarias gariepinus*,
SD: standard deviation, **CV:** coefficient of variation

Table 9: Phospholipid composition for salted and oven dried fish sample

Phospholipid	C2	F2	I2	Mean	SD	CV %
Phosphatidic acid	35.656	30.619	40.694	35.656	5.038	14.128
Phosphatidylethanolamine	137.925	119.779	141.736	133.147	11.733	8.812
Lysohosphatidylcholine	17.372	15.399	20.054	17.608	2.336	13.269
Phosphatidylcholine	526.411	520.97	582.783	543.388	34.225	6.299
Phosphatidylserine	31.794	30.742	38.216	33.584	4.046	12.047
Sphingomyelin	36.127	31.115	40.651	35.964	4.77	13.263
Phosphatidylinositol	30.486	24.111	28.238	27.612	3.233	11.71
Diphosphatidylglycerol	11.589	6.242	13.12	10.317	3.611	35.002

C2: Salted *Hyperopisus bebe*, **F2:** Salted *Hepsetus odeo*, **I2:** Salted *Clarias gariepinus*, **SD:** standard deviation, **CV:** coefficient of variation.

The phospholipid content of the processed fish samples was determined using the methods described by Aremu *et al*. (2016) and Aremu *et al*. (2021). 0.1 g of the extracted oil was added to the test tubes. To ensure complete dryness of the sample, it was subjected to heating in an oven at 100 °C for 30 min. The extraction solvent was added in the ratio of chloroform-methanol (2:1 v/v), ensuring thorough mixing. The solution was allowed to settle before being filtered to remove any undissolved particles. The solvent was evaporated using

a rotary evaporator, and the extracted phospholipids were subjected to further purification. To remove neutral lipids, the sample was treated with acetone and left to stand for 20 min before centrifugation at 1000 rpm for 10 min. The purified phospholipids extract was then subjected to gas chromatography analysis using pulse flame photometric detection. The chromatographic column used was a capillary column, and the carrier gas was helium. The temperature of the gas chromatograph was programmed to rise gradually from an initial temperature to allow for proper separation of the phospholipid's components.

CONCLUSION

Traditional processing methods of fishes have shown that Smoking preserved the highest levels of DHA and produced stable phospholipid fractions, making it the most nutritionally beneficial for brain and cardiovascular health. Sun drying retained a more balanced profile of unsaturated fatty acids, especially oleic and linoleic acids, with high stability, though it showed inconsistent preservation of essential fatty acids like DHA and EPA. Salting and oven drying, while yielding the highest phosphatidylcholine and some omega-3 fractions, was the least stable with wide variability and reduced polyunsaturated fatty acid content. Overall, smoking emerged as the best method for maintaining essential lipids, sun drying offered better balance and consistency, while salting/oven drying was least favourable nutritionally.

Recommendations

From the findings of this study on the effects of traditional processing methods on the lipid quality of *Hyperopisus bebe*, *Hepsetus odoe*, and *Clarias gariepinus* from Doma River, the following recommendations are proposed:

- ✓ Smoking should be adopted as the most suitable traditional method for processing fish, as it helps to maintain better lipid quality and improves the nutritional and functional properties of fish lipids, thereby reducing cardiovascular health risks. Sun-drying practices should be improved through the adoption of solar-assisted drying systems or mechanical dryers to minimize oxidation and loss of essential fatty acids due to exposure to direct sunlight. Salting techniques should be standardized to control salt concentration and duration, as excessive salting may alter lipid composition and reduce overall nutritional quality.
- ✓ There is a need for training and enlightenment programs for local fish processors on improved traditional and semi-modern fish preservation methods to enhance product quality, shelf life, and consumer safety.
- ✓ Further research should be conducted on the effects of these processing methods on other biochemical parameters such as protein and mineral content, as well as on the sensory and storage characteristics of the processed fish.
- ✓ The Federal and State Governments, through relevant agricultural and fisheries agencies, should provide necessary support and modern processing equipment to rural fish processors to ensure high-quality fish products that meet both nutritional and commercial standards.

Conflict of interest: The authors declare no conflict of interest reported in this work.

REFERENCES

Abraha, B., Admassu, H. and Mahmud, A. (2018). Effect of processing methods on nutritional and physico-chemical composition of fish: A review. *MOJ Food Processing & Techn.*, 6(4), 376–382. https://doi.org/10.15406/mojfpt.2018.06.00191

Ahmed, I., Jan, K., Fatma, S. and Dawood, M. A. (2022). Muscle proximate composition of various food fish species and their nutritional significance: A review. *Journal of Animal Physiology and Animal Nutrition*, 106(3), 690–719. https://doi.org/10.1111/jpn.13711

Akintola, S. L. and Fakoya, K. A. (2017). Small-scale fisheries in the context of traditional post-harvest practice and the quest for food and nutritional security in Nigeria. *Agric. & Food Security*, 6(1), 34. https://doi.org/10.1186/s40066-017-0110-z

AOAC (2012). *Official Methods of Analysis* (19th ed., Method 969.33). AOAC International.

Akpomie, T. M., Nmagbo, P. G., Onwuka, J. C. and Augustine, A. U. (2024). Determination and modeling of heavy metal concentrations in River Rutu and Doma Dam in Doma LGA, Nasarawa State. *FULafia IAC Book of Proceedings*, 1–11. https://doi.org/10.62050/faic2024.bop24.001

Aremu, M. O., Ajine, P. L., Omosebi, M. O., Baba, N. M., Onwuka, J. C., Audu, S. S. and Suhaibu, B. S. (2021). Lipid profiles and health-promoting uses of carrot (*Daucus carota* L.) and cucumber (*Cucumis sativus* L.). *Int. J. of Sci.*, 10(7), 22–29. https://doi.org/10.18483/ijSci.2485

Aremu, M. O., Ibrahim, H. and Aremu, S. O. (2016). Lipid composition of black variety of raw and boiled tigernut (*Cyperus esculentus* L.) grown in North-East Nigeria. *Pakistan Journal of Nutrition*, 15(5), 427–438. https://doi.org/10.3923/pjn.2016.427.438

Aremu, M. O., Waziri, A. A., Faleye, F. J., Magomya, A. M. and Okpaegbe, U. C. (2019). Lipid profiles of bitter melon (*Momordica charantia*) fruit and ebony tree (*Diospyros mespiliformis*) fruit pulp. *Bangladesh Journal of Science and Industrial Research*, 54(4), 367–374. https://doi.org/10.3329/bjsir.v54i4.44571

Badoni, P., Nazir, I., Aier, M., Maity, P. B., Samanta, S. and Das, A. (2021). Significant role of fish nutrients with special emphasis to essential fatty acid in human nutrition. *Int. J. of Current Microbio. and Applied Sci.*, 10(2), 2034–2046. https://doi.org/10.20546/ijcmas.2021.1002.243

Berger, A., Jones, P. J. H. and Abumweis, S. S. (2014). Plant sterols: Factors affecting their efficacy and safety as functional food ingredients. *Lipids in Health and Disease*, 3(5).

Birie, S., Mingist, M., Kibret, M., Atlog, T. Y., Geremew, H. and Getnet, B. (2025). Effect of salt concentrations on the proximate composition, microbial load, and sensory attributes of dry-salted species. *Food Science & Nutrition*, 13(9). https://doi.org/10.1002/fsn3.70867

Danielli, M. M., Tayz, F. R., Wande, M. B., Rozilaine, A. P. G. de F., Camila de S. P., Pete, B. F., Sandra, M. and Xisto, R. de S. (2019). Fatty acid profiles and cholesterol content of five species of pacu-pevas from the Pantanal region of Mato Grosso, Brazil. *Journal of Food Composition and Analysis*, 83(2), 103283. https://doi.org/10.1016/j.jfca.2019.103283

Desouky, H. E., Sayed, N. M., Abasubong, K. P. and others. (2025). Nutritional and physiological effects of high-fat diets in finfish: Effects on growth, immunity, lipid metabolism, and intestinal health: A review. *Journal of Comparative Physiology B*, 195, 415–437. https://doi.org/10.1007/s00360-025-01626-z

Dhanasiri, A. K. S. (2025). Performance, skin and gut health, and fillet quality in Arctic-farmed Atlantic salmon—Effects of increased EPA+DHA and organic zinc source in feed. *SSRN*. https://doi.org/10.2139/ssrn.5185067

Donghia, D., Baldassari, S., Drava, G., Ailuno, G. and Caviglioli, G. (2025). Insights on natural membrane characterization for the rational design of biomimetic drug delivery systems. *Pharmaceutics*, 17(7), 841. https://doi.org/10.3390/pharmaceutics17070841

Fakoya, K. A. (2015). Strategic prioritization for sustainable fisheries production in Nigeria. In *An Agendum for National Development* (pp. 585–608). Center for Human Security, Olusegun Obasanjo Presidential Library.

Ghasemi Fard, S., Wang, F., Sinclair, A. J., Elliott, G. and Turchini, G. M. (2018). How does high DHA fish oil affect health? A systematic review of evidence. *Critical Reviews in Food Science and Nutrition*, 59(11), 1684–1727. https://doi.org/10.1080/10408398.2018.1425978

Grabon, A., Bankaitis, V. A. and McDermott, M. I. (2019). The interface between phosphatidylinositol transfer protein function and phosphoinositide signaling in higher eukaryotes. *Journal of Lipid Research*, 60(2), 242–268. https://doi.org/10.1194/jlr.R089730

Hassan, A. M. (2024). Physical, chemical and microbiological changes associated with dry-fish. In A. Ranjan and S. A. Shanmugam (Eds.), *Dry Fish: A Global Perspective on Nutr. Security and Econ. Sustainab*. (pp. 145–162). Springer. https://doi.org/10.1007/978-3-031-62462-9_8

Hu, Q., Sommerfeld, M., Jarvis, E., Ghirardi, M., Posewitz, M., Seibert, M. and Darzins, A. (2008). Microalgal triacylglycerols as feedstocks for biofuel production: Perspectives and advances. *Plant Journal*, 54(4), 621–639.

Huang, J. and Sathivel, S. (2020). Purifying salmon oil using adsorption, neutralization, and a combined neutralization and adsorption process. *Journal of Food Engineering*, *96*(1), 51–58.

Islam, R., Islam, M. D. M., Shoeb, M. and Nahar, N. (2018). Fatty acid compositions in marine fish samples of Bangladesh. *Journal of Nutrition & Food Sciences*, 8(4), 723. https://doi.org/10.4172/2155-9600.1000723

Karadaş, N. F. (2024). Effects of fish on human health and nutrient content. *Agro Science Journal of Igdir University*, 2(1), 32–38.

Khan, S. K., Dutta, J., Ahmad, I., Rather, M. A., Badroo, I. A. and Taj, S. (2025). Fish protein: A nutritional solution for global food security. In J. K. Sundaray, M. A. Rather, I. Ahmad, & A. Amin (Eds.), *Food Security, Nutrition and Sustainability through Aquaculture Technologies* (pp. 621–640). Springer. https://doi.org/10.1007/978-3-031-75830-0_27

Kris-Etherton, P. M., Richter, C. K., Bowen, K. J., Skulas-Ray, A. C., Jackson, K. H., Petersen, K. S. and Harris, W. S. (2019). Recent clinical trials shed new light on the cardiovascular benefits of omega-3 fatty acids. *Methodist DeBakey Cardiovascular Journal*, 15(3), 171–178.

Li, Z.-Z., Xiao, H.-X., Hu, J.-J., Xie, W., Wang, Z.-X., Pan, Y.-P., Li, X.-H. and Yu, X.-F. (2025). The mechanisms and implications of cardiolipin in the regulation of cell death. *Cell Biochemistry and Function*. https://doi.org/10.1002/cbf.70066

Liu, Q., Ni, X., Chen, C., Xu, J., Pei, E., Yang, A., Xu, M., Wang, X., Fu, S., & Yu, R. (2025). Exploring the impact of dietary EPA/DHA supplementation on lipid metabolism of *Tenebrio molitor* larvae. *Insects*, 16(10), 1007. https://doi.org/10.3390/insects16101007

Lutfi, E., Berge, G. M., Bæverfjord, G. (2023). Increasing dietary levels of the n-3 long-chain PUFA, EPA and DHA, improves the growth, welfare, robustness and fillet quality of Atlantic salmon in sea cages. *British J. of Nutr.*, 129(1), 10–28. https://doi.org/10.1017/S0007114522000642

Mohanty, B. P. and Singh, S. D. (2018). Fish and human nutrition. In *Aquaculture in India* (pp. 561–581). Narendra Publishing House.

Nesa, J., Dey, A., Faisal, M. (2025). Nutritional variation in muscle type, body segments, and cooking effects of four commercially important marine fish (*Carangoides malabaricus*, *Scomberoides commersonnianus*, *Dussumieria acuta*, and *Sardinella fimbriata*) of the Bay of Bengal, Bangladesh. *Food Science and Technology International*. Advance online publication. https://doi.org/10.1177/10820132251343355

Olgunoglu, M. P., & Olgunoglu, I. A. (2025). Assessment of micro–macro elements and fatty acid profiles in Turkish salmon fillets during traditional hot smoking: Implications for human health risks. *Quality Assurance and Safety of Crops & Foods*, 17(2), 200–212.

Pal, M., Bekele, A., Rebuma, T. and Ragasa, T. (2025). Contribution of fisheries to food security in Ethiopia: A comprehensive review. *AUCTORES Journal of Nutrition and Food Processing.* https://doi.org/10.31579/2637-8914/297

Palabiyik, A. A. and Palabiyik, E. (2025). Effects of omega-3 fatty acids (n-3 PUFAs) on cardiovascular and muscular health across various populations: A review of supplementation benefits. *Nutrire*, 50(1), 73. https://doi.org/10.1186/s41110-025-00381-z

Pegu, A. and Baruah, C. (2025). Amino acid and fatty acid profile of five small indigenous fish species (SIS) from Assam, India. *Journal of Applied and Natural Science*, 17(2), 582–591. https://doi.org/10.31018/jans.v17i2.6255

Pegu, A., Kalita, R., Das, P. and Baruah, C. (2023). Nutritional composition of small indigenous species of fishes of Northeast India: A systematic review. *Journal of Applied and Natural Science*, *15*(2), 649–662. https://doi.org/10.31018/jans.v15i2.4490

Rasul, M. G., Yuan, C. and Shah, A. K. M. (2021). Chemical composition and nutritional value of dried fish in Bangladesh. *Egyptian Journal of Aquatic Biology and Fisheries*, 25(4), 379–399. https://doi.org/10.21608/ejabf.2021.189666

Reshi, Q. M., Ahmad, I., Nabi, N., Ahmed, I. and Sidiq, M. (2025). Global food insecurity: Role of fishes to compensate food insecurity and nutritional demand. In J. K. Sundaray, M. A. Rather, I. Ahmad, & A. Amin (Eds.), *Food Security, Nutrition and Sustainability through Aquaculture Technologies* (pp. 101–120). Springer. https://doi.org/10.1007/978-3-031-75830-0_5

Singh, R. D., Arambam, K., Singh, A. M. and Singh, S. K. (2025). Health and nutritional benefits of fish as human food. In J. K. Sundaray, M. A. Rather, I. Ahmad, & A. Amin (Eds.), *Food Security, Nutrition and Sustainability through Aquaculture Technologies* (pp. 41–60). Springer. https://doi.org/10.1007/978-3-031-75830-0_3

Tahiluddin, A. B. and Kadak, A. E. (2022). Traditional fish processing techniques applied in the Philippines and Turkey. *Menba Kastamonu University Faculty of Fisheries Journal*, 8(1), 50–58.

Tan, K., Huang, L. and Luo, C. (2025). Effectiveness of low-temperature storage on lipid nutritional quality of fish: A meta-analysis. *Aquaculture International*, 33, 473–489. https://doi.org/10.1007/s10499-025-02131-4

World Health Organization (2022). *Obesity and overweight.* https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Yashim, E. Y., Dambo, A. and Adole, A. (2025). Effect of some processing methods on the proximate composition of some frozen marine fishes. *Journal of Science Research and Reviews*, 2(1), 127–132. https://doi.org/10.70882/josrar.2025.v2i1.54

Zeisel, S. H., Char, D. and Sheard, N. F. (1986). Choline, phosphatidylcholine and sphingomyelin in human and bovine milk and infant formulas. *Journal of Nutrition*, 116(1), 50–58. https://doi.org/10.1093/jn/116.1.50

Zhang, H., Zhao, H., Zhang, Y., Shen, Y., Jin, J., Jin, Q. and Wang, X. (2018). Characterization of positional distribution of fatty acids and triacylglycerol molecular compositions of marine fish oils rich in omega-3 polyunsaturated fatty acids. *BioMed Research International.* https://doi.org/10.1155/2018/4562742