Chapter 8

Fatty Acids in Fish

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Additional information is available at the end of the chapter

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Abstract

The human body cannot synthesize certain fatty acids: these essential fatty acids must be consumed in the diet. Fish and other aquatic foods are known to be the main sources of polyunsaturated fatty acids (PUFA); therefore, humans obtain most of their eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) by consuming fish, aquatic invertebrates, and algae. The increasing demand for fish and the stabilization of marine fish and freshwater landings have contributed to a widening gap between demand and supply for fish and fish products. This leads to a necessity to improve aquaculture production. Fish are the main contributors of n-3 PUFA in the human diet, although there are some interspecific and intraspecific differences in fatty acid profiles. The fatty acid composition of fish differs depending on a variety of factors, including species, diet, as well as environmental factors such as salinity, temperature, season, geographical location, and whether the fish are farmed or wild. In this chapter, information will be provided on fish fatty acids based on their ecology, feeding habits, lipid contents, and environmental conditions where they are harvested.

Keywords: marine fish, freshwater fish, EPA, DHA, PUFA, HUFA, n3/n6

1. Introduction

Many studies have investigated the effects of lipids and fatty acids in human nutrition on health. This has resulted in an increasing consumer interest and a tendency to consume healthy foods.

Among the fatty acids, highly unsaturated n-3 fatty acids (n-3 HUFA) or long-chain n-3 poly unsaturated fatty acids (LC n-3 PUFA), particularly 20:5 n-3 (eicosapentaenoic acid [EPA]) and 22:6 n-3 (docosahexaenoic acid [DHA]) affect human health, early development, and the prevention of some diseases; therefore, dieticians increasingly recommend consuming foods containing these fatty acids [1]. The recommended n-6/n-3 fatty acid ratio in human nutrition is 5:1, but this ratio (n-6/n-3) varies between 7:1 and 20:1 in the diets of most West Europeans and North Americans [1, 2]. The n-3/n-6 fatty acid ratio recommended by the World Health Organization is 1:1 or above [3]; hence, fish consumption should be increased or foods rich in n-3 fatty acids should be consumed for proper nutrition and disease prevention.

Fish are the most important sources of these fatty acids; fatty fish, such as sardines, mackerel, anchovies, and some salmon species, are rich in EPA and DHA. In these fish, the ratio of n-3 fatty acid to n-6 fatty acid approaches 7. Fish cannot synthesize these fatty acids; they obtain them from food they consume (algae and planktons) [4].

However, lipid composition and thus fatty acid composition in fish differ depending on various factors: usually, their aquatic environment (marine water, freshwater, and cold or warm water) and the biological, physical, and chemical properties of that environment. Also, seasonal changes, migration, sexual maturity and spawning period, species, feeding habits, and whether reared in aquaculture or grown in natural habitats affect the lipid/fatty acid composition [5].

Therefore, detailed information on the changes in lipid and fatty acid compositions among fish and the importance of fish consumption in human health are provided in this chapter by examining these subjects.

2. The importance of fatty acids and fish consume

The interest in fat, which holds an important place in human nutrition, has increased with the recently increasing interest in, and awareness of, human health. Fats are important components of hormones, cell membranes, and signaling molecules, as well as being important energy sources. Fat ingested into the body is first stored in the liver, hypodermic connective tissues, mesentery, and muscles and used when necessary [6].

Fatty acids have a methyl group on one end and have long hydrocarbon chains carrying a carboxyl group on the other end. Fatty acid molecules are classified based on the presence and number of double bonds: saturated fatty acids have no double bond, and monounsaturated fatty acids have a single double bond; polyunsaturated fatty acids (PUFA) have two or more double bonds. The number and position of the double bonds determine the physical properties and functional characteristics of fatty acids. The human body can produce some of these fatty acids, but others, some of which also contain n-3 and n-6 PUFA, cannot be produced by the body. These essential fatty acids (EFAs) need to be obtained through food intake. In current human diets, n-6 fatty acid and, especially, linoleic acid (LA) sources are soya and maize oil, and arachidonic acid (AA); the main n-3 alpha-linolenic acid (ALA) source is meat. Linoleic acid (LA), an n-6 fatty acid, can be converted to fatty acids with longer chains, and n-3 ALA can be converted to eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA); these conversion rates vary between 1 and 10%. Even though EPA and DHA, with 20–22 long chain n-3 fatty acids, have a critical role in human health, their consumption is relatively low, stemming from the deficiency in consumption of fish and fish products in developed countries [7–9].

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Many recent studies have shown the importance of and necessity for n-3 fatty acids in human development and health. Some studies show that they have a positive effect on maternal and fetal health during pregnancy and on newborn and childhood health. These studies emphasize an important role for fatty acids in prevention of hormone-related cancers and important functions in the prevention of cardiovascular diseases. These fatty acids also are purported to relieve dementia, hyperactivity, and some psychiatric disorders [10].

Many studies have carefully evaluated the effects of the lack of fatty acids in the diet following the onset of pregnancy on the prenatal and on postnatal development of newborns and children [6, 10–12]. One study investigated the effect of the lack of n-6 and n-3 long chain PUFA on children with attention-deficit hyperactivity [13]. Moreover, several studies have evaluated the relationship between n-3 PUFA deficiency and depression and mood disorders [14–16]. Various studies have reported the cardio-protective effect of n-3 PUFA (EPA and DHA) supplementation and recommend 1 g EPA intake per day to prevent coronary heart disease [17]. Although their anti-cancer roles have yet to be proven, many studies have shown that n-3 and n-6 PUFA positively affected the prevention of development of different types of tumors. The n-3 PUFA has been reported to alter cell growth by modulating cell replication, interfering with the components of the cell cycle, or by increasing cell death through necrosis or apoptosis [18, 19]. Other studies on the same subject have focused on breast cancer, colon and colorectal cancers, prostate cancer, lung cancer, and neuroblastoma [20].

Fish consumption has an important role in n-3 PUFA (EPA and DHA) intake. Although fatty acids of the n-3 group that cannot be synthesized in the body vary in different species and individuals, fish contain significant amounts of n-3 fatty acids. The nutritional contents and fatty acid compositions of fish differ, depending on various factors. For example, fatty fish, such as herring and mackerel have 400 mg of PUFA per 15 g; thus, weekly consumption of 300 g fatty fish or a daily 200 mg EPA and DHA intake is reported to be sufficient [21]. Furthermore, the n-3/n-6 ratio is reported to be a good index for comparison of the relative nutritional value of fish oils [22]. Although there is no specific recommendation for the n-3/n-6 ratio, evidence found in wild animals and estimated food intake during human evolution indicates a dietary ratio of 1:1 [3].

3. How the fatty acid profiles vary in fish?

Among vertebrates, fish have the highest species diversity and, as stated previously, the nutritional content and fatty acid compositions of fish vary. The most important causes of the variation in the fatty acid profiles of fish are the differences among species. Moreover, living in aquatic environments with different ecological conditions is an important source of variation in nutritional components. The fishing season, size, and reproduction status of the individuals from the same species living in a certain region also affect this variation. Moreover, the aquaculture conditions and feeds used in fish aquaculture also cause variations in the fatty acid compositions of fish that were supplied to the market using aquaculture. These factors are elaborated in the sub-sections that follow.

3.1. Fish bioecology

Fish are divided into two groups based on their habitat: marine fish and freshwater fish. Water temperature and salinity are the most important environmental factors; thus, fishes are first studied based on water temperature and then divided into two groups, the warm-water fish group and cold-water fish group. The optimal temperatures for warm-water species are around 25–30°C, whereas cold-water species prefer temperatures below 20°C. In addition to this classification, both cold-water and warm-water fish are further classified as freshwater and marine fish. Moreover, some fish species migrate from seas to fresh waters or from fresh waters to seas. These fish, such as salmonids and eels, are termed diadromous species [23]. The nutritional compositions of fish (especially lipids and fatty acids) substantially vary due to the differences in their habitats.

In general, freshwater fish require either linoleic acid (18:2 n-6), linolenic acid (18:3 n-3) or both, whereas marine fish require EPA (20:5 n-3) and/or DHA (22:6 n-3) [24].

The studies on the essential fatty acid (EFA) requirement of marine fish showed that their n-3 EFA requirement can be met by EPA (20:5 n-3) and DHA (22:6 n-3). These two fatty acids are termed n-3 HUFA (highly unsaturated fatty acid) or LC (long chain) n-3 PUFA (poly unsaturated fatty acid). The EPA and DHA requirements of fish respond to the n-3 HUFA rich nutrients in marine environments because primary food sources, such as marine algae and planktons, and also other food sources, are known to be rich in EPA and DHA and contain lower levels of linoleic acid and linolenic acid [25, 26].

Studies on freshwater fish have shown that their n-3 EFA requirements are mostly focused on linolenic acid (18:3n-3). The fact that EPA and DHA in vertebrates are biologically active forms of n-3 EFA led to the conclusion that many freshwater fish can convert 18:3 n-3 fatty acids to EPA and DHA. This is less straightforward in marine fish. When compared to marine microalgae, freshwater microalgae contain higher levels of 18:3 n-3 fatty acids than EPA and DHA. Moreover, even though there is not a great amount of 18:2 n-6 fatty acid in marine microalgae, freshwater microalgae contain plenty of this fatty acid. This explains why freshwater fish require higher amounts of linoleic and linoleic acid as compared to marine fish [25, 26]. On the other hand, only one species among the freshwater fish (*Esox lucius*) has the ability to convert 18:3 n-3 fatty acid to EPA and DHA. Because this fish species is an extreme carnivore consuming smaller fish, it does not have high amounts of 18:3 n-3 and 18:2 n-6 fatty acids [27].

The nutritional compositions of the foods in the natural environment of marine and freshwater fish necessitate providing farmed fish with food sources that meet the requirements of their species. The essential fatty acid amount required in the feeds of commercial freshwater and marine fish (preadult or older juvenile) is determined in terms of dry diet%. For example, the 18:3 n-3 fatty acid requirement of trout is 0.7–1.0, and the n-3 HUFA requirement of trout is 0.4–0.5. The 18:2 n-6 fatty acid requirement of common carp is 1.0, whereas their 18:3 n-3 fatty acid requirement ranges from 0.5 to 1.0. The 18:2 n-6 fatty acid requirements of *Tilapia zilli* and *Oreochromis niloticus* are 1.0 and 0.5, respectively. Channel catfish require 18:3 n-3 fatty acid between 1.0 and 2.0, and n-3 HUFA between 0.5 and 0.75. Among the marine fish species, turbot require n-3 HUFA at a ratio of 0.8, and red sea bream (*Pagrus major*) require n-3 HUFA at a ratio of 0.5. The EPA and DHA requirements of red sea bream are 1.0 and 0.5, respectively. The n-3 HUFA requirement of gilthead sea bream (*Sparus aurata*) is between 0.9 and 1.9, whereas the n-3 HUFA requirement of sea bass (*Dicentrarchus labrax*), another important marine species, is 1.0 [25, 26].

Many studies have focused on determining the lipid and fatty acid compositions of marine and freshwater fish (both cold water and warm water). The goal of these studies was both to find the differences among fatty acid compositions of fish from different aquatic environments and to evaluate these fatty acids in terms of human health.

The results obtained in a study from Turkey on the fatty acid compositions of eight different marine fish species that were either farmed or caught in their natural habitats (waker, tub gurnard, whiting, mackerel, blue fish, sea bream, sea bass, and marbled spinefoot) and six different freshwater fish species caught in their natural habitats offer an insight into this subject. The PUFA ratios of the marine species were between 25.2 and 48.2%, whereas they were between 23.2 and 43.8% in freshwater species. The EPA and DHA values of marine species were 4.23–7.02% and 11.7–36.01%, respectively. The EPA and DHA values of freshwater species were between 2.10 and 13.8%, and between 6.72 and 24.8%, respectively. Among marine fish, at 22.6%, the lowest n-3 PUFA ratio was found in waker and, at 44.2%, the highest ratio was found in blue fish. Among the freshwater fish, North African catfish had the lowest n-3 PUFA (11.05%) value, whereas at 28.4%, zander had the highest value. In addition, the n-6 PUFA ratios in the marine fish were between 0.43 and 14.4% and between 5.27 and 16.8% in the freshwater fish [28]. The researchers reported that n-6/n-3 ratios in both the freshwater fish and marine fish were below the ratio recommended by the UK Department of Health (4.0 at maximum) [29].

The results obtained in a study on 34 different marine fish species from the Mediterranean Sea showed that the fatty acid levels of all fish were at the desired levels for human health and quality food consumption. The EPA and DHA values of fish were between 1.94 and 10.0%, and 3.31 and 31.03%, respectively. The n-3 PUFA levels were between 12.66 (annular sea bream) and 36.54% (European hake), whereas oceanic puffer had the lowest n-6 PUFA level at 1.24% and flathead mullet had the highest n-6 PUFA level at 12.76%; the n-6/n-3 ratio varied between 0.04 and 0.91 [30].

A study was carried out with marine and freshwater fish from Malaysia found EPA ratios in freshwater fish between 0.63 and 1.41%, whereas they were between 4.68 and 10.62% in marine fish. The DHA levels were between 0.14 and 0.25%, and 2.50 and 10.05% in freshwater fish and marine fish, respectively. Moreover, that study reported that the n-3/n-6 ratios in all marine species were above 1, whereas the highest level reached was 0.73 in freshwater fish [31]. The World Health Organization recommended that the n-3/n-6 ratio should be at least 1 [3].

Overall, the studies reported that marine species and species that show carnivorous feeding habits and species living in cold water contained high amounts of EPA and DHA and therefore can be used as an important source of food for human health.

3.2. Feeding habits

Aquatic animals (organisms) have environmental and biological characteristics. The most important biological characteristics are feeding habits. Fish are classified as carnivorous, herbivorous, omnivorous, and detritivorous (detritivore, detrivore, or detritus feeder) based on their usual food source preferences in their natural habitats [32]. Moreover, each class is further classified based on their food source preferences as euryphagous (feed on a great variety of foods), stenophagous (feed on a limited variety of foods), or monophagous (feed on only one type of food) [33]. The detritivorous species is *Cirrhinus molitorella*, known as mud carp, and does not have much commercial value.

The most frequently consumed and farmed fish species worldwide have carnivorous, herbivorous, and omnivorous feeding habits; thus, these fish are rich in nutrients and popular among consumers. The fish species that are widely farmed are: euryphagous carnivores, such as salmon, basses, breams, halibut, flounders, and groupers; euryphagous herbivores, such as some carp and tilapia species, milkfish; or euryphagous omnivores, such as common carp, channel catfish, grey mullet, and eels.

The anatomic structures of fish digestion systems differ depending on their feeding habits. Carnivores have shorter intestines and larger stomachs as compared with the other groups, and their stomachs are usually tube-shaped [34]. The digestion ratio of food is higher in carnivorous fish when compared with other groups because semi-digested foods are stored in the chyme, that is, in the stomach, for shorter periods [35].

Common carp, one of the omnivorous species, does not have a stomach because it tends to consume herbal foods; however, some omnivorous species have pouch-shaped stomachs that are smaller than those of the carnivorous species. Moreover, their intestinal structure is more developed and longer. Herbivorous species do not have stomachs and have the longest and most complex intestinal structure because they consume only herbal food sources [34, 36].

The energy requirements of fish differ depending on their feeding habits; therefore, lipid digestion and requirement for lipids, the most important energy source, vary among the fish species. In addition to fish species and feeding habits, some other factors also affect lipid digestion. The age of the fish is the most important factor in lipid digestion [37–39]. The ability of young fish and, especially, fish at the larval stage to digest foods containing high amounts of lipid and lipids in feeds is markedly insufficient [36, 37, 39, 40]. Temperature also affects lipid digestion: warm-water fish species have the greatest ability to digest lipids [41, 42].

In general, carnivorous species can better digest the lipids in high-fat nutrients in their natural habitat—or pellet feeds under farming conditions [43–46]. Their ability to better digest lipids is attributable to their genetic potential to store lipids [47]. In contrast, fish species that have herbivorous and omnivorous feeding habits have a lower capacity to digest nutrients or feeds with high lipid content [48]. Although the ability to digest lipids is affected by many factors, the superior lipid digestion ability of carnivorous species is attributable to their more specific and higher lipase activity when compared with herbivorous and omnivorous species [49].

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Based on the results obtained in relevant studies, the fatty acid requirements and compositions of fish were divided into three groups. The first group is the salmon and rainbow trout group, which are freshwater and anadromous carnivore species from the Salmonidae family; the second group is the carnivorous marine fish group which contains sea bass and sea bream; the third group is the temperate-climate fish group, that mostly have herbivorous and omnivorous feeding habits (tilapia, carp, eel, among others) [50].

For the fish in the first group, α-linolenic acid (18:3 n-3) is the main fatty acid that must be in their feeds, especially under farming conditions. Certain levels of EPA and DHA can only be synthesized from linolenic acid by elongation if there is sufficient α-linolenic acid and insufficient of EPA and DHA in feeds. This does not imply that EPA and DHA are unimportant for trout; on the contrary, trout require these two fatty acids in high amounts but can partially met their requirements with linolenic acid when EPA and DHA are insufficient; however, in some cases, the synthesized amount may itself be insufficient [46, 50].

The most important fatty acids for carnivorous marine fish, especially for sea bass and sea bream, are EPA and DHA. Their ability to synthesize EPA and DHA using other fatty acids is inferior to that of the fish of the Salmonidae group; therefore, they tend to feed on nutrients rich in EPA and DHA, either in their natural habitats or under farming conditions [50].

Linoleic acid (18:2n-6) is known to be the most important fatty acid requirement of species that have herbivorous and omnivorous feeding habits. These fish species, along with linoleic acid, require linolenic acid (18:3n-3) and arachidonic acid (20:4n-6) [50].

Table 1 shows the fatty acid requirements of some carnivorous and herbivorous fish species [50].

3.3. Lipid contents

There are three different lipid compositions of fish: lean fish (less than 5% fat), mid-fat fish (5–10% fat), and fatty fish (10–25% fat). Although the lipid contents of fish depend on many factors, they are generally divided into three groups based on their composition: lean, mid-fat or medium fat, and fatty fish. This classification and the lipid levels in fish have been reported somewhat inconsistently in publications and research. For example, in one paper, fish were divided into four groups based on their lipid levels and lean fish were evaluated under two categories. These groups were:

Very low fat (less than 2%): cod, haddock, flounder/sole, and tuna

Low fat (2–5%): tilapia, halibut, ocean perch, and salmon (chum, pink)

Medium fat (5–10%): bluefish, catfish, rainbow trout, and sword fish

High fat (10% or more): herring, mackerel, sardines, and salmon (Atlantic, sockeye, coho, and chinook) [51].

In another study, fish were separated into three different classes. Fish having lipid levels below 2% were regarded as lean fish; fish having lipid levels between 2 and 8% were regarded

Species	Requirements of fatty acids (in dry feed%)
1. Carnivores	
Rainbow trout (*Oncorhynchus mykiss*)	Linolenic 1% Linolenic 0.8% EPA + DHA 0.4–0.5%
Sea bass (*Dicentrarchus labrax*)	EPA + DHA 1%
Sea bream (*Sparus aurata*)	EPA + DHA 1%, EPA:DAHA = 1 EPA + DHA 1.9%, EPA:DAHA = 0.5
2. Omnivores	
Common carp (*Cyprinus carpio*)	Linoleic 1%; linolenic 0.5–1%
Japanese eel (*Anguilla japonicus*)	Linoleic 0.5%; linolenic 0.5%
3. Herbivores	
Grass carp (*Ctenopharyngodon idella*)	Linoleic 1%; linolenic 0.5%
Tilapia (*Tilapia zilli*)	Linoleic 1%; arachidonic 1%
Tilapia (*Oreochromis niloticus*)	Linoleic 0.5%

Table 1. Fatty acid (in dry feed%) requirements of some carnivorous, omnivorous, and herbivorous fish species [50].

as mid-fat fish; fish having lipid levels above 8% were regarded as fatty fish. Cod fish was given as the best example of lean fish, and some salmon species, herring and mackerel, were placed in the fatty fish group. Another important issue, which should not be overlooked, is that the lipid content in fish can vary significantly. In wild fish, seasonal changes, sexual maturity, reproduction period, and the nutrients they consume; in farmed fish, the feed content and quality directly affect the lipid content [52].

The lipid ratio in lean or fatty fish usually depends on how and where the lipids are stored. Cod fish are known to be lean fish; they do not store lipids in their muscle tissues (fillet) but store them only in the liver, whereas salmon and trout species store lipids in their muscle tissues and the surrounding organs and do not store lipids in their liver [53].

Table 2 shows the nutritional composition in lean, mid-fat, and fatty fish [52].

The lipids in fish vary with body composition. In general, the differences in lipid compositions of certain fish species depend on the spawning period and seasonal changes. For instance, seasonal changes were reported to significantly affect the lipid compositions of herring (*Clupea harengus*) and mackerel (*Scomber scombrus*). In herring, the lowest lipid level was around 5% and observed in April; the highest lipid level was above 25% and was observed in July. In fillets of mackerel, the lowest lipid level was 5% and observed between June and July, whereas the lipid level was above 20% during September–January and approached 30% in December [54].

Because these fish are rich in n-3 fatty acids, the consumption of fatty fish is also important for human health, both EPA and DHA-rich species including salmon, herring, mackerel, anchovies, and sardines. In these fish, the n-3 fatty acid contents are sevenfold or more higher than their n-6 fatty acid contents [55].

Fish species	Fat (g)	Protein (g)	Water (g)
Lean fish			
Haddock	0.2	16.6	81
Cod	0.3	18.1	80
Common sole	0.5	14.8	84
Bluefish tuna	1.0	24.0	74
European perch	1.3	18.1	81
Medium fat fish			
Turbot	2.4	15.9	79
Redfish/ocean perch	2.8	17.1	79
Sea trout	3.3	20.0	74
Char	7.1	16.1	73
Fatty fish			
Farmed trout	10.2	17.2	70
Halibut	10.4	16.2	72
Wild salmon	11.5	19.7	66
Farmed salmon	13.4	19.9	67
Mackerel	20.2	18.5	60
Fatty herring	25.0	17.0	56
Eel	32.5	17.3	46

Table 2. Nutritional content per 100 g in different fish species.

The lipid, EPA, and DHA levels in fillets determined in a study that investigated the lipid levels in fish are given in **Table 3** [52].

In India, researchers examined the EPA, DHA, and fatty acid compositions of 34 fish, 3 prawns, and 2 mussels with different lipid contents (lean, mid-fat, and fatty) and, again, found that EPA and DHA levels were high in the fatty fish group. Among these fish, 12 were obtained from marine water, 3 were obtained from brackish water, 14 were obtained from freshwater, and 5 were obtained from cold water. *Sardinella longiceps* (marine water) and *Tenualosa ilisha* (freshwater) had the highest lipid contents (9.2 and 10.5%, respectively). It was observed that the fatty acid compositions of both fatty fish were especially rich in HUFA, EPA, DHA, and n-3 fatty acids. *Sardinella longiceps* had 12.3% EPA, 6.9% DHA, and 21.4% ∑ n-3 fatty acid. The fatty acid composition of *Tenualosa ilisha,* a freshwater species, contained 2.9% EPA, 8.9% DHA, and 14.2% ∑ n-3 fatty acid [56].

Although the lipid level of *Catla catla* fish, which is a freshwater species having low lipid levels (2–4%) and was obtained from farms, was low in the body composition, it had high levels of EPA, DHA and ∑ n-3 fatty acid. Again, although *Rastrelliger kanagurta* and *Stolephorus waitei*

Fish species	Fat (g)	EPA (g)	DHA (g)
Lean fish			
Haddock	1.0	0.07	0.27
Cod	0.6	0.07	0.16
Saithe/coalfish	0.3	–	–
Tusk	0.3	–	–
European plaice	1.5	0.24	0.26
Medium fat fish			
Halibut	3.9	0.28	0.41
Atlantic wolffish	2.7	0.40	0.20
Rainbow trout	6.7	0.32	1.16
Spotted wolffish	4.8	0.70	0.40
Fatty fish			
Greenland Halibut	15.6	1.00	0.90
Salmon	10.0	0.65	1.80
Mackerel	24.4	1.27	3.17
Herring (summer)	14.5	0.57	1.25
Herring (winter)	19.0	2.48	2.24
Eel	31.5	1.27	2.07

Table 3. Fat, EPA, and DHA content in selected fish species.

(lean fish; less than 2% fat) from marine water had low lipid content, they were rich in EPA, DHA, and $\sum$ n-3 fatty acid relative to the other fish in the same group [56].

3.4. Wild or farmed fish

There are significant differences in nutritional compositions of farmed fish and wild fish. Many recent studies have focused on this issue and have tried to determine to what degree the nutritional composition of fish affects human health and has nutritional benefits [57–64]. The nutritional quality of farmed fish has improved in the recent years thanks to environmentally friendly and advanced aquaculture techniques. In addition, the advancing feed sector now can offer the most suitable and best quality feeds.

In its early years, aquaculture was carried out in small areas using artificial feeds and simple techniques, and the only way to handle disease factors was to use antibiotics. However, more recently, aquaculture has improved significantly and has begun to yield quality products that are both environmentally friendly and beneficial to human health. Many studies have shown that the nutritional, and especially, the lipid compositions in farmed fish are more consistent than in wild fish; therefore, they are richer in n-3 fatty acids [59, 63, 65].

A study that compared individual farmed fish with individual wild fish using the sharp snout sea bream (*Diplodus puntazzo*). In the farmed fish, EPA, DHA, ∑PUFA, ∑n-3 fatty acid levels, and the n-3/n-6 ratio were 4.23 (g/100 g total fatty acid), 10.09 (g/100 g total fatty acid), 35.39, 28.65, and 4.25, respectively. In the wild fish, the EPA level was 6.86, DHA level was 9.28, ∑PUFA level was 32.29, ∑n-3 level was 24.75, and n-3/n-6 ratio was 3.53 [57].

Sea bass (*Dicentrarchus labrax*) is frequently farmed, both in Europe and in Turkey; many studies have focused on this species. Alasavar et al. reported the nutritional compositions of farmed and wild sea bass. In the farmed fish, EPA and DHA values were 6 and 18.1%, respectively, whereas they were 10.06 and 19.5% in the wild fish. In that study, the n-3/n-6 ratios were 2.88 and 3.02 in farmed and wild fish, respectively. The researchers attributed the lower levels in farmed fish to SFA and MUFA-rich, but PUFA-poor, feeds. They also stated that the wild fish were living in a nutrient-rich region and fed on n-3 fatty acid-rich food sources [58].

Different results were obtained in a study that compared the nutritional compositions of three different fish species (sea bass, sea bream, and rainbow trout) to each other. For sea bass, the EPA level was 7.32%, the DHA level was 14.8%, and the ∑n-3 level was 26.2%; for sea bream, the levels were 5.48, 12.4, and 23.3%, respectively; for rainbow trout, the levels were 6.16, 19.04, and 31.1%, respectively. The n-3/n-6 ratios for each fish species were 3.84, 2.85, and 4.54, respectively. Considering that, in general, the n-3/n-6 ratio in a healthy aquaculture food should be at least 1:1, and these three species were well above this value, an indicator of the quality of the aquaculture environment and feeds used in aquaculture [59].

In a study carried out in Turkey, the nutritional compositions of wild fish caught in the Atatürk Dam Lake were investigated: the EPA level was 7.18%, the DHA level was 5.39%, the ∑PUFA level was 23.09%, the ∑n-3 level was 15.64%, the ∑n-6 level was 7.45%, and the n-3/n-6 ratio was 2.10 [60].

Males and females (a total of 10 individual fish) from the shabbout (*Barbus grypus*) species obtained from the same region were used. The samples taken from the species, an omnivorous and rapidly growing species, weighed between 1.5 and 2 kg. Evaluating individual fishes separately showed that EPA values to be between 2.7 and 3.7% and DHA values between 5.2 and 10.7%; the highest value was determined in a male fish. Their ∑PUFA values were between 19.2 and 26.1%; ∑n-3 values between 14.7 and 18.2%, and, again, the highest value was determined in a male fish. The lowest ∑n-6 value was 3.9 and determined in a female, whereas the highest ∑n-6 value was 7.6 and determined in a male fish; thus, at 2.4, the lowest n-3/n-6 ratio was determined in male fish and, at 4.8, the highest n-3/n-6 was determined in female fish [61].

A similar study was carried out on spiny eel (*Mastacembelus mastacembelus*) and EPA and DHA values were 1.62 and 8.41%, respectively. The ∑PUFA level was 21.74%; ∑n-3 level, 14.16%, and ∑n-6 level, 7.11%. The researchers found a n-3/n-6 ratio = 2, and asserted that it could be a beneficial species for human health [62]. The researchers asserted that these were the first studies on wild shabbout and spiny eel in the region studied and stated that their results showed that the nutritional and fatty acid compositions of both species were of high quality and can have economic value.

Interesting results were obtained in a study carried out with individual farmed and wild trout. The nutritional compositions of fish obtained from earthen ponds, sea cages, lake (freshwater) cages, and from their natural habitats in lakes were compared. The highest EPA value (8.74%) was found in the wild fish, whereas the lowest EPA value (3.14%) was determined in the lake-caged fish. To the contrary, at 5.66%, the lowest DHA level was determined in the wild fish and, at 18.49%, the highest DHA value was determined in sea-caged fish. The ∑n-3 levels varied between 18.21 and 26.31%; the highest value was determined in sea-caged fish, the ∑n-6 values varied between 7.11% (wild fish) and 13.1% (lake-caged fish). The n-3/n-6 ratios were 1.33, 1.75, 2.58, and 2.71 for lake-caged fish, earthen pond fish, sea-caged fish, and wild fish, respectively. The n-3/n-6 ratios of fish from each different environment were reported to be at acceptable values [63].

4. Conclusion

The nutrients in fish are important for human health, but are easily obtained from fish oils. Fish fatty acids and particularly poly unsaturated fatty acids (PUFA) play an important role in human health, from embryological development to prevention and treatment of some diseases— including arthritis and inflammation, autoimmune disease, type 2 diabetes, hypertension, kidney and skin disorders, and cancer in children and in adults. The human body cannot synthesize certain fatty acids: these essential fatty acids must be consumed in the diet. Therefore, consumption of fish should routinely take place in human nutrition. The fish resources attract consumer interest and have been discussed in detail in the recent years; therefore, many studies have been carried out to investigate the nutritional value of farmed fish. Most of the studies showed that there was no significant difference between farmed and wild fish in terms of nutritional composition. A significant number of these studies mostly focused on the quantity and quality of fish feeds and the edible parts of fish.

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References

[1] Jobling J, Leknes O: Cod liver oil: feed oil influences on fatty acid composition. Aquaculture International. 2010, **18**:223-230. doi:10.1007/s10499-008-9238-y

[2] Ruxton CHS, Reed SC, Simpson MJA, Millington KJ: The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence. Journal of Human Nutrition and Dietetics. 2007, **20**:275-285. doi:10.1111/j.1365-277X.2007.00770.x

[3] Simopoulos AP: Omega-3 fatty acids in health and disease and in growth and development, a review. The American Journal of Clinical Nutrition. 1991, **54**:438-463.

[4] Falk-Petersen S, Sargent JR, Henderson J, Hegseth EN, Hop H, Okolodkov YB: Lipids and fatty acids in ice algae and phytoplankton from the Marginal Ice Zone in the Barents Sea. Polar Biology. 1998, **20**(1):41-47. doi:10.1007/s003000050274

[5] Aras NM, Haliloğlu Hİ, Atamanalp M: Balıklarda Yağ Asitlerinin Önemi. Atatürk Üniversitesi Ziraat Fakültesi Dergisi. 2002, **33**(3):331-335.

[6] Lee JH: Polyunsaturated fatty acids in children. Pediatric Gastroenterology, Hepatology & Nutrition. 2013, **16**(3):153-161. doi:10.5223/pghn.2013.16.3.153

[7] Williams CA: Diatery fatty acids in human health. Annales de Zootechnie. 2000, **49:**165-180. doi:10.1051/animres:2000116

[8] Hossu B, Korkut AY, Fırat A: Balık Besleme ve Yem Teknolojisi I. Ege Üniversitesi Basımevi, Bornova İzmir. 2000, p. 276.

[9] Kaya Y, Duyar HA, Erdem ME: Balık yağ asitlerinin insan sağlığı için önemi. E.U. Journal of Fisheries & Aquatic Sciences, 2004, **21**(3-4):365-370

[10] Umhau JC, Dauphinais KM: Omega-3 polyunsaturated fatty acids and health. Low-Cost Approaches to Promote Physical and Mental Health, Springer. New York, USA, 2007, Chapter 4, pp. 87-101

[11] Innis SM: Fatty acids and early human development. Early Human Development 2007, **83**:761-766. doi:10.1016/j.earlhumdev.2007.09.004

[12] Osendarp SJM: The role of omega-3 fatty acids in child development. Oilseeds & fats, Crops and Lipids. 2011, **18**(6):307-313. doi:10.1051/ocl.2011.0417

[13] Burgess JR, Stevens L, Zhang W, Peck L: Long-chain polyunsaturated fatty acids in children with attention-deficit hyperactivity disorder. American Journal of Clinical Nutrition. 2000, **71** (Suppl):327-330.

[14] Deacon G, Kettle C, Hayes D, Dennis C, Tucci J: Omega 3 polyunsaturated fatty acids and the treatment of depression. Critical Reviews in Food and Nutrition. 2017, **57**(1):212-223. doi:10.1080/10408398.2013.876959

[15] McNamara RK: Role of omega-3 fatty acids in the etiology, treatment, and prevention of depression: current status and future directions. Journal of Nutrition & Intermediary Metabolism. 2016, **5:**96**-**106. doi:10.1016/j.jnim.2016.04.004

[16] Messamore E, Almeida DM, Jandacek RJ, McNamara RK: Polyunsaturated fatty acids and recurrent mood disorders: phenomenology, mechanisms, and clinical application. Progress in Lipid Research. 2017, **66:**1-13. doi:10.1016/j.plipres.2017.01.001

[17] Duda1 MK, O'Shea KM, Stanley WC: n-3 polyunsaturated fatty acid supplementation for the treatment of heart failure: mechanisms and clinical potential. Cardiovascular Research. 2009, **84:**33-41. doi:10.1093/cvr/cvp169

[18] Carayol M, Grosclaude P, Delpierre C. Prospective studies ofdietary alpha-linolenic acid intake and prostate cancer risk: a meta-analysis. Cancer Causes Control. 2010, **21**:347-355. doi:10.1007/s10552-009-9465-1

[19] Burlingame B, Nishida C, Uauy R, Weisell R. Fats and fattyacids in human nutrition: introduction. Annals of Nutrition & Metabolism. 2009, **55**:5-7. doi:10.1159/000228993

[20] Huerta-Yépez S, Tirado-Rodriguez AB, Hankinson O: Role of diets rich in omega-3 and omega-6 in the development of cancer. Boletin Medico del Hospital Infantil Mexico. 2016, **73**(6):446-456. doi:10.1016/j.bmhimx.2016.11.001

[21] Hagstrup IP: Marine n-3 fatty acids, wine intake, and heart rate variability in patients referred for coronary angiography, Circulation. 2001, **103**:651-657. doi:10.1161/01.CIR.103.5.651

[22] Piggott GM, Tucker BW: Seafood: effects of technology on nutrition. New York: Marcel Dekker. 1990, p. 384.

[23] Hertrampf JW, Pascual FP, editors. Handbook on Ingredients for Aquaculture Feeds. 1st ed. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2000. pp. 4-35.

[24] Committee on animal nutrition board on agriculture National Research Council: nutrient requirements of fish. 1st ed. Washington: National Academy Press; 1993. p. 115.

[25] Halver, J E, Hardy, RW: Fish Nutrition. 3th ed. USA: Academic Press, Elsevier Science; 2002. p. 824.

[26] Tocher, DR: Fatty acid requirements in ontogeny of marine and freshwater fish. Aquaculture Research, 2010, **41**:717-732. doi:10.1111/j.1365-2109.2008.02150.x

[27] Henderson, RJ, Park MT, Sargent JR: The desaturation and elongation of ^{14}C-labelled polyunsaturated fatty acids by pike (*Esox lucius* L.) in vivo. Fish Physiology and Biochemistry. 1995, 14:223-235. doi:10.1007/BF00004313

[28] Özoğul Y, Özoğul F, Alagöz S: Fatty acid profiles and fat contents of commercially important seawater and freshwater fish species of Turkey: a comparative study. Food Chemistry. 2007, **103**:217-223. doi:10.1016/j.foodchem.2006.08.009

[29] HMSO, UK: Nutritional aspects of cardiovascular disease (report on health and social subjects No. 46). London: HMSO; 1994.

[30] Özoğul Y, Özoğul F, Çiçek E, Polat A, Küley E: Fat content and fatty acid compositions of 34 marine water fish species from the Mediterranean Sea. International Journal of Food Sciences and Nutrition. 2009, **60(6):**464-475. doi:10.1080/09637480701838175

[31] Muhamad NA, Muhamad J: Fatty acids composition of selected Malaysian fishes. Sains Malaysiana. 2012, 41(1):81-94.

[32] New MB. Feed and fish shrimps – A manual on the preparation and of compounds of feeds for shrimps and fish in aquaculture. In: Hertrampf JW, Pascual FP, editors. Handbook on Ingredients for Aquaculture Feeds. 1st ed. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2000. pp. 4-35.

[33] Moyle P B, Cech J J. Fishes: An Introduction to Ichthyology. In: Halver, J E, Hardy, RW, editors. Fish Nutrition. 3th ed. USA: Academic Press, Elsevier Science; 2002. pp. 368-451.

[34] Çetinkaya O. Balık Besleme. 1st ed. Van: Yüzüncü Yıl Üniversitesi, Yayın No:9; 1995. p. 137.

[35] Friesecke H. Handbuch der praktischen Fütterung von Rind, Schaf, Pferd, Schwein, Geflügel und Süβwasserfischen. Hertrampf JW, Pascual FP, editors. Handbook on Ingredients for Aquaculture Feeds. 1st ed. Dordrecht, The Netherlands: Kluwer Academic Publishers; 2000. pp. 4-35.

[36] Morais S, Koven W, Ronnestad I, Dinis MT, Conceicao LEC: Dietary rotein:lipid ratio and lipid nature affects fatty acid absorption and metabolism in teleost larva. British Journal of Nutrition. 2005, **93**:813-820. doi:10.1079/BJN20051378

[37] Morais S, Conceicao LEC, Ronnestad I, Koven W, Cahu C, Zambonin Infante JL: Dietary neutral lipid level and source in marine fish larvae: effects on digestive physiology and food intake. Aquaculture. 2005, **268**:106-122. doi:10.1016/j.aquaculture.2007.04.033

[38] Bogevik AS, Tocher DR, Waagbo R, Olsen RE: Triacylglycerol-, wax ester- and sterol ester-hydrolases in midgut of Atlantic salmon (*Salmo salar*). Aquaculture Nutrition. 2008, **14**:93-98. doi:10.1111/j.1365-2095.2007.00510.x

[39] Sargent JR, McEvoy LA, Bell JG: Requirements, presentation and sources of polyunsaturated fatty acids in marine fish larval feeds. Aquaculture. 1997, **155**:117-127. doi:10.1016/S0044-8486(97)00122-1

[40] Kolkovski S: Digestive enzymes in fish larvae and juveniles–implications and applications to formulated diets. Aquaculture, 2001, **200**:181-201. doi:10.1016/S0044-8486(01)00700-1

[41] Cho CY, Slinger SJ: Apparent digestibility measurement in feedstuff for rainbow trout. In: Halver JE, Tiews K, editors. Finfish Nutrition and Fish Food Technology. Heenemann GmbH. Et Co KG. Berlin, Germany, 1979, Vol. 2, pp. 239-247.

[42] Hepher B: Nutrition of Pond Fishes. Cambridge: Cambridge University Press; 1988.

[43] Peres H, Oliva-Teles A: Effect of the dietary lipid level on growth performance and feed utilisation by European sea bass juveniles (*Dicentrarchus labrax*). Aquaculture, 1999, **179**:325-334. doi:10.1016/S0044-8486(01)00700-1

[44] Williams KC, Barlow C, Rodgers L, Hocking I, Agcopra C, Ruscoe I: Asian seabass *Lates calcarifer* perform well when fed pelleted diets high in protein and lipid. Aquaculture, 2003, **225**:191-206. doi:10.1016/S0044-8486(03)00278-3

[45] Denstadli V, Vegusdal A, Krogdahl A, Bakke-McKellup AM, Berge GM, Holm H: Lipid absorption in different segments of the gastrointestinal tract of Atlantic salmon (*Salmo salar*). Aquaculture, 2004, **240**:385-398. doi:10.1016/j.aquaculture.2004.06.030

[46] Glencross BD: Exploring the nutritional demand for essential fatty acids by aquaculture species. Reviews in Aquaculture, 2009, **1**:71-124. doi:10.1111/j.1753-5131.2009.01006.x

[47] Lupatsch I, Kissil GW, Sklan D: Comparison of energy and protein efficiency among three fish species *Sparus aurata*, *Dicentrarchus labrax* and *Epinephelus aeneus*: energy expenditure for protein and lipid deposition. Aquaculture, 2003, **225**:175-189. doi:10.1016/S0044-8486(03)00288-6

[48] Chou BS, Shiau SY: Optimal dietary lipid level for growth of juvenile hybrid tilapia, *Oreochromis niloticus* × *Oreochromis aureus*. Aquaculture, 1996, **143**:185-195. doi:10.1016/S0044-8486(97)89568-3

[49] Patankar VB: Esterases in the stomach of fishes with different food habits. Folia of Histochemistry and Cytochemistry, 1973, **11**:253-282.

[50] Polat A: BalıkBesleme. 1st ed. Adana: Çukurova Üniversitesi, Su Ürünleri Fakültesi, Seri No:10; 2003. P.182.

[51] Seafood health facts [Internet]. 2016. Available from: http://www.seafoodhealthfacts.org/printpdf/seafood-nutrition/patients-and-consumers/seafood-nutrition-overview. [Accessed: 2017.01.25]

[52] Nutritional content and benefit of sea food. Prepared by the Norwegian Food Safety Authority, Norwegian Directorate of Health and the University of Oslo. 3th ed. in English language is designed by Treehouse [Internet]. 2017. Available from: http://www.feap.info/Docdownload.asp?ID=B488944A4D0706030BE2. [Accessed: 2017.01.25].

[53] Fat storage. The National Institute of Nutrition and Seafood Research [Internet]. 2017. Available from: https://www.nifes.no/en/research-topics/aqua-culture/robust-fish/fat-storage/ [Accessed: 2017.01.25].

[54] Çelik M, Küçükgülmez A: Taze balıkta kalite ve kalite değisimleri. 1st ed. Ankara, Nobel Yayın Dağıtım Ltd. Sti.; 2007, p. 195.

[55] Falk-Petersen S, Sargent JR, Henderson J, Hegseth EN, Hop H, Okolodkov YB: Lipids and fatty acids in ice algae and phytoplankton from the Marginal Ice Zone in the Barents Sea. Polar Biology, 1998, **20(1):**41-7. doi:10.1007/s003000050274

[56] Mohanty BP, Ganguly S, Mahanty A, Sankar TV, Anandan R, Chakraborty K, Paul BN, Sarma D, Dayal JS, Venkateshwarlu G, Mathew S, Asha KK, Karunakaran D, Mitra T, Chanda S, Shahi N, Das P, Akhtar MS, Vijayagopal P, Sridhar N: DHA and EPA Content and Fatty Acid Profile of 39 Food Fishes from India. BioMed Research International, 2016, Article ID 4027437, doi:10.1155/2016/4027437

[57] Rueda FM, Hernandez MD, Egea MA, Aguado F, Garcia B, Martinez FJ: Differences in tissue fatty acid composition between reared and wild sharpsnout sea bream, *Diplodus puntazzo* (Cetti, 1777). British Journal of Nutrition, 2001, **86**:617-622. doi:10.1079/BJN2001438

[58] Alasalvar C, Taylor KDA, Zubcov E, Shahidi F, Alexis M: Differentiation cultured and wild sea bass (*Dicentrarchus labrax*) total lipid content, fatty acid and trace mineral composition. Food Chemistry, 2002, **79 (2)**:145-150. doi:10.1016/S0308-8146(02)00122-X

[59] Testi S, Bonaldo A, Gatta PP, Badiani A: Nutritional traits of dorsal and ventral fillets from three farmed fish species. Food Chemistry, 2006, **98 (1)**:104-111. doi:10.1016/j.foodchem.2005.05.053

[60] Celik M, Gokce MA, Basusta N, Kucukgulmez A, Tasbozan O, Tabakoglu SS: Nutritional quality of rainbow trout (*Onchorhynchus mykiss*) caught from the Ataturk Dam Lake in Turkey. Journal of Muscle Food, 2007, **19**:50-61. doi:10.1111/j.1745-4573.2007.00099.x

[61] Gokce MA, Tasbozan O, Tabakoglu SS, Celik M, Ozcan F, Basusta A: Proximate composition and fatty acid profile of shabbout (*Barbus grypus*Heckel) caught from the Ataturk Dam Lake, Turkey. Journal of Food, Agriculture & Environment, 2011, **9(2):**148-151.

[62] Tasbozan O, Gokce MA, Celik M, Tabakoglu SS, Kucukgulmez A, Basusta A: Nutritional composition of Spiny eel (*Mastacembelus mastacembelus*) caught from the Atatürk Dam Lake in Turkey. Journal of Applied Biological Sciences, 2013, **7(2):**78-82.

[63] Tasbozan O, Gokce MA, Erbas C: The effect of different growing conditions to proximate composition and fatty acid profiles of rainbow trouts (*Oncorhynchus mykiss*). Journal of Applied Animal Research, 2016, **44(1):**442-445. doi:10.1080/09712119.2015.1091323

[64] Gökçe MA, Tasbozan O, Çelik M, Tabakoğlu SS: Seasonal variations in proximate and fatty acid compositions of female common sole (*Solea solea*). Food Chemistry, 2004, **88(3):**419-423. doi:10.1016/j.foodchem.2004.01.051

[65] Cahu C, Salen P, De Lorgeril M: Farmed and wild fish in the prevention of cardiovascular diseases: assessing possible differences in lipid nutritional values. Nutrition Metabolism Cardiovascular Diseases, 2004, **14**(**1**):34-41. doi:10.1016/S0939-4753(04)80045-0

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