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Review Article

Nutritional composition of Indian freshwater fishes and their health benefits

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Fish are recognised as a crucial nutritional source of high-quality proteins, lipids, amino acids, minerals, and vitamins vital for human health. This review synthesises data from studies published between 2009 and 2023 on Indian freshwater fish species, highlighting significant interspecies variability in proximate and micronutrient composition. The objectives of this review are to summarise and compare proteins, lipids, amino acids, and vitamin content. *Chara punctatus* had the highest protein content (22.75%), and *Barbodes sarana* had the highest lipid content (9.5%). There were 83.8% essential amino acids in *Cirrhinus mrigala*, and *Puntius saphore* displayed the highest vitamin A (~861.38 mg/100 g) and vitamin E content (~30685.8 mg/100 g), while *Sperata seenghala* had the highest vitamin D (~18737.51 mg/100 g) and vitamin K content (~16670.12 mg/100 g) in the considered list of fish species. These findings indicate that regular inclusion of these species in daily diets can mitigate protein-energy malnutrition and micronutrient deficiencies. These data provide valuable information for meal planning, promoting public health initiatives, and facilitating further research in aquaculture and nutrition. However, knowledge gaps persist in understanding nutritional bioavailability, the impacts of processing, and the standardisation of nutrient assessment. This review provides a comprehensive reference for nutrition-sensitive aquaculture, dietary planning and national food security plans in India.

Keywords: *freshwater fish, nutritional composition, protein, lipids, vitamins, amino acids*

Introduction

Nutrients are essential for the body to remain healthy, grow, heal, and remain strong. It is usually obtained from dietary resources (Khalili Tilami & Sampels, 2018). They are categorised as macronutrients, proteins, fats, lipids, micronutrients, vitamins, and minerals. Both are necessary for maintaining bodily functions (Taşğin, 2017). Fish are often considered an excellent source of essential nutrients required by the human body, constituting a major part of the wholesome diet (Balami et al., 2019). More than a billion people worldwide depend on fish for food and living (Pauly & Zeller, 2017; Kumar et al., 2018). In India alone, 14.5 million people depend on fish for their livelihood (Bhatt et al., 2016). Fish have been acknowledged for a long time, not just for their excellent flavour and easy digestibility, but also for their exceptional nutritional value, including polyunsaturated fatty acids, essential amino acids, and important minerals (Paul et al., 2016). Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are important ω-3 fatty acids and their precursor is alpha linoleic acid (Chen et al., 2022), are present in reasonable amounts in fish. These compounds are particularly beneficial, playing key roles in maintaining cell membranes (Tocher, 2003) and structural integrity, and aiding in the adequate functioning of the brain and retina (Hei, 2020). These fatty acids also function as signalling molecules (Surette, 2008; Calder, 2010; Hou et al., 2015) and building blocks for anti-inflammatory substances (De Caterina & Massaro, 2005; Calder, 2015). They protect against heart and brain diseases (Moyad, 2005; Gebauer et al., 2006) and improve health and well-being (Nichols et al., 2014). Along with lipids, high-quality animal proteins containing essential amino acids needed for the human body can be derived from fish (Boyd et al., 2022; Singh

et al 2025). Protein levels in fish usually range from 15% to 25%. These levels vary across species and are affected by factors such as age, sex, weight, eating habits, and other environmental conditions (Romharsha & Sarojnalini, 2019). A mere 140 g of fish provide 50% to 60% of the protein you need daily, highlighting its importance in global nutrition. Small native fish are an excellent source of essential micronutrients (Byrd et al., 2021). These important micronutrients can help solve people's "hidden hunger" and stop many diseases that can occur when people do not get enough of them (Nazir et al., 2021). Although marine fish are nutritionally superior, freshwater fish are more widely available and consumed in many regions. Because India has many ecosystems and rivers, freshwater fish is significant for the country's fish production. India ranks second in the world in terms of fish farming and production. Over 80% of the country's freshwater fish yield comes from carps, such as *Catla* sp. and *Mrigal* sp., as well as some exotic carp, such as grass carp and silver carp (Paul & Giri, 2015; Das & Mishra, 2016; Sharma et al., 2018). By 2070, Rohu is expected to be responsible for approximately 35% of all carp caught in freshwater (Mohanta et al., 2008).

The objectives of this review are to summarise and compare the protein, lipid, amino-acid, and vitamin composition of Indian freshwater fishes and to highlight their implications for human nutrition and public health. This review synthesises relevant literature published in the past 15 years (2009-2023) on the protein, lipid, amino acid, and vitamin composition of Indian freshwater fishes through Google Scholar, Research Rabbit, PubMed, Research Gate, Embase, Web of Science, Scopus, and peer-reviewed journals, using keywords such as 'Freshwater fishes,' 'Proximate composition,' 'Protein,' 'Lipids,' 'Amino acids,' 'Vitamins,' and 'Indian River Habitats' (Figure 1). The main inclusion criteria were quantitative and qualitative data on Indian freshwater species. Only peer-reviewed journal articles providing original nutritional composition data were included, while studies without quantitative data, non-peer-reviewed articles, and papers limited to marine species and the effects of different diets on nutritional composition were omitted. This review uses a methodical screening and evaluation process to identify the most nutritionally valuable freshwater fish species, giving readers a perspective on the dietary significance and potential benefits.

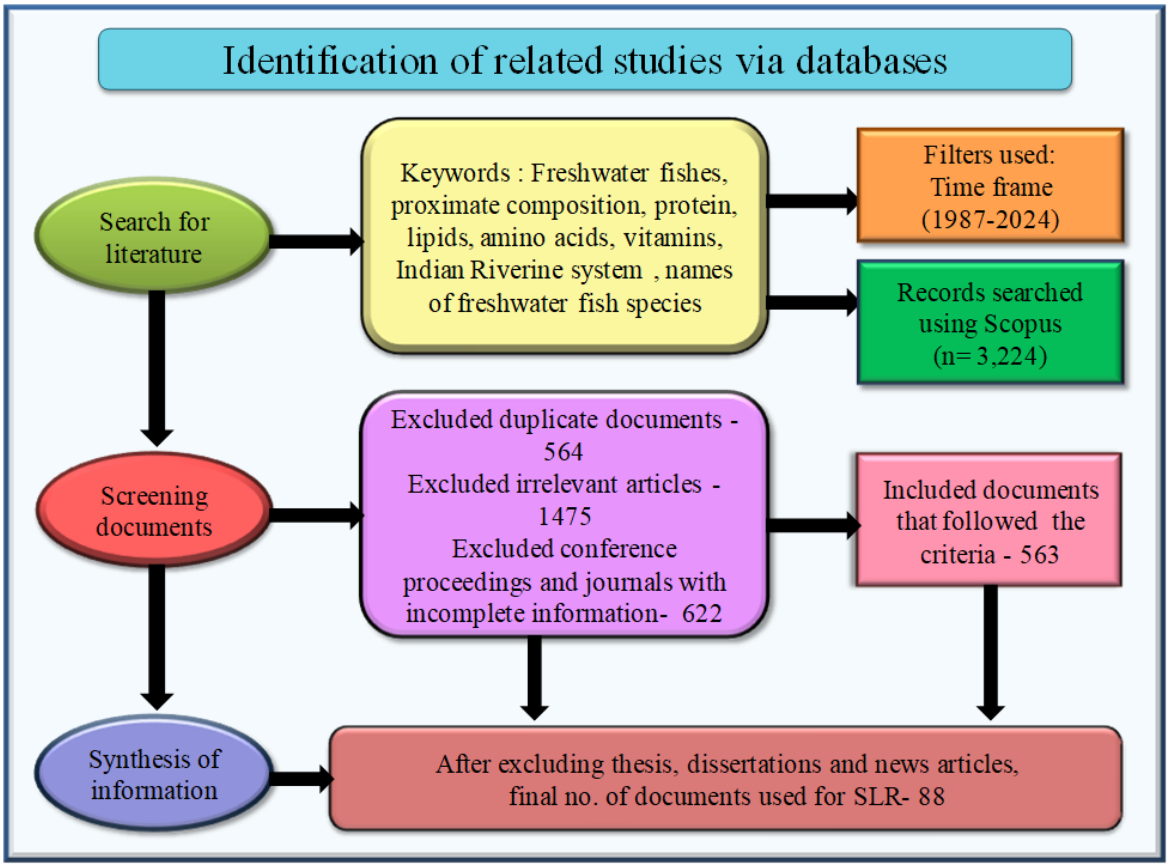

Figure 1. Literature review conducted by applying the PRISMA Methodology

Protein

Proteins are vital nutrients required by the human body to ensure the smooth operation of essential functions such as muscle development, hormone regulation, cellular repair, and overall good health (Sanz et al., 2000; Roefs et al., 2020; van Wijnen et al., 2021; Nunes et al., 2022). Proteins are composed of approximately 20 different building blocks

known as amino acids. Nine are known to be "indispensable amino acids" because the human body cannot synthesise them; thus, they must be derived from dietary components (Akram et al., 2011). Key essential amino acids include valine, methionine, phenylalanine, threonine, lysine, histidine, and tryptophan (Sheeshka & Murkin, 2002; Hou & Wu, 2018). Fish protein is considered to be of good quality and biological importance, as it encompasses all the essential and functional amino acids necessary for sustaining physiological functions and life (Mohanty et al., 2019). Furthermore, proteins are rich in nitrogen, which is crucial for the synthesis of various compounds indispensable for growth and development (Yu & Fukagawa, 2020). Proteins have various essential functions and can be classified into several categories. Enzymes that facilitate most biochemical reactions in the human body are primarily composed of proteins. Numerous hormones, such as the growth hormone somatotropin, thyroid hormones, and insulin, contain protein constituents (Gancheva et al., 2019). Transport proteins, including albumin, transferrin, and haemoglobin, are responsible for transporting crucial molecules throughout the body (Debnath et al., 2014). Furthermore, structural proteins are integral to the development of muscles and connective tissues. Proteins produce antibodies and immunoglobulins and thus are an integral component of the immune system (Keyt et al., 2020). The amount and relative ratios of essential amino acids and the availability and digestibility of proteins were the main factors used to evaluate their standards. The total amount of protein required by an individual is affected by factors such as weight, height, caloric consumption, and overall health status (Sheeshka & Murkin, 2002). Animal sources, particularly fish, are recognised as complete protein sources because they provide essential amino acids in sufficient amounts (Pawar & Sonawane, 2013).

Protein content in freshwater fishes varies considerably (Figure 2). Generally, major carps show 18-21% protein, catfishes 17-20%, and small indigenous species 19-23%, depending on species, habitat, diet, and environmental conditions (Mohanty et al., 2016; Ahmed et al., 2022). *Channa punctatus* exhibited the protein content (22.75%) (Goyal et al., 2015), followed by *Channa gachua* (21.41%) and *Notopterus notopterus* exhibits relatively lower levels (18.28%) (Chakraborty et al., 2015). Other species, including *Rita rita*, contain 19.50% protein (Mohanty et al., 2016), whereas *Barbus putitora* has a protein content of 19.37% (Ahmed et al., 2022). *Sperata seenghala* was reported to contain 19.00% protein (Mohanty et al., 2016). *Oreochromis niloticus* has a protein level of 18.80% (Geremew et al., 2020), whereas that of *Clarias magur* is 18.75%. *Cirrhinus mrigala* has a protein content of 18.74% (Ahmed et al., 2022). Thus, freshwater fish serve as accessible and affordable sources of high-quality protein that can significantly contribute to dietary protein security in developing regions.

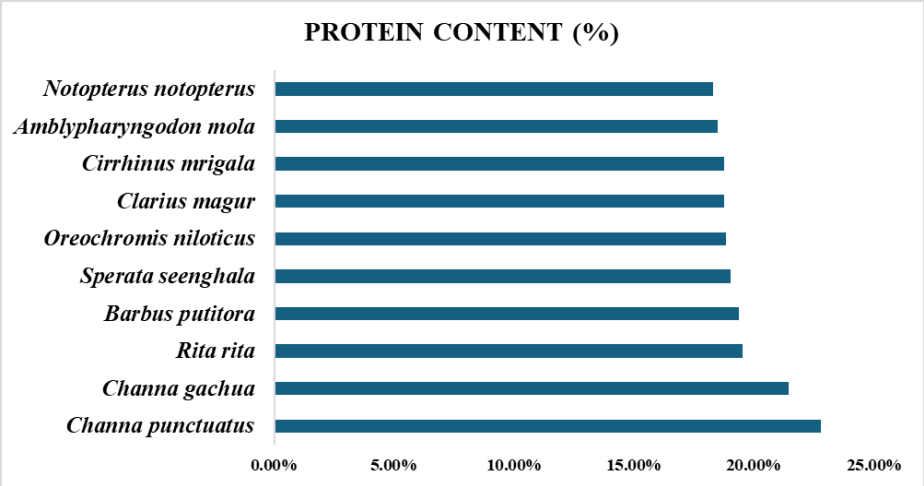

Figure 2. Variation in reported protein content (%) among selected Indian freshwater fish species

Compared to mutton, beef, and chicken, fish provide a greater satiety effect and are less expensive (Balami et al. 2019). Fish muscles have a relatively low content of connective tissue, which makes them an excellent source of high-quality protein, with digestibility rates exceeding 90%. Regular fish consumption can help alleviate protein deficiency-related disorders, affecting approximately 870 million individuals worldwide (Mohanty et al., 2015). In India, freshwater fish serve as an affordable and highly nutritious source of animal protein, contributing significantly to public food security (Aon et al., 2014; Dey et al., 2017).

Amino Acids

Amino acids are important molecules that aid in different metabolic processes and are the basic building blocks of proteins (Häusler et al., 2014). They are essential for synthesising neurotransmitters, peptide hormones, and nucleotides

(Dalangin et al., 2020) and play a crucial role in cell signalling, gene expression, protein phosphorylation, nutrient transport, and immune responses (Kimball & Jefferson, 2004; Mahanty et al., 2014; Paudel et al., 2021).

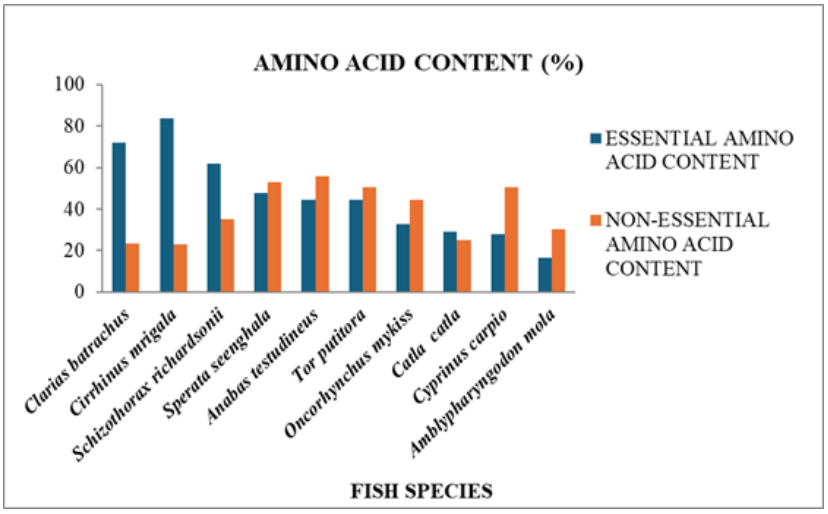

Figure 3. Essential and Non-Essential Amino Acid Content (%) of Selected Freshwater Fish Species of the Indian Region

Fish proteins are important for health because they contain sufficient essential amino acids, such as methionine, lysine, histidine, threonine, and valine, which help to produce growth hormones, produce energy, build muscles, absorb calcium, support the immune system, aid digestion, and improve sleep quality. Non-essential amino acids, such as glycine, glutamine, glutamate, proline, and arginine, are crucial for gene expression, blood circulation, metabolism, and cellular signalling (Relekar et al., 2024). A well-balanced diet containing adequate amino acids is necessary for efficient protein utilisation. Restricting essential amino acids can limit protein synthesis, whereas excess amino acids can lead to metabolic stress and poor protein absorption. The digestible indispensable amino acid score measures how well a protein is by examining how well the body can digest its amino acids and how available they are for use (Brestenský et al., 2019). The total percentage of essential amino acids is 40.41% in freshwater species (Saad & Alim, 2015). The amino acid profile of freshwater fishes demonstrates wide interspecies variability (Figure 3). All amino acid values are expressed as a percentage of total amino acid composition (%). *Cirrhinus mrigala* (mrigal fish) had the most essential amino acids at [83.8±5.36], followed by *Clarias batrachus* at [72.05±4.96] and *Schizothorax richardsonii* at [62.02±0.012]. *Amblypharyngodon mola* had the lowest EAA content [16.71±0.22] (Mohanty et al., 2014; Joshi et al., 2018; Kalita & Basumatari, 2024). In contrast, non-essential amino acids were found to have the highest amount in *Anabas testudineus* at 55.8±0.091, followed by *Sperata seenghala* at 52.91±0.61 and *Cyprinus carpio* at 50.53±4.09, while *Cirrhinus mrigala* had the lowest amount at 23.1±2.62%.

Lipid

One of the most valuable substances obtained from the muscles of fish is lipids, which serve as energy storage and fundamental building blocks of cellular biological membranes (Rochette et al., 2023). Lipids, composed of long-chain hydrocarbon groups, originate from living organisms and act as the primary source of cellular energy, which can be preserved now and can be used in future (Aon et al., 2014). Lipids also form a protective barrier that isolates living cells from the external environment and aids in the structural maintenance of cells in animals and plants. Across different species, the lipid composition also differs and is affected by factors such as season, what kind of food fish take in, and which habitat fish occupy (Maurya et al., 2018). Odd-numbered fatty acids, such as heptadecanoic and heptadecenoic acid, can improve the body's response to insulin and reduce the risk of developing type-2 diabetes. They are found in significant amounts in lipids (Al Solami & Korish, 2024). Polyunsaturated fatty acids (PUFAs), particularly n-6 and n-3, are essential to human health and are abundant in fish. ω-3 fatty acids are present in significant quantities in fish flesh and oils, including docosahexaenoic acid (DHA, 22:6n-3), eicosapentaenoic acid (EPA, 20:5n-3), and α-linolenic acid, which are their precursors. Fish contain higher levels of n-3 PUFAs than beef and chicken do. PUFAs are recognised for their cardioprotective, anti-arrhythmic, anti-atherosclerotic, and antithrombotic properties (Sanderson et al., 2002; Calder, 2004; Givens et al., 2006). Additionally, they help regulate cholesterol and prostaglandin production, aid in wound healing, and stabilise the electrical activity of heart cells. Fish with a high n-3: n-6 ratio is considered the most beneficial flesh for human health (Jakhar et al., 2012). *Cirrhinus mrigala* exhibits an n-3: n-6 ratio of approximately 1.8, indicating a favourable lipid profile for cardiovascular protection (Dhaneesh et al., 2012). Salmonids and freshwater fish demonstrate a remarkable ability to biosynthesise LC-PUFA, converting C18 PUFAs, such as α-linolenic acid (ALA,

18:3n-3) and linoleic acid (LA, 18:2n-6) into bioactive forms, including n-3 EPA, DHA, and n-6 arachidonic acid (ARA, 20:4n-6) (Naylor et al., 2009). PUFA composition varies among fish species, with freshwater fish containing significant amounts of PUFAs, such as EPA and DHA, as well as MUFAs, including palmitoleic and oleic acid, which may reduce the risk of coronary heart disease (Kharazmi-Khorassani et al., 2021). The predominant saturated FAs in fish lipids are myristic acid (C14:0), palmitic acid (C16:0), and stearic acid (C18:0) (Jakhar et al., 2012).

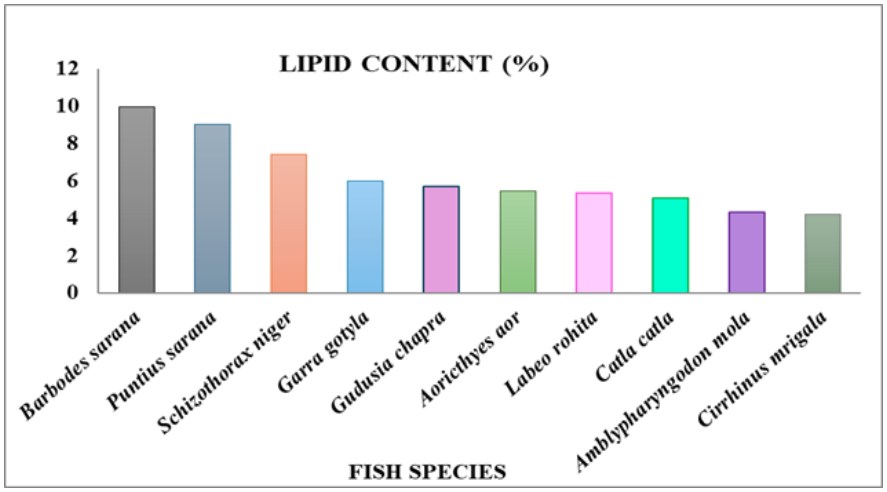

Figure 4. Lipid content (%) of the most potent fishes from the selected freshwater fish species

The lipid content of freshwater fish species also varies considerably. Reports indicate that *Barbodes sarana* contains higher lipid levels (9.95%) (Hussain et al., 2016), followed by *Puntius sarana* (9.00%) and *Cirrhinus mrigala* exhibits diminished amounts (4.19%) (Figure 4). Additional species, including *Schizothorax niger*, have 7.24% lipid content (Gul et al., 2017), whereas *Garra gotyla*, a freshwater fish found in northern Indian streams, has 6.00% lipid content. *Gudusia chapra* contains 5.70% lipids (Mohanty et al., 2016), whereas *Aoricthyes aor* contains 5.46% lipids (Hussain et al., 2016). *Labeo rohita* contains 5.36% lipids, whereas *Catla catla* contains 5.06% lipids (Hussain et al., 2016). The ninth- and tenth-highest lipid contents were recorded in *Amblypharyngodon mola* (4.30%) and *Cirrhinus mrigala* (4.19%). Among these, *Labeo rohita*, *Catla catla*, *A. mola*, and *Cirrhinus mrigala* are recognised as freshwater fish with moderate lipid contents, typically ranging between 0.40 and 5.30%. A previous study found that mrigal contains the most arachidonic acid, which is important for the production of essential prostaglandins (Paul et al., 2015). EPA and DHA play important roles in retinal health and brain development (Dhaneesh et al., 2012). Fish oils are rich in ω-3 fatty acids and have numerous health benefits, including a reduction in the risk of attention deficit hyperactivity disorder (ADHD), cardiovascular issues, hypertension, atherosclerosis in adults, asthma in children, and dementia and age-related macular degeneration (AMD) (Lawrenson & Evans, 2015; Mohanty et al., 2015; Muley et al., 2015; Bowen et al., 2016; Burckhardt et al., 2016; Zehr & Walker, 2017; Agostoni et al., 2017; Eltweri et al., 2017; Chang et al., 2018; Bercea et al., 2021).

Vitamins

Fish provide all the vitamins considered important for a healthy body, with specific vitamin levels varying by species. They are a rich source of B group and fat-soluble vitamins A, E, K, and D. These vitamins contribute to growth, bone and tooth development, vision improvement, immune system support, and cell regeneration (Balami et al., 2019). Vitamin D is crucial in bone health, immunity, and calcium absorption. The human body produces vitamin D after exposure to sunlight. However, deficiency is linked to osteomalacia, osteoporosis, rickets, reduced bone mineral density (BMD), fractures, and increased risk of diabetes (Badoni et al., 2021; Romharsha & Sarojnalini, 2019). Fish consumption helps prevent malnutrition in children and pregnant women by providing sufficient levels of vitamins A, D, and B. Vitamin A, a group of compounds known as retinoids, supports immune function, vision, and skin health. Vitamin deficiency may result in hair loss, vision impairment, weakened immunity, and skin disorders (Romharsha & Sarojnalini, 2019). After UV exposure, fish can synthesise vitamins from 7-dehydrocholesterol to produce vitamin D (ergocalciferol). Fatty fish are particularly rich in vitamins A and D, which are essential for children's growth, whereas white fish provide a plentiful supply of B-group vitamins (Badoni et al., 2021). Fish vitamin A is more bioavailable than plant-based sources and is vital for bone development and normal vision. Retinoic acid, a form of vitamin A, plays several biological roles. Vitamin E is essential for immune functions, capillary permeability, heart muscle activity, and red blood cell stability. As lipid-soluble vitamins, they protect lipids, lipoproteins, and biological membranes from oxidation. Its primary function is to protect unsaturated fatty acids from free radical-induced. (Mohanty et al., 2012).

Freshwater fishes are also a valuable source of fat-soluble vitamins (Table 1). Literature reports indicate that *Puntius saphore* had the highest vitamin A content (~861.38 mg/100 g) and vitamin E content (30685.8 mg/100 g) (Mohanty et al., 2014). *Sperata seenghala* has the highest vitamin D content (~ 406.66 mg/100 g), and vitamin K levels (~ 16670.12 mg/100 g) (Mahanty et al., 2014; Mohanty et al., 2012, 2016). Other fish, such as *Cirrhinus mrigala*, *Oncorhynchus mykiss*, and *Heteropneustes fossilis*, also show high levels of vitamins (Harlioglu, 2012; Khatun et al., 2024; Paul et al., 2017).

Table 1. Reported Vitamin content of selected Indian Freshwater fish Species

S.No.	Fish species	Vitamin A (mg/100 g)	Vitamin D (mg/100 g)	Vitamin E (mg/100 g)	Vitamin K (mg/100 g)	References
1.	*Puntius saphore*	~861.38	~406.66	~30685.8	~8842	(Mohanty et al., 2014)
2.	*Sperata seenghala*	~168.73	~406.66	~8654.25	~16670.1	(Mohanty et al., 2012)
3.	*Tenualosa ilisha*	~0.7129	~0.1336	~841.545	~1.1638	(Alam et al., 2012)
4.	*Amblypharyngodon mola*	~0.1665	~2.3280	~1.4762	~4092.2	(Mohanty et al., 2016)
5.	*Anabas testudineus*	~0.02817	~0.00107	~0.8523	~0.00115	(Paul et al., 2017)
6.	*Heteropneustes fossilis*	~0.01747	~0.00410	~0.2751	~0.00041	(Khatun et al., 2024)
7.	*Onchorhynchus mykiss*	~0.0124	~0.0132	~0.714	~0.392	(Harlioglu, 2012)
8.	*Cirrhinus mrigala*	~0.00138	~0.0013	~0.3893	~0.00015	(Paul et al., 2017)
9.	*Clarias batrachus*	~0.00117	~0.00077	~0.2013	~0.0004	(Mohanty et al., 2016)
10.	*Labeo rohita*	~0.00096	~0.00077	~0.10738	~0.00016	(Paul et al., 2016)

The role of fish in enhancing human life

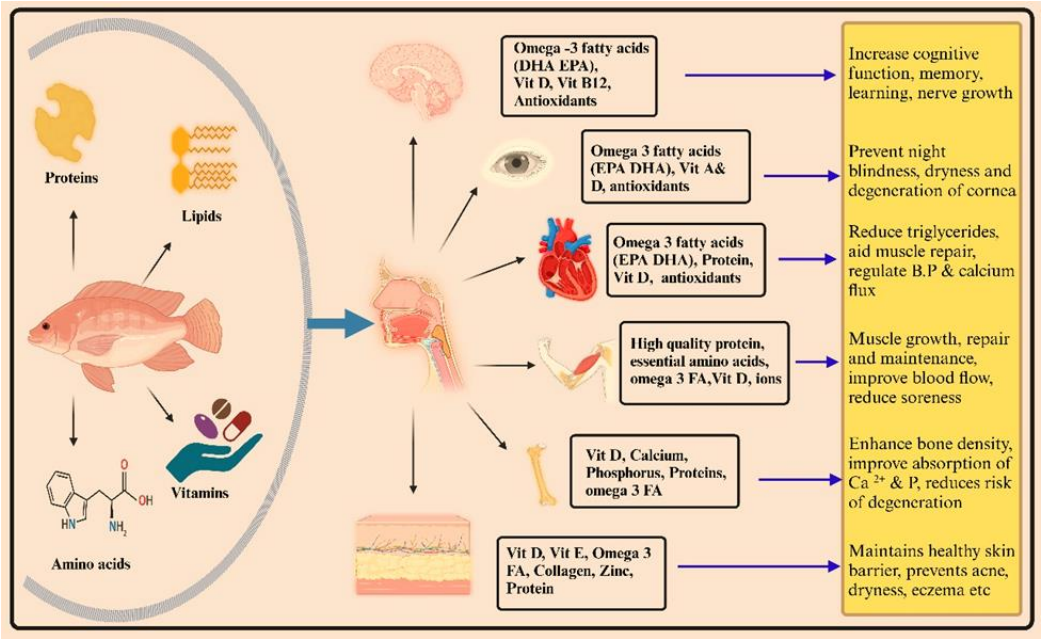

Figure 5. Representation of the significant role fish can play in the enhancement of human life and disease prevention by providing important nutritional elements

Global fish production is estimated at 167.2 million tons, with 146.3 million tons believed to be utilised for human consumption. The increasing demand for fish and fishery products is due to their rich nutritional profile (Maurya et al., 2018). Fish are functional foods that offer health benefits beyond basic nutrition. Fish provide essential nutrients that help combat protein-energy malnutrition (PEM) (Figure 5), support muscle growth and repair, and strengthen the heart and bones (Debnath et al., 2014). Fish lipids supply essential fatty acids, especially omega-3 fatty acids, which promote the production of high levels of EPA and DHA. These compounds play a critical role in brain function by reducing triglycerides, lowering cholesterol levels, and lowering the risk of developing heart disease. Omega-3 fatty acids also

enhance metabolism in the body (Sanderson et al., 2002; Calder, 2004; Givens et al., 2006). Both essential and nonessential amino acids in fish contribute to vital body functions, supporting growth, repair, maintenance, and protein synthesis (Diaz de Barboza et al., 2015; Kelly & Pearce, 2020; Ma & Ma, 2019; Kamei et al., 2020; Zhao et al., 2020). Additionally, fish provide a rich source of micronutrients, including vitamins, zinc, selenium, calcium, phosphorus, and antioxidants, which benefit vision and help prevent various deficiency-related diseases (Romharsha & Sarojnalini, 2019). The nutrient composition data compiled in this review can directly inform dietary planning frameworks, public-health initiatives, and aquaculture policies. Emphasising nutrient-rich species in community nutrition programs and mid-day meal schemes could enhance protein and micronutrient intake in vulnerable populations. Such data-driven nutritional insights can support national dietary guidelines, strengthen mid-day meal programs, and improve community-level nutrition outcomes.

Research gaps and future directions

Despite extensive documentation of proximate and micronutrient composition in selected freshwater species, significant gaps persist. Studies on nutrient bioavailability are limited; future research ought to assess the impact of cooking, preservation, and processing on the retention and absorption of nutrients derived from fish. The majority of accessible data pertains to a limited number of widely consumed species, whereas several indigenous and underutilised freshwater fish remain inadequately defined. Additionally, limited research has linked nutrient composition with health outcomes in human populations. Addressing these gaps will enhance scientific comprehension, facilitate the creation of nutrient databases, guide direct aquaculture production, and inform nutrition and public health policies.

Conclusion

This review highlights the nutritional composition of various freshwater fish species, focusing on their nutritional benefits. The findings support previous studies confirming freshwater fish as vital sources of high-quality protein, essential amino acids, and PUFAs. *Channa punctatus* exhibited the highest protein content, and *Barbodes sarana* showed the highest lipid content. *Puntius saphore* and *Sperata seenghala* are abundant in vitamins, and *Cirrhinus mrigala* are rich in essential amino acids. Future incorporation of nutrient-rich freshwater fish into nutrition-sensitive aquaculture and food policies can address protein-energy malnutrition and micronutrient deficits. The outcome of this review aligns with previously existing nutritional theories, reinforcing and establishing the understanding of the dietary significance of freshwater fishes and emphasising the need for standardised nutrient databases to enable accurate nutritional evaluation and policy formulation.

Author contributions

RK, HK: conceptualisation, drafting of the manuscript, overall coordination of the review work.
SD, AS: collection, organisation, and critical evaluation of published literature. **DM, KT**: analysis and interpretation of nutritional composition data and assistance in manuscript refinement. **KT, HK**: final editing and review of the manuscript.

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Conflict of interest

The authors declare no conflicts of interest. The research was conducted independently without any financial or personal relationships that could have influenced the results or interpretations presented in this paper.

Ethics approval

Not applicable.

AI tool usage declaration

No AI and associated tools are used for writing scientific content in the article.

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