International Journal of Agriculture and Plant Science
www.agriculturejournal.in
Online ISSN: 2664-7664, Print ISSN: 2664-7656
Received: 19-11-2025, Accepted: 18-12-2025, Published: 02-01-2026
Volume 8, Issue 1, 2026, Page No. 1-7

Nutritional characterization of Pangasius (*Pangasianodon hypophthalmus*) fillets: Proximate composition, fatty acid profile and mineral content

S Dhariniswara, AU Pagarkar, A Mugunthan, A Sudharshan, B Hemavarshini, J Tharunika Sri
Department of Fish processing Technology, College of Fisheries, Shirgaon Ratnagiri, Dr BSKKV, Maharashtra, India
DOI: https://doi.org/10.66856/ijaps.2026.8.1.7156

Abstract
The present study evaluated the nutritional composition of *Pangasianodon hypophthalmus* fillets with emphasis on proximate composition, fatty acid profile and mineral content. The results revealed notable variation in nutritional composition among different anatomical portions of the fillets. Proximate analysis showed moisture content ranging from 70.86% to 73.45%, protein from 15.96% to 16.74%, and fat from 8.97% to 9.76%, indicating region-specific distribution of major nutrients. Fatty acid analysis demonstrated that saturated fatty acids were the predominant lipid fraction (46.79–53.04%), followed by mono-unsaturated fatty acids (39.83–40.70%), while poly-unsaturated fatty acids were present in lower proportions (6.94–7.07%). The dominance of saturated and mono-unsaturated fatty acids and the relatively low contribution of n-3 polyunsaturated fatty acids highlight the nutritional limitations of Pangasius lipids. A decreasing trend in saturated fatty acid content from head to tail portions was observed. Mineral composition analysis showed that Pangasius fillets are a good source of essential minerals, with phosphorus, calcium, sodium, magnesium, zinc and iron present in appreciable amounts. Ventral and body portions generally exhibited higher mineral concentrations compared to head and tail portions. Overall, the findings indicate that Pangasius fillets possess distinct nutritional characteristics depending on anatomical location and the results support the need for suitable pre-processing or fat-reduction strategies to improve lipid quality while retaining high protein and mineral content.

Keywords: Pangasius, proximate composition, fatty acid profile, minerals

Introduction
The genus *Pangasius* comprises several catfish species that are widely distributed in the South-East Asian region and belong to the family *Pangasiidae*. Among these, *Pangasianodon hypophthalmus* is the most commonly cultured species. This fish is also known as Sutchi catfish, striped catfish, or Tra fish. Among freshwater fish species, Pangasius is recognized as one of the fastest-growing species in aquaculture, attaining a body weight of approximately 1.2–1.3 kg within six months, although it is usually harvested after eight months of culture.

Pangasius is now traded globally in various forms, including skinless and boneless fillets, steaks, portions and several value-added products (Jeyakumari *et al*., 2016; Thi *et al*., 2013) [9, 16]. Due to its mild flavour, white flesh, and absence of intramuscular bones, Pangasius fillets have gained wide consumer acceptance and are considered a suitable substitute for other white-fleshed fish species. In the European market, Pangasius is predominantly marketed as frozen, skinned and boneless fillets and at present, these products are exported to more than 100 countries worldwide (Noseda *et al*., 2012) [14].

The growing demand for fish-based convenience foods has resulted in the rapid expansion of the filleting industry, which generates substantial quantities of by-products such as heads, bones, skin and scrap meat. With appropriate processing techniques, these by-products can be converted into high-value products, thereby improving economic efficiency and sustainability. The utilization of Pangasius processing waste thus represents a promising opportunity for the development of value-added products, including fish-enriched pasta and other functional foods.

Nutritionally, Pangasius fillets are characterized by high moisture content (approximately 80%) and relatively low crude protein (15.8%) and lipid (3.0%) levels. The lipid fraction is reported to contain low cholesterol levels (about 40 mg/100 g) but is dominated by saturated fatty acids (approximately 47.5% of total fatty acids), with comparatively lower proportions of polyunsaturated fatty acids (around 20%), mainly represented by linoleic acid (Domiszewski *et al*., 2011) [3]. The mineral composition of Pangasius fillets is notable for relatively high sodium content, along with appreciable levels of essential macro- and micro-minerals.

Pasta is traditionally produced from wheat flour, which contains about 10–15 g/100 g protein but lacks certain essential amino acids, rendering it a nutritionally incomplete protein source. Fish proteins, owing to their balanced amino acid profile, high digestibility and affordability, can effectively complement cereal-based products. Pangasius, being a widely cultured freshwater fish in India, represents a valuable source of high quality protein, fatty acids and minerals. Therefore, the present study focuses on evaluating the nutritional composition of Pangasius fillets, with particular emphasis on proximate composition, fatty acid profile and mineral content (Mahmoud *et al*., 2012) [12].

Materials and Methods
Materials
Fresh *Pangasianodon hypophthalmus* were collected from Madurai AM Fish Farm and local fish markets. Immediately after collection, the fish were placed in insulated iceboxes to minimize dehydration and temperature fluctuations, thereby delaying spoilage. Flake ice produced using a flake ice machine was used during transportation and processing. Ice flakes of approximately 2–3 cm size were layered in the icebox and the fish were placed between ice layers before further processing.

Methods

Sampling procedure

Random sampling was adopted for the analysis. Raw Pangasius meat samples were collected from different anatomical regions, namely the head, body, ventral and tail portions. These samples were used for proximate composition, fatty acid composition and mineral composition analyses.

Proximate composition analysis

Proximate composition, including moisture, protein, fat, ash and carbohydrate content was determined according to standard AOAC methods (2000) [2]. Protein content was estimated using the Kjeldahl method for which approximately 1 g of wet sample was used. Digestion was carried out at 300–400 °C, followed by distillation for 8 minutes.

Fat content was determined using the Folch extraction method (1957) [5], employing a chloroform–methanol (2:1) solvent system, with approximately 4.5–5.0 g of sample. Moisture content was analyzed by drying 10 g of wet sample in a hot air oven at 100 °C for 12 hours. Ash content was determined by incinerating 2 g of dried sample in a muffle furnace at 550 °C for 24 hours. Carbohydrate content was calculated by difference.

Reagents used for protein estimation included concentrated sulfuric acid, digestion mixture (copper sulfate, 0.1 g; potassium sulfate, 2.5 g), sodium hydroxide (40%), boric acid (4%), mixed indicator (methyl red, 0.16 g; bromocresol green, 80 mg in 100 ml of 95% ethanol), and standard sulfuric acid (0.1 N). Fat analysis also involved the use of potassium chloride (0.74%) and petroleum ether (40–60 °C) for Soxhlet extraction where applicable.

Fatty acid composition analysis by gas chromatography

Fatty acid composition was determined using gas chromatography (GC), which is a widely employed technique for lipid analysis. Lipids were extracted from 10 g of fish sample using the Folch method. Fatty acid methyl esters (FAMEs) were prepared through saponification and methylation under alkaline conditions as described by AOAC (1990) [1], using methanol and boron trifluoride.

For esterification, approximately 250 mg of lipid extract was dissolved in toluene in a round-bottom flask. Sodium hydroxide was added, and the mixture was refluxed for 5–10 minutes until fat droplets disappeared. Methanol was then added, and refluxing was continued for an additional minute. After cooling, saturated sodium chloride solution and hexane were added and the mixture was shaken thoroughly. The hexane layer was separated, and the extraction was repeated twice. Combined hexane extracts were evaporated to dryness using a rotary evaporator at 55–60 °C, and the methyl esters were dissolved in 1 ml of HPLC-grade hexane for GC analysis.

Separation of FAMEs was carried out using a GC column maintained at 210 °C for 30 minutes. Standard FAME mixtures (0.5 ml) were injected to identify retention times, followed by injection of sample FAMEs. Individual fatty acids were identified by comparing retention times with standards and results were expressed as percentage of total fatty acids based on peak area normalization.

Mineral composition analysis

The mineral composition of raw and defatted Pangasius meat samples was determined using standard analytical methods. Calcium, magnesium and zinc contents were estimated by EDTA titration. Sodium content was analyzed using a flame photometer. Phosphorus was determined using the amino-naphthol-sulphonic acid method, and iron content was estimated using the 1:10 phenanthroline method.

Mineral concentrations were calculated using the following formula:

Mineral content (mg/100 g) =T.V×N×100×D.FW×0.05

where *T.V* is the titre value, *N* is the normality, *D.F* is the dilution factor and *W* is the sample weight.

Statistical analysis

Statistical analysis was performed using SPSS software version 19 (IBM, 2010) [8]. The experimental results were expressed as mean ± standard deviation for triplicate determinations. Differences among samples were evaluated using appropriate statistical tests and significance was assessed at the 95% confidence level.

Result

Proximate composition of raw Pangasius fillets

Table & Fig 1 Proximate composition of Pangasius fillets

Raw Pangasius – Head portion

Composition	Sample-1	Sample-2	Sample-3	Mean ± SD
Moisture (%)	72.34	72.34	72.32	72.33 ± 0.01^{b}
Protein (%)	16.18	16.16	16.18	16.17 ± 0.01^{b}
Fat (%)	9.32	9.35	9.35	9.34 ± 0.02^{b}
Ash (%)	1.43	1.47	1.47	1.46 ± 0.02^{a}
Carbohydrate (%)	0.73	0.68	0.68	0.70 ± 0.03^{b}

Raw Pangasius – Body portion

Composition	Sample-1	Sample-2	Sample-3	Mean ± SD
Moisture (%)	71.37	71.38	71.37	71.37 ± 0.01^{c}
Protein (%)	16.75	16.73	16.75	16.74 ± 0.01^{a}
Fat (%)	9.76	9.72	9.72	9.73 ± 0.02^{a}
Ash (%)	1.45	1.45	1.44	1.45 ± 0.01^{a}
Carbohydrate (%)	0.67	0.72	0.72	0.70 ± 0.03^{b}

Raw Pangasius – Ventral portion

Composition	Sample-1	Sample-2	Sample-3	Mean ± SD
Moisture (%)	73.45	73.45	73.47	73.45 ± 0.01^{a}
Protein (%)	15.98	15.95	15.95	15.96 ± 0.02^{c}
Fat (%)	8.99	8.94	8.99	8.97 ± 0.03^{c}
Ash (%)	1.35	1.39	1.35	1.36 ± 0.02^{b}
Carbohydrate (%)	0.23	0.27	0.24	0.25 ± 0.02^{c}

Raw Pangasius – Tail portion

Composition	Sample-1	Sample-2	Sample-3	Mean ± SD
Moisture (%)	70.89	70.85	70.85	70.86 ± 0.02^{d}
Protein (%)	16.64	16.67	16.64	16.65 ± 0.02^{ab}
Fat (%)	9.78	9.75	9.75	9.76 ± 0.02^{a}
Ash (%)	1.14	1.16	1.14	1.15 ± 0.01^{c}
Carbohydrate (%)	1.55	1.57	1.62	1.58 ± 0.04^{a}

Combined proximate composition of raw meat portions

Parameter	Head portion	Body portion	Ventral portion	Tail portion
Moisture	72.33 ± 0.01^{b}	71.37 ± 0.01^{c}	73.45 ± 0.01^{a}	70.86 ± 0.02^{d}
Protein	16.17 ± 0.01^{b}	16.74 ± 0.01^{a}	15.96 ± 0.02^{c}	16.65 ± 0.02^{ab}
Fat	9.34 ± 0.02^{b}	9.73 ± 0.02^{a}	8.97 ± 0.03^{c}	9.76 ± 0.02^{a}
Ash	1.46 ± 0.02^{a}	1.45 ± 0.01^{a}	1.36 ± 0.02^{b}	1.15 ± 0.01^{c}
Carbohydrate	0.70 ± 0.03^{b}	0.70 ± 0.03^{b}	0.25 ± 0.02^{c}	1.58 ± 0.04^{a}

Values with different superscripts (a–d) in the same row differ significantly ($p < 0.05$).

Data were expressed as mean ± standard deviation (n = 3). Statistical differences among different anatomical portions were analyzed using one-way ANOVA followed by mean separation at $p < 0.05$. Different superscript letters indicate significant differences within the same row.

Table 1a. T-test and F-test results for proximate composition of raw Pangasius fillets

Raw Pangasius – Head portion

Parameter	T-test	F-test
Moisture	0.000	0.10
Protein	0.000	0.20
Fat	0.000	0.60
Ash	0.000	0.00
Carbohydrate	0.000	0.00

Raw Pangasius – Body portion

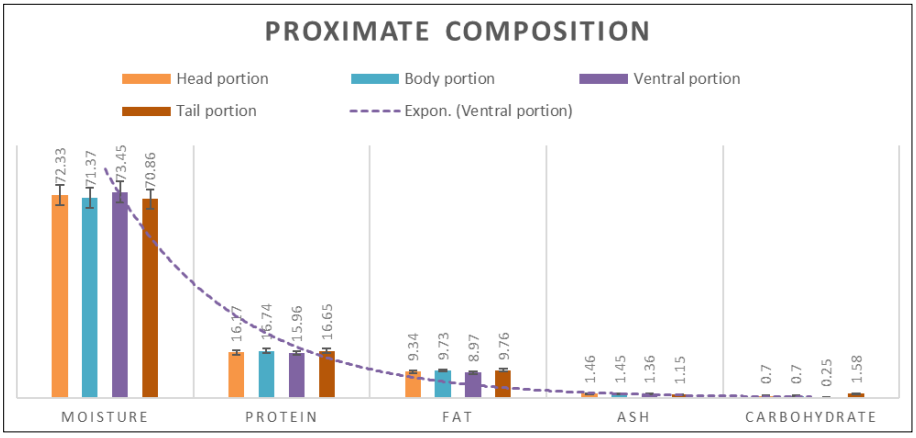
Parameter	T-test	F-test
Moisture	0.000	0.00
Protein	0.000	0.00
Fat	0.000	0.00
Ash	0.000	0.00
Carbohydrate	0.000	0.00

Raw Pangasius – Ventral portion

Parameter	T-test	F-test
Moisture	0.000	0.10
Protein	0.000	0.50
Fat	0.000	0.00
Ash	0.000	0.00
Carbohydrate	0.000	0.00

Raw Pangasius – Tail portion

Parameter	T-test	F-test
Moisture	0.000	0.00
Protein	0.000	0.30
Fat	0.000	0.00
Ash	0.000	0.00
Carbohydrate	0.000	0.00



1. T-test

- The T-test value of 0.000 indicates no significant variation among triplicates within the same portion
- This confirms good repeatability and experimental precision
- This is acceptable and common when SD is low

2. F-test

- F-test values > 0.05 (e.g., 0.10, 0.20, 0.60) indicate minor variation
- F-test values ≈ 0.00 indicate negligible variation
- Overall, F-test results confirm homogeneity within samples

The proximate composition of raw *Pangasianodon hypophthalmus* fillets from different anatomical portions (head, body, ventral, and tail) is presented in Table 1 as mean ± SD (n = 3). Moisture content differed significantly ($p < 0.05$) among portions, ranging from 70.86 ± 0.02% in the tail portion to 73.45 ± 0.01% in the ventral portion. The

ventral portion exhibited significantly higher moisture content compared to all other portions.

Protein content showed significant variation ($p < 0.05$), with values ranging from 15.96 ± 0.02% in the ventral portion to 16.74 ± 0.01% in the body portion. The body and tail portions recorded higher protein levels compared to the head and ventral portions.

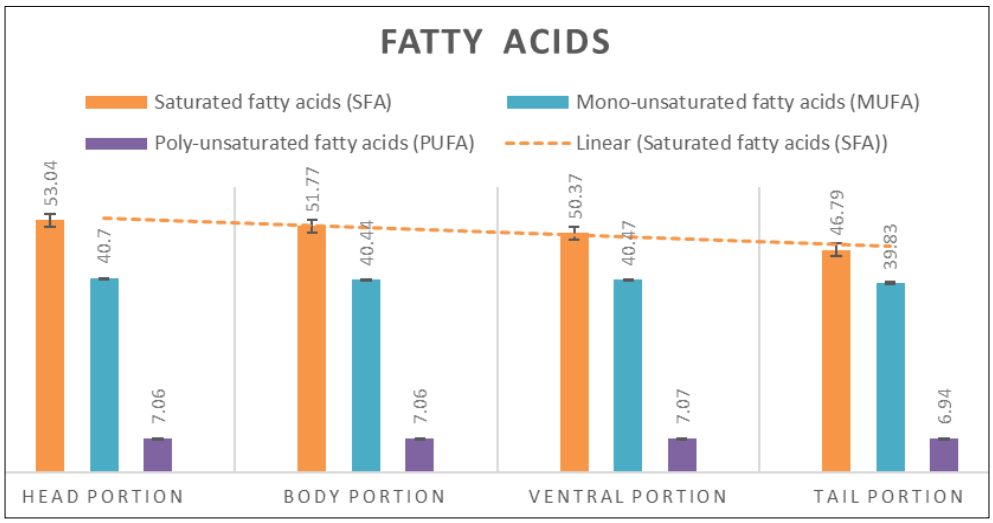
Fat content varied significantly among portions ($p < 0.05$). The highest fat content was observed in the tail portion (9.76 ± 0.02%), followed by the body portion (9.73 ± 0.02%), while the ventral portion showed the lowest fat content (8.97 ± 0.03%). Ash content ranged from 1.15 ± 0.01% to 1.46 ± 0.02%, with significantly higher values in the head and body portions. Carbohydrate content remained low across all portions but showed significant differences ($p < 0.05$), with the tail portion exhibiting the highest value (1.58 ± 0.04%).

Fatty acid composition of the Pangasius fillets

Table & Fig:2- Fatty acid composition of Pangasius fillets

Compounds	Fatty acids	Raw head portion	Raw body portion	Ventral portion	Tail portion
C 4:0	Butyric acid	0.46	0.47	0.44	0.39
C 12:0	Lauric acid	0.42	0.3	0.35	0.2
C 14:0	Myristic acid	7.20	7.15	6.87	5.38
C 14:1	Myristoleic acid	0.91	0.73	0.84	0.87
C 15:0	Pentadecanoic acid	0.18	0.37	0.24	0.42
C 15:1	Cis-10 Pentadecanoic acid				
C 16:0	Palmitic acid	34.23	34.62	33.78	32.16
C 16:1	Palmitoleic acid	1.85	1.91	1.97	1.89
C 17:0	Heptadecanoic acid	0.16	0.18	0.24	0.14
C 17:1	Cis-10 Heptadecanoic acid	0.00	0.16	0.15	0.18
C 18:0	Stearic acid	6.74	6.98	6.34	6.25
C 18:1t	Vaccenic acid	36.64	36.48	35.21	35.78
C 18:2t	Linolelaidic acid	4.86	4.78	4.63	4.79
C 18: 2 n6c	Linoleic acid	0.16	0.19	0.21	0.14
C 18:3n3	α-Linolenic acid	0.34	0.49	0.41	0.31
C 13:3 n6	ϒ-Linolenic acid	0.25	0.29	0.31	0.28
C 20:1	Cis-11 Eicosenoic acid	1.14	1.16	1.17	1.11
C 20:2	Eicosadienoic acid	0.2	0.23	0.25	0.19
C 20:4n6	Arachidonic acid	1.25	1.08	1.26	1.23
C 20:3	Dihomo-γ-linolenic acid	0.00	0.00	0.00	0.00
C 21:0	Henicosanoic acid	2.26	0.41	0.6	0.58
C 22:0	Behenic acid	0.17	0.19	0.21	0.15
C 22:1n9	Erucic acid	0	0	0	0
C 22:2	Docosadienoic acid	0	0	0	0
C 22:6n3	Docosahexanoic acid	0	0.0	0.0	0.0
C 23:0	Tricosanoic acid	0.05	0.07	0.09	0.03
C 24:0	Lignoceric acid	1.10	1.03	1.21	1.09
C 24:1	Nervonic acid	0	0.0	0.0	0.0
Unknown		4.39	0.73	1.04	4.44
Total		100	100	100	100

Samples	Raw meat head portion	Raw body portion	Raw ventral region	Raw tail portion
Saturated fatty acids	53.04	51.77	50.37	46.79
Mono-unsaturated fatty acids	40.7	40.44	40.47	39.83
Poly-unsaturated fatty acids	7.06	7.06	7.07	6.94



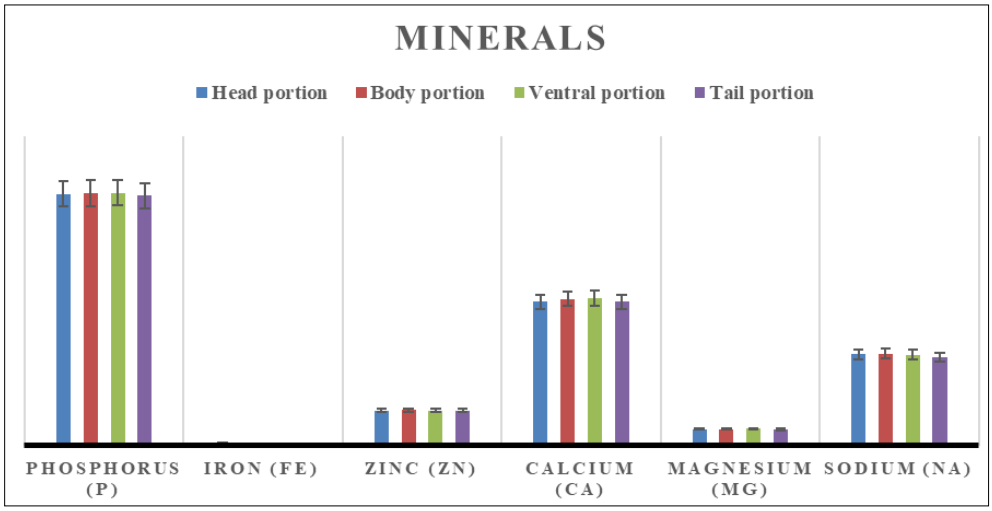
The fatty acid composition of raw *Pangasianodon hypophthalmus* fillets from different anatomical portions (head, body, ventral, and tail) is presented in Table 2. Saturated fatty acids (SFA) were the dominant lipid fraction in all portions, accounting for 53.04% in the head portion, 51.77% in the body portion, 50.37% in the ventral portion, and 46.79% in the tail portion. A decreasing trend in SFA content was observed from the head towards the tail region.

Mono-unsaturated fatty acids (MUFA) constituted the second major lipid fraction, ranging from 39.83% to 40.70%, with only minor variation among the different portions. The head portion exhibited the highest MUFA content (40.70%), whereas the tail portion showed the lowest value (39.83%). Poly-unsaturated fatty acids (PUFA) were present in relatively lower proportions compared to SFA and MUFA. PUFA content ranged from 6.94% in the tail portion to 7.07% in the ventral portion. Among individual fatty acids, palmitic acid (C16:0) and vaccenic acid (C18:1t) were the most abundant saturated and mono-unsaturated fatty acids, respectively, across all anatomical portions.

Minerals composition of Pangasius meat

Table 3: Minerals composition of Pangasius meat

Samples	Phosphorous (P) ppm	Iron (Fe) ppm	Zinc (Zn) ppm	Calcium (Ca)ppm	Magnesium (Mg) ppm	Sodium (Na) ppm
Raw meat-H	4062	37	563	2321	265	1470
Raw meat-B	4074	33	568	2365	264	1485
Raw meat-V	4082	35	562	2376	268	1467
Raw meat-T	4032	31	564	2320	261	1421



The mineral composition of raw *Pangasianodon hypophthalmus* fillets from different anatomical portions (head, body, ventral, and tail) is presented in Table 2. Phosphorus content ranged from, with slightly higher values observed in the ventral and body portions compared to the head and tail.

Iron content varied among portions, with the highest value recorded in the head portion (37 ppm) and the lowest in the tail portion (31 ppm). Zinc content ranged from 562 to 568 ppm, with the body portion exhibiting the highest concentration. Calcium content showed noticeable variation, ranging from 2320 ppm in the tail portion to 2376 ppm in the ventral portion.

Magnesium content varied between 261 and 268 ppm, with the ventral portion showing the highest value. Sodium content ranged from 1421 ppm in the tail portion to 1485 ppm in the body portion, indicating higher sodium accumulation in the body region compared to other portions.

Overall, the mineral composition showed clear anatomical variation, with ventral and body portions generally exhibiting higher concentrations of major minerals.

Discussion

Proximate composition of raw Pangasius fillets

The observed variation in proximate composition among different anatomical portions of Pangasius fillets reflects differences in muscle structure, lipid deposition and moisture retention. The significantly higher moisture content in the ventral portion may be attributed to higher connective tissue and lower lipid concentration, a trend commonly reported in freshwater catfish species (Ersoy and Özeren, 2009; Marimuthu *et al*., 2012) [4, 13].

Protein content was significantly higher in the body and tail portions, which are dominated by well-developed muscle fibers responsible for locomotion. Similar distribution patterns have been reported in Pangasius and other white-fleshed fishes, where the trunk region contributes the highest protein yield (Domiszewski *et al*., 2011) [3]. The lower protein content in the ventral portion may be associated with higher moisture and lower muscle density.

Fat content showed significant anatomical variation, with the tail and body portions recording higher lipid levels than the ventral region (Thi *et al*.2013) [16]. This uneven fat distribution has been previously documented and is influenced by metabolic activity and lipid storage behaviour in cultured Pangasius (Gall *et al*., 1983; Gokoglu *et al*., 2004) [6, 7]. The relatively high fat content in the tail portion may contribute to textural and sensory differences during processing.

Ash content was significantly higher in the head and body portions, indicating greater mineral accumulation, possibly due to proximity to skeletal tissues. Carbohydrate content

remained minimal across all portions, which is typical of fish muscle and confirms Pangasius as a high-protein, low-carbohydrate food source (AOAC, 2000) [2].

Overall, the results clearly demonstrate that anatomical location significantly influences the proximate composition of Pangasius fillets. These variations are important for selecting appropriate portions for processing, defattening, and development

Fatty acid composition of Pangasius fillets

The predominance of saturated and mono-unsaturated fatty acids observed in the present study is characteristic of *Pangasianodon hypophthalmus* and other freshwater catfish species. Similar fatty acid profiles have been reported earlier, where SFA and MUFA together constituted more than 85% of total fatty acids in Pangasius fillets (Domiszewski *et al*., 2011) [3]. The relatively lower PUFA content compared to marine fish species can be attributed to freshwater habitat, feeding regime,and limited availability of long-chain n-3 polyunsaturated fatty acids.

The gradual decline in SFA content from head to tail portions suggests differential lipid deposition along the fish body (Thi et. Al 2014) [17]. Higher SFA levels in the head and body portions may be associated with metabolic and structural functions, whereas the tail region, being more actively involved in locomotion, tends to store comparatively lower saturated fat. This anatomical variation in lipid distribution has also been observed in previous studies on fish muscle (Gall *et al*., 1983) [6].

The dominance of vaccenic acid (C18:1t) among MUFA and the presence of linoleic and arachidonic acids among PUFA indicate that Pangasius lipids are primarily composed of n-6 fatty acids by Pikul, J., & Wojciechowska, K. (1994) [15]. Although the PUFA content is relatively low, the presence of essential fatty acids still contributes to the nutritional value of Pangasius fillets. However, from a health perspective, the high proportion of SFA highlights the importance of adopting suitable processing or defattening methods to improve the lipid quality of Pangasius-based products, as suggested by Kolakowska and Bienkiewicz (1999) [11].

Overall, the fatty acid profile obtained in the present study provides valuable baseline information for the nutritional evaluation of Pangasius fillets and supports the need for pre-processing strategies aimed at reducing saturated fat content while retaining essential fatty acids.

Mineral composition of Pangasius fillets

The variation in mineral composition among different anatomical portions of Pangasius fillets observed in the present study can be attributed to differences in muscle structure, metabolic

activity, and proximity to skeletal tissues. Higher phosphorus and calcium levels in the ventral and body portions may be associated with greater bone proximity and connective tissue presence, which has been reported earlier in freshwater fish species (Gokoglu *et al*., 2004) [7].

The relatively higher iron content observed in the head portion may be due to the presence of blood-rich tissues and heme proteins, as iron is closely associated with myoglobin and hemoglobin content in fish muscle. Similar trends have been reported in catfish and other freshwater species (Ersoy and Özeren, 2009) [4].

Zinc and magnesium contents showed moderate variation across portions, indicating their relatively uniform distribution in Pangasius muscle. These minerals play important roles in enzymatic activity and muscle metabolism, contributing to the nutritional value of Pangasius as a food fish. Sodium content was higher in the body portion, which may be linked to ionic regulation and muscle function, as sodium is a key electrolyte involved in osmoregulation (Gokoglu *et al*., 2004) [7].

Overall, the mineral profile obtained in the present study confirms that Pangasius fillets are a good source of essential macro- and micro-minerals. The observed anatomical variation highlights the importance of portion selection during processing and value addition, particularly for products targeting enhanced mineral nutrition.

Conclusion

The present research was carried out to study nutritional composition of defattening of catfish (*Pangasianodon hyphoththalmus*) fillets. This study focused on analysis of proximate, fatty acid and mineral composition from different portion of fish meat such as head, body, ventral and tail portion. Proximate composition gradually increased is based on portion of meat. Main composition affect moisture and fat content gradually decreased and ash and protein content was increased is based on portion of meats. Fat composition of fillets was affected the heart and brine diseases it is mainly focused on the saturated and mono-unsaturated fatty acid composition and poly un-saturated fatty acid. Nutritional composition such as proximate composition moisture and fat content was gradually decreasing from the raw composition. Ash and protein content was gradually increased is based on the portion of meats. Saturated and mono-unsaturated fatty acid is this content was gradually decrease from the raw composition and poly un-saturated fatty acid was increased is based on the portion of meats.

After heat treatment SFA and MUFA content decreased and PUFA content was increased. Mineral composition gradually increased after heat treatment.

Acknowledgement

The authors express their sincere gratitude to the Department of Fish Processing Technology, College of Fisheries for providing the necessary laboratory facilities and technical support to carry out this research work. The authors also acknowledge the assistance received from Madurai AM Fish Farm and local fish markets for the supply of Pangasius samples. The support and guidance provided by faculty members and technical staff during sample collection, analysis and data interpretation are gratefully acknowledged.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Data Availability

The data generated and analyzed during the present study are included in this published article. Additional data related to the study are available from the corresponding author upon reasonable request.

Ethics Statement

The present study did not involve any live animal experimentation or human participants. Pangasius

(*Pangasianodon hypophthalmus*) samples used in this study were procured from commercial fish farms and local fish markets. All procedures were conducted in accordance with institutional guidelines and standard laboratory practices for food and fish product analysis. Therefore, ethical approval was not required for this study.

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