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Nutrient Quality and Microbial Load of Different Preservative Methods of Hake Fish (*Merluccius merluccius*) Sold at Eyenkorin Market, Ilorin, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author ATM carried out the market survey, performed the statistical analysis and wrote the first draft of the manuscript. Author KAI wrote the protocol, reviewed and edited the manuscript. Author POB-U designed the study and reviewed the manuscript. All authors read and approved the final manuscript.

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Abstract

The processing and preservative methods significantly impact nutrient quality of hake fish (*Merluccius merluccius*). This survey research was conducted to investigate the nutrient quality and microbial load of Chilled, smoked and fried *M. merluccius* fish sold at Eyenkorin Market, Ilorin Kwara State. The three

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samples were bought from different market vendors, kept separately in ziplock nylon bags and transported to University of Ilorin Central Research Laboratory for analysis. The fish were separately kept in freezer and analysed at day zero and seventh. Highest moisture values (77.43±0.01%; 78.04±0.01%) were recorded in chilled fish at day zero and seventh of freezed condition. At both days, highest protein values (67.73±0.02%; 66.92±0.25%) were recorded from fried fish while least (17.37±0.03%;15.23±0.06%) from chilled fish. Smoked and fried fish retained higher concentrations of amino acid composition, reflecting enhanced protein quality. Microbial evaluation showed that viable counts in chilled fish increased markedly from 35.0×10^5 CFU/g at day zero to 118.0×10^5 CFU/g at day seventh of freezed storage condition. Smoked and fried fish maintained comparatively lower microbial loads at both days. Smoking and frying reduce moisture content, microbial proliferation and preserve essential nutrients, thereby enhanced shelf stability and nutrient concentration. The *M. merluccius* fish sold at Eyenkorin Market is nutritious and healthy for consumption because it meet the nutritional demands for proper development and good health. Additionally, fried fish is recommended to consumed because of its high nutritional values and minimal microbial loads.

Keywords: Nutrition; Merluccius merluccius; microbial analysis; fish preservation; microbial loads.

1. Introduction

Eyenkorin Market is located in Ilorin, the capital city of Kwara State, Nigeria. Ilorin lies within the North-Central geopolitical zone of Nigeria, between latitude 8°28′N and longitude 4°33′E. Kwara State shares boundaries with Niger State to the North, Kogi State to the East, Oyo and Ekiti States to the South, and the Republic of Benin to the west (Aberoumand, 2014). Eyenkorin is a peri-urban settlement along the Ilorin–Ogbomosho expressway and serves as a major trading point for chilled and processed fish in the region. Eyenkorin market was selected for this survey research because it is a central hub where different food items, fresh, chilled alongside smoked and fried hake fish (*Merluccius merluccius*) and other fish products are sold to consumers and retailers. The lower price, high volume of *M. merluccius* sales and the mixture of different preservative methods practiced in this market make it a suitable location for assessing nutritional quality and microbial load of *M. merluccius* fish products under typical handling and storage conditions (Magbanua & Ragaza, 2024).

European hake (*Merluccius merluccius)* is a demersal species, member of merlucciidae family and often found in the northern and southern seas at 50–600 m depth (Brandts *et al*., 2025). Its affordability and geographical distribution make it a high-value food product mostly consumed in Nigeria (Iyorah, 2024; Sullivan *et al*, 2020). European hake (*M. merluccius*) is classified as a lean fish, indicating it has a comparatively low fat content relative to other fish varieties which makes it an excellent choice for anyone seeking to have a delectable dinner while managing their fat consumption. It is essential to recognise that not all fats are detrimental to health. The human body needs healthy fats such as monounsaturated and polyunsaturated fats to perform daily activities (Brennan, 2018).

The omega-3 fatty acids found in *M. merluccius*, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are essential for sustaining brain health and enhancing cognitive performance (Serefko *et al*., 2024). Research indicates that sufficient consumption of omega-3 fatty acids throughout gestation and early infancy might facilitate brain development in newborns and children. Omega-3 fatty acids present in *M. merluccius*, are linked to enhanced mood and a decrease in symptoms associated with sadness and anxiety (Magbanua & Ragaza, 2024; Granero & Guillazo-Blanch, 2025).

M. merluccius is an excellent source of selenium, an important trace mineral vital for maintaining a robust immune system. Selenium enhances the immune system by facilitating the production and maintenance of optimal antioxidant levels, which neutralise detrimental free radicals, safeguard cellular integrity, and mitigate inflammation. Selenium enhances immune system functionality and reduces inflammation, hence improving its efficacy in combating infections, viruses, and other pathogens. European hake (*M. merluccius*) fish is an excellent source of vitamin B12, or cobalamin, which is crucial for red blood cell synthesis and the optimal functioning of the brain system. Vitamin B12 is mostly present in animal-derived foods, with *M. merluccius* being one of the several marine sources that provide this essential ingredient.Erythrocytes facilitate the transmoked fisher of oxygen from the lungs to the body and eliminate carbondioxide.Vitamin B12 is

essential for DNA synthesis, which is required for the production of new red blood cells (Dike-Ndudim et al., 2014).

However, *M. merluccius* similar to other fish products are highly perishable if not properly preserved (Mendes *et al*., 2021). Fish start deterioration process immediately they leave their environment after catch due to various biochemical and microbial breakdown as well as the environmental factors such as the catching region, season, and handling conditions post mortem which contribute to the short shelf-life of hake fillets (Sullivan *et al*, 2020) and it is estimated that 30 – 50 % of all harvested fish are lost in the supply chain (Garcia *et al*., 2015).

Fish are susceptible to microbial contamination throughout several phases of processing, handling, and storage, which presents considerable health risks for consumers, resulting in food borne illnesses and other health-related issues (Musuka, 2023). The consumption of *M. merluccius* is prevalent in Eyenkorin metropolis owing to its availability, affordability for lower-income individuals, and nutritional benefits that enhance a balanced diet for customers (Moustafa & Assem, 2024). The spoilage of fish poses a substantial issue in the seafood business, directly affecting the quality and safety of the product (Salama & Chennaoui, 2024). Fish processing and preservation aim to guarantee that fish is delivered to customers in a safe and edible state (Ali *et al*., 2022). This research was conducted to assess the nutritional quality and safety of chilled, smoked and fried *M. merluccius* fish sold at Eyenkorin Market, Ilorin, Kwara State, Nigeria.

2. Materials and Methods

2.1 Purchase of the Fish Samples

Three different preserved *M. merluccius* (chilled, smoked and fried) fish were bought from three different vendor at Eiyenkorin Market, kept separately in ziplock nylon bag and transported to the University of Ilorin Central Research Laboratory for nutrient composition and microbial load analysis. The fish were separately kept in freezer and analysed at day zero and day seventh. The analysis was done in triplicates at day zero and day seventh of freezed storage condition.

2.2 Nutrient Composition of the Fish Samples

The nutrient composition of the three different preserved *M. merluccius* (chilled, smoked and fried) fish, bought at Eiyenkorin Market, Ilorin, Kwara State, were chemically analysed for proximate, fatty acid and amino acid composition at day zero of procurement and day seventh of freezed storage condition following a standard method of Omitoyin *et al*., (2025).

2.3 Serial Dilution of Sample

Serial dilution was performed for preparation of microbial count of each fish samples. Approximately one gram of each sample was serially diluted with 5ml of potassium buffer saline solution using syringe. The serial 10-fold dilution was prepared in 5ml dilution tubes for each of the samples, of which the first bottle containing the prepared sample and 9 sterile tubes containing 4.5ml of phosphate buffer solution each were placed on the rack. 0.1ml of the processed sample was mixed with 4.5ml of the first bottle of buffer solution, which produced the 10-1 dilution. Then 0.1ml from the first bottle was mixed with the second bottle solution and 0.1ml from the second to the third and serially in the same order until the last bottle, which is the 10 - 9 diluted sample.

2.4 Bacterial Count of Sample

Bacterial count was done as described by (Oghenochuko *et al*., (2023). The samples obtained from serial dilution were inoculated on nutrient agar medium in petri dishes for microbial count. Firstly, 0.1ml was taken from the 10-1 dilution sample and seeded at a triangular distance on a nutrient agar media. This process is repeated until the 10-9 dilution sample, giving 9 inoculated plate with each plate from a dilution. After incubation at 37℃ for 24 hours three round shaped colonies from the nutrient agar medium were observed on the dish which were counted meticulously to determine the microbial load count.

2.5 Statistical Analysis

The proximate, amino, fatty acid and microbial were done in triplicates and data generated were statistically analysed using One-way ANOVA and descriptive statistics on the Statistical Package for Social Sciences version

(SPSS) version 20. The Duncan Multiple Range Test (DMRT) for post hoc analysis was expressed as mean ± SD (standard deviation). The significance level adopted was 95% ($P \leq 0.05$).

3. Results

3.1 Proximate Composition of Chilled, Smoked and Fried *Merluccius merluccius* Fish at Day Zero and Day Seventh of Freezed Storage Condition

The proximate composition of chilled, smoked and fried fish bought at Eyenkorin market used for this study was represented in Table 1. The moisture of chilled fish (77.43±0.01%) was higher than the values recorded in smoked (15.10±0.0%) and fried (10.24±0.01%) fish samples at day zero of procurement. The moisture values increased across the treatment at day seventh of freezed storage. Smoked fish recorded least moisture value (11.82±0.00%) at day seventh. The reduction in moisture value in both smoked and fried fish indicated that smoking and frying processes are effective in lowering the body fluids, thereby enhanced the shelf stability. There was a significant difference ($p<0.05$) in moisture values across the treatments at both days. Crude fiber was low (<1%) in all the three samples. Chilled fish showed a decline from 0.41±0.01% to 0.36±0.00% over the storage period. Smoked and fried fish maintained relatively higher values with minimal variation at day seventh. Although crude fiber contributed little to fish composition, its relative stability in smoked and fried fish suggested minimal alteration during storage. Ash values varied significantly among treatments. Chilled fish had the least ash value of 1.24±0.01% at day zero, but increased to 2.16±0.02% at day seventh of freezed condition. Smoked fish had moderate values (5.32±0.01%; 5.12± 0.01%), while fried fish consistently recorded the highest ash levels (6.36 ± 0.01%; 6.49±0.03%) at both days. The higher ash values in both smoked and fried fish might be attributed to concentration effects resulting from moisture reduction, while the relative stability across storage days suggests mineral content was largely preserved.

Chilled fish showed moderate reduction in lipid value from 2.62±0.01% at day zero to 2.44±0.01% at day seventh of freezed condition. The slight reduction in lipid levels during storage may be linked to oxidative deterioration. Fried fish recorded highest lipid value of 13.15±0.03% at day zero, reflecting oil absorption during frying, and decreased slightly to 12.86±0.02% at day seventh of freezed condition. Smoked fish showed a slight increase in lipid value from 12.24±0.01% at day zero to 12.55± 0.02% at day seventh of freezed condition. The higher lipid values in processed (smoked and fried) fish samples, particularly fried fish, enhances energy density but also predisposes them to rancidity during prolonged storage, significant difference was observed in lipid values across the treatments. Lipid values of fried fish at both days are significantly difference ($p<0.05$) among others.

Protein value was significantly higher in processed fish (fried and smoked) compared to chilled fish. At day zero, fried fish (67.73±0.02%) and smoked fish (66.65±15.13%) had higher protein concentrations than chilled fish (17.37± 0.03%). At day seventh, protein value decreased slightly in smoked fish (64.17± 0.03%) and fried fish (66.92± 0.03%), while chilled fish recorded a sharper decline (15.23±0.06%). The protein values of fried fish at both days are significantly higher ($p<0.05$) than the values of chilled and smoked fish. The high protein value in smoked and fried fish is partly due to moisture loss during smoking and frying processes, which concentrated protein. However, the gradual decline during storage suggests protein denaturation or degradation, possibly due to enzymatic or microbial activity. Carbohydrate level was generally low across treatments. Chilled fish showed an increased from 0.92±0.06% at day zero to 1.76±0.08% at day seventh of freezed storage condition, while smoked fish rose from 1.06±0.02% to 1.88± 0.02%. Fried fish, however, exhibited a slight reduction from 1.67±0.01% at day zero to 1.62± 0.44% at day seventh of freezed storage condition. Carbohydrate value of smoked fish at day seventh of freezed condition was significantly difference ($p<0.05$) compared to other values at both days. These variations may be due to compositional adjustments as a result of changes in other proximate components during storage (Table 1).

3.2 Fatty Acid Profile of Chilled, Smoked and Fried *Merluccius merluccius* Fish at Day Zero

The fatty acid profiles of chilled, smoked and fried *Merluccius merluccius* fish samples at day zero is presented in Table 2**.** The predominant saturated fatty acids identified were myristic acid (C14:0), palmitic acid (C16:0) and stearic acid (C18:0). Among these, palmitic acid recorded the highest proportion across the samples, ranging from 22.70±0.18% in chilled fish to 24.52±0.20% in fried fish; followed by stearic acid with value ranging from 4.63±0.12% (chilled fish) to 5.79±0.05% (fried fish). Myristic acid was the least abundant, varying

Table 1. Proximate composition of chilled, smoked and fried *Merluccius merluccius* fish at day zero and seventh of freezed storage condition

Days	Fish Sample	Moisture Content (%)	Crude Fiber (%)	Ash Content (%)	Lipid (%)	Protein (%)	Carbohydrate (%)
Zero	Chilled	77.43 ± 0.01^{a}	0.41 ± 0.01^{c}	1.24 ± 0.01^{d}	2.62 ± 0.01^{d}	17.37 ± 0.03^{e}	0.92 ± 0.06^{e}
	Smoked	15.10 ± 0.00^{b}	0.72 ± 0.01^{b}	5.32 ± 0.01^{b}	12.24 ± 0.01^{c}	66.65 ± 15.13^{c}	1.06 ± 0.02^{d}
	Fried	10.24 ± 0.01^{c}	0.83 ± 0.02^{a}	6.36 ± 0.01^{a}	13.15 ± 0.03^{a}	67.73 ± 0.02^{a}	1.67 ± 0.01^{c}
Seventh	Chilled	78.04 ± 0.01^{a}	0.36 ± 0.01^{c}	2.16 ± 0.02^{c}	2.44 ± 0.01^{d}	15.23 ± 0.06^{f}	1.76 ± 0.08^{b}
	Smoked	15.53 ± 0.00^{b}	0.74 ± 0.01^{b}	5.12 ± 0.01^{b}	12.55 ± 0.02^{b}	64.17 ± 0.03^{d}	1.88 ± 0.02^{a}
	Fried	11.82 ± 0.01^{c}	0.78 ± 0.01^{a}	6.49 ± 0.03^{a}	12.86 ± 0.02^{b}	66.92 ± 0.25^{b}	1.62 ± 0.44^{c}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

Table 2. Fatty acid profile of chilled, smoked and fried *M. merluccius* fish at day zero

Fish Sample	Saturated fatty acids (SFA) (%)			Monounsaturated fatty acids (MUFA) (%)		Polyunsaturated fatty acids (PUFA) (%)			
	Myristic acid (C14:0)	Palmitic acid (C16:0)	Stearic acid (C18:0)	Palmitoleic acid (C16:1)	Oleic acid (C18:1n - 9)	Linoleic acid (C18:2n – 6)	Arachidonic acid (C20:4n – 6)	Eicosapentaenoic acid (C20:6n – 3)	Docosahexaenoic acid (C22:6n – 3)
Chilled	3.66±0.12^{c}	22.70±0.18^{c}	4.63±0.12^{c}	8.26±0.13^{c}	29.01±0.30^{a}	2.51±0.03^{c}	1.19±0.04^{c}	14.01±0.28^{b}	10.03±0.28^{c}
Smoked	3.99±0.10^{b}	24.32±0.06^{b}	5.45±0.09^{b}	9.18±0.04^{b}	25.25±0.03^{c}	2.77±0.05^{b}	1.29±0.03^{b}	14.30±0.04^{a}	10.38±0.04^{b}
Fried	4.32±0.04^{a}	24.52±0.21^{a}	5.79±0.05^{a}	9.80±0.042^{a}	25.78±0.13^{b}	2.90±0.04^{a}	1.50±0.04^{a}	14.39±0.48^{a}	10.79±0.04^{a}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

from 3.66±0.12% (chilled fish) to 4.32±0.04% (fried fish). There was a significant difference ($p<0.05$) among the saturated fatty acid values of chilled fish at day zero of procurement. Processing techniques (smoking and frying) significantly increased saturated fatty acids content, particularly palmitic and stearic acids, compared to chilled fish. This increase may be attributed to lipid oxidation and thermal changes in fatty acid structure during processing. Palmitoleic acid (C16:1) and oleic acid (C18:1n-9) were the major monounsaturated fatty acids (MUFA) detected. Oleic acid was predominant, accounting for 29.01±0.30% in chilled fish, but decreased slightly in both smoked (25.25±0.03%) and fried fish (25.78±0.13%) samples. Palmitoleic acid also increased with processing, rising from 8.26±0.13% in chilled fish to 9.80±0.04% in fried fish. There was a significant differences ($p<0.05$) among the monounsaturated fatty acids values across the treatments. These results indicated that processing method, particularly frying process enhanced palmitoleic acid concentration but may reduce oleic acid levels, possibly due to thermal degradation.

Polyunsaturated fatty acids detected included linoleic acid (C18:2n-6), arachidonic acid (C20:4n-6), eicosapentaenoic acid (EPA, C20:6n-3), and docosahexaenoic acid (DHA, C22:6n-3). Among these, EPA and DHA were the most abundant, contributing significantly to the nutritional quality of *M. merluccius* fish sold at Eyenkorin market. EPA values ranged from 14.01±0.23% (chilled fish) to 14.39±0.48% (fried fish), while DHA ranged from 10.03±0.28% (chilled fish) to 10.79±0.04% (fried fish). Both EPA and DHA showed slight increase in smoked and fried fish samples compared to chilled fish, indicating that processing methods might helped retained or even concentrate long-chain omega-3 fatty acids. Linoleic acid and arachidonic acid were present in smaller quantities, with linoleic acid ranging from 2.51±0.03% (chilled fish) to 2.90±0.04% (fried fish); and arachidonic acid from 1.19±0.04% (chilled fish) to 1.50±0.04% (fried fish). The eicosapentaenoic acid (C20:6n – 3) values were significantly difference ($p<0.05$) in all the treatment compared to polyunsaturated fatty acids detected. Their relative stability across treatments suggests minimal losses during smoking and frying process (Table 2).

3.3 Fatty Acid Profiles of Chilled, Smoked and Fried *M. merluccius* Fish at Day Seventh of Freezed Condition

The fatty acid composition of chilled, smoked, and fried *M. merluccius* fish sold at Eyenkorin market and preserved in freezed condition for seventh day is presented in Table 3. The major saturated fatty acids (SFA) identified were myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0). Among these, palmitic acid dominated the SFA fraction, increasing from 15.13±0.34% in chilled fish to 21.36±0.12±0.34% in smoked fish and 22.95±0.16% in fried fish. Stearic acid ranged from 2.68±0.05% (chilled fish) to 5.08±0.02% (fried fish), while myristic acid also increased significantly across the treatments (3.09±0.02% in chilled fish to 4.07±0.04% in fried fish). There was a significant difference ($p<0.05$) among the saturated fatty acid profiles at day seventh of freezed storage condition. This result indicated that processing and storage promote an elevation of saturated fatty acids, particularly palmitic and stearic acids, possibly due to oxidative breakdown of unsaturated fatty acids, which leads to an apparent concentration of more stable saturated lipids.

The predominant Monounsaturated Fatty Acids (MUFA) were palmitoleic acid (C16:1) and oleic acid (C18:1n-9). Palmitoleic acid increased progressively from 6.45±0.11% in chilled fish to 8.64±0.13% in fried fish, while oleic acid rose from 18.10±0.33% in chilled fish to 23.63±0.06% in fried fish. There was a significant difference ($p<0.05$) among the monounsaturated fatty acid profiles of *M. merluccius* fish sold at Eyenkorin market at day seventh of freezed storage condition. This finding demonstrated that processing and storage enhance MUFA content, with frying fish showing the most significant increase. The higher MUFA levels, especially oleic acid, are nutritionally desirable because they have been linked to cardiovascular health benefits. The polyunsaturated fatty acids (PUFAs) identified were linoleic acid (C18:2n-6), arachidonic acid (C20:4n-6), eicosapentaenoic acid (EPA, C20:6n-3), and docosahexaenoic acid (DHA, C22:6n-3). EPA and DHA were the dominant PUFAs, with EPA increasing from 11.67±0.254% (chilled fish) to 13.61±0.04% (fried fish), while DHA rose from 7.50±0.04% in chilled fish to 9.20±0.04% in fried fish. This increase suggested that omega-3 fatty acids remained stable and concentrated during processing and short-term storage, highlighting *M. merluccius* fish as a valuable source of essential fatty acids. Linoleic acid values rose slightly from 2.04±0.03% (chilled fish) to 2.43±0.03% (fried fish), while arachidonic acid showed an increased from 1.02±0.01% in chilled fish to 1.38±0.01% in fried fish. These moderate increments reflected the preservation of essential omega-6 fatty acid despite thermal processing (Table 3).

3.4 Essential Amino Acid Profiles of Chilled, Smoked and Fried *M. merluccius* Fish at Day Zero and Seventh of Freezed Condition

The essential amino acid profiles of chilled, smoked and fried *M. merluccius* fish sold at Eyenkorin market at day zero and seventh of chilled storage is presented in Table 4. Lysine was highest in fried fish (4.75±0.03 g/100g) at day zero, followed by smoked fish (4.47±0.13 g/100g), while chilled fish had the least lysine value (3.65±0.42 g/100g). At seventh day, lysine level declined significantly in chilled fish (2.47±0.12 g/100g), while smoked and fried fish maintained relatively high levels (4.21±0.15 g/100g and 4.55±0.04 g/100g, respectively). This suggests that thermal processing enhanced lysine retention, whereas storage negatively affects lysine stability in chilled fish. Histidine content followed a similar trend of lysine. At day zero, fried fish (3.44±0.04 g/100g) and smoked fish (3.19±0.03 g/100g) recorded higher values than chilled fish (2.73±0.02 g/100g); while at day seventh of freezed condition, histidine dropped sharply in chilled fish (1.98±0.05 g/100g) but remained high in smoked fish (3.08±0.04 g/100g) and fried fish (3.27±0.02 g/100g). This indicates better preservation of histidine in processed fish compared to chilled fish.

Tryptophan levels were relatively low across all the fish samples. At day zero, fried fish had the highest concentration (0.40±0.02 g/100g), followed by smoked fish (0.34±0.01 g/100g) and chilled fish (0.26±0.01 g/100g). At day seventh of freezed condition, tryptophan decreased in all the fish samples, with chilled fish showing the least value (0.21±0.01 g/100g). The decline during storage reflects the susceptibility of tryptophan to oxidative degradation. Threonine ranged from 1.70±0.02 g/100g in chilled fish to 2.14±0.03 g/100g in fried fish at day zero. At day seventh, threonine declined in chilled fish (1.20±0.04 g/100g) but was better retained in smoked fish (1.90±0.03 g/100g) and fried fish (2.02±0.04 g/100g). This demonstrates that processing improves threonine stability relative to chilled fish. At day zero, valine was higher in smoked fish (4.70±0.03 g/100g) and fried fish (4.77±0.01 g/100g) compared to chilled fish (4.32±0.04 g/100g). At day seventh, valine value in chilled fish dropped significantly to 3.39±0.02 g/100g, while smoked fish (4.32±0.08 g/100g) and fried fish (4.26±0.06 g/100g) retained higher levels, showing that smoking and frying reduced valine losses during storage.

Methionine values increased slightly with processing techniques (2.04±0.04 g/100g in chilled fish versus 2.29±0.11 g/100g in smoked fish and 2.53±0.39 g/100g in fried fish) at day zero. At day seventh of condition, methionine dropped in chilled fish (1.56±0.04 g/100g), while smoked fish (2.46±0.12 g/100g) and fried fish (2.50±0.19 g/100g) maintained higher levels. This suggests that methionine stability is enhanced by smoking and frying methods. Isoleucine was recorded lowest in chilled fish (2.15±0.04 g/100g) and highest in fried fish (2.77±0.06 g/100g) at day zero. At day seventh of freezed condition, isoleucine value declined in chilled fish to 2.04±0.04 g/100g, while smoked fish and fried fish retained higher levels (2.26±0.05 g/100g and 2.58±0.05 g/100g, respectively). Again, processing methods demonstrated a protective effect against amino acid degradation.

Leucine was the most abundant essential amino acid across the samples, ranging from 5.74±0.04 g/100g in chilled fish to 6.52±0.04 g/100g in fried fish at day zero. At day seventh, leucine decreased to 4.93±0.12 g/100g in chilled fish, while smoked fish (6.15±0.08 g/100g) and fried fish (6.22±0.06 g/100g) preserved higher concentrations. This highlights leucine's dominance and stability in the processed fish. Phenylalanine levels ranged from 3.08±0.01 g/100g in chilled fish to 3.34±0.04 g/100g in fried fish at day zero. At day seventh of freezed storage, phenylalanine level decreased to 2.83±0.08 g/100g in chilled fish, while smoked fish (3.04±0.06 g/100g) and fried fish (3.14±0.04 g/100g) maintained higher concentrations.

Overall, essential amino acids were significantly higher in smoked and fried fish sample compared to chilled fish, both at day zero and day seventh of freezed storage. Chilled fish showed sharp declines in essential amino acid levels during storage, likely due to microbial and enzymatic degradation. In contrast, processing (smoking and frying) enhanced essential amino acid concentration (due to moisture loss) and preserved stability during storage. Fried fish consistently recorded the highest levels of most amino acids, followed by smoked fish, while chilled fish had the least. These findings underscore the nutritional advantage of processing in retaining essential amino acids and suggested that frying and smoking improve the protein quality and storage stability of *M. merluccius* fish compared to chilled fish. However, the essential amino acid profiles of fried fish at both days were significantly difference ($p<0.05$) compared to chilled and smoked fish (Table 4).

Table 3. Fatty acid profiles of chilled, smoked and fried *M. merluccius* fish at Day seventh of freezed condition

Fish Sample	Saturated fatty acids (SFA) (%)			Monounsaturated fatty acids (MUFA) (%)		Polyunsaturated fatty acids (PUFA) (%)			
	Myristic acid (C14:0)	Palmitic acid (C16:0)	Stearic acid (C18:0)	Palmitoleic acid (C16:1)	Oleic acid (C18:1n - 9)	Linoleic acid (C18:2n – 6)	Arachidonic acid (C20:4n – 6)	Eicosapentaenoic acid (C20:6n – 3)	Docosahexaenoic acid (C22:6n – 3)
Chilled	3.09±0.02^{c}	15.13±0.34^{c}	2.68±0.05^{c}	6.45±0.11^{c}	18.10±0.34^{c}	2.04±0.03^{b}	1.02±0.01^{c}	11.67±0.25^{c}	7.50±0.04^{c}
Smoked	3.66±0.06^{b}	21.36±0.12^{b}	4.78±0.06^{b}	8.10±0.22^{b}	21.96±0.20^{b}	2.41±0.03^{a}	1.14±0.04^{b}	12.76±0.10^{b}	8.80±0.04^{b}
Fried	4.07±0.04^{a}	22.95±0.17^{a}	5.08±0.02^{a}	8.64±0.13^{a}	23.63±0.06^{a}	2.43±0.03^{a}	1.38±0.05^{a}	13.61±0.04^{a}	9.20±0.04^{a}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

Table 4. Essential amino acid composition of chilled, smoked and fried *M. merluccius* fish at day zero and day seventh of freezed condition

Day	Fish Sample	Essential Amino Acid composition								
		Lysine	Histidine	Tryptophan	Threonine	Valine	Methionine	Isoleucine	Leucine	Phenylalanine
Zero	Chilled	3.65±0.04^{d}	2.73±0.02^{e}	0.26±0.01^{d}	1.70±0.02^{d}	4.32±0.04^{b}	2.04±0.04^{d}	2.15±0.04^{d}	5.74±0.04^{d}	3.08±0.014^{d}
	Smoked	4.47±0.13^{b}	3.19±0.03^{c}	0.34±0.01^{c}	2.09±0.02^{b}	4.70±0.03^{a}	2.29±0.11^{c}	2.56±0.01^{b}	6.49±0.04^{a}	3.25±0.06^{b}
	Fried	4.75±0.03^{a}	3.44±0.04^{a}	0.40±0.02^{a}	2.14±0.03^{a}	4.77±0.01^{a}	2.53±0.39^{a}	2.77±0.06^{a}	6.52±0.04^{a}	3.34±0.04^{a}
Seventh	Chilled	2.47±0.12^{e}	1.98±0.05^{f}	0.21±0.01^{d}	1.20±0.04^{e}	3.39±0.02^{c}	1.56±0.04^{e}	2.04±0.04^{e}	4.93±0.12^{e}	2.83±0.08^{e}
	Smoked	4.21±0.15^{c}	3.08±0.04^{d}	0.32±0.01^{c}	1.90±0.03^{c}	4.32±0.08^{b}	2.46±0.12^{b}	2.26±0.05^{c}	6.15±0.08^{c}	3.04±0.06^{d}
	Fried	4.55±0.04^{b}	3.27±0.02^{b}	0.37±0.02^{b}	2.02±0.04^{b}	4.26±0.06^{b}	2.50±0.19^{a}	2.58±0.05^{b}	6.22±0.06^{b}	3.14±0.04^{c}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

3.5 Non-Essential Amino Acid Profile of Experimental Fish at Day Zero and Seventh of Preservation

The non-essential amino acid (NEAA) composition of chilled, smoked and fried hake fish at day zero and day seventh is presented in Table 5. At day zero, asparagine was highest in fried fish (3.52±0.01 g/100g protein), followed closely by smoked fish (3.46±0.01 g/100g), while chilled fish had the lowest value (3.19±0.03 g/100g). At day seventh, asparagine declined in chilled fish (2.38±0.04 g/100g), while smoked fish (3.26±0.02 g/100g) and fried fish (3.29±0.04 g/100g) retained higher levels. This indicates that processing (smoking and frying) methods helps maintain asparagine during storage.

Fried fish (5.35±0.03 g/100g) and smoked fish (5.29±0.04 g/100g) had significantly higher arginine value than chilled fish (4.60±0.03 g/100g) at day zero; while arginine dropped to 3.31±0.04 g/100g in chilled fish. However, smoked fish (5.07±0.06 g/100g) and fried fish (5.14±0.06 g/100g) maintained better stability at day seventh of chilled storage. This suggests that smoking and frying protect arginine from degradation during storage. Alanine value was highest in fried fish (6.99±0.06 g/100g), followed by smoked fish (6.60±0.04 g/100g), with chilled fish having the least value (6.12±0.02 g/100g) at day zero. At seventh day of freezed storage condition, alanine reduced across the samples, most notably in chilled fish (5.29±0.04 g/100g), while smoked fish (6.28±0.04 g/100g) and fried fish (6.66±0.10 g/100g) preserved higher concentrations.

Aspartic acid was highest in fried fish (8.11±0.01 g/100g), followed by smoked fish (7.90±0.04 g/100g) and chilled fish (7.82±0.02 g/100g) at day zero. The values decreased in all the samples at seventh day, particularly in chilled fish (6.60±0.04 g/100g), while fried fish (7.78±0.06 g/100g) and smoked fish (7.47±0.04 g/100g) retained higher values. This indicates that aspartic acid, though sensitive to storage, is better preserved in processed fish. Cysteine values varied from 0.74±0.04 g/100g to 0.79±0.04 g/100g at day zero. At day seventh of freezed condition, a significant decline was observed across the samples; in chilled fish (0.56±0.02 g/100g), smoked fish (0.65±0.03 g/100g) and fried fish (0.73±0.02 g/100g) but fried fish was significantly higher than others. This highlights that cysteine, a sulfur-containing amino acid, is vulnerable to oxidative losses in chilled fish.

Glutamic acid, the most abundant non-essential amino acid, was significantly higher in both smoked fish (7.70±0.04 g/100g) and fried fish (7.83±0.02 g/100g) compared to chilled fish (7.53±0.02 g/100g) at day zero. At day seventh, glutamic acid decreased markedly across the samples with highest values recorded from fried fish (7.48±0.02 g/100g) confirming the protective benefit of thermal processing. Fried fish (2.89±0.04 g/100g) had the highest glycine value at day zero of preservation, followed by smoked fish (2.80±0.04 g/100g) and chilled fish (2.50±0.04 g/100g). At day seventh, glycine decreased across the treatments, with chilled fish recording the least value (2.18±0.03 g/100g). Fried fish (2.63±0.06 g/100g) and smoked fish (2.56±0.02 g/100g) exhibited significantly better retention.

Non-essential amino acid was consistently higher in smoked and fried fish compared to chilled fish sample both at day zero and seventh of freezed storage. Chilled fish showed significant decline across all NEAAs during storage, reflecting enzymatic degradation and microbial spoilage. Smoked and fried fish demonstrated better amino acid retention due to reduced moisture and lower microbial activity. Among the NEAAs, glutamic acid, aspartic acid, and alanine were the most abundant, while cysteine and glutamine were the least concentrated. Processing (particularly frying) enhanced the concentration and stability of most NEAAs, highlighting its role in preserving protein quality during storage. However, the non-essential amino acid profiles of fried fish at both days were significantly difference ($p<0.05$) compared to chilled and smoked fish (Table 5).

3.6 Microbial Load of Experimental Fish at Day Zero and Day Seventh of Preservation

The microbial load of chilled, smoked and fried hake fish sold at Eyenkorin market was presented in Table 6**.** At day zero, the viable count was recorded highest (35.0×10^5 CFU/g) in chilled fish. An increase was observed across the three samples at day seventh of preservation. The significant increase in microbial load during storage, particularly in chilled fish, reflects the influence of high moisture content and lack of preservative barriers, whereas the relatively lower counts in smoked and fried samples indicated the inhibitory effect of heat processing on microbial survival.

Table 5. Non-essential amino acid profiles of chilled, smoked and fried *M. merluccius* fish at Day zero and day seventh of freezed condition

Day	Hake Sample	Non-Essential Amino Acid Profiles										
		Asparagine	**Arginine**	**Alanine**	**Aspartic acid**	**Cysteine**	**Glutamic acid**	**Glycine**	**Proline**	**Serine**	**Glutamine**	**Tyrosine**
zero	Chilled	3.19±0.03^{c}	4.60±0.03^{d}	6.12±0.02^{d}	7.82±0.02^{cb}	0.74±0.04^{b}	7.53±0.02^{b}	2.50±0.04^{c}	2.85±0.03^{c}	4.20±0.03^{c}	1.04±0.01^{d}	2.29±0.01^{d}
	Smoked	3.46±0.01^{b}	5.29±0.04^{a}	6.60±0.04^{b}	7.90±0.04^{b}	0.74±0.01^{b}	7.70±0.04^{a}	2.80±0.04^{a}	3.07±0.04^{b}	4.39±0.04^{b}	1.19±0.02^{c}	2.56±0.02^{b}
	Fried	3.52±0.01^{a}	5.35±0.03^{a}	6.99±0.06^{a}	8.11±0.01^{a}	0.79±0.04^{a}	7.83±0.02^{a}	2.89±0.04^{a}	3.27±0.05^{a}	4.61±0.03^{a}	1.30±0.01^{a}	2.69±0.06^{a}
seventh	Chilled	2.38±0.04^{d}	3.31±0.04^{e}	5.29±0.04^{e}	6.60±0.04^{d}	0.56±0.02^{d}	5.92±0.13^{e}	2.18±0.03^{d}	2.18±0.02^{e}	3.46±0.11^{e}	0.85±0.02^{e}	1.98±0.01^{e}
	Smoked	3.26±0.02^{c}	5.07±0.06^{c}	6.28±0.04^{c}	7.47±0.06^{c}	0.65±0.03^{c}	7.29±0.04^{d}	2.56±0.02^{c}	2.61±0.04^{d}	4.12±0.04^{d}	1.01±0.01^{d}	2.28±0.02^{d}
	Fried	3.29±0.04^{c}	5.14±0.06^{b}	6.66±0.10^{b}	7.78±0.04^{b}	0.73±0.02b	7.48±0.03^{c}	2.63±0.06^{b}	2.95±0.03^{c}	3.29±0.03^{f}	1.20±0.02^{b}	2.34±0.02^{c}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

Table 6. Microbial load of chilled, smoked, and fried hake fish (day zero and seventh)

Days	Sample Code	TVC (CFU/g ×10^{5})	TCC (CFU/g ×10^{5})	TFC (CFU/g ×10^{5})
Zero	Chilled Fish	35.0 ± 2.82^{c}	0.0 ± 0.00^{a}	6.0 ± 1.41^{a}
	Smoked Fish	23.50 ± 2.12^{b}	0.0 ± 0.00^{a}	11.50 ± 2.12^{b}
	Fried Fish	12.0 ± 2.82^{a}	0.0 ± 0.00^{a}	3.50 ± 0.70^{a}
Seventh	Chilled Fish	118.0 ± 4.24^{e}	0.0 ± 0.00^{a}	35.0 ± 2.82^{d}
	Smoked Fish	71.50 ± 4.94^{d}	2.50 ± 0.70^{b}	19.0 ± 2.82^{c}
	Fried Fish	23.00 ± 2.82^{b}	0.0 ± 0.00^{a}	7.50 ± 0.70^{ab}

Means ± SD values in each column with different superscripts are significantly different (p = .05)

Coliforms were absent in chilled and fried fish at both days but was detected (2.50×10^5 CFU/g) only in smoked fish at seventh day of freezed storage condition. The absence of coliforms in chilled and fried fish suggested minimal contamination from enteric bacteria or effective elimination through frying, which achieved higher thermal penetration. The presence of coliform in smoked fish at seventh day, though relatively low, indicated possible post-processing contamination during handling or storage, as smoking temperatures may not completely eliminate coliform spores.

Fungal growth was observed in all samples, with varying degrees. At day zero, chilled fish had highest (6.0×10^5 CFU/g) fungal count and fried fish had least (3.50×10^5 CFU/g) fungal count. At day seventh of freezed storage condition, fungal growth increased substantially in chilled fish (35.0×10^5 CFU/g) and smoked fish (19.0×10^5 CFU/g), while fried fish showed only a marginal increase (7.50×10^5 CFU/g). The higher fungal growth in chilled and smoked fish may be attributed to residual moisture and environmental contamination, while the lower values in fried fish can be linked to oil impregnation and higher frying temperature, which reduces fungal viability.

4. Discussion

The findings provide critical insights into the nutritional and microbial quality of chilled, smoked, and fried hake fish (*Merluccius merluccius)* sold at Eyenkorin Market, Ilorin. This result highlight significant difference in proximate composition, fatty acid profiles, amino acid content, and microbial loads across the three processing methods, each with implications for consumers health, shelf stability, and food safety. Chilled *M. merluccius* fish exhibited the highest moisture content, which contributed to its rapid spoilage, as evidenced by the substantial increase in total viable microbial counts (TVC). The report confirmed that elevated moisture in chilled fish creates a suitable environment for microbial proliferation, thereby accelerating spoilage and nutrient losses. This is consistent with Chi *et al.,* (2025), who reported that the high moisture activity of chilled fish supports microbial growth and rapid biochemical deterioration during storage. Similarly, Wang *et al.,* (2022) emphasized that the retention of excessive moisture in chilled fish is the principal factor limiting its shelf life, as it enhanced enzymatic activity and bacterial contamination. In a related study, Gong *et al.,* (2025) observed that microbial proliferation in chilled fish was directly associated with protein denaturation and amino acid degradation, leading to reduced nutritional value.

The decline in crude protein and essential amino acids such as lysine underscored the perishable of chilled fish when not preserved through smoking, frying, or other moisture-reducing methods (Ali *et al.,* 2022). In contrast, smoked and fried fish demonstrated significant lower moisture levels, which enhanced their shelf stability. Smoking, through dehydration and the antimicrobial properties of smoke, effectively reduced microbial growth compared to chilled fish. Nutritionally, smoked and fried fish had higher protein concentrations compared to chilled fish, a result of moisture loss concentrating the nutrients rather than increase in protein content. This aligns with the findings of Altan (2025), who observed similar trends in processed fish products. The fatty acid profiles revealed trade-off: chilled fish retained higher levels of beneficial omega-3 polyunsaturated fatty acids (PUFAs), such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), while processing led to reduction in these essential fats. Smoked fish maintained a better PUFA profile than fried fish, likely because frying introduced additional saturated fat from cooking oil, as seen in the increased palmitic acid. These changes may diminish the cardiovascular health benefits typically associated with fish consumption (Noreen *et al.*, 2025). Amino acid analysis showed that smoked and fried fish had higher retention of essential amino acids, such as lysine and leucine, compared to chilled fish. This is significant because these amino acids are vital for human metabolism and muscle synthesis (Zhu *et al.,* 2025). The degradation of amino acids in chilled fish over time highlights the importance of proper preservation to maintain nutritional value. Non-essential amino acids, such as glutamic acid and aspartic acid, remained relatively stable across all samples, indicating that protein quality is more affected by processing than by intrinsic biochemical changes.

From a food safety perspective, the microbial findings emphasize the risks associated with poor handling and storage. The absence of coliforms in chilled and fried fish suggested initial sanitary conditions, but their emergence in smoked fish points to cross-contamination during packaging or transportation. Fungal growth in smoked fish also raised concerns, as certain molds can produce mycotoxins under favorable conditions (Alves Rodrigues *et al.,* 2026). These findings align with research by Huss *et al.* (2015), who stressed the need for stringent hygiene protocols in fish processing. However, the presence of coliforms in smoked fish at day seventh of freezed condition suggests potential post-processing contamination, likely due to unhygienic handling or

storage conditions. This finding is consistent with studies by Omojowo *et al.* (2019), who reported similar contamination risks in smoked fish from Ipata and oja tuntun markets. Fried fish exhibited the least viable counts, attributed to the high temperatures during frying, which inactivate bacteria. However, the elevated lipid content in fried fish raised concerns about oxidative rancidity, which could compromise both nutritional quality and sensory properties over time (Desai *et al.,* 2018).

5. Conclusion

This survey research concluded that chilled, smoked and fried *Merluccius merluccius* fish sold at Eyenkorin Market are healthy for human consumption because of their nutritional profiles. In addition, microbial loads detected of these fish samples are within the permissible limit for human consumption. However, fried *M. merluccius* fish is therefore recommended among others for consumption because of its high nutritional profiles and minimal microbial loads at day zero and day seventh of freezed storage condition.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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