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ARTICLE

Dietary and Nutritional Value of Fish Oil, and Fermented Products

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ABSTRACT

Present review article explains the dietary and nutritional value of various fish derived natural food products. Fish is a good source of important nutrients such as proteins, fats, vitamins and minerals. Fish oil contains polyunsaturated fatty acids (PUFAs) mainly omega-3 fatty acids, eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and eicosanoids. Fish contains high-quality protein (~ 14-16 percent) and is consumed worldwide. This article also emphasizes therapeutic uses of fish nutrients and oil in healing of wounds, hyper pigmentation, dermatitis, and in cardiovascular risks. Fish oil polyunsaturated fatty acids (PUFAs) are highly beneficial in cardiovascular problems and dermatitis. Fish oil is good for skin-related diseases such as photo-ageing and melanogenesis These also affect anticancer, wound healing and anti-depressant activity. In the present review various local, national, and international processed fish derived food currently available in the market fish dishes have been mentioned.

1. Introduction

Fish is a major source of food for millions of people throughout the globe. Fish derived food has high nutritional value as it is rich in protein, fat, mineral, vitamins, etc. [1]. Fish derived food possess high-quality protein and approximately 16-17% of the animal proteins come from fish eating at global level by the people. Fish protein is a good substitute of livestock protein in various parts of the world. In coastal areas fish eating is significantly much higher than land locked areas. Consumption of marine fish is more than fresh water fishes. Coastal countries consume fish foods at large scale as fish supplies <10% of animal protein consumed in North America and Europe. It is 17% in Africa, 26% in Asia and China uses 22% fish foods. Fish trade is of very high economic importance. According to an estimate fish export by US$ is 51 billion per annum alone that has been exceeded much higher in these two decades. Both fishery and aquaculture has social implications as more than 37 million people are directly involved in it, and more than 200 million people seek direct and indirect income from fish production (FAO 2003) [2]. Global production of aquatic animals becomes 179 million metric tons (mmt) in 2018, valued at US$401 billion, of

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which 97 mmt originated from capture fisheries. About 25% of capture fisheries is diverted to non-food uses; mainly fishmeal and fish oil used in aquaculture feeds. Of total fish production 46 percent of the total production comes from aquaculture farming and 52 percent of fish for human consumption. China becomes a major fish producer and it produced 35 percent of global fish production in 2018. Other than China 34 percent production is noted from Asia (34 percent), followed by the Americas (14 percent), Europe (10 percent), Africa (7 percent) and Oceania (1 percent) in 2018. The global average supply of aquatic food (excluding seaweeds) has grown by about 1.5% per annum, to reach 20.5 kg per capita in 2018 (FAO, 2020) [3]. This high consumption rate is due to easy availability of variety of fish products. For better utilization and usage fish processing and fermentation industries turn out large quantities of fisheries products in the international market. Fish foods consumption is increasing every year because of its high nutritional and health benefits. Both fresh water fishes and marine fishes are major source of high-quality animal protein, oil, vitamins and minerals throughout the globe. Freshwater fishes are more edible and have higher consumption rate in plane areas. There is a large demand of freshwater inland fish species like singhi (*Heteropneustes fossilis*), magur (*Clarias batrachus*), murrels (*Channa* sp.), and koi (*Anabas testudineus)* in India, Nepal, Bangladesh and other coastal south-east Asian countries. These are also famous for their therapeutic properties.

Fish and fish products are of historical, regional, and cultural significance. These are used since ancient times. Nutritionally fish is used an important source of proteins, oils, enzymes, hormone, vitamins, micronutrients and minerals and oils. Fish is, used to prepare the various types of fermented food products. These possess high nutritional value. A variety of fish are used as an ingredient in many curries, food items, and sauces. Besides fish oil, fish food, fish manure, fish glue are the main commercial products. Present review article explains nutritional and therapeutic value of various fish foods used round the world.

2. Nutritional Value of Fish Derived Food

Fish derived foods are a rich source of proteins, amino acids lipids, minerals, lipids, vitamins, and carbohydrates. Fish contains 15 to 20% protein contents that vary according to size, liver body weight and species. The fish derived food products possesses physiologically required amounts of essential amino acids which improve the overall protein quality of a mixed diet and its health benefits. In addition, fishes are good sources of PUFAs as 40% of these possess 5 or 6 double bonds (C14 - C22) [4]. Fish lipids (oils) are nutritionally much better in quality than mammalian lipids. Fish liver oils possess vitamin B complex and fat-soluble vitamins A and D.

2.1 Fish Proteins

Fish origin foods possess higher contents of nutritionally important proteins than other terrestrial animal meats [5]. In addition, aquatic proteins are easily digestible and contain so many peptides and essential amino acids [6]. Dietary use of fish proteins is highly beneficial for human health it lowers down insulin resistance, leptin and TNFα, it improves hyperglycemia and decreased adipose tissue oxidative stress [7]. Dietary use of fish protein hydrolysates lowers down tumor necrosis factor a (TNFα) in comparison to casein hydrolysates in human macrophages. PUFA and fish protein hydrolysates synergistically decrease expression levels of TNFα (Arginine an amino acid from fish minimizes the production of superoxide anions by nitric oxide synthase (iNOS) while glycine repress the expression of TNF-α and the pro-inflammatory interleukin-6 (IL6) in cell cultures [8]. Similarly, taurine, is an amino acid excreted as fish by product , it suppresses the production of TNFα, IL6, and interleukin-1b (IL-1b). Its consumption delays type 2 diabetes through different molecular mechanism [9]. Sardine is good source of omega-3 fatty acids (EPA & DHA) which have multiple health benefits. Thus, consumption of fish food is highly beneficial as it cut down both glucose and lipid levels, and reduce the chances of cardiovascular problems in man [10].

Dietary use of salmon fish also lowers down inflammation while consumption of cod protein increases improvement in insulin sensitivity in rats [11-13]. Fish proteins also promote growth and regeneration of skeletal muscle after trauma compared to peanut protein and casein. Salmon calcitonin, is an 32 amino acid peptide cut-down blood calcium. This is 40 to 50 times more potent than human calcitonin. Supplementation of fish protein in diet improves health of children affected with Kwashiorkor (chronic protein deficiency) and marasmus (chronic deficiency of calories). It is much beneficial in eradication of protein deficiency diseases.

2.2 Micronutrients

Fish supplies important minerals calcium, phosphorus, iron, copper selenium trace elements like fluorine, and zinc. Calcium obtained from fish bones is easily absorbable. [14] Marine fishes contain zinc in higher quantities. Zinc is also required for activity of several enzymes which participate in catabolism carbohydrates, cell division, growth, development and in making immune defence Zinc is also required for enzymes which assist in recognition of senses of smell and taste. Fish derived food items contain higher contents of vitamin D. A. E. K and B complex mainly thiamine and B complex mainly thiamine, riboflavin and niacin (vitamins B1, B2 and B3) (Table 2) Fish liver contains higher amounts of vitamin D and oils, both are required for bone growth, calcium absorption and metabolism of. Vitamin D is required for preparation of immune defence and protection against carcinoma [15]. Fish eating is good for health as it supplies few important mineral elements including calcium and phosphorus (Table 2).

3. Fermented Fish Products

Thousands of fermented fish derived food items are

Table 1. The Calories value and nutritional information of different edible fishes provided by the USDA

Fish type	Calories	Fat	Sat. fat	Omega -3	Proteins	Carbohydrates	Sugar	Fibre	Sodium	Mercury levels
Anchovies	111	4 g		1.7 g						
Bass	82	1.7 g, 0.4 g	0.4 g	506 mg	15.7 g	9 g		0 g	58 mg	120 ppb
Catfish	81	2.4 g	0.6 g	309 mg	13.9 g	0 g	0 g	0 g	37 mg	144 ppb
Clams	73	0.8 g	0.2 g	91 mg	12.5 g	3 g	0 g	0 g	511 mg	28 ppb
Cod	70	0.6 g	0.1 g	156 mg	15.1 g	0 g	0 g	0 g	125 mg	70 ppb
Crawfish	61	0.8 g	0.1 g	122 mg	12.6 g	0 g	0 g	0 g	53	34 ppb
Flounder	60	1.6 g	0.4 g	208 mg	10.6 g	0 g	0 g	0 g	252 mg	115 ppb
Grouper	78	0.9 g	0.2 g	210 mg	16.5 g	0 g	0 g	0 g	45 mg	417 ppb
Haddock	63	0.4 g	0.1 g	112 mg	13.9 g	0 g	0 g	0 g	181 mg	164 ppb
Halibut	186	2.7 g	0.6 g	396 mg	37.9 g	0 g	0 g	0 g	139 mg	261 ppb
Lobster	65	0.6 g	0.2 g	145 mg	14 g	0 g	0 g	0 g	360 mg	200 ppb
Oysters	43	1.4 g	0.4 g	263 mg	4.8 g	2.3 g	0.5 g	0 g	71 mg	18 ppb
Rainbow Trout	101	2.9 g	0.6 g	499 mg	17.4 g	0 g	0 g	0 g	26 mg	344 ppb
Salmon	177	11.41 g	2.6 g	1,671 mg	17.4 g	0 g	0 g	0 g	50 mg	26 ppb
Sardines	177	9.7 g	1.3 g	835 mg	21 g	0 g	0 g	0 g	261 mg	79 ppb
Scallops	59	0.42 g	0.1 g	88 mg	10.3 g	0 g	0 g	0 g	333 mg	40 ppb
Shrimp	72	0.4 g	0.1 g	52 mg	17 g	0 g	0 g	0 g	481 mg	52 mg
Snapper	85	1.1 g	0.2 g	264 mg	17.4 g	0 g	0 g	0 g	54 mg	230 ppb
Spanish Mackerel	118	5.4 g	1.6 g	1,140 mg	16.4 g	0 g	0 g	0 g	50 mg	440 ppm
Squid	78	1.2 g	0.3 g	415 mg	13.2 g	0 g	0 g	0 g	37 mg	44 ppb
Swordfish	122	5.7 g	1.4 g	641 mg	16.7 g	0 g	0 g	0 g	69 mg	893 ppm
Tilapia	81	1.4 g	0.5 g	77 mg	17 g	0 g	0 g	0 g	44 mg	19 ppb
Tuna	93	0.4 g	0.1 g	85 mg	20.7 g	0 g	0 g	0 g	38 mg	270 ppb

Table 2. Major vitamins and minerals reported in Salmon, Sardine, Trout and Mackerel per 100 gram flash.

Salmon	Sardine	Trout	Mackerel
Vitamins % of RDAs(Recommended Dietary Allowances)			
Vitamin C-6%	Vitamin B6-10%	Riboflavin-19%	Vitamin D-90%
Vitamin B12-53%	Vitamin D-48%	Vitamin B12-130%	Vitamin B12-145%
Vitamin B6-30%	Vitamin B12-148%	Thiamin-23%	Vitamin B6-20%
Vitamin A-%	Vitamin A2%	Niacin-23%	Vitamin A-3%
Minerals			
Selenium-34%	Iron-16%	Selenium-18%	Selenium-63%
Magnesium-6%	Magnesium-9%	Magnesium-43%	Magnesium-19%
Potassium-10%	Potassium -11%	Potassium-10%	Potassium-9%
Phosphorus-24%	Calcium-38%	Phosphorus-24%	Phosphorus-22%

available in the market having different brand names. Different fish fermentation methods are available in different countries, which have special and unique taste and nutritional value. For development of different tastes salt is added during fermentation processing. The taste of natural fish and digestibility of fish derived food items differs from geographical location, water quality, and fish food preference [16]. During fermentation a series of desirable biochemical changes are done to generate unique taste of finished product. For making fish products more edible and digestible steaming, drying, pasting and saltation are followed. For fermentation various microorganisms and enzymes are used. Both microorganisms and enzymes make food items soft after acidification, gelation of myofibrillar and sarcoplasmic muscle proteins. These also do degradation of fish proteins and lipids. More specifically, acidification generates some antimicrobial substances, which cause de-contamination of processed food material and extend their shelf life. Due to gelation of protein muscle loss its elasticity, cohesion and hardness. Enzymatic degradation of proteins and lipids provides a flavored taste to the dietary nutrients [17].

Fermentation is done under strict controlled conditions for preservation of primary and secondary microbial metabolites in final finished. Fermentation has important steps such as washing, degutting, salting, drying, and smoking. These steps are followed to develop unique flavor, texture and color of finished products. Few traditional methods are also used for fish fermentation. These methods have important operation steps i.e. dry salting and brine salting, freezing, and smoking, fermentation [18]. The major fish products are dried, salted, fermented, and smoked fish. Fermentation significantly enhances the quality of meat such as taste, texture and nutritional value [19,20].

3.1 Traditional Fermented Fish Products

Various traditional methods of fish fermentation are available throughout the world. For fermentation large size edible fish is chopped in to pieces or a small size fish is used as whole [21]. Now it is used to make a paste and finally a products fish sauce is prepared [22]. For increasing the edibility and taste few fermented products are fully changed into a liquid state [23]. Generally silver carp is used for preparation of fish slurry [24]. For providing a desirable unique taste, quality and scaling of product fermentation is done by using few selected microorganisms in controlled conditions. More especially bacteriocins or other antimicrobials are used to check the growth of undesirable organisms [25]. For production of fermented fish paste four commercially available mold starters are used [26]. These are few fungal species belong to *Aspergillus* and *Actinomuco*r genus which are used for fermentation [27,28]. These micro-organisms should be nonpathogenic in nature and aid in production of unique taste- and flavor. For fermentation lactic acid bacteria (LAB) are also used as starter culture to obtain final finished fish products [29-32]. In different countries various methods of fish fermentation are prevlant. Moreover, in Thailand Som-fug, is prepared by using *Lactobacillus plantarum*, *Pediococcus acidilactici,* and *P. pentosaceus*. Similarly, for fermentation of Thai fish. *L. plantarum*, *Lactococcuslactis subsp. lactis* and *L. helveticus* are used. For the production of ferment mackerel mince fermentation is done at 37 °C temperature [33]. A mixed-strain culture of *L. plantarum 120, L. plantarum 145, and P. pentosaceus* 220 is used in fermentation of Suanyu, a traditional Chinese fermented fish. For improvement of quality of the whole carp-based product fermentation is done for very short time duration [34].

Type of substrate used, salt contents, and carbohydrate material is added to generation of aroma/smell and unique taste in final products. For this purpose, generally rice, millet, flour, and even syrup or sugar are used. Millet is used as a major carbohydrate source in Northeastern Asian countries, whereas in Southeastern Asian countries, rice is commonly used as a carbohydrate source [35]. Carbohydrates addition to a mixture of fish serve as energy source and accelerate the fermentation, it also helps in the absorption of excess moisture and provides a distinctive flavor to the final product [36]. Salt also inhibits the growth of food spoilage microorganisms and increases the growth of halophilic and salt-tolerant bacteria during fermentation. Addition of salt lowers down effects of water on the finished product, and generates desirable taste. Furthermore, on the basis of addition of salt fermented fish products are classified as high-salt (more than 20% of the total weight), low-salt (3-8%), and no-salt products. Today, fermented fish products are available in the market and become very popular in Asia, Africa, and Northern Europe due to their unique flavor and taste. This making it tasty and maintain its quality non pathogenic microbial starter cultures, crude materials, unique fermentation conditions, are used different parts of the world.

3.2 Fermented Fish in Europe

In many European countries, various traditionally fermented fish derived products are available in the market with different brand names for sale. Fish sauce is very popular in many European countries. A fermented fish sauce "Garum" was used traditionally used by Ancient Greeks and Romans" [37]. For the preparation of it both Mackerel and herring fish were used because they possess best edible ingredients. Hakarl, a fish item most popular in Iceland and other European countries are famous for its delicacy. This is prepared from sharks; it can be preserved and used for several years [38]. The fermented Hakarel provides good energy and quality nutrition to mostly old age people. Many European MNCs are producing fish sauces by following traditional Garum production methods [49]. Similarly, Surströmming is prepared from herring by fermentation; it is very popular in Sweden because of its special smell and taste. For this herring fish is pre-salted, and saturated in salt solution before fermentation. Only fleshy muscular portion of fish is used for fermentation at 16-19 °C for 21-28 days. After fermentation soup is filled in vessels including brine and finished product. Fermentation is continuously done for about six months. Starter culture used is halophilic bacteria, *Haloanaerobium* and anaerobic is used for generation of Surstr€omming product with a unique taste and flavor and contains contain protein (11.8%), salt (8.8%) and fat (3.8%) and the pH ranges between 7.1-7.4 [40]. In Norway Rakfisk a native fish dish is very popular due to its taste and flavor; it is commonly eaten during Christmas season in many European countries. Trout or char freshwater salmon are used to prepare this dish. For obtaining unique taste 3-5% salt is used with little amount of sugar. Fermentation is done at 5-7 °C for more than 120 days. LAB used as dominant bacteria is used in Rakfisk fermentation [41].

3.3 Fermented Fish in Africa

In African countries, whole fish is preserved after fermentation. For getting fresh fish for dietary utilization, It is treated with salt before drying because of extremely unfavorable climatic conditions. In Africa are Lanhouin, is a salt treated fermented fish item. This is prepared by using condiments and fermentation of whole cassava fish (*Pseudotolithus senegalensis* is used [42]. In Ghana Momone is a very popular fermented fish product having an unique taste and flavor [43]. Besides this, fermentation products are produced from different African freshwater fishes. Similarly, in Egypt, Feseekh is salted fermented products prepared from un-dried fish. In African countries fish fermentation is done for a very short period of time and usually done after adding some higher amounts of salt, and the product is used either whole or in pieces.

3.4 Fermented Fish in Asian Countries

In Southeast Asian countries dozens of processed and fermented fish products are traditionally prepared and available in market. These are famous for their special taste, flavor and differ from the rest of the world. Fish fermentation is based on traditional culture and is relatively done for a longer period from 15 days to several months or even longer. Several fermented dishes and recopies and sauces are prepared by fermentation process and are available in Asian markets. Most of these items are prepared by using traditional methods by local people. Their market is expanding at the global level year after year. Among these items variety of sauces prepared from fish fermentation are sold in different names in different countries for example in Thailand it "Nampla" [44] in Malaysia "Budu" [45]; in Philippines "Patis" [46]; in Indonesia "Bakasang" [47] and in China, Yu-lu are very famous [48].

Hundreds of fermented fish items/ products such as Plaa-som a Thai product are very popular because of its salty taste. Its other preparations are such as full fermented fish, fillets and dry salted flakes are also sold. These are prepared by mixing little bit of salt, and cooked with rice and meshed garlic. In some cases, palm syrup and roasted rice are used to in some preparations cooked rice and garlic are replaced by palm syrup and roasted rice for generation of special taste and aroma [49]. A fermented fish item Plaa-som. Suanyu is made by using very less amount of salt. Fresh water fishes i.e. *P. pentosaceus* and *Z. rouxii* are also used for fermentation. Pekasam is very popular in Malaysia, it is prepared by fermentation of whole fish traces of salt and rice both roasted and uncooked.

In India Shidal a fermented fish product is prepared from dried salt-free punti fish (*Puntius sophore*) and phasa fish (*Setipinna phasa*) Shidal is fermented fish item that is made by using traditional methods. This is very popular in rural and semi-urban India [50]. It is prepared by using *Staphylococcus* as starter culture, while *Micrococcus* and *Bacillus* are used in phasashidal fermentation. For preparation of Shidal punti and pahsma fish (*Puntius sophore* and *Setipinna phasa*) are dried without adding salt. Similarly, small fish puthymaas (Ticto barb) is fermented with traces of salt and chopped green chilies, tomatoes, ginger, and rice after roasting [51]. This fish recipe is very popular in North-East India. Another fish product Ngari is also very popular in Manipur is also very popular. People eat it with cooked rice. This is prepared after fermentation for 2-3 days and two days drying in sunshine or in heat [52]. In Korea, Jeotgal and dried bonito fermented fish product Katsuobushi is highly popular dish in Japan. Both are traditionally fermented fish foods. Skipjack is a traditionally prepared fermented fish item by rural people, they use *Aspergillus* and *Eurotium* species as starter culture. It is prepared by fermentation of mackerel, bonito and tuna fish species are used (*Auxis rochei S. orientalis, E. affinis, A. thazard*) [53]. It is famous for its special taste and is much better than raw fish products.

3.5 Health Benefits of Fermented Fish Food

Dietary use of fish provides major ingredients which are essentially required for body growth and metabolism. Fish is an important source of human diet; it is highly beneficial for human health. Fish proteins and fatty acids are easily absorbed and provide energy. Pekasam and shidal are fermented fish food products are highly edible, tasty and are good source of nutrients and natural antioxidants. These were found highly effective in prevention of ROS-related chronic diseases [54-56]. Jeotgal contains high amount of coenzyme Q10 (CoQ10) (291 mg/g). CoQ10 is a powerful antioxidant and an essential cofactor that assists in energy production and boost up immune function [57,58]. CoQ-10 deficiency results in several clinical disorders like chronic heart failure [59], hypertension [60], Parkinson's disease [61], and malignant growth [62]. Fermented fish proteins and peptides show antihypertensive activity and show inhibition of ACE (angiotensin I-converting enzyme) activity. In Japan dried bonito is "Katsuobushi," a traditionally prepared fish origin food item, its dietary use regulate blood pressure without any adverse side effects [63]. This is also used as a nutritional supplement that assists in recovery from fatigue [64]. In addition, some other fish products such as Narezushi showed antihypertensive while Kajami-sikhae (flatfish), chuneobamjeot (shad gizzard) anticancer activity. Jeotgals, stops proliferation of liver hepatocellular carcinoma HepG2 cells [65]. Fish food items contain various peptides, glutamic acid, and glumatine and tripeptides showed immunomodulatory effects [66]. Fish food contains several ingredients which act as stable fibrin-clotting inhibitors. These show anticoagulant and anti-platelet effects. Fibrinolytic enzymes are used to for maintaining softness in fermented fish such as small cyprinid fish (*Puntius sophore*) fibrinolytic enzymes are used which break fibrin and fibrinogen [67]. In addition, fish oil is highly beneficial for human health. More often, omega-3 fatty acids, eicosapentaenoicacid (EPA), and docosahexaenoic acid (DHA) have great therapeutic value in disease prevention (Table 3). These are good nutritional supplements that can be used by any age group [68,69] and have multiple health benefits against many physiological diseases [70]. Fish oils are precursors to eicosanoids which lowers down inflammation [71] and ischemic heart disorders [72]. The PUFAs in fish oils assist in curing rheumatoid arthritis, psoriasis, ulcerative colitis, asthma, Parkinson's disease, osteoporosis, diabetes mellitus, cardiovascular events, cancers, and depression [73].

4. Fish Oil

Table 3. Principal fatty acids (%) of major commercial fish oil.

Fish oil/s	Myristic C14:0	Palmitic 16:0	Palmitoleic C16:1	Oleic C18:1	Eicosaenoic C20:1	Eurucic C22:1	ώ-3 fatty acids	Docosahexaenoic Acid (C22:6)
Anchovy	9	19	9	13	5	2	17	9
Capelin	7	10	10	14	17	14	8	6
Cod liver	3	13	10	23	0	6	11	12
Herring	7	16	6	13	13	20	5	6
Horse mackerel	8	18	8	11	5	8	13	10
Mackerel	8	14	7	13	12	15	7	8
Menhaden	9	20	12	11	1	0.2	14	8
Norway pout	6	13	5	14	11	12	8	13
Pilchard	8	18	10	13	4	3	18	9
Sprat	1	16	7	16	10	14	6	9
Sand eel	7	15	8	9	15	16	9	9
Marine menhaden	7	15	10	15	3	2	17	10

Fish oil is mostly extracted from fishes menhaden (Brevoortia sp., *Ethmidium maculatum*); tuna and mackerel; sardine and herring; anchovy; halibut (*Hippoglossus* sp.); salmon (*Oncorhynchus* sp. and *Salmon* sp.); and cod (*Gadus sp*.). Whale (Order Cetacea) blubber, seal (clade Pinnipedia) blubber, and shark liver [74,75] (Table 3). Its quality depends on fish species, water quality and climate. Fish production also, depends on method of fish culture and technology used. Although many species of fish are used to produce fish oil, a single species is typically used for any single production run of fish oil [76]. Fleshy marine fish oil, possess higher contents of oil in their liver hence single species largely used for oil production (Rizliya and Mendis, 2014). Peru is a major producer of most fish oil as it covers one-third of the global market [77]. According to FAO, 2020 data Denmark, Japan, and Iceland are also prominent producers of fish oil. Overall, Peru is the world's largest exporter of fish oil; together, Peru and Chile are responsible for 39% of global fish oil exports. Most of the fish oil produced in many countries like Norway, United States, Canada Peru, Chile, and other South American countries. Fish oil extraction is a major source of socioeconomic benefits in small scale coastal communities, it is a ocean based livelihoods of millions of people [78]. Enzyme assisted oil extraction is done from whole fish that provides oil in large quantities [79]. In few countries more than 70% of fish are used exclusively for the production of fish meal and fish oil. Approximately 58% of total fish oil production comes from non-species-specific.

4.1 Physical Properties of the Fish Oil

Refined fish oil possess triglycerides in the mixture, it partially solidifies because triglycerides have a higher melting point than fish oil. Generally fish oil is liquid at room temperature (20 °C). For dietary use triglycerides are removed to increase EPA and DHA concentrations in the fish oil and its products up to an efficient range [80] (Table 4).

Table 4. Physical Properties of fish oil

Property	Value
Appearance	Amber colored oil
Odour	Characteristic fish odour
Molecular weight	EPA :302.45, DHA 328.49, other oils vary
Melting point	10-15 degree C
Flash point(fatty acids)	Approximately 220 degree C
Boiling point	>250 degree C
Specific gravity (30 degree C)	0.91

4.2 Chemical Composition of the Fish Oil

Fish oil contains omega-3 PUFAs, whose concentration depends upon the type of fish, the body part for oil extraction and procedure followed [81]. Fish oil contains long-chain fatty like saturated, monounsaturated, polyunsaturated fatty acids of carbon chains ranging from 14 to 22 carbon atoms. Approximately one-third of the fatty acids present in fish oil are omega-3 long-chain polyunsaturated fatty acids (LC-PUFAs). Omega-3 fatty acids possess carbon chains ranging from 18 to 22 carbon atoms possess a double bond located at the third carbon atom from the end of the carbon chain (i.e., the methyl or omega [ω] end). EPA has a 20-atom carbon chain; DHA has a 22-atom carbon chain. The ratio of fatty acids in fish oil depends on species and type of fish, geographical location of fish culture (Table 4). Important omega-3 fatty acids found in fish oil are EPA, DHA, ALA, stearidonic acid, docosapentaenoic acid (DPA), and arachidonic acid. The omega-3 LC-PUFAs in fish oil are mostly EPA and DHA with some DPA [82] have been linked to potential health benefits [83] (Tables 5 & 6).

Table 5. Chemical composition of various fish oil

Fatty acids	Lipid Number	% by Weight in Fish Oil
Polyunsaturated fatty acids		
Omega-3 Fatty		
α-Linolenic acid/ ALA	C18:3 (n-3)	6.0%
Stearidonic acid	C18:4 (n-3)	-
Arachidonic acid	C20:4 (n-3)	-
Eicosapentoenoic acid/ EPA	C20:5 (n-3)	27.5%
Docosapentoenoic acid/DPA	C22:5 (n-3)	2.2%
Docosahexaenoic acid	C22:6 (n-3)	8.9%
Omega-6 Fatty Acids		
Linoloeic acid	C18:2 (n-6)	-
ϒ-Linoloeic acid	C18:3 (n-6)	1.6%
Eicoatetraenoic acid	C20:4 (n-6)	1.2%
Monounsaturated Fatty Acids		
Palmitoleic acid	C16:1 (n-7)	11.3%
Vaccenic acid	C18:1 (n-7)	2.8%
Oleic acid	C18:1 (n-9)	7.8%
Eicosenoic acid	C20:1 (n-9)	
Cetoleic acid	C22:1 (n-11)	
Saturated Fatty Acids		
Myristic acid	C14:0	6.1%
Heptadecanoic acid	C16:0	7.6%
Palmitic acid	C17:0	2.0%
Stearic acid	C18:0	6.2%

Unrefined fish oil is containing approximately 90 percent

Table 6. Comparison of LC-PUFAs Concentrations from Herring, Salmon, Cod Liver, eel oil, Shark oil, Tuna oil, Lemuru oil

LC-PUFA	Salmon Oil (mg/g FA)	Herring Oil	Cod Liver Oil	Eel oil	Shark oil	Tuna oil	Lemuru oil
DHA	140	20-62	96-114	0.16	0.28	24.56	4.60
EPA	194	39-88	100-104	0.19	0.05	7.81	14.36
Myristic acid	67	46-84	40-50	5.42	0.12	2	8.80
Palmitic	156	101-150	112-122	10.41	1.21	12.93	15.71
Palmitoleic	82	63-120	74-91	0.17	0.28	2.25	9.76
Oleic acid	140	93-214	238-259	28.25	2.68	11.18	7.78
Eicosenoic acid	18	110-199	71-110	0.17	0.21	1.96	0.23
ALA	8	2-11	12-20	7.77	0.21	0.32	0.39
GLA	3	NR	2	0.56	NR	0.02	0.04
n-6 Linoleic acid	15	6-29	23-42	0.10	NR	0.04	0.28

*NR- not reported

long chain fatty acids (EPA, DHA, and others), sterols (including cholesterol), fatty acid esters, cholesterol, and free fatty acids [84] (Table 6). Unrefined fish material contains vitamins A, D, E, and some water-soluble amino acids, peptides, and minerals. Shark liver oil contains hydrocarbons such as squalene in more quantity, but commercial fish oils usually contain hydrocarbons less than 0.2 percent. The lipid number takes the form C:D (n-x), where C is the number of carbon atoms, D is the number double bonds, and n-x symbolizes the location of the last (or ω) double-bond. A lipid number ending in n-3 displays an omega-3 fatty acid (Tables 5 & 6).

4.3 Fish Oil Processing

Fish oil is extracted from muscles and liver. Living fishes are caught for maintaining oil quality [85]. For oil extraction fish are chopped in fine pieces, it is heated and steamed at 100 °C for wet reduction [86]. This steamed and cooked material is then strained and sent to a press, and oil is separated from the pressed liquid fish mass [87]. For obtaining fish oil liquid is allowed to centrifuge at high speed for 1-2 hrs. Now separated oil is washed with hot water for polishing [88]. After separation in pure form oil is filled in tanks for storage. The remaining fish solids are dried and used as fish meal. At this point in the process, the only additions to the fish oil are water, heat, and pressure. The waste streams from this process include emissions of the volatile organic compounds. Net yield obtained is about 20 -80 kilograms/ ton of fish.

Further, fish oil is processed by hardening, and extracted oil is allowed treat with an alkaline solution e.g., sodium hydroxide, potassium hydroxide, or other alkali metal. It reacts with free fatty acids present in the oil and form soaps. The soaps are then removed from the solution by washing with hot water. For dietary use fish oil is filtered through carbon filter (e.g., dioxins/furans, polybrominateddiphenyl ethers [PBDEs], polychlorinated biphenyl 309[PCBs], polycyclic aromatic hydrocarbons [PAHs]) to reduce contaminants [89]. For generation of quality fish oil is passed through selective hydrolysis, followed by filtration. For final purification both solvent extraction and supercritical fluid extraction (SFE) method are used.

4.4 Encapsulation of Fish Oil

PUFAs are polyunsaturated fatty acids found naturally in purified fish oils. For pharmaceutical applications fish oil PUFAs are encapsulated with tocopherols and vitamin E. These are considered as packaged in protective capsule (usually made of gelatin) to protect the oils from oxidation [90-92].

5. Therapeutic Uses of Fish Oil

PUFAs found in fish oil are highly beneficial to human health. PUFAs are important for the development of the nerve conduction, immune defense, visual sensation, and integuetary systems in infants [93-96].Fish oil supplements rich in DHA and EPA are highly useful in asthma [97] and lower down in plasma triglyceride concentration, and decrease the chances of hyperlipidemia [98]. PUFAs significantly lowers down the risks of cardiovascular diseases mainly thrombosis, high blood pressure [99]. Dietary consumption of PUFAs decreases the risk factor of type 2 diabetes mellitus via enhanced insulin sensitivity [100]. Daily consumption PUFAs are highly beneficial in cancer prevention and therapy [101,102]. The PUFAs extracted from cod liver are natural antibacterial and anti-infectious agents [103]. Intravenous lipid emulsions are used for supplying energy releasing to PUFAs [104-106]. PUFAs reduce trans-epidermal water loss (TEWL), maintain epidermal homeostasis and its deficiency (K17) [107]. Fish oil is also used in preparation of pharmaceutical products which are highly useful in dermatological therapy [108,109] (Table 7).

Table 7. Therapeutic and Cosmetics properties of fish oil

Therapeutic activity	Mode of action	Source
Lowering of cardiovascular risks	Reduction of lipogenesis; decrease triglyceride synthesis and an increase FA oxidation; and the promotion of apolipoprotein B degradation in the liver through the stimulation of an autophagic process.	Balk, E. M.; Lichtenstein, A.H., 2017
Photoprotective activity	Omega-3 PUFAs suppress UV-induced keratinocyte damage via COX-2, NF-Kb, and mitogen-activated protein kinase (MAPK)/ extracellular-signal-regulated kinase (ERK) pathways.	(Pilkington et al., 2011)
Anti-carcinogenic	The omega-3 PUFAs act as the inducers of anti-inflammatory IL-10, suppressors of IL-6 and TNF-α to depress cell growth	(Rehman and Zulfakar 2017)
Anti-dermatitis	GLA-rich oil modified fatty acid metabolism and increased the skin barrier function.	(Brosche et al., 2000)
Cutaneous Wounds Healing	Omega-3 and omega-6 PUFAs modulate or enhance local inflammatory response at wound areas, and accelerating the rate of wound healing.	.(Kiecolt-Glaser et al., 2014)
Anti-Hyper-pigmentation	DHA ALA and LA cause skin whitening capability through the mechanism of tyrosinase inhibition.	(Ando et al., 1998,. Shigeta et al., 1004)
Antidepressant activity	PUFAs cause membrane modification by direct interaction with the plasma membrane and via modification of the G-protein signalling.	Erb et al., 2016)
Antioxidant activity	DHA inhibits oxidative reactions and pro-inflammatory responses in microglia cell.	(Saldeen et al.,1997)

5.1 Lowering of cardiovascular risks

Omega-3 FA plays important role in cardiovascular disease control [110]. It lowers down risks of cardiac failure due to blockage of arteries [111]. Fish oil possesses low levels of LDL cholesterol that is physiological much safer. It contains typically 4g/d of eicosapentaenoic acid and docosahexaenoic acid and cut down high levels of triglycerides [112]. Use of fish oil omega-3 fatty acids lowers down the risk of arrhythmias, myocardial infarction, and heart failure [113]. It is highly beneficial in coronary artery disease, hypertriglyceridemia and diabetes [114] (Table 7). Omega-3 fatty acid most likely reduces serum triglyceride levels by modulating very-low-density lipoprotein (VLDL) and chylomicron metabolism [115].

Major problems in cardiac flow and pumping are caused by very low density lipoproteins because they mark with high percentage of cholesterol in their structural composition [116]. Dietary use of fish oil improves cardio-logical health it decreases the hepatic secretion of VLDL17 that is a major endogenous source of triglycerides. The main reason of lower synthesis of triglycerides and increased rate of fatty acid oxidation is that omega-3 fatty acid as are un-preferred substrates for enzyme diacylglycerol O-acyltransferase, these never interacts with nuclear transcription factors. It massively controls lipogenesis; and apolipoprotein B degradation in the liver by stimulation of a cellular autophagy [117]. It regulates formation of VLDL particles and their secretion. Further, dietary use of omega-3 fatty acid accelerates VLDL and chylomicron clearance by inducing lipoprotein lipase activity (Table 7). For treatment of hypertriglyceridemia patients fenofibrate provided with fish oil found highly effective and safe. Omega-3 fatty acid in diet show improvement in mixed lipid disorder mainly those facing metabolic syndrome and/or type II diabetes mellitus [118].

5.2 Photoprotective Activity

A repeated ultraviolet (UV) exposure from sunlight elicits both acute and chronic adverse effects on the skin. It activates sunburn, photosensitivity, inflammation, immunosuppression, and also induces photocarcinogenesis and main cause of photo aging in damaged human skin cells [119]. This damage in skin cells is caused due to formation of reactive oxygen species (ROS) that lead to the massive infiltration of immune cells such as neutrophils and macrophages in viable skin epidermis and dermis [120]. In this process a protein cyclooxygenase-2 (COX-2), proteins mediate the inflammatory signals generated due to UV-induced injury in skin cells. It also catalyzes the biosynthesis process of prostaglandins [121]. Omega-3 PUFAs can decrease the production of proinflammatory eicosanoids through direct competition with the metabolism of AA [122]. Dietary use of Omega-3 PUFAs suppress the UV-induced keratinocyte damage. It also regulates COX-2, NF-Kb, and mitogen-activated protein kinase (MAPK)/extracellular-signal-regulated kinase (ERK) pathways [123]. Interleukin (IL)-

8 mediates UVB-induced keratinocyte inflammation. This is proinflammatory cytokine that belongs to C-X-C chemokine subfamily. [124] its modulation is done by both DHA and EPA which are responsible for inhibition of UVB-induced inflammation in keratinocytes and skin fibroblast cells. In keratinocytes. A similar pattern was observed in fibroblasts. Oleic acid showed no influence on IL-8 release [125] explored the ability of DHA to influence the resistance to UV-activated apoptosis in keratinocytes (Table 7). DHA reverted HaCaT cell resistance to UV-induced apoptosis, increasing the Bax/Bcl-2 ratio and caspase-3 activity. It decreases COX-2 by the inhibition of human antigen R (HuR). That is a COX-2 mRNA stabilizer in keratinocytes. For evaluation of inhibitory effect DHA is applied on UVB-induced skin in hairless mice [126,127]. Topical pretreatment of DHA (2.5 and 10 μmol) significantly decreased COX-2 and nicotinamide adenine dinucleotide phosphate (NADPH): oxidase-4 (NOX-4) in mouse skin. Both COX-2 and NOX-4 are important in evoking oxidative stress and inciting inflammation [128-130]. The molecular mechanisms of this inhibition could be the suppression of UVB-induced NF-KB activation and COX-2/NOX-4 expression by blocking the phosphorylation of stress-activated kinase-1(MSK1), which is a kinase down-stream of ERK and p38 [131-133]. From UV induced injury few photoprotective agents are used to receive photo protection from sunburn and skin damage.

Oral and topical administration of oils enriched with LA and ALA lowered the erythema occurrence in UV-induced hairless mice [134]. But dietary use of ALA displays greater erythema inhibition than LA by the oral route. Hence, both omega-6 and omega-3 PUFAs finish the UVB-elicited lesions. However, PUFAs from fish oil prevent skin aging caused in patients after use of cosmetic products, when these are provided oral or topical application.

5.3 Anti-carcinogenic

UVA causes oxidative stress and continuous inflammation in skin cells, it starts its action as procarcinogenic agent [135] that finally results skin photocarcinogenesis [136]. These skin cancers are either melanoma or non-melanoma skin carcinoma (NMSC). Use of fish oil PUFAs obstructs both initiation and promotion phases of cutaneous carcinogenesis. The cause synergistic inhibition of carcinogenesis and operate premalignant keratinocyte apoptosis [137]. Fish oil DHA and EPA enhance molecular permeation and improve drug delivery into the skin [138] (Table 7). Fish oil combined with imiquimod is used to treat human basal (BCC) and squamous carcinoma cells (SCC) [139]. For this purpose a combined dose of 21% DHA and 42% EPA is administrated. The pure DHA or EPA also generate immunomodulatory effects against the carcinoma cells. Fish oil PUFAs work as the inducers of IL-10, an anti-inflammatory cytokine, and suppress of IL-6 and TNF-α production to depress cell growth [140]. Topical use of the imiquimod cause significant reduction tumor size by gel (2.07 mm) and the commercial imiquimod cream (1.98 mm) as compared with the sham control (6.48 mm). Fish oil intake could increase the latency to the development of UVB-induced tumor and decrease the size of the papilloma, keratoacanthoma, and carcinoma in mice. Similarly, topical application of fish oil rich in omega-3 PUFAs reduce skin papilloma formation by benzo (a) pyrene and croton oil [141]. Fish oil inhibits binding of benzo (a) pyrene to DNA that causes reduction in mean papilloma number per mouse from 6.0 to 3.1. Dietary use of omega-3 PUFAs represses UVB-induced carcinogenesis and melanoma patients [142,143]. Dietary use of fish oil rich in omega-3 fatty acids also lower down risk of melanoma development. A DHA-paclitaxel covalent conjugate more effectively work against tumors and block its increase in size [144] (Table 7).

5.4 Anti-dermatitis

Dermatitis is severe dehydration of skin. It is also characterized by cutaneous flexure, inflammation and itching. Dry skin occurs due to loss of epidermal water content due to stratum corneum barrier function loss [145]. Use of fish oil in diet was found highly useful for ameliorating dermatitis symptoms [146]. These successfully cause reduction in cutaneous dryness and pruritus when provided as oral supplementation. A regular dietary use of fish oil for 60 days cause a 30% increase in cutaneous hydration in the acetone-induced dry skin animal model. It also finished itch-related scratching behavior after 90 days regular supplementation. It also causes significant reduction in the ear thickness, cutaneous eosinophils, and mast cells. PUFAs also decrease the inducible nitric oxide synthase (iNOS) expression and collagen fibers [147]. Supplementation of both DHA and AA in diet decrease intensity of dermatitis in mice. PUFAs, especially GLA, in diet improve dry skin, dermatitis and reverse hyper proliferation of epidermis [148]. Regular consumption of GLA-rich enhances the skin barrier function and inflammation [149] (Table 7).

5.5 Healing of Cutaneous Wounds

PUFAs were also found curative in healing of skin wounds. These induce skin cell formation, replacement of affected cells and promote synthesis of wound healing metabolites. These were found highly effective in second-degree burns, chronic wounds, and ulcers [150]. These acts at all three stages of wound healing suppress inflammatory response, proliferation of wounds and maturation [151]. PUFAs regulate synthesis and activity of cytokines during inflammatory phase of wound healing [152]. These play a key role in cell membrane structure and anabolic events during skin cell formation and tissue reconstruction. Both omega-3 and omega-6 PUFAs modulate or enhance local inflammatory response at wound areas and accelerate the rate of wound healing [153,154]. The topical use of DHA (30 μM) accelerates the skin wound healing through the inflammatory activity modulation in rats [155]. It may happen due to activation of the G-protein-coupled receptor (GPR) 120, to which DHA binds during anti-inflammatory activity. DHA treatment increases production of pro-inflammatory cytokines at the wound site (Table 7).

5.6 Hyperpigmentation

Melanin is synthesized in melanocytes found distributed in skin cells [156]. In biosynthesis of melanin an enzyme tyrosinase catalyzes the conversion of tyrosine to 3, 4-dihydroxyphenylalanine (DOPA) and the oxidization of DOPA to dopaquinone that finally changes into melnin [157]. Skin hyperpigmentation is caused due to long term repetitive exposure of UV light. It stimulates melenogenesis and by inducing synthesis of endothelin-1, α-melanocyte stimulating hormone (α-MSH), growth factors, and cytokines [158]. Dietary use of DHA ALA and LA stop skin whitening via mechanism of tyrosinase inhibition [159,160] (Table 7).

5.7 Antidepressant Activity of Fish Oil

Dietary uses of fish oil show antidepressant effects and exert anti-inflammatory response in neural cells. Fish oil contains omega-3 polyunsaturated fatty acids (PUFA), and there are several mechanisms by which PUFAs are thought to induce an antidepressant effect, including anti-inflammatory action and direct effects on membrane properties [161]. Both EPA and DHA to prevent decrease, the incidence of IFNα -induced depression [162,163]. This is the main reason that fish oil is used to treat depression and inflammation effect. Fish oil use in the treatment of depression sites of action of PUFAs at the cell membrane with special attention being placed on lipid rafts and G-proteins [164]. Omega-3 fatty acids showed antidepressant effects due to their association with rafts, they modify raft structure, and/or release raft-associated proteins into non raft membrane sections There are two ways by which the PUFAs might be affecting the membrane: by DHA's preference to localize into non-raft membrane samples might create a DHA-rich domain capable of altering conformation of both membrane domains and signaling proteins [165]. In such circumstance, PUFAs could affect neurotransmitter signaling and second messengers. PUFAs also facilitate the coupling between the estrogen GPCR, GPER1, G α s, and adenyl cyclase. These specially regulate the palmitoylation of several different proteins[166,167].

5.8 Antioxidant Activity of Fish Oil

Studies in experimental models suggest that n-3 polyunsaturated fatty acids (PUFAs) improve metabolic and anti-inflammatory/antioxidant capacity of the heart. PUFA-treated patients compared with untreated, interestingly, PUFA patients had greater nuclear transactivation of peroxisome proliferator-activated receptor-γ (PPARγ), fatty acid metabolic gene expression, and enhanced mitochondrial respiration supported by palmitoyl-carnitine in the atrial myocardium, despite no difference in mitochondrial content. Myocardial tissue from PUFA patients also displayed greater expression and activity of key antioxidant/anti-inflammatory enzymes. PUFAs enhance mitochondrial fatty acid oxidation and antioxidant capacity in human atrial myocardium, and that this preoperative therapeutic regimen may be optimal for mitigating oxidative/inflammatory stress associated with cardiac surgery [168].

Fish oil EPA- and DHA-rich oil diets lower down blood lipid levels and increase blood glucose levels [169]. It may be due to increased lipid peroxidation[170,171] in the pancreatic cells that also decreased the insulin production[172,173]. DHA also peroxidizes the blends of different fatty acids, inhibits oxidative reactions and pro-inflammatory responses in microglial cells. DHA is anti-inflammatory and anti-oxidative in nature [174].

6. Conclusions and Future Directions

More than 37% of world trade is related to various fish derived food items and more than 50% has been captured by fish products. For the economic growth of any country fish and fisheries become highly important. Fish derived food possess immense nutritional value, its consumption in daily diet is beneficial for the skin and muscles. Fish food is good for mental health and improves neural complications. It assists in relieving stress and depression. Omega-3 fatty acids found in fish oil restore eye sight, photoreception, remove sleep deprivation, replace harmful fats and lowers down LDL levels or "bad" cholesterol levels in blood. Use of PUFAs restores blood pressure and cause a significant decrease in risks of cardiovascular problems, brain strokes and type 1- diabetes. Fish foods are good source of minerals such as calcium, iron, phosphorus and vitamin D. These are highly important for body physiology, immune functions and metabolism. Fermented fish products are easily digestible and absorbable and show a positive effect on body metabolism. Fish foods possess high therapeutic value as these lower down risk of fatty liver diseases and cancer. Both vitamin D and fish PUFAs accelerate metabolic rates during exercise, fat oxidation and energy supply. Fish in daily diet restores premenstrual symptoms in young women. Dietary use of fish oil alleviates the swelling and pain in rheumatoid arthritis and relieves from chronic inflammation. Fish food also lowers down risk of Alzheimer's disease. Fish oil has many possibilities of new human health-related products which can be used in cosmetology and dermatology. Fish consumption is beneficial for removal of fatigue and assists in muscle regeneration.

Authors' Contributions

Ravi Kant Upadhyay and Shweta Pandey were responsible for conception, literature review, writing and revising the manuscript.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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