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Research Article

Amino acid and fatty acid profile of five small Indigenous fish species (SIS) from Assam, India

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Abstract

Both proteins and fatty acids are significant macromolecules that control vital metabolic processes and act as building blocks for forming compounds crucial to biological processes. Fish are a significant source of high-quality protein and fatty acids in human nutrition. In this study, the amino acid fatty acid profile of five sun-dried small Indigenous fish species (SIS), viz., *Anabus testudineus, Barilius barila, Gudusia chapra, Nandus nandus* and *Puntius sophore*. The amino acid profile was determined using standard analytical techniques, while the fatty acid composition was assessed according to the AOAC method by preparing fatty acid methyl esters (FAME).The total detected essential amino acid concentrations in *A. testudineus, B. barila, G. chapra, N. nandus,* and *P. sophore* were 2788.23±5.74, 2939.86±7.6, 2750.44±12.93, 2534.41±4.77 and 1319.21±8.45µmol/L, and the concentrations of nonessential amino acids are 9141.48±6.18, 9493.55±9.58, 8523.89±13.1, 8261.06±9.96 and 4572.77±7.69 µmol/L. The study identified 23 fatty acids, with palmitic acid being the most abundant saturated fatty acid, followed by Myristic, Arachidic, Pentadecanoic, Margaric, Stearic, and Tridecanoic acids, with very low amounts of Behenic and Lignoceric acids. The present study has examined the amino acid compositions of significant dietary fish from various habitats (viz., River, beel, reservoirs, ponds and tanks, etc). Therefore, these can be recommended as a healthy supplement to the human diet, an alternate source of protein, and another nutrient requirement.

Keywords: Small Indigenous fish, Sun-dried, amino acid, fatty acid profile

INTRODUCTION

More than 80% of all fish produced around the globe is consumed. The demand for fish is expected to expand on all continents and reach 17.9 kg per capita by 2020 (Kiczorowska *et al*., 2019). When it comes to fatty acids that are good for human health, including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), and their low-fat content when compared to animal flesh, fish is thought to be an important part of a balanced and beneficial diet (EFSA, 2014; USDA, 2015-2020). It is commonly recognized that the primary sources of necessary fatty acids are fish and other aquatic dietary products. As a result, eating fish and other aquatic food products provides the body with the majority of essential fatty acids, including docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Singh, 2020). Three different types of fatty acids—monounsaturated (MUFA), polyunsaturated (PUFA), and saturated (SFA)—are found in fish oil and are important for human health. PUFA is one of these fatty acids that the human body cannot synthesize, hence it must be consumed through food (Jabeen and Chaudhry, 2011). Fish provide high levels of omega-3 fatty acids. To receive enough long-chain polyunsaturated fatty acids (LCPUFAs), a balanced diet should include two to three times more fatty fish consumption (FAO/WHO, 2011; Singh, 2020).

As building blocks of proteins and substances involved in several metabolic processes, amino acids are essential biomolecules. A wide range of physiologically significant compounds, such as nucleotides, peptide hormones, and neurotransmitters, are synthesized using them as precursors. Aside from their numerous biological functions, amino acids also regulate gene expression, protein phosphorylation, nutrition transport, animal cell metabolism, and both innate and cell-mediated immunological responses (Wang *et al*., 2013; Mohanty *et al*., 2014; Wu, 2010). Fish include many macro and micronutrients, including amino acids, fatty acids (including EPA and DHA), vitamins, and minerals (Mahanty *et al.,* 2014). Nutritional Estimates also provide proof that a variety of health benefits are related. With regular fish consumption. For example, Japanese and Nordic populations have longer lifespans. Populations are said to be partly due to their increased diet of fish and seafood (Mohanty and Singh, 2018).

As the most common macromolecule in biological systems, proteins can be found in many different forms, including structural components, hormones, enzymes, antibodies, receptors, signalling molecules, and so on, each of which has a distinct biological function. Key bodily processes, such as the production of essential amino acids and the growth and maintenance of muscles, depend on protein. The deadly type of malnutrition or hunger is called protein-energy malnutrition, also known as protein-calorie malnutrition, which results from insufficient intake of high-quality proteins and calories from food. The severe protein-calorie malnutrition diseases known as kwashiorkor and marasmus, primarily seen in children, are brought on by long-term protein and energy deficiencies, respectively. Adults with long-term dietary deficiencies also experience PCM. In 2022, an estimated 37 million children were overweight, 45 million were wasted (too thin for their height), and 149 million children under the age of five were stunted (too short for their age) (WHO, 2022).

Assam, a northeastern state in India, has the greatest per capita fish consumption among its inland states. With about 95% of the population consuming fish, there is high demand for all types of fish. Small indigenous fish species (SIS) are nutrient-dense but are commonly disregarded in developing countries (Roos *et al*., 2007; Pegu *et al.,* 2023). The species that reach a maximum length of 25–30 cm during the mature or adult stage of their lifecycle are known as small indigenous fish species (Mohanty *et al*., 2013). Because of their vast numbers and abundance, they make up a considerable portion of the finfish population in inland fisheries (Jena *et al*., 2018; De *et al.,* 2019).

Sun-drying is a common and oldest method of fish preservation in Assam, as fish undergo deteriorating processes like autolysis, lipolysis, and rancidity over time. The process involves evaporating water from fish flesh using heat and wind, resulting in a unique colour, texture, and flavour in fish products. Sun-dried fish is a delicacy with high nutritional components, including crude protein levels, essential fatty acids, and minerals. Mineral ratios are crucial for dietary balance and predicting metabolic dysfunctions. Dried fish have fewer cholesterol, salt, and high minerals for growth and development, making them essential for a balanced diet. Sun-drying fish reduces moisture content, increasing nutritional components like protein, lipid, and ash. This reduces microbial growth, increasing shelf life. However, consumption is limited to tribal sections, accounting for only 12.4% of the population. Disregarding stems from myths about its nutritional efficiency (Kalita *et al*., 2024). Considering the above, the present study was undertaken to investigate the amino acid profile of five sun-dried small indigenous fish species (SIS) from Assam, India.

MATERIALS AND METHODS

Sample collection, identification and reparation

A total of 5 small indigenous fish species (SIS) *viz. Puntius sophore, Barilius barila, Gudusia chapra, Anabus testudienus* and *Nandus nandus* were collected from different fish markets (viz., Biswanath fish market, Gohpur fish market, Rajabari fish market, Rawnamukh fish market, Collegeguri fish market etc.) in the Biswanath district of Assam. After collecting specimens, they were identified at the species level using the identification keys provided by Talwar and Jhingran (1991). Fish were cleaned, beheaded, descaled and degutted before being sun-dried. *B. barila*, *G. chapra*, and *P. sophore* were considered whole fish as they are smaller in size and for analysis. Only their guts were removed. To dry the samples, they were placed on bamboo trays (known as '*Salon*i') in the sun for 10-15 days from 9 am to 4 pm (Kalita *et al.,* 2024). During sun-drying, care was paid to prevent contamination from any other contamination agent. Dried fish is then ground into a fine powder using a grinder and kept in an airtight plastic container until further analysis.

Amino acid analysis with Amino acid analyser

About 200 mg of grounded fish mince was taken into a test tube filled with 30ml 6M HCL and digested at 100 º C for 6 hours in the oven. After cooling, the test tube's contents were filtered through a 0.5 µm syringe-driven filter. The hydrolyzed samples were analyzed using a Biochrom 30+ Amino Acid Analyzer with a ninhydrin reagent and lithium buffer system, injecting 20 µl for 4 hours. This apparatus employs ion exchange chromatography (IEC) to separate amino acids and a postcolumn detector to quantify ninhydrin (NIN) reactive compounds. NIN-derivatized amino acids were identified at 570 nm (Zhang *et al*., 2014; Nath *et al*., 2024).

Fatty acid analysis

Lipid extraction

Singh *et al.* (1990) procedure was followed to extract lipids from the fish sample using a 2:1 chloroform-methanol mixture.

Fatty acid methyl esters (FAMEs) preparation

FAMEs (fatty acid methyl esters) were prepared using the Metcalfe *et al.* (1966) procedure. After weighing

150 mg of lipids, 4 ml of 0.5N NaOH was added. The mixture is brought to a steam bath temperature to dissolve the fat globules. After adding 5 ml of the complex solution of boron trifluoride methanol (BF_3CH_3 OH), the mixture was allowed to reflux for an additional 5 minutes. To separate the fatty acid methyl esters, 16 mL of saturated sodium chloride solution were added to the mixture. The liquid was then put into a separating funnel. The top layer was gathered, mixed twice with 20 millilitres of petroleum ether, and allowed to stand for one minute. Subsequently, the mixed solution was evaporated by passing it through anhydrous sodium sulphate. The ester was prepared for injection in GC MS after it had been dissolved in 5 millilitres of hexane.

Fatty acid analysis using Gas Chromatography Mass Spectrometry (GC-MS)

The methyl esters of fatty acids were studied using Shimadzu GCMS-QP2010 plus Gas chromatography-mass spectrometry, which had an ionization energy of 70 eV. A Rxi-5Sil MS capillary column (30 m × 0.25 mm; film thickness 0.25μm) was used, and helium gas was used as the carrier gas. The sample was injected using a split mode injection port, with an injection volume of 2μl and a constant flow of 1.21 ml/min at 260 °C. The oven temperature was designed to rise from 140 °C to 280 °C at a rate of 4 °C per minute, maintaining a steady temperature for 50 minutes (Singh, 2023).

Statistical analysis

Microsoft Excel (2007) and the SPSS software (version 16.0) were used to analyse the data. The mean ± standard deviation was used to present the data.

Animal ethics approval

The research is not covered by any regulation of Animal ethics.

RESULTS

Amino acid profile

The present study reported the Amino acid profile of small Indigenous fish species viz., *A. testudienus, B barila, G. chapra, N. nandus* and *P. sophore* were determined by amino acid analyzer shown in Table 1. The sum of nonessential amino acids (NEAA) and essential amino acids (EAA) of all studied SIS fish is shown in Fig. 6. The total 19 standard amino acids viz.,Histidine (His), Isoleucine (Ile), Leucine (Leu), Lysine (Lys), Methionine (Met), Phenylalanine (Phe), Threonine (Thr), Tryptophan (Trp), Valine (Val), Alanine (Ala), Arginine (Arg), Aspartic Acid Asp, Cysteine (Cys), Glutamic Acid (Glu), Glutamine (Gln) , Glycine (Gly), Proline (Pro), Serine (Ser), and Tyrosine (Tyr) were reported in five sun-dried SIS fish. The amino acids are divided into two types, i.e., essential amino acid (EAA) and nonessential amino acid (NEAA). There are nine essential amino acids: histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The eleven nonessential amino acids are alanine, arginine, asparagine, aspartic acid, cysteine, glutamic acid, glutamine, glycine, proline, serine, and tyrosine (Lopez and Mohiuddin, 2023).

According to this study, sun-dried *A. testudineus* contained thirteen different amino acids, of which seven were essential amino acids and six were nonessential amino acids (Fig. 1). The most abundant essential and nonessential amino acids in *A. testudineus* were lysine (1057.29±0.76 μmol/L) and proline (4488.02±1.53 μmol/L), respectively. The total detected essential amino acid concentration in *A.testudineus* was 2788.23 μmol/L and the nonessential amino acid concentration was (9141.48±6.18) μmol/L. In *B. barila,* thirteen amino acids were detected, out of which seven amino acids are essential and six are nonessential (Fig. 2). The most abundant essential amino acid in *B. barila* was lysine (1055.75±1.32 μmol/L) and the nonessential amino acid was proline (5525.28±1.3 μmol/L). The total detected essential amino acid concentration in *B. barila* was 2939.86±7.6 μmol/L and the nonessential amino acid concentration was 9493.55±9.58 μmol/L. In *G. chapra,* fifteen amino acids were detected out of that eight amino acids are essential and seven are nonessential (Fig. 3). The most abundant essential and nonessential amino acids in *Gudisia chapra* were lysine 937.39±162 μmol/L and proline 5163.12±3.1 μmol/L respectively. The total essential amino acid concentration in *B. chapra* was 2750.44±12.93 μmol/L, and the nonessential amino acid concentration was 8523.89±13.1μmol/L. In *N. nandus,* fourteen amino acids were detected, out of which seven amino acids were essential and seven were nonessential (Fig. 4). The most abundantly detected essential amino acid was lysine 980.34±0.98 μmol/L and the nonessential amino acid was proline 4484.93±2.54 μmol/L. The total essential amino acid concentration in *N. nandus* was 2534.41±4.77 μmol/L and the nonessential amino acid concentration was 8261.06±9.96 μmol/L. In *P. sophore,* fourteen amino acids were reported. Out of that, seven amino acids were essential and seven were nonessential amino acids (Fig. 5). The most abundant essential and nonessential amino acids were lysine 451.46±0.35 μmol/L and proline 2201.67±1.67 μmol/L, respectively. The total essential amino acid concentration in *P. sophore* was 1319.21±8.45 μmol/L, and the nonessential amino acid concentration was 4572.77±7.69 μmol/L.

Fatty acid profile

The fatty acid content of five sun-dried small indigenous fishes is shown in Table 2. A total of 23 fatty acids were detected, of which ten fatty acids are saturated, six are monounsaturated (MUFA) and seven were

Table 1. Concentration of essential and nonessential amino acids profile in five Small Indigenous Fish Species (SIS)

Sample	*Anabas testudineus*	*Barilius barila*	*Gudusia chapra*	*Nandus Nandus*	*Puntius sophore*
Essential Amino Acid (EAA)(μmol/L)					
Arg	495.97±0.47	510.09±0.16	491.24±0.55	416.85±0.55	222.37±0.97
His	228.81±0.94	226.93±0.39	145.92±2.32	260.95±0.72	92.68±1.24
Leu	209.97±0.3	238.99±1.54	BDL	173.99±0.68	126.84±0.68
Ile	BDL	BDL	237.42±2.76	BDL	BDL
Lys	1057.29±0.76	1055.75±1.32	937.39±1.62	980.34±0.98	451.46±0.35
Met	333.73±1.51	367.39±2.15	346.16±1.69	286.68±0.53	188.11±1.58
Phe	325.69±0.18	359.97±1.58	373.58±1.99	291.65±0.47	172.9±0.56
Thr	BDL	BDL	BDL	BDL	BDL
Val	136.77±1.58	180.74±0.46	190.66±1.04	123.95±0.84	64.85±3.07
Trp	BDL	BDL	28.07±0.96	BDL	BDL
∑EAA	2788.23±5.74	2939.86±7.6	2750.44±12.93	2534.41±4.77	1319.21±8.45
Nonessential Amino Acid (NEAA) (μmol/L)					
Ala	2420.26±0.89	2401.53±2.59	2532.84±2.4	1833.79±3.14	818.73±1.7
Asp	BDL	BDL	BDL	15.86±0.67	BDL
Cys	117.67±0.97	118.72±1.18	142.24±1.13	105.18±1.01	66.19±1.07
Glu	BDL	BDL	1760.9±1.76	BDL	930.33±1.3
Gly	171.39±1.53	173.18±1.97	185.17±2.37	149.4±1.17	78.9±0.65
Pro	4488.02±0.7	5525.28±1.3	5163.12±3.1	4484.93±2.54	2201.67±1.69
Ser	BDL	BDL	BDL	BDL	BDL
Gln	1678.85±1.14	1024.84±1.0	1016.69±1.68	1468.42±1.35	471.56±0.58
Tyr	226.68±0.95	242.08±1.54	255.77±0.66	203.48±0.08	5.39±0.7
Asn	BDL	BDL	BDL	BDL	BDL
∑NEAA	9141.48±6.18	9493.55±9.58	8523.89±13.1	8261.06±9.96	4572.77±7.69

Values are mean (±SD) of three replicates; BDL, Below detection Level

unsaturated (PUFA). The sum of SFA, MUFA, and PUFA of all studied SIS fish is shown in Fig. 7. The most abundant detected saturated fatty acid (SFA) was Palmitic acid (C16:0), followed by Myristic acid (C14:0), Arachidic acid (C20:0), Pentadecanoic acid (C15:0) Margaric acid (C17:0), Stearic acid (C18:0) and Tridecanoic acid (C13:0). Other SFA, Behenic acid (C22:0) and Lignoceric acid (C24:0) was detected very low amount.

The concentration of Palmitic acid (C16:0) ranged from 1.27±0.1% to 31.55±0.03%, which showed the highest concentration in *A. testudineus* followed by *B. barila* (1.83±0.4%) *N. nandus* (1.44±0.5%) and *P. sophore* (1.27±0.1%). In *G. chapra*, Palmitic acid was not detected. Myristic acid (C14:0) was detected as the second highest concentration among SFA in *A. testudineus* (30.42±0.5%) which is followed by *B. barila* (27.12±0.44%), *G. chapra* (25.02±0.07%), *N. nandus* (15.84±0.6%) and *P. sophore* (11.93±0.4%) respectively. Arachidic acid (C20:0) was the third-highest SFA found highest concentration in *B. barila* (9.79±0.1%) and detected very low amounts in other species. The fourth-highest abundant SFA, pentadecanoic acid (C15:0) was found to be highest in *G. chapra* (8.18±0.9%) and lowest in *A. testudineus* (0.55±0.3%). Margaric acid (C17:0) and Stearic acid (C18:0) were the fifth and sixth-highest abundant SFA found highest in *N. nandus.*

The most abundant monounsaturated fatty acid (MUFA) was Oleic acid (C18:1) followed by Palmitoleic acid (C16:1) and Erucic acid (C22:1), respectively. The concentration of Oleic acid (C18:1) ranged from 0.59±0.02% to 3.09±0.5%, which was found highest in *N. nandus* and lowest in *B. barila.* The other predominant MUFA are Palmitoleic acid (C16:1) and Erucic acid (C22:1), with concentrations shown in the range of 0.39±0.05% to 1.3±0.4% and 0.36±0.2% to 1.19±0.2% respectively. The other MUFAs which were detected in very low amounts in concentration were Heptadecenoic acid (C17:1) Eicosenoic acid (C20:1) and Nervonic acid (C24:1).

Among the n-3 Poly-unsaturated fatty acids (PUFAs), Linolenic Acid (C18:3n3) was the most abundant PUFA which was followed by Eicosapentaenoic acid (EPA, C20:5n3) and Docosahexaenoic acid (DHA, C22:6n3) respectively. The concentration of Linolenic Acid (C18:3n3) was found to be lowest in *B. barila* (0.16±0.1%) and highest in *A. testudineus* (24.09±0.5%). The concentration of EPA was 0.20±0.01% to 1.6±0.3%, which was highest in *B. barila*

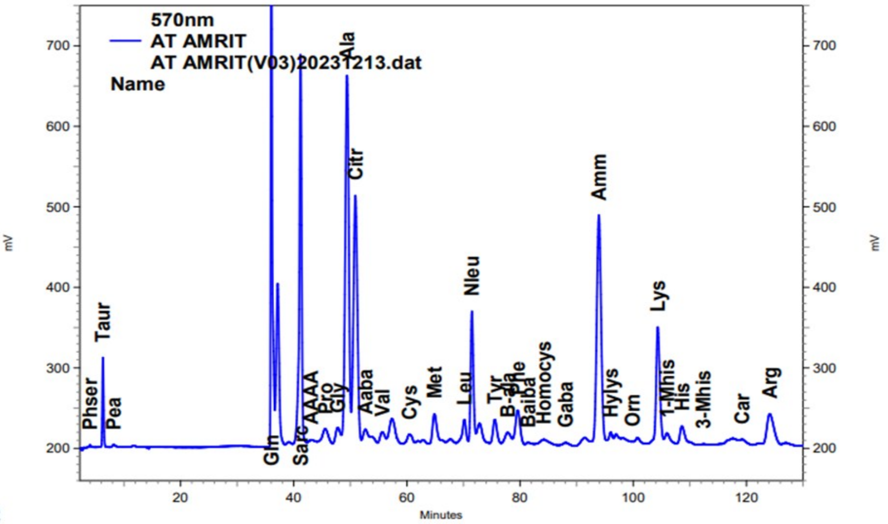

Fig. 1. *Amino acid analyzer chromatograms of Anabas testudineus*

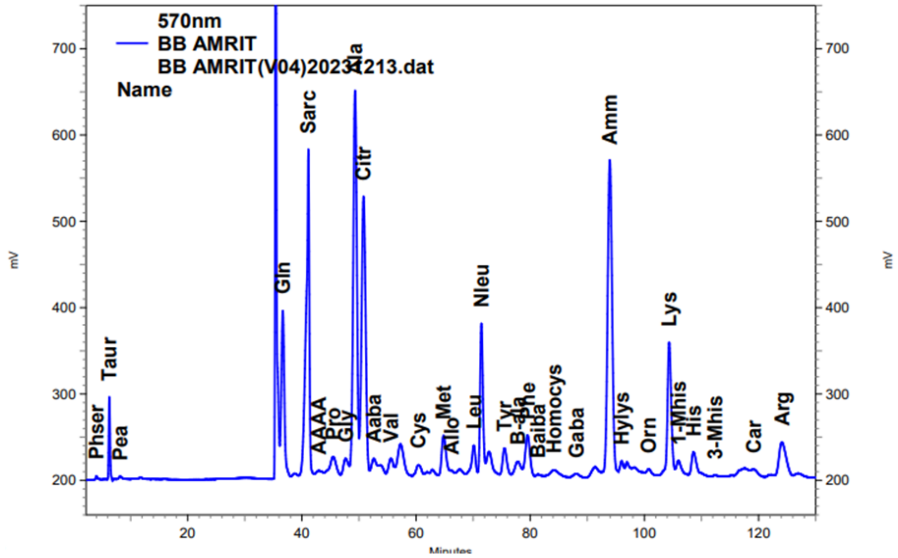

Fig. 2. *Amino acid analyzer chromatograms of Barilius barila*

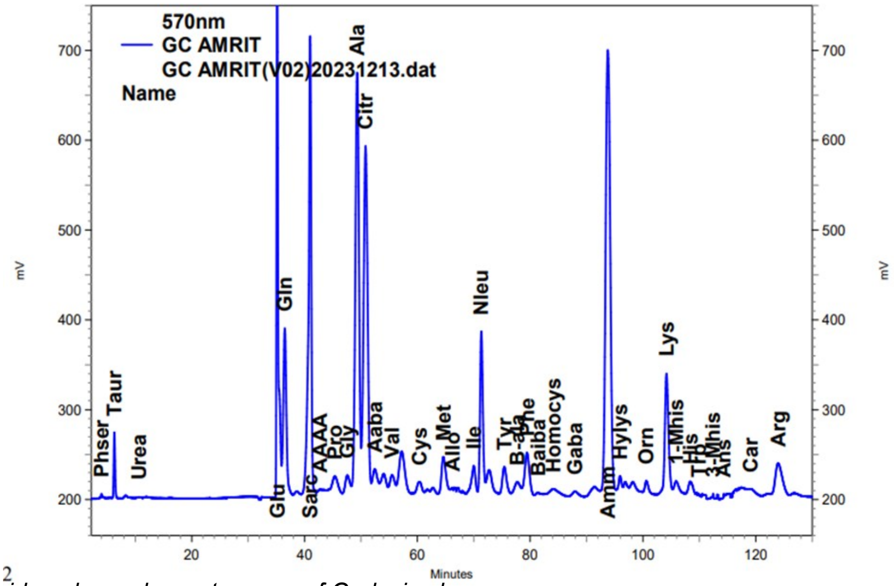

Fig. 3. *Amino acid analyzer chromatograms of Gudusia chapra*

Table 2. Concentration of fatty acids in five small Indigenous fish species (SIS)

Fatty acid	*Nandus nandus*	*Anabas testudineus*	*Barilius barila*	*Gudusia chapra*	*Puntius ophore*
Saturated fatty acid (SFA) (%)					
C12:0 (Lauric acid)	1.49±0.03	0.08±0.01	0.04±0.02	0.25±0.2	BDL
C13:0 (Tridecanoic acid)	1.73.±1.1	2.12±0.7	BDL	0.16±0.03	0.82±0.13
C14:0 (Myristic acid)	15.84±0.6	30.42±0.34	27.12±0.44	25.02±0.07	11.93±0.4
C15:0 (Pentadecanoic acid)	1.34±0.5	0.55±0.3	7.42±1.01	8.18±0.9	2.02±0.11
C16:0 (Palmitic acid)	1.44±0.5	31.55±0.03	1.83±0.4	BDL	1.27±0.1
C17:0 (Margaric acid)	4.87±0.8	BDL	BDL	BDL	0.32±0.01
C18:0 (Stearic acid)	2.81±1.3	0.55±0.2	1.23±0.5	0.1±0.01	BDL
C20:0 (Arachidic acid)	BDL	0.55±0.12	9.79±0.1	0.05±0.05	0.2±0.1
C22:0 (Behenic acid)	BDL	BDL	BDL	0.1±0.01	0.54±0.01
C24:0 (Lignoceric acid)	BDL	0.56±0.12	1.23±0.9	0.02±0.02	BDL
∑SFA	29.52±4.83	66.38±1.82	48.66±3.37	33.88±1.29	17.1±0.86
Monounsaturated fatty acid (MUFA) (%)					
C16:1 (Palmitoleic acid)	0.39±0.05	2.01±0.02	BDL	BDL	1.3±0.4
C17:1 (Heptadecenoic acid)	1.09±0.5	0.06±0.03	BDL	BDL	0.2±0.1
C18:1 (Oleic acid)	3.09±0.5	BDL	0.59±0.02	0.78±0.4	2.4±0.98
C20:1 (Eicosenoic acid)	0.13±0.03	0.21±0.2	0.28±0.5	1.11±0.3	BDL
C22:1 (Erucic acid)	1.19±0.2	BDL	BDL	BDL	0.36±0.2
C24:1(Nervonic acid)	BDL	BDL	BDL	0.33±0.2	0.24±0.11
∑MUFA	5.89±1.28	2.28±0.25	0.87±0.52	2.22±0.9	4.5±1.79
Poly-unsaturated Fatty acid (PUFA) (%)					
C18:2	BDL	0.08±0.1	BDL	0.32±0.2	0.83±0.6
C18:3 n-3 (Linolenic Acid)	1.39±0.3	24.09±0.5	0.16±0.1	0.34±0.2	5.1±0.7
C20:2 n-6 (Eicosadienoic acid)	BDL	BDL	0.07±0.1	0.23±0.2	BDL
C20:4 n-6 (Arachidonic acid)	0.05±0.01	BDL	BDL	1.5±0.3	2.1±0.3
C20:5 n-3 (EPA)	BDL	0.21±0.03	0.20±0.01	BDL	1.6±0.3
C22:4 n-6 (Adrenic acid)	BDL	BDL	0.23±0.01	0.34±0.1	BDL
C22:6 n-3 (DHA)	0.13±0.02	1.05±0.01	0.07±0.05	0.41±0.2	0.44±0.3
∑PUFA	1.57±0.33	25.43±0.64	0.73±0.27	3.14±1.2	10.07±2.2

Values are mean (±SD) of three replicates; BDL, Below detection Level

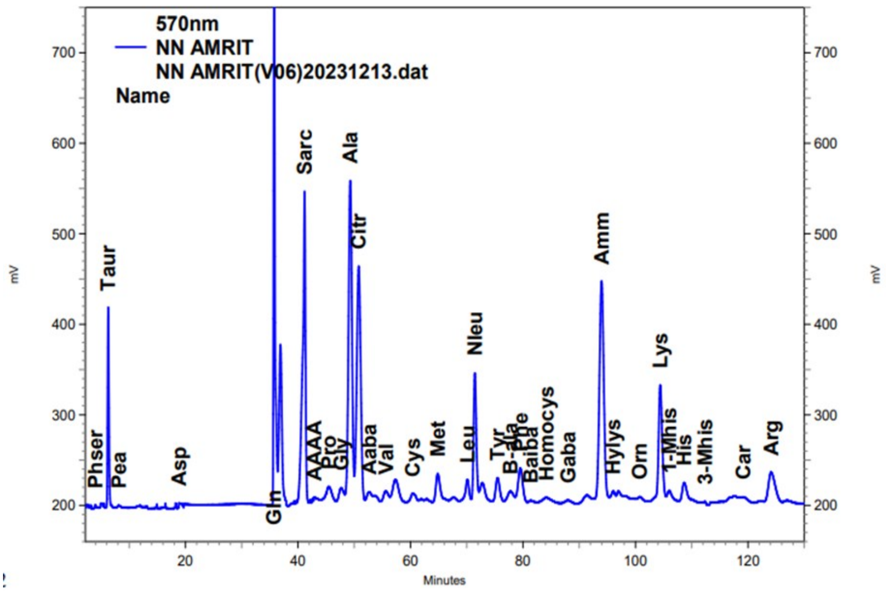

Fig. 4. *Amino acid analyzer chromatograms of Nandus nandus*

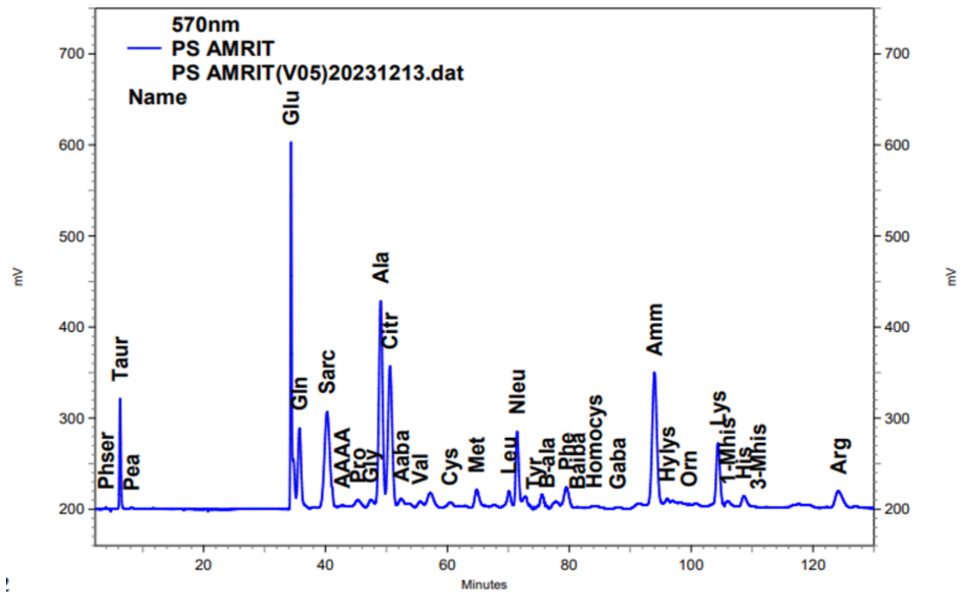

Fig. 5. *Amino acid analyzer chromatograms of Puntius sophore*

and lowest in *P. sophore*. The highest concentration of DHA was shown in *N. nandus* (0.13±0.02%) and lowest in *B. barila* (1.6±0.3%).

The most abundant n-6 PUFA was Arachidonic acid (C20:4n6), which was found highest in *P. sophore* (2.1±0.3%) and lowest in *N. nandus* (0.05±0.01%). However, other n-6 PUFAs, such as linoleic acid, eicosadienoic acid, and adrenic acid, have very low concentrations.

DISCUSSION

Fish protein is a significant and high-quality source of animal protein; studies have shown that it has a more satiating impact than other animal protein sources, such as beef and chicken. Fish is a more affordable source of protein than other animal sources, particularly in tropical areas (FAO, 2013; Uhe *et al.,* 1992; Ahmed *et al.,* 2022). This study reported that the most abundant essential amino acid was lysine among all the five small indigenous fish species (SIS), and the nonessential amino acid was proline. Lysine, an essential amino acid, is crucial for growth, and lack of it can cause immunodeficiency (Chen *et al*., 2003). It helps to prevent and heal cold sores. For this purpose, it can be administered orally or applied to the skin (Mohanty *et al*., 2014). The lysine concentration of all studied small indigenous fish ranged between 451.46±0.35 µmol/L to 1057.29±0.76 µmol/L. The highest lysine content was found in *A. testudineus* (1057.29±0.76 µmol/L) second highest in *B. barila* (1055.75±1.32 µmol/L) followed by *N. nandus* (980.34±0.98 µmol/L), *G. chapra* (937.39±1.62 µmol/L) and *P. sophore* (451.46±0.35 µmol/L). In contrast, the lysine content of *A. testudineus* reported by Mohanty *et al*., (2014) was 2045.9082 µmol/L, (8.2 ± 0.3%) which is comparatively higher than the present report. During the sun-drying process, heat causes a decrease in lysine content. High temperatures

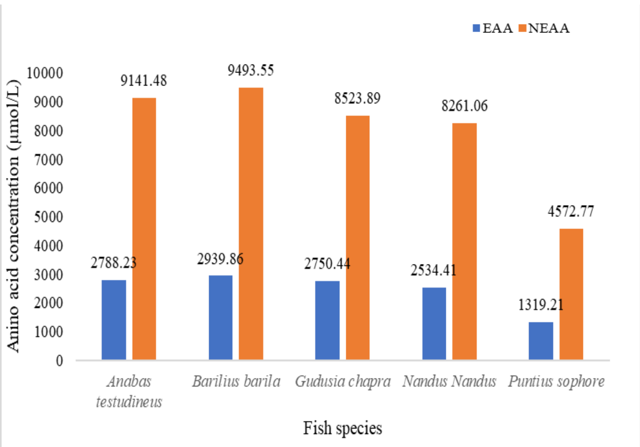

Fig. 6. *Total essential amino acid (EAA) and non essential amino acid (NEAA) concentration in five Small indigenous fish species (SIS)*

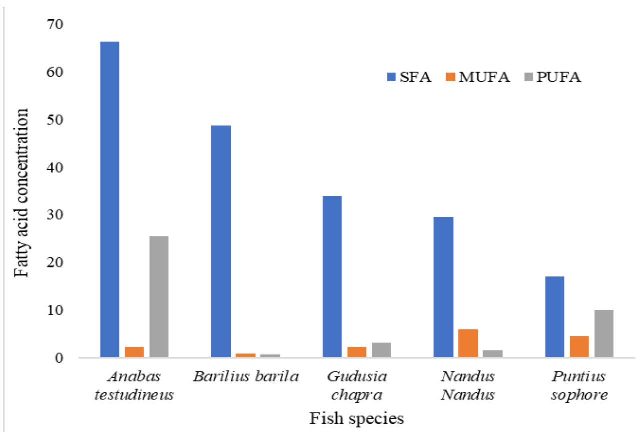

Fig. 7. *Total saturated fatty acid (SFA), monounsaturated fatty acid (MUFA) and polyunsaturated fatty acid (PUFA) concentration in five Small indigenous fish species (SIS)*

can lead to the degradation or alteration of amino acids; in the case of lysine, it is particularly susceptible to heat-induced changes. As a result, the amino acid structure may break down or undergo chemical reactions, reducing its overall concentration in the dried product. (Fitri *et al*., 2022; Kalita and Basumatari, 2024). The proline concentration ranged between 2201.67±1.69 µmol/L to 5525.28±1.3 µmol/L. The highest proline content was found in *B. barila* and the lowest in *P.* s*ophore*. Proline regulates important metabolic processes that enhance an organism's growth, development, lactation, reproduction, and overall health (Wu, 2010; Wu, 2013; Luo *et al.,* 2022).

This study identified alanine, glutamine, arginine, histidine, methionine, and phenylalanine as the dominant amino acids rather than lysine and proline. The highest glutamine content was found in *A. testudineus* (1678.85±1.14 µmol/L), followed by N. nandus (1468.42±1.35 µmol/L) and *B. barila* (1024.84±1.0 µmol/L). Luo *et al*., (2022) reported that lysine (Lys) is the most abundant essential amino acid (EAA) in *A. testudineus*, while glutamic acid (Glu) is the most abundant nonessential amino acid (NEAA). Methionine was most abundant in *B. barila* (367.39±2.15 µmol/L), while arginine peaked in *B. barila* (510.09±0.16 µmol/L) as well. *N.* nandus had the highest histidine content (260.95±0.72 µmol/L). Serine, threonine, and asparagine were absent in all five sun-dried fish samples, while isoleucine and tryptophan were detected only in sun-dried *G. chapra*. Additionally, glutamic acid was found only in *G. chapra* and *P. sophore*, and aspartic acid only in *N. nandus*. Kalita and Basumatari (2024) reported that the predominant essential and nonessential amino acids in sun-dried *P. sophore* as Histidine and Glutamic acid, respectively. Other studies have found that in dried P. sophore, Lysine is the predominant essential amino acid, with concentrations of 3.36 ± 0.15 g/100g, followed by Leucine at 3.00 ± 0.11 g/100g, corresponding to this study. In the case of sun-dried *P. sophore*, Glutamic acid is the dominant nonessential amino acid (5.76 ± 0.13 g/100g), followed by Glycine (3.22 ± 0.12 g/100g), in contrast, proline is the predominant NEAA in this study (De *et al*., 2019).All of the essential amino acids are present in dried fish, including sulfur-containing amino acids like cysteine and methionine, which are not found in plant protein, and methionine and lysine, which are not found in terrestrial animal protein. Fish and dried fish provide high-quality protein that contains all the essential amino acids necessary for body growth, maintaining lean muscle, supporting metabolism, repairing tissues, and preventing certain diseases (Rasul *et al.,* 2021).

Table 2 shows the fatty acid content of total lipids isolated from fish. A total of 30 fatty acids are isolated and grouped into three major classes, including saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and poly-unsaturated fatty acids (PUFAs). Fish lipids are rich in essential nutrients, especially n-3 polyunsaturated fatty acids (PUFAs), which have been shown to help prevent cardiovascular disease and other health issues. Marine fish lipids are distinct from other fats due to their higher levels of highly unsaturated and long-chain fatty acids. EPA and DHA, the key omega-3s found in fish and seafood, offer numerous health benefits (Pal *et al*., 2018; Rasul *et al*., 2021). DHA and EPA are used to prevent and reverse various clinical conditions like heart disease, asthma, cancer, lung diseases, SLE, high cholesterol, high blood pressure, psoriasis, rheumatoid arthritis, bipolar disorder, ulcerative colitis, and migraines (Mohanty *et al.,* 2016). Marine dried fish generally have a higher lipid content than freshwater dried fish, likely due to differences in the initial fat content of the raw materials used for processing. Fish fat content can vary based on factors like season, species, and maturity. Additionally, lipid oxidation contributes to variations in lipid content, with high oxidation levels observed in traditional dried fish products in Bangladesh (Majumdar *et al*., 2018; Rana *et al*., 2019; Rasul *et al*., 2020; Rasul *et al*., 2021; Khan *et al.,* 2024)

Palmitic acid (C16:0), Myristic acid (C14:0), Arachidic acid (C20:0), Pentadecanoic acid (C15:0) Margaric acid (C17:0), Stearic acid (C18:0) were determined as the most abundant saturated fatty acid in all of the examined species. According to Enrique *et al*. (2014), Palmitic acid (C16:0) was the most dominant SFA, followed by Stearic acid (C18:0) in four eastern central Pacific native fish species. Danielli *et al*., (2019) also found that C16:0 and C18:0 are the most common SFA in five species of pacu-pevas. Renata and Danuta (2017) reported a high concentration of both Palmitic acid (C16:0) and Stearic acid (C18:0) in grass carp, bighead carp and wels catfish. Islam *et al.* (2018) studied on the fatty acid profile of the fish species *Clarias batrachus* revealed palmitic acid as the most abundant (i.e., 37.41%), similar to this study. The myristic acid concentration of *P. sophore* in this study is 11.93±0.4% which is higher than the myristic acid concentration of *P. sophore* (7.57 ± 0.06%) reported by Mohanty *et al.* (2014). Oleic acid (C18:1n9) is the most common MUFA found in all studied fish. The amount of oleic acid in this study ranges between 0.59±0.02% to 3.09±0.5%, which is lower than the 28.63 ± 0.02% recorded by Mahanty *et al.,* (2014) in *Puntius sophore*.

The present study found that the examined fish species had lower levels of Omega-6 and Omega-3 fatty acids, which is agreed upon in the previous report by Chakrabarti *et al.* (2018). Although sun-drying has modified the composition of the fish, the current study demonstrates that sun-dried fish can effectively meet the body's requirements for various macro and micronutrients, contributing to overall health.

Conclusion

For many developed and developing countries, especially those with low incomes, dried fish is a more accessible and nutrient-rich source than fresh fish. It is a natural product and an important source of protein and fats. This study provides information about the amino acid and fatty acid profileof five sun-dried small Indigenous fish species (SIS) viz., *A. testudineus, B. barila, G. chapra, N. nandus* and *P. sopho*re. in Assam. Among all the studied SIS fish species, A. testudineus is the most significant in terms of amino acid and fatty acid content. According to the analysis, these fish species may be excellent providers of high-nutrient value. Therefore, these can be recommended as a healthy supplement to the human diet, an alternate source of protein, and another nutrient requirement.

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Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Ahmed I., Jan K., Fatma S., Dawood M. A. O. (2022). Muscle proximate composition of various food fish speciesand their nutritional significance: A review, *Journal of Animal Physiology and Animal nutrition,* 106 (3), 690-719. *DOI: 10.1111/jpn.13711*
2. Chen, C., Sander, J. E., & Dale, N. M. (2003). The effect of dietary lysine deficiency on the immune response to Newcastle disease vaccination in chickens. *Avian Diseases*, 47(4), 1346–1351. https://doi.org/10.1637/7008
3. Danielli, M.M., Tayz,F.R., Wande, M.B., Rozilaine,A.P.G. de F., Camila de S.P., Pete, B.F., Sandra, M. & 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
4. De, B., Das, S.R., Chakraborty, R., Choudhury, K., Kalita, P., Sen ,S. (2019). Nutritional assessment of certain dry fishes consumed by the tribal people of Tripura, India. *Annals: Food Science &Technology,* 20(4). DOI:10.59415/ijfas.v7i3.121
5. Enrique, M., Rao, K.S. and Durant, A.A. (2014) The lipid content and fatty acid composition of four eastern central Pacific native fish species. *Journal of Food Composition and Analysis.* 33,1–5. DOI: 10.1016/j.jfca.2013.08.007
6. European Food Safety Authority (EFSA) Scientific Opinion on Dietary Reference Values for zinc. EFSA. 2014;12:3844. doi: 10.2903/j.efsa.2014.3844.
7. FAO, IFAD, and WFP (2013). The State of Food Insecurity in the World 2013—The Multiple Dimensions of Food Security, FAO, Rome, Italy.
8. FAO/WHO (2011). Report of the Joint FAO–WHO Expert Consultation on the Risks and Benefits Associated with Fish Consumption. *FAO Fisheries and Aquaculture*. Technical Paper 978
9. Fitri, N., Chan, S. X. Y., Che Lah, N. H., Jam, F. A., Misnan, N. M., Kamal, N., Sarian, M. N., Mohd Lazaldin, M. A., Low, C. F., Hamezah, H. S., Rohani, E. R., Mediani, A., & Abas, F. (2022). A Comprehensive Review on the Processing of Dried Fish and the Associated Chemical and Nutritional Changes. *Foods,* 11(19), 2938. https://doi.org/10.3390/foods11192938
10. Jabeen, F. and Chaudhry, A. (2011). Chemical compositions and fatty acid profiles of three freshwater fish species. *Food Chemistry*. 125: 991-996. DOI: 10.1016/j.foodchem.2010.09.103
11. Jena, D., Jena, A. K., Panda, A., Parhi, J., Biswas, P., & Pattanaik, S. S. (2018). Proximate analysis of some small indigenous fish species (SIS) of Tripura, India. *Journal of Entomology and Zoology Studies*, 6(4), 470–474.
12. Kalita K., Basumatari D. and Ghosh S. S. (2024). Comparative proximate and mineral analysis of fresh and sun-dried fish species with special reference to *Puntius sophore* (Hamilton, 1822), *Gudusia chapra* (Hamilton, 1822), *Indian Hydrobiology*, 23(1): 87–98. 10.56557/upjoz/2024/v45i184423
13. Khan, M.A., Hossain, M.A., Chowdhury, M.A., Sultana, N., Begum, Islam, M.N. (2024) Nutritional Quality Assessment of Small Indigenous Fish Species (SIS) from the Mathabhanga River in Bangladesh. *Egyptian Journal of Aquatic Biology and Fisheries*, 28, 207- 216. https://doi.org/10.21608/EJABF.2024.346585
14. Kiczorowska, B., Samolińska, W., Grela, E. R., & Bik-Małodzińska, M. (2019). Nutrient and Mineral Profile of Chosen Fresh and Smoked Fish. *Nutrients*, 11(7), 1448. https://doi.org/10.3390/nu11071448.
15. Lopez, M. J., & Mohiuddin, S. S. (2023). Biochemistry, Essential Amino Acids. In StatPearls. StatPearls Publishing.
16. Luo, Q. , Zha, G. , Lin, L. , Huang, Y. , Zou, X. (2022). Comparison of physicochemical properties of different tissues from China climbing perch Anabas testudineus and crucian carp *Carassius auratus*. *Food Science & Nutrition*, 10, 936–944. https://doi.org/10.1002/fsn3.2727
17. Mahanty, A., Ganguly, S., Verma, A., Sahoo, S., Mitra, P., Paria, P., Sharma, A.P., Singh, B.K., Mohanty, B.P. (2014). Nutrient profile of small indigenous fish *Puntius sophore*: Proximate composition, amino acid, fatty acid and micronutrient profiles. *National Academy Science Letters*, 37(1),39–44. DOI: 10.1007/s40009-013-0186-3
18. Majumdar, B.C.; Afrin, F.; Rasul, M.G.; Shaha, D.C. and

Shah, A.K.M.A. (2018). Changes in physicochemical, microbiological, and sensory properties of sun-dried *Mystus vittatus* during storage at ambient temperature. *Fishes*, 3(3), 32. DOI: 10.3390/fishes3030032
19. Mohanty, B.P., Pati, M.K., Bhattacharjee, S., Hajra, A., Sharma, A.P. (2013). Small indigenous fishes and their importance in human health. *Advances in Fish Research*, 5:257- 278.
20. Mohanty, B., Mahanty, A., Ganguly, S., Sankar, T. V., Chakraborty, K., Rangasamy, A., Paul, B., Sarma, D., Mathew, S., Asha, K. K., Behera, B., Aftabuddin, M., Debnath, D., Vijayagopal, P., Sridhar, N., Akhtar, M. S., Sahi, N., Mitra, T., Banerjee, S., Paria, P., … Sharma, A. P. (2014). Amino Acid compositions of 27 food fishes and their importance in clinical nutrition. *Journal of Amino acids*, 2014, 269797. https://doi.org/10.1155/2014/269797
21. Mohanty, B.P. and Singh, S.D. (2018). Fish and human nutrition.*Aquaculture in India*,Narendra Publishing House: New Delhi, India, pp. 561–581.
22. Mohanty, B.P., Ganguly, S., Mahanty, A., Sankar, T.V., *et al*. (2016). DHA and EPA content and fatty acid profile of 39 food fishes from India, *BioMed Research International*, 2016:4027437. http://dx.doi.org/10.1155/2016/4027437
23. Nath, K.D., Nickhil C., Borah D., Pandiselvam R., & Sankar Chandra Deka S. C. (2024). Preparation, characterization, and nutritional analysis of Napham: An Indian traditional smoke-dried-fermented fish paste', *Journal of Food Biochemistry*, pp. 1–11. doi:10.1155/2024/7410065.
24. Pegu, A. Kalita R., Das P. & 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
25. Rasul, M.G.; Yuan, C. and Shah, A.K.M.A. (2020). Chemical and microbiological hazards of dried fishes in Bangladesh: A food safety concern. *Food and Nutrition Sciences*, 11(6), 523-539. DOI: 10.4236/fns.2020.116037
26. 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. doi: 10.21608/ejabf.2021.189666
27. Renata, P.A. and Danuta, K.P. (2017). Fatty acid profile of fat of grass carp, bighead carp, Siberian sturgeon, and Wels catfish. *Journal of Food Quality*. Volume 2017, Article ID 5718125, 6 pages.
28. Roos, N., Wahab, M. A., Chamnan, C., & Thilsted, S. H. (2007). The role of fish in food-based strategies to combat vitamin A and mineral deficiencies in developing countries. The Journal of nutrition, 137(4), 1106–1109. https://doi.org/10.1093/jn/137.4.1106Singh H.R. (2020). Biochemical composition and nutritional properties of some coldwater fishes of Manipur (Ph.D. thesis). Department Of Life Sciences, Manipur University.
29. Singh K.B. (2023). Evaluation of nutritional and toxicological profiles of ice-packed fishes available in Imphal, Manipur, Manipur University.
30. Singh M. S. (2020). Studies on nutritional qualities of some small indigenous fishes of Manipur, (Ph.D. thesis) Department of Life Sciences, Manipur University.
31. Talwar PK, Jhingran AG. (1991). *Inland fishes of India and adjacent countries*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi; 1:525.
32. Uhe, A.M., Collier, G.R. and O'Dea, K. (1992).A comparison of the effects of beef, chicken and fish protein on satiety and amino acid profiles in lean male subjects. *The Journal of Nutrition,* 122(3), 467–472. doi:10.1093/jn/122.3.467.
33. USDA (2015-20). U.S. Department of Health and Human Services and U.S. Department of Agriculture 2015–2020 Dietary Guidelines for Americans. 8th Edition.
34. Wang, W., Wu, Z., Dai, Z., Yang, Y., Wang, J., & Wu, G. (2013). Glycine metabolism in animals and humans: implications for nutrition and health. *Amino acids*, 45(3), 463–477. https://doi.org/10.1007/s00726-013-1493-1
35. WHO (2022). Obesity and overweight. WHO. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight
36. Wu G. (2010). Functional amino acids in growth, reproduction, and health. *Advances in nutrition (Bethesda, Md.)*, *1*(1), 31–37. https://doi.org/10.3945/an.110.1008Wu G. (2013). Functional amino acids in nutrition and health. *Amino acids*, *45*(3), 407–411. https://doi.org/10.1007/s00726-013-1500-6Islam, 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(5): 723. DOI: 10.4172/2155-9600.1000723
37. Zhang, H., Wang, Z. Y., Yang, X., Zhao, H. T., Zhang, Y. C., Dong, A. J., Jing, J., & Wang, J. (2014). Determination of free amino acids and 18 elements in freeze-dried strawberry and blueberry fruit using an Amino Acid Analyzer and ICP-MS with micro-wave digestion. *Food Chemistry,* 147, 189–194. https://doi.org/10.1016/j.foodchem.2013.09.118