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LIPID HEALTH INDEX IN FISH and NUTRACEUTICAL NUTRITION

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Özet

Gıda kaynaklarımızdan balık ve diğer su ürünleri, içerdiği terapötik etkilere sahip biyotik bileşenler nedeniyle insan sağlığı ve beslenmesi açısından günümüzdeki önemi giderek artmaktadır. Yağ asitleri, enerji verici özelikleriyle birlikte vücut metabolizmasında düzenleyicilik ve sinyal iletişimi gibi çeşitli fonksiyonları vardır. Su ürünleri, içerdiği sağlık ve besin kalite değerleri yanı sıra uygun fiyatlı olması nedeniyle de tercih edilmiştir. Balıklar, kapsadığı fosfolipit, çoklu doymamış yağ asitleri ve mineral maddeler nedeniyle temel besin kaynağıdır. Balık ve deniz ürünleri, EPA ve DHA gibi önemli yağ asitleri içerir.

Balıklarla ilgili güncel çalışmalarda, yağ asitlerindeki aterojenik indeks (AI), trombojenik indeks (TI), hipokolesterolemik/ hiperkolesterolemik (H/H) oranı, sağlığı geliştiren indeks (HPI), ARA/EPA oranı ve et-lipit kalite indeksi (FLQ) değerleri vurgulanmıştır. Bu çalışma, lipitlerin insan sağlığı ve besin kalitesi değeri ilgili kısa bir derleme sunmayı amaçlamaktadır.

Anahtar kelimeler: Yağ asitleri, sağlık indeksleri, HPI, besin indeksleri, insan sağlığı

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ABSTRACT

Fish and other seafood, among our food sources, are becoming increasingly important in human health and nutrition due to the biotic components they contain that have therapeutic effects.

Fatty acids, along with their energy-yielding properties, serve various functions, including regulation of body metabolism and signaling. Seafood has been favored not only for its healthful and nutritional value but also for its affordability. Fish is a key nutritional source due to its phospholipids, polyunsaturated fatty acids, and minerals. Fish and seafood contain essential fatty acids such as EPA and DHA.

Recent studies on fish have highlighted the atherogenic index (AI), thrombogenic index (TI), hypocholesterolemic/hypercholesterolemic (H/H) ratio, health-promoting index (HPI), ARA/EPA ratio, and meat-lipid quality index (FLQ) values of fatty acids. This study aims to provide a concise review of the human health and nutritional quality value of lipids.

Keywords: Fatty acids, health indices, HPI, nutritional indices, human health

1. INTRODUCTION

Today, people value the relationship between the food they consume and their health. With the growing global population, the demand for affordable, nutritious fish is also increasing. Many types of lipids serve different functions in every living organism. The positive effects of n3/n6 fatty acids, in particular, with their functional nutritional value, on human health have led to numerous studies. Research on the fatty acids in lipids has been reported to have yielded significant results in various diseases that vary among individuals (Tutoret et al., 2024). Lipid health index research dates back to the 1970s. Some studies have observed that Inuit people have low heart disease mortality rates despite consuming large amounts of fish oil. Research conducted in Greenland in the 1970s showed that ischemic heart disease accounts for only 3.5% of all deaths (Bang & Dyerberg, 1980). Fish is rich in protein, vitamin D, and minerals (selenium, phosphorus, calcium), and its nutritional content and quality depend on its diet. Polyunsaturated fatty acids, such as EPA+DHA, in fish fatty acids are used to assess lipid health and nutritional quality (Kalkan et al., 2025, Haq et al., 2025, and Chen & Liu, 2020).

Today, consuming foods with high HUFA (EPA+DHA), low AI and TI values, and high h/H ratio and HPI values is recommended for a healthy diet. Fish with high lipid content, such as anchovy, salmon, mackerel, and tuna, are important nutritional sources for human development and well-being due to their omega fatty acid content. It is recommended to consume marine products because the amount of high fatty acid n3/n6, HUFA (EPA + DHA), AI and TI in seafood is higher than in freshwater products (Bayraklı, 2023; Duyar & Bayrakli, 2023; Chen et al., 2025). Functional foods such as fish contain AI, TI, HPI, H/H, ARA/EPA, and n3/n6, which have made significant inroads in the prevention and treatment of certain diseases. Fish and its by-products also contain bioactive and functional substances such as antioxidants, anti-inflammatory agents, and therapeutics (Chakraborty et al., 2025; Akhila et al., 2024).

Some epidemiological studies have indicated that high PUFA intake is associated with a lower risk of CVD and type 2 diabetes (Petersen et al., 2024). Omega-3 fatty acids, which contribute to human health, include α-linolenic acid, DHA, and EPA; and Omega-6 fatty acids, which contribute to human health, include linoleic acid and arachidonic acid. Polyunsaturated fatty acids (PUFAs)—such as ALA, EPA, DHA, ARA/EPA, and HPI—have been shown to positively affect blood sugar and triglyceride levels, preventing atherosclerosis and strengthening the immune system (Petersen et al., 2025; Wang & Guo, 2025). This review includes literature studies examining the positive effects of dietary lipid health indices on diseases and symptoms.

2. Fatty Acids and Nutraceutical Nutrition

Today, inadequate nutrients found in processed foods and unhealthy diets contribute to many diseases, such as high blood pressure, diabetes, heart disease (CVD), and obesity. To offset the harm caused by these unhealthy foods, people have turned to fish and functional foods, which offer beneficial health benefits (Wang & Guo, 2025; Bakir et al., 2025). Marine fish rich in n-3 and n-6, along with some vitamin blends, have positively impacted health indices. Consuming fish is recommended due to the health-promoting HPI index and the HUFA (EPA+DHA) fatty acids, which are important components of the human brain's gray matter (Ward & Singh, 2005; Kris-Etherton et al., 2009; Mechaly et al., 2025). Because the fatty acids in fish fall under the purview of nutraceutical (nutrition + pharmaceutical) nutrition, they are widely used in healthcare, pharmacy, and complementary and alternative medicine.

Functional foods, also known as nutraceuticals, provide the bioactive compounds and nutrients needed to treat certain diseases. Some fish by-products carry bioactive and other beneficial compounds important for human life, such as functional food products, dietary supplements, and growth supplements (Haq et al., 2025; Wang & Guo, 2025). Nutraceuticals were first used by Stephen L. DeFelice in 1989 and were offered for consumption as food supplements or medicinal drugs in capsule form (Mallikarjunaiah & Pattabhiramaiah, 2025).

In various supplements taken for human health, the risks of missing ingredients, heavy metals, and contamination should not be overlooked in terms of food safety. A GC-MS analysis study found that some imported capsule labels were consistent with EPA data, while there was a significant difference in DHA syrups (Karsli, 2021). Despite this, human health studies have found that the positive effects of fish consumption outweigh the negative effects.

Therefore, it has been determined that consuming fish at least twice a week is important for human health (Salar & Uz, 2021; Tacon et al., 2024). Bioactive, nutraceutical and other products obtained from fish and seafood are given in Figure 1.

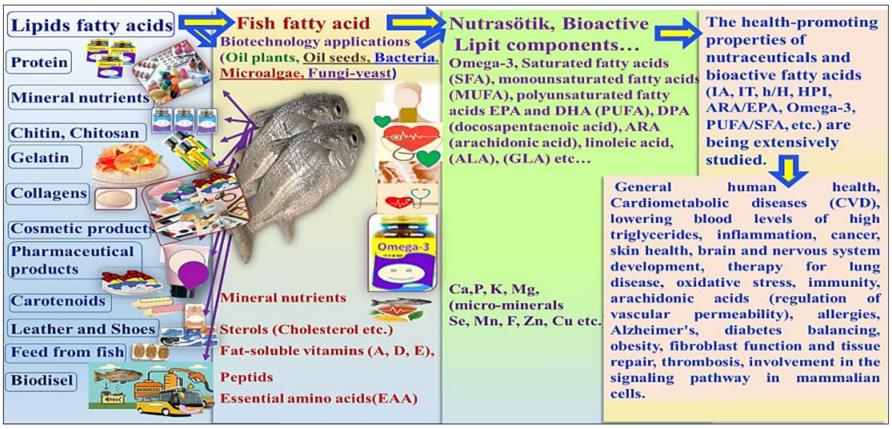

Figure 1. Many products are obtain from fish and their waste, along with nutraceutical substances.

As shown in Figure 1, many products are obtained from fish and other aquaculture wastes. While n-3 fatty acids and ALA (alpha-linolenic acid) in fish strengthen immunity against viruses and pathogenic bacteria, in some cases they can lead to inflammation and atherosclerosis (Kalkan et al., 2025; Badoni et al., 2021; Awuchi et al., 2022). Adequate and balanced nutrition for human health requires the intake of essential fatty acids (EFAs), which the body cannot produce. Exogenous linoleic acid (LA) and α-linolenic acid (ALA) are converted to EPA and DHA in the body, and therefore, they are essential fatty acids that must be consumed along with macro and micronutrients in aquatic products (Awuchi et al., 2022; Balami et al., 2019a). In a balanced diet, some organisms living in seas and oceans contain important nutrients for human nutrition. Some of these products have been reported to be sources of functional and bioactive products (Martínez et al., 2025).

3. The Importance of Nutritional Calculations in Fatty Acids

Fatty acids in lipids, the primary components of organic compounds, play a role both as structural and as an energy source in human and animal metabolism. Nutrients in aquatic products, various physicochemical parameters, and environmental conditions influence the amount of fatty acids in the bodies of fish species. Some important nutritional quality indices based on fatty acids are calculated as follows.

Nutrient health indices in fish and estimates:

IA(Index of Atherogenicity)= ((C12:0)+(4×C14:0)+(C16:0))/ ((MUFA)+(PUFA)) (Ulbricht & Southgate, 1991; Martínez et al., 2025). (1)

IT (Index of thrombogenicity)=((C14:0)+(C16:0)+(C18:0))/ ((0.5×MUFA)+ (0.5×n6PUFA)+ (3×n3PUFA)+ (n3/n6)) (Ulbricht & Southgate; Kalkan, et al., 2025; Bayraklı, 2023). (2)

h/H (hypocholesterolemic / hypercolesterolemic index)= ((C18:1n9)+ PUFA)/ ((C12:0+C14:0+C16:0)) (Haq et al., 2025; Chen et al., 2025). (3)

DFA (Desired fatty acid)=UFA(MUFA+PUFA)+C18:0 (Łuczyńska et al., 2025; Özer et al., 2022). (4)

OFA (H, Undesired fat acid) = OFA = C12:0 + C14:0 + C16:0 (Łuczyńska et al., 2025). (5)

PI (Polyunsaturation index) =((C18:2n-6)+(C18:3n-3×2)) (Balami et al., 2019a). (6)

HPİ (Health-Promoting Indexs=UFA/(C12:0+C14:0+C16:0), (Chen et al., 2016).(7)

HUFA (Highly unsaturated fatty acids) = EPA + DHA (Özer et al., 2022; Siol et al., 2025). (8)

FLQ (Flesh Lipid Quality) = (C20:5 n3 + C22:6 n3 /(total FA)*100. (Dinh et al., 2021). (9)

Delta-9-desaturase -(D9D = 100((18:1)/(18:1+18:0)), (Nakamura& Nara, 2004; Tosi et al., 2014; Magalhães et al., 2020). (10)

Delta-6-desaturase (D6D =100((18:3)/(18:3+18:2)), (Nakamura& Nara, 2004; Tosi et al., 2014; Magalhães et al., 2020). (11)

Delta-5-desaturase (D5D)= 100((20:5n-3)/(20:4n-3)), (Nakamura& Nara, 2004; Tosi et al., 2014;

Magalhães et al., 2020). (12)

Polyene index (PI) = ((EPA)+(DHA))/(16:0), (Bayraklı, 2023; Karsli, 2021). (13)

NVI, Nutritive value index = (C18:0+C18:1)/(C16:0), (Benítez-Santana et al., 2007). (14)

4. Nutritional Quality and Health Indexes of Fatty Acids

Some seafood species, such as salmon, mackerel, and sardines, have gained significant importance in human nutrition due to their positive effects on indices such as anticoagulant TI and cholesterol-lowering AI. Along with the thrombogenic index (TI), which prevents clotting by reducing human cholesterol, indices such as the atherogenic index (AI), HUFA (EPA+DHA), hypocholesterolemic/hypercholesterolemic (H/H), health-promoting index (HPI), and nutrient value index (BDI, NVI) are also gaining acceptance (Ulbricht & Southgate, 1991; Łuczyńska et al., 2025; Chen et al., 2016; Özer et al., 2022). Data on atherogenic, thrombogenic, and HPI indices relative to SFA, MUFA, and PUFA have revealed their importance for human cardiovascular (CVD) health. Studies have suggested that the atherogenic and thrombogenic index should be between 0.5 and 1.0, and the health-promoting HPI index should be above 2. High h/H and HPI ratios above 2, as well as AI and TI values, have positive effects on human health (Siol et al., 2025; Dinh et al., 2021). A h/H ratio above 2 indicated a higher amount of unsaturated fatty acids. The atherogenicity (AI) and nutritional value index (NVI) of consumed seafood and other foods, and the nutritional value index (BDI, NVI), which is the ratio of the sum of stearic and oleic acids to palmitoleic acid in fish and red meat foods, indicate the overall quality of fatty acids in meats. Generally, a higher BDI (NVI) value is desired than the AI (Chen et al., 2016). Desirable or desired fatty acids (DFA) are desired to be higher than undesirable fatty acids (OFA-H) in fish and other foods. A higher proportion of desirable fatty acids (DFA) than undesirable fatty acids (OFA-H) has been found to be important for food safety (Łuczyńska et al., 2025). PI, or polyunsaturation index, is the relationship between linoleic and A-linolenic acids, which are found in fish and various oilseed plants such as walnuts and hazelnuts. Linoleic acid (LA) and A-linolenic acid (ALA) are found primarily in fish, as well as in oilseeds and plants such as flaxseed, soybean oil, hazelnuts, and walnuts. Studies on fish have shown that those receiving a normal HUFA diet were able to escape better than those receiving a deficient diet, and that some larvae receiving a deficient HUFA diet also exhibited decreased visual response (Vagner et al., 2024; Benítez-Santana et al., 2007). In many studies, the PUFA/SFA (poly unsaturated / mono unsaturated) ratio has been recommended primarily for cardiovascular diseases (CVD). It has been reported that high PUFA/SFA ratios increase the risk of lipid peroxidation due to increased oxidative stress in body metabolism, and a ratio of 1.0–1.5 has been recommended (Kang et al., 2005). The FLQ index in fish reflects the relationship between meat and fat, and varies depending on the ecological factors of the fish's habitat and nutritional status (Erdem & Dinçer, 2023). A high FLQ value in fish or other animal organisms indicates that the fish possesses good quality meat and dietary lipids (Abrami et al., 1992; Guler et al., 2007). The preservation and storage chain of aquatic products such as fish, which preserves their nutritional value, is important for human health. The polyene index, which indicates oxidative degradation of fatty acids, is considered an important criterion for determining fatty acid degradation during fish preservation, storage, and transport chain processes (Karsli, 2021). It has been suggested that the PI value, which measures polyunsaturated fatty acid (PUFA) oxidation, should be low (Bayraklı, 2023; Łuczyńska et al., 2025).

The n3/n6, PUFA, PUFA/SFA, AI, TI, h/H, and HPI ratios of anchovy, rainbow trout, silvery crucian carp, and *A. grypus* (shabut), which are consumed extensively in Turkey, and *S. triostegus* (Mesopotamian catfish) naturally living in the Euphrates-Tigris waters, are compared in Table 1. Of these species, anchovy (*E. encrasicolus*) is a natural marine product; rainbow trout (*O. mykiss*) is an introduced alien economic species; *C. gibelio* is an invasive species; and *A. grypus* and *S. triostegus* are local endemic species (Table 1).

Table 1. Lipid nutritional and health qualities in fish

Örnekler	n3/n6	PUFA	PUFA/SFA	AI	TI	h/H	HPİ	Referances
Engraulis encrasicolus	8.0	32.45	0.95	0.85	0.25	1.76		Bayraklı & Duyar, 2019
Engraulis encrasicolus	5.12 5.41	34.7-36.70	31.65/30.85 (1.03)	0.63-0.70	0.26-0.27	1.83-2.02		Kaya & Turan, 2008
Oncorhynchus mykiss	1.11	41.56	1.52	0.38	0.33	2.50	2.57	Bengü, 2024
C. gibelio	2.13	30.86	36.48/30.86 (1.18)	0.67	0.44			Yakar et al., 2023
A. grypus	1.33	22.63-30.50	0.80-0.95	0.43	0.38	2.69	3.05	Bozkurt et al., 2023
S. triostegus	1.12	29.18	0.88	0.33	0.42	2.45	2.82	Bozkurt, 2025

In Table 1, n3/n6 ratios were compared, and it was determined that the values in anchovy, a marine product, varied between 8.0 (Bayraklı ve Duyar, 2019) and 5-6 (Kaya ve Turan, 2008). When some health-promoting HPI ratios not given in Table 1 were also calculated, it was seen that many of them were around 2 (Bayraklı & Duyar, 2019; Kaya & Turan, 2008; Bengü, 2024). Literature studies have shown that seafood such as anchovy, which has a high n-3/n-6 ratio, are beneficial and functional foods (Table 1). In Table 1, the highest n-3/n-6 amount after anchovy was observed in *C. gibelio* (2,13). It was observed that the health and nutritional quality values such as AI, TI, h/H, and HPI contained in the examined fish were within the recommended limits. In the calculations, the AI and TI ratios being below 1 and h/H and HPI values being around 2 showed that all the fish examined were a nutritious and healthy source in terms of lipid content (Chen, &Liu, 2020; Kang et al., 2005; Fernandes et al., 2014; Bazarsadueva et al., 2024). Delta-9 (D9D) desaturase index, one of the fatty acids considered to be a precursor and biomarker of metabolic disorders, is required for the synthesis of MUFAs; EPA and DHA; Delta-6 (D6D) desaturase index and Delta-5 (D5D) desaturases have functional roles in the synthesis of HUFAs, which ensure the fluidity of cell membranes in humans

(Nakamura & Nara, 2004; Tosi et al., 2014). HUFAs (highly unsaturated fatty acids), which regulate the interactions (signaling) in cells, are also reported to affect water cold perception (D6D) in plants and some fish (Nakamura & Nara, 2004; Tosi et al., 2014; Magalhães et al., 2020). Recent studies have determined that ARA (arachidonic acid), which is required for the synthesis of eicosanoids, affects growth and developmental performance. In some recent studies, the ARA/EPA ratio has been stated to be as beneficial as n-3/n-6 with the nutritional value index (NVI) (Özer et al., 2022; Nakamura & Nara, 2004; Magalhães et al., 2020). Byproducts such as shells, skin, scales, bones, internal organs, heads, and shells obtained from aquaculture processing are rich in various bioactive and nutraceutical compounds. In addition to fatty acids, fish and aquaculture waste products also yield biotic substances such as collagen, chitin, chitosan, gelatin, pharmaceuticals, capsules, cosmetics, feed, and biodiesel (Figure 1) (Bozkurt & Yüksel, 2019; Roy et al., 2023).

5. Obtaining Omega-3 and Other Compounds from Non-Aquaculture Sources

Today, the growing population and the ever-increasing number of prepared foods, such as fast food, have increased the demand for aquatic products, along with other terrestrial animals. Conversely, the consumption of foods rich in n-3 fatty acids and other health indices has decreased among adolescents and adults. An increase in the consumption of unhealthy trans fatty acids, replacing healthy n-3-based foods, has been noted (Dvoretsky et al., 2025). Despite the growing global population, white meat fish, which contribute 25% of animal protein intake, contain important nutrients such as beneficial fatty acids (PUFA), essential amino acids (EAA), various minerals (Fe, P, F, Se, Zn, Ca), and vitamins (A, D, E, K) (Fisheries, F.A.O., 2018; Derbyshire et al., 2024). The biotechnological production of omega PUFAs using microorganisms represents a significant gain for the food supplement and pharmaceutical industries. Omega-3s (ALA, EPA, DHA), which cannot be produced by the body, are obtained through supplements such as medicines, capsules, or syrups, in addition to food. While biotic extracts extracted from fish oils and fats are currently the primary source, they are expensive and lack market availability. While fish-derived omega-3 supplements are beneficial, excessive consumption can sometimes lead to oxidation, off-flavors/odors, and depletion of aquatic resources (Akonjuen et al., 2023). Obtaining omega-3 (ALA, EPA, DHA) supplements from fish and other aquatic products leads to the depletion of these resources over time. Today, advances in genetic engineering are boosting the commercial potential of microbial fats used in the production of omega fatty acids. Biotechnological studies are underway on the sustainable and economical production of non-fish oil-rich plants and seeds, as well as EFA-derived biotic factories (microorganisms, algae, yeast, and fungi, etc.). From an economic perspective, focusing on bacteria (*E. coli*, *Shewanella*, *Arthrobacter* sp., *Gammaproteobacteria*, *Acinetobacter calcoaceticus*, *Rhodococcus opacus*, *Bacillus* sp. etc.), oleaginous microalgae (*Thraustchytrids*, *Schizochytrium* sp. etc.) and fungi such as yeasts is promising for the production of n-3, recombinant EPA+DHA and other useful biotic sources (Amiri-Jami & Griffiths, 2010; Kannan et al., 2021; Rawat et al., 2023). While algae have an advantage over bacteria in omega-3 production, they are currently not as advantageous as fish oils. Traditional foods and supplements containing EPA and DHA are increasingly used in the pharmaceutical and cosmetic industries due to their skin-moisturizing properties, and their health claims have been approved by the United States Food and Drug Administration (FDA). The nutraceutical and other supplement market, now a food and pharmaceutical industry, is projected to grow from $9.32 billion in 2025 to approximately $17.86 billion by 2034 (Precedence Research, 2025).

CONCLUSIONS AND RECOMMENDATIONS

In many studies, the positive effects of lipid nutrient indices and their antithrombotic properties on conscious consumers have increased the demand for seafood products containing nutraceutically rich bioactive compounds. Consequently, indices such as meat-lipid quality (FLQ), trans fatty acid (TFA) amounts, n-3/n-6, LA/ALA, ARA/EPA ratio, AI, TI, h/H, and HPI ratios are gaining importance in functional and nutraceutical nutrition (Kalkan et al., 2025; Özer et al., 2022; Bozkurt, R., 2025; Kaçar et al., 2024). Conscious consumers are increasingly turning to seafood products for their rich mineral content. Furthermore, products derived from aquaculture waste, such as chitin, chitosan, collagen, gelatin and biodiesel, are attracting attention with their benefits in the medical, cosmetic, and pharmaceutical sectors (Figure 1). The role of fatty acids in fish in various human health issues, as well as their food safety and economic value, has gained importance. With the increasing global demand for fish, nutraceutical and functional foods derived from aquaculture and other aquaculture products will significantly benefit the public's overall health. Consequently, further scientific studies are needed to determine the impact of lipid health and nutritional indices on human health. This review aims to provide information on the nutritional and health index values of fatty acids, as well as their functional and therapeutic properties.

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