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Review Article

CURRENT PERSPECTIVE ON OMEGA-3 FATTY ACIDS IN FRESHWATER FISH FROM INDIA: A REVIEW OF SCIENTIFIC PROGRESS

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ABSTRACT

Omega-3 fatty acids, especially docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), are critical for important physiological activities including foetal brain and infant eye development, lipid metabolism, and cognitive health. They also help guard against chronic diseases such as atherosclerosis, dementia, rheumatoid arthritis, and Alzheimer's. Since these fatty acids cannot be synthesized predominantly in the body, their dietary supplementation is necessary, and the quest for affordable sources is a key focus of public health. Fish is a significant source of omega-3 polyunsaturated fatty acids (PUFAs) and offers a diverse range of options based on cost and availability. India, with its rich biodiversity, offers a diverse range of freshwater fish species with varying nutrient profiles. This review compiles recent data on omega-3 fatty acid content in Indian freshwater fish, highlighting species-specific variations, geographical differences, and environmental influences on fatty acid levels. It also focuses on the nutritional value of omega-3 fatty acids in Indian diets and public health. The overall objective of this review was to encourage further research and to advocate for the inclusion of high omega-3 fish in dietary guidelines.

Keywords: Chronic diseases, Freshwater fish, Lipid, Omega-3 fatty acid, PUFA.

INTRODUCTION

Fish are highly nutritious and easily digestible. Due to their low energy content and favourable amino acid composition, fish offer significant nutritional benefits. Globally, Asia accounted for 70% of the world's production of aquatic animals, followed by America (13%), Europe (9 %), Africa (7 %), and Oceania (1%) (FAO, 2024). Out of 70%, India contributes 10.3% share in the worldwide aquaculture production of aquatic animals. In India, 13,254 thousand tonnes of aquatic foods and fish have been produced, where fish proteins share 2.5 grams/ person/ day out of 67.8 total proteins (share of fish proteins over total protein 3.6%) (FAO, 2024). In this world of a predominantly processed food diet, the levels of omega-3 FAs have dropped in many diets along with source ALA (18:3n-3), which is mostly found in vegetable oils but lacks EPA (C20:5n-3) and DHA (22:6n-3) (Olgunoglu, 2017). It has been reported that both EPA & DHA are essential for child brain development by generating neuroprotective metabolites and also lowering the risk of premature deaths (Kidd, 2007). Apart from their neuroprotective effect, EPA reduces the risk of ischemic heart disease (IHD) while DPA lowers the likelihood of developing congestive heart failure (Bhatt *et al*., 2019; Singh *et al*., 2016; Sun *et al*., 2008; Mozaffarian *et al*., 2011) and DHA decreases triglycerides, inflammation markers, and reduces the risk of endothelial dysfunction (Fahs *et al*., 2010; Honda *et al*., 2015; Qi *et al*., 2008; Wang *et al*., 2017; Yang *et al*., 2013). In animals, omega-3 FAs are metabolized from their precursors EFAs, obtained from dietary sources, as they cannot be synthesized de novo inside the human body. The primary EFAs include LA and ALA, which serve as precursors of omega-3 and omega-6 FA families (Figure 1).

Importance of n-3 fatty acids in diet

The significance of PUFAs was first recognized in studies of rats, in which their deficiency produced several

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physiological problems (Spector & Kim, 2015). The benefits of DHA and EPA for health were first discovered in Greenland, and the continued abundance of marine fish stocks and their long-standing availability to fish oils have helped their highly developed and prosperous cultures (Ackman *et al*., 2002). Freshwater fish are an important dietary source of the fatty acids EPA and DHA, especially in countries like India, where fish-based diets are popular. EPA and DHA are fascinated by cognitive functions, visual acuity and skeletal or muscle mass/function of skeletal to muscle mass. They may also prevent sarcopenia and cancer cachexia (Troesch *et al*., 2020). Additionally, it was mentioned previously that omega-3 fatty acids may impede muscle loss during stress states. EPA and DHA have within them anti-inflammatory properties and "may" stimulate muscle protein synthesis, which has great effects on one's physical performance and quality of life as they age (Troesch *et al*., 2020). Both EPA and DHA have been found to possess therapeutic potential within clinical scenarios for inflammatory disorders (e.g., arthritis), mental health disorders (i.e., depression, schizophrenia), which is important considering the potential benefit for COVID-19 symptoms due to the immune-modulating implications of EPA and DHA (Djuricic & Calder, 2021).

Biophysical and antioxidant properties of PUFAs

PUFAs are essential in membrane biophysics because of their structural diversity and their impact on membrane shape and dynamics. The PUFAs of greatest interest are omega-3 fatty acids: EPA, DHA and omega-6 fatty acids: AA. In general, different fatty acids vary in fatty acid length, hydrocarbon chain length, and the number and position of double bonds within the hydrocarbon chain. The cardiorespiratory biophysical behavior and function of fatty acids within membranes is very different because of these factors. As an example, saturated fatty acids = 18:0, n3-FA DHA = 22:6, and EPA = 20:5; the latter has an additional 2 carbons and 1 more double bond than EPA. The degree of unsaturation in PUFAs influences membrane fluidity. Highly unsaturated PUFAs, such as DHA, with six double bonds, increase membrane fluidity more than less unsaturated ones like EPA (five double bonds) and AA (four double bonds). DHA has been shown to significantly decrease membrane order and increase lipid bilayer disorder, which impacts processes like membrane protein function and cell signaling.

EPA has many unsaturations, but it seems to have an even lesser effect on membrane fluidity than DHA, yet it has more stability than AA and is perhaps beneficial to cardiovascular health. Sherratt *et al*. (2016) observed that DHA increased the fluidity of membranes and cholesterol domain formation much greater than EPA and their use of fluorescence anisotropy and examination of rotational correlation indicated that the steepest decline in rotational correlation was with DHA rather than EPA. The antioxidant potential of PUFAs is dependent on their structure. Generally, EPA shows a stronger antioxidant effect than DHA and the other PUFAs. Both can reduce lipid oxidation; however, DHA has a greater effect on bilayer width and reducing rotational correlation (Sherratt *et al*., 2016). Omega-3 supplementation also causes antioxidant enzymes (such as, SOD2) in the liver and uterus to increase, improving resistance to oxidative stress through dietary means (Garrel *et al*., 2012). Because EPA has a longer half-life of antioxidant protection than DHA, it showed a greater efficacy in protecting LDL oxidation than DHA (Sherratt *et al*., 2022).

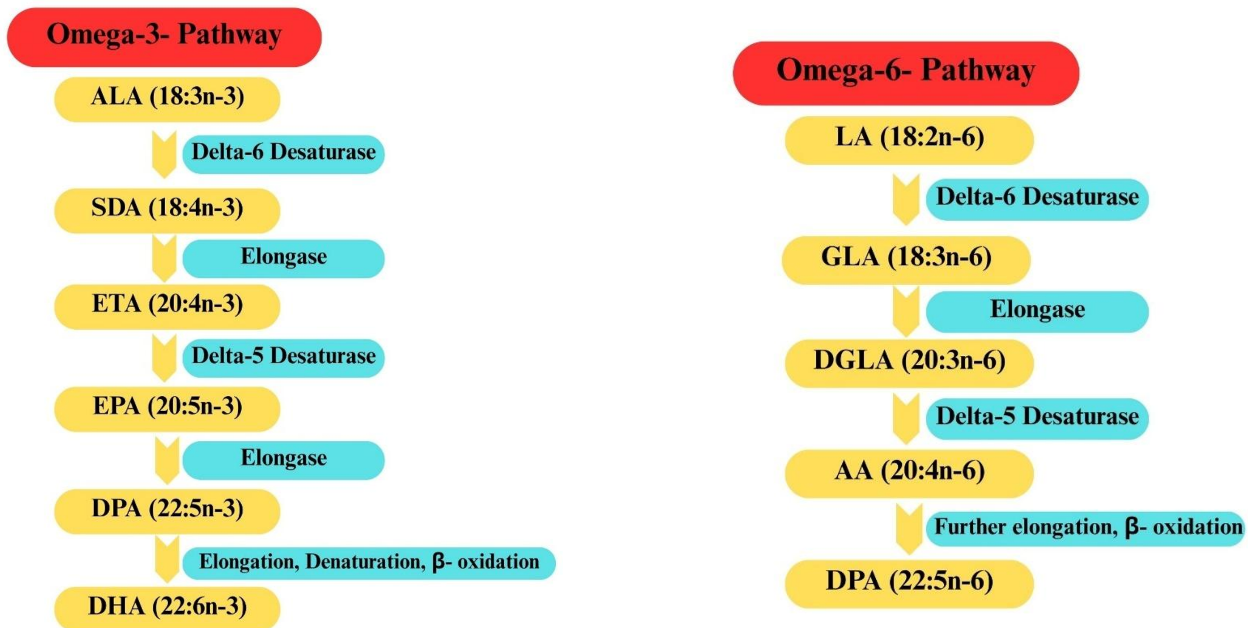

Figure 1. Polyunsaturated fatty acids (PUFAs) categories: omega-3 and omega-6 families.

Omega-3 PUFA and Human Health

Anti-inflammation properties of PUFAs

The active omega-3 fatty acids EPA and DHA have been extensively studied, and their very strong anti-inflammatory capability is well established. They have several anti-inflammatory mechanisms, beginning when EPA and DHA are incorporated into cell membranes. They disrupt membrane fluidity, impacting the signaling processes leading to inflammation. For example, DHA can reduce lipid raft formation by 30%, resulting in dramatically decreased signaling processes that lead to pro-inflammatory pathways (Shaikh *et al*., 2009). Omega-3 specific fatty acids also have action on the pro-inflammatory pathway NF-κB, which controls genes that produce inflammatory cytokines such as TNF-α, IL-1β and IL-6 (Inoue *et al*., 2017) and by activating nuclear receptors (PPARs) that suppress inflammatory cytokines (Coniglio & Shumskaya, 2023). EPA and DHA have the capacity to generate specialized molecules such as resolvins, protectins, and maresins that help return tissue to homeostasis by helping clear inflammatory cells (Dalli *et al*., 2013; Y. Wang *et al*., 2021). For example, resolvins can halt neutrophil migration and inhibit pro-inflammatory cytokines (Sansbury & Spite, 2016). Omega-3s also repurpose immune cells, for example, by switching polarized macrophages from an M1 pro-inflammatory state to the M2 anti-inflammatory state to promote healing and suppress chronic inflammation (Xu *et al*., 2021).

DHA, EPA, and CVDs

According to the WHO, CVDs accounted for 32% of global mortality in 2019, which is nearly 17.9 million people, over 75% of which occurred in low- and middle-income countries (WHO, 2021). Patients with diabetes or metabolic disease have high triglyceride-rich lipoproteins (TGRLs), and this class of lipoproteins increases acquired CVD risk (Ganda *et al*., 2018). There is evidence that omega-3 fatty acids, mainly EPA, can continue to reduce this risk even with controlled LDL-C levels and increased triglycerides (Sherratt *et al*., 2023). Omega-3s can have anti-triglyceride actions by promoting fatty acid oxidation, decreasing hepatic TG synthesis, and potentially inhibiting diacylglycerol acyltransferase enzyme (DGAT). Omega-3s can also decrease VLDL, activate GPR120, promoting fat metabolism, and act as peroxisome proliferator-activated receptor (PPAR) agonists, regulating pathways involved with lipid metabolism and inflammation (Oscarsson & Hurt-Camejo, 2017; Shearer *et al*., 2008). The EPA also enhances cholesterol efflux via ABCA1, whereas DHA is less effective in regulating it (Sherratt *et al*., 2023). In clinical trials, EPA (in the form of icosapent ethyl or IPE) reduces atherothrombotic cardiovascular (CV) events and events such as atherosclerosis much more effectively than DHA, lowers apoC3 and improves endothelial function by increasing NO and decreasing stress but DHA does not appear to have this same effect (Pisaniello *et al*., 2020; Sherratt *et al*., 2022).

DHA, EPA and Brain Development and Cognition

Omega-3 fatty acids, primarily DHA and EPA are necessary for brain development and healthy lifelong functioning (Djuricic & Calder, 2021). Omega-3 fatty acids maintain cell fluidity, promote neuronal signaling, and reduce inflammation (Djuricic and Calder, 2021). DHA is one of the most abundant molecules in the brain and retina; it is essential for the brain's neuroplasticity, neural signaling and vision (Lauritzen *et al*., 2001; Salem *et al*., 2001). DHA and AA are transported to the fetus and consumed for brain creation during pregnancy; though typically, maternal stores of DHA and AA are depleted in the process, which highlights the importance of adequate intake (Al *et al*., 1995; Kuipers *et al*., 2011). Low omega-3 levels in mothers increased mothers' risk of perinatal depression and lower omega-3 levels increased the risk of children having impaired cognition (von Schacky, 2020). When mothers took DHA during pregnancy, it led to an increase in brain volume and cognitive outcomes in babies (Gould *et al*., 2013; Ogundipe *et al*., 2018). Low levels of DHA, EPA, and AA were associated with autism for those already diagnosed with the condition; supplementation with omega-3s may be useful for improving social behavior of those diagnosed (Mazahery *et al*., 2017). In older adults, a higher intake of omega-3 fatty acids is associated with improved memory, decreased risk of dementia and Alzheimer’s disease (Schaefer *et al*., 2006). The early initiation of taking omega-3 supplements and consistent supplementation in middle age and older life is likely to help sustain brain health across life stages (Burckhardt *et al*., 2015; Coley *et al*., 2018).

Omega-3 and Neurological Diseases

Bioactive compounds called polyunsaturated fatty acids (PUFAs) lower inflammation and control gene activity to help protect the brain. Movement issues and low dopamine are caused by the death of nerve cells in the substantia nigra in Parkinson's disease (PD) (Kousparou *et al*., 2023). According to research, omega-3 PUFAs, particularly DHA, can help maintain the health of neurons and their membranes and slow the progression of symptoms (Kousparou *et al*., 2023). According to a study, PD patients who took Neuroaspis PLP10®, a supplement high in omega-3, omega-6 and gamma-tocopherol, in addition to their regular treatment, saw a slower rate of disease progression (Pantzaris *et al*., 2021).

By lowering oxidative stress and inflammation, two major contributors to ALS, omega-3 polyunsaturated fatty acids may help reduce the risk of the disease and slow its progression (Fitzgerald *et al*., 2014). Despite the paucity of research, some studies indicate that a higher omega-3 intake may reduce the risk of developing ALS (Torres *et al*., 2020). Autoimmune-driven inflammation leading to neuronal demyelination is a key feature of multiple sclerosis. TNF-α and interleukins are two inflammatory cytokines involved in the pathophysiology of multiple sclerosis, and DHA and EPA reduce them. Omega-3 PUFAs may help MS patients experience fewer and milder relapses by supporting neuronal repair and decreasing inflammation (Pantzaris *et al*., 2013; Weinstock-Guttman *et al*., 2005).

Omega-3 and Cancer Cachexia

Omega-3 fatty acids, particularly DHA and EPA, may reduce cancer cachexia largely because of their anti-inflammatory activity. Evidence suggests that supplementation stabilizes weight, improves lean body mass and improves the quality of life in cancer patients (Arends *et al*., 2017). However, there is still limited evidence on survival rates and toxicity during treatment. To gain significant muscle mass appears to require higher doses, such as 1000 mg/day DHA and 2200 mg/day EPA (Van Der Meij *et al*., 2010). Omega-3 PUFAs may also serve as adjuncts to chemotherapy as they enhance tumor response and inhibit toxicity (de Aguiar Pastore Silva *et al*., 2015). More evidence is required to determine these effects and how best to achieve them. Managing cancer cachexia looks most promising with early interventions, higher doses of omega-3s and a mix of nutrition, exercise and medications.

n-3 and n-6 Fatty acids in Freshwater Fish species

The fat content in fish varies significantly, ranging from as little as a few percent to over 20%. As a result, fish can be categorized into lean types up to 5% fat and fatty fish can have up to 20% fat content (Kępińska-pacelik & Biel, 2024). For example, rohu and Common carp can be categorized as low-fat fishes, while tilapia, mrigal and catla as very low-fat fishes (Swapna *et al*., 2010). Generally, the composition of fatty acids in fish is influenced by various factors, including species, diet, captured area, temperature and season. In cultured fish, the fat content is strongly dependent on the feed it receives. All fish species contain EPA and DHA, but the levels of these substances vary significantly among and within species. In comparison to marine species, freshwater fish contain a lesser amount of lipids (Kępińska-pacelik & Biel, 2024). Although they have a lower lipid content, making them easy to digest, they are still rich in omega-3 fatty acids. These fish meats are also high in protein content, with very high digestibility, which helps maintain the protein requirements in our bodies. The fat content among freshwater fish varies from species to species, as depicted in Table 1. The table comprises 28 freshwater fish species with their protein and lipid content (% w/w) from various reports.

Table 1. n-3 and n-6 fatty acid profiling in Freshwater fish in India.

Fish Species	Protein Content (%w/w)	Lipid content (% w/w)	EPA (% of total lipid extract)	DPA (% of total lipid extract)	DHA (% of total lipid extract)	References
Ailia coila	12.9	1.8	2.2	-	3.1	(Mohanty *et al*., 2016)
Amblypharyngodon mola	16.3	4.3	-	-	9.3	
Anabas testudineus	16.9	6.9	0.4	-	2.7	
Catla catla	16.2	2.8	6.8	-	4.7	
Cirrhinus mrigala	15.5	2.8	1.5	-	-	
Clarias batrachus	16.4	3.7	-	-	0.5	
Gudusia chapra	14.1	5.7	9.8	-	6.0	
Heteropneustes fossilis	16.3	2.7	1.5	-	2.2	
Labeo rohita	15.9	2.7	0.9	-	0.4	
Puntius sophore	16.3	4.9	6.2	-	3.3	
Rita rita	19.5	1.6	3.8	-	5.0	
Sperata seenghala	19.0	0.8	4.4	-	6.2	
Tenualosa ilisha	20.7	10.5	2.9	-	8.9	
Xenentodon cancila	15.7	0.7	0.4	-	0.1	
Pangasianodon hypophthalamus	13.60	4.98	1.93	-	4.48	(Jakhar *et al*., 2012)
Oreochromis mossambicus	-	10.8	9.1	13.1	16.9	(Swapna *et al*., 2010)
Cyprinus Carpio	-	23.6	10.5	6.1	18.6	
Mystus vittatus	14.94	6.91	1.61	-	2.3	(Paul *et al*., 2018)
Ompok bimaculatus	13.93	3.92	0.13	-	4.8	
Channa striata	14.46	2.09	4.81	-	4.78	
Wallago attu	14.13	3.58	2.80	-	0.31	
Johnius gangeticus	-	6.71	3.59	-	3.18	(Nath *et al*., 2014)
Clupisoma garua	-	2.42	0.40	0.48	2.05	
Eutropiicthys vacha	-	0.53	4.17	1.23	4.52	
Pseudapocryptes	-	0.78	10.32	3.06	8.07	

lanceolatus						
Scomberomorus commerson	-	8.82	62.30	1.82		(Rajaram *et al*., 2018)
Labio bata	-	10.05	7.5	3.9	3	(Ackman *et al*., 2002)
Labeo calbasu	-	6.8	1.2	2.9	2.1	

Optimal Daily Intake of EPA and DHA

Sufficient amounts of EPA and DHA are important for heart health, brain health, and health in general. The American Heart Association recommends that people get at least 500 mg of summed EPA+DHA per day, ideally from fish, to support general cardiovascular health, or about 1 g/day of EPA+DHA for those with documented coronary heart disease (Froyen & Maarafi, 2022). General recommendations for healthy adults tend to land in the 250 – 500 mg/day range and show a connection with lower cardiovascular risk (Racey *et al*., 2021). For brain-related benefits and cognitive outcomes, particularly in aged populations and during pregnancy, two servings of fatty fish per week (approximately ~500 to 1000 mg EPA+DHA per day) is associated with better cognitive performance and less risk of a later diagnosis of neurodegenerative disease (Lehner *et al*., 2021). Pregnant and lactating women should aim for between 200 and 300 mg DHA per day and although there are different opinions on how and which forms of Omega-3 EPA+DHA work, it is still generally supported that between 600 and 800 mg of EPA+DHA daily should provide sufficient dietary support for brain development and to prevent preterm birth (von Schacky, 2020). Dietary omega-3 supplements have also been shown to be beneficial for alleviating symptoms of rheumatoid arthritis by attenuating inflammatory cytokines and modulating the function of the patient. EPA, DHA and LA intake also contributes to the influence of pathways in human cellular and molecular interactions related to brain disorders (Kousparou *et al*., 2023) and high-dose omega-3s are being studied for safety and efficacy in severe traumatic brain injury and hypoxic brain injury recovery (Bailes *et al*., 2020).

CONCLUSION

This review contends that omega-3 fatty acids are essential polyunsaturated fatty acids that are essential for human health, especially EPA and DHA, which are involved in brain function, cardiovascular health, and cellular functions. Since these essential fatty acids cannot be synthesized in the human body, dietary sources of these fatty acids are the only source. Freshwater fish can be a very practical food source for everyone wishing to obtain a relatively easy and natural source of omega-3 fatty acids in the diet. To maximize the benefits of omega-3 fatty acids in the diet, incorporating many varieties of fish in the diet ensures adequate and appropriately balanced consumption of the levels of these essential fatty acids needed to support mental and physical health. Thus, it can be inferred that including freshwater fish as a food source in the diet may help to support cognitive function and enhance health for everyone.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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