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Review on Omega-3 (n-3) Fatty Acids in Fish and Seafood

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Abstract
Aquatic organisms (fish, algaes and other sea organisms) are the main natural sources of essential fatty acids in the human diet in particular. The fish oil is considered to have the highest amounts of n-3 PUFAs (Poly-Unsaturated Fatty Acids), which play important roles in the human body, such as in the synthesis of specific active compounds, in the brain and eye development of infants, as well as in the prevention of coronary heart disease. However, public opinion is commonly that different species of fish are of similar nutritional value, and fish selections are made only based on availability freshness, flavor, and other physical factors. Therefore, when fish is suggested for consumption, the PUFA composition must be considered. Extensive research has been done on fatty acids composition of some fish species. However, significant variations have been noted in the PUFA composition of various fish species.
Keywords: essential fatty acids, PUFAs, n-3, fish, seafood

1. Introduction

Sea and freshwater fish species, which constitute the majority of aquatic products, make up an important part of animal food sources for human (Kandemir & Polat 2007). Fish constitutes almost 50% of the total number of recognized vertebrate species. Approximately 39% of these fish species are found always or almost always in fresh water (Cengiz *et al.* 2010). With more than 30.000 known species, fish forms the biggest group in the animal kingdom that is used for the production of animal-based foods. Approximately 700 of these species are commercially breaded and used for food production. Besides that, some 100 crustacean and 100 molluscan species (for example mussels, snails and cephalopods) are processed as food for humans (Oehlenschlager & Rhbein 2009).

Fish are nutritious and highly digestible. As fish contains low energy and a favourable composition of amino acids, they are beneficially nutritionally. The fish is not only a source of beneficial protein, but it also contains more omega-3 (ω3 or n-3) PUFAs (Poly-Unsaturated Fatty Acids) than meat (beef, pork and veal) and vegetable oils (Kandemir & Polat 2007; Osibona *et al.* 2009; Luczynska *et al.* 2012, Ljubojevic *et al.* 2013).

The human diet has changed considerably over the last century and the levels of n-3 fatty acids are low in many modern diets, particularly in those, in which highly processed foods predominate (Richardson 2003; Abeywardena &Patten 2011)**.** In most modern societies, the quantitatively most important source of n-3 fatty acids is derived from α-linolenic acid (ALA, also designated 18:3n-3) found mostly in vegetable oils. Linseed oil, canola oil and soybean oil contain approximately 57%, 8% and 7% α-linolenic acid, respectively, but these oils are without any eicosapentaenoic acid (EPA, C20:5n-3) or docosahexaenoic acid (DHA, 22:6n-3) (Drevon 2009). PUFAs are required for maintenance of optimal health. Recently, there has been an important increase in the scientific scrutiny of and public interest in n-3 and n-6 fatty acids and their impact on personal health (Maggie&Covington 2004). For example, the n-3 fatty DHA and the n-6 fatty acid arachidonic acid (AA) are the major Long Chain PUFAs in the brain. DHA is also the preferred fatty acid for the correct construction and functioning of all membranes in the body, particularly those in very active tissue such as nerves and active muscle. Both EPA and DHA are important in the cardiovascular system. EPA, in particular, contributes to the anti-inflammatory response. It is the building block of a group of cell messengers, called eicosanoids, which. These affect blood pressure, blood clotting, immune function and allergic response. There is also a suggestive evidence for a beneficial effect of early exposure to n-3 fatty acids on children's cognitive development (IFFO 2017; Osendarp 2011).

The distinction between n-6 and n-3 fatty acids is based on the location of the first double bond, counting from the methyl end of the fatty acid molecule. n-6 fatty acids are represented by linoleic acid (LA, 18:2n-6) and n-3 fatty acids-by alpha-linolenic acid (ALA, 18:3n-3), respectively. Both essential fatty acids are metabolized to longer-chain fatty acids of 20 and 22 carbon atoms. The parent n-6 fatty acid, linoleic acid (LA) is desaturated in the body to form arachidonic acid (AA, 20:4n-6), while parent n-3 fatty acid alpha-linolenic acid (ALA) is desaturated by microsomal enzyme system through a series of metabolic steps to form eicosapentaenoic acid (EPA, 20:5n-3) and decosahexaenoic acid (DHA, 22:6n-3). This can be achieved by increasing the chain length and the degree of unsaturation by adding extra double bonds to the carboxyl end of the fatty acid molecule. These fatty acids are effectively synthesized only by aquatic organisms; therefore humans can receive these fatty acids by marine and freshwater fishes. Thus, regular ingestion of fish is important in the maintenance of human health (Singh 2005; Chang *et al*. 2009; Cengiz *et al*. 2010; Bratu *et al*. 2013;

Ljubojevic *et al.* 2013, Simopoulos 2016).

2. Literature Review

2.1. Properties and Structure of Fatty Acids

Fatty acids consist of a hydrocarbon chain (CH_2) or with an acid or carboxyl group (COOH) at one end and a methyl group at the other. They have the general structure $CH_3(CH_2)_nCOOH$. Fatty acids are commonly classified as saturated or unsaturated, depending on the number of hydrogen atoms present. Saturated fats (SFAs) have the maximum number of hydrogen atoms and therefore no double bonds, while PUFAs contain two or more double bonds. Monounsaturated fatty acids (MUFAs) are made up of a chain of carbon atoms, containing one double bond. The poly-unsaturated fatty acids, termed as n-3 fatty acids, are distinguished by having the first double bond positioned on the third carbon atom from the methyl- or N-terminal end of the fatty acid chain (Hossain 2001; Querques *et al*. 2011) The n-3 PUFAs family consists of α-linolenic acid and its longer-chain metabolites, eicosapentaenoic acid (EPA, C20:5n-3), docosapentaenoic (C22:5n-3) and docosahexaenoic (DHA, C22:6n-3) acids (Moussa *et al*. 2014). Structures of some of the n-3 fatty acids are shwon in figure 1 (http://chemistry.tutorvista.com/biochemistry/omega-3-fatty-acids.html).

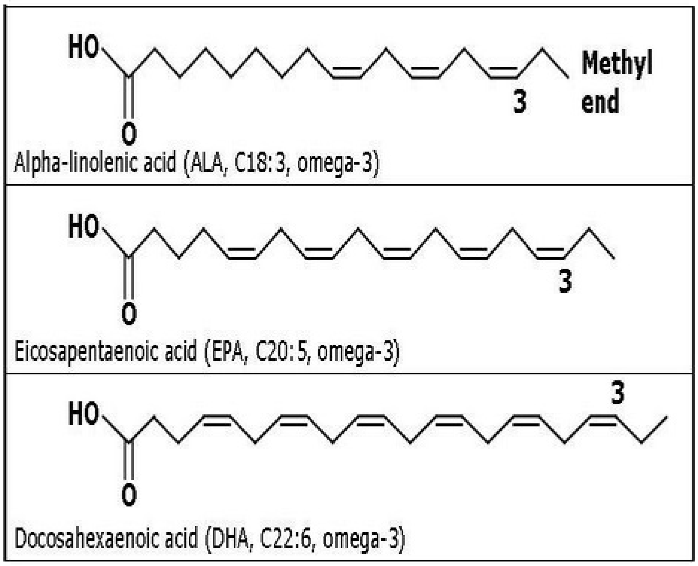

Figure 1. Structure of some of the n-3 fatty acids (http://chemistry.tutorvista.com/biochemistry/omega-3-fatty-acids.html)

2.2. Importance of n-3 Fatty Acids in Fish for Human Diet

Today we know that the beneficial effect of fish consumption on human health for prevention of coronary artery diseases, diabetes, hypertension and cancer. Especially, DHA and EPA play an important role in the prevention of diseases (Visentainer *et al*. 2007; Cengiz *et al*. 2010; Ljubojevic *et al*. 2013)

2.2.1. Some Benefits of n-3 Fatty Acids

The n-3 fatty acids are essential for the living systems, as they are not produced in body. Thus, these acids must be obtained from the diet. Some benefits of n-3 fatty acids are as follows.

1. Fish or n-3 fatty acids consumption has been shown to be related to reduce the cardiovascular risk factors. In a population-based, nested, case control study, a strong negative relationship was reported between fish intake and risk for sudden death (ie, 5.5 g of n-3 fatty acids per month, equivalent to two fatty fish meals per week, was associated with a 50% reduced risk of primary cardiac arrest) (Etherton *et al*. 2002).
2. Consumption of oily fish is essential for optimal development of the brain and neural system in children, as n-3 fatty acids in the form of DHA rather than ALA are needed to secure optimal brain development. Because n-3 fatty acids are important components of nerve cell membranes, they help the nerve cells to communicate with each other, which is an essential step in maintaining good mental health. A recent FAO/WHO expert consultation concluded that fish in the diet lowers the risk of women giving birth to children with sub-optimal development of the brain and neural system, compared with women not eating fish (Suvarna, 2008; FAO 2014). Hereby, the consumption of marine sourced n-3 LC PUFAs also possesses many benefits for the women's health, including depression, mental health, maternal and poly-cystic ovarian syndrome, dysmenorrhoea and some cancers (Manus &Hunt, 2013).
3. n-3 fatty acids are effective in the growth of children. They also possess effects on the cognitive

performance, learning, and problems solving skills in the children, which, on the other hand, helps to reduce risks of asthma in children, eyesight, and IQ (Visentainer *et al*. 2007).

4. There are indications that the consumption of fish or of n3-fatty acids might help reducing hypertension, hyperlipidemia, hyperglycemia, inflammation, and the fish consumption has also positively influences the risk of certain tumor diseases (Fisger&Glei 2015).
5. It is reported that the consumption of fatty fish reduces the risk of dementia by 28%, whereas the consumption of lean fried fish had no protective effect (Fotuhi *et al*. 2009).
6. The researchers note that the n-3 fatty acids and fish oil especially may be effective in the prevention of diabetic disease (Soltan 2012).

2.3. The Indices of PUFAS/SFAS, n-3/n-6 and n-6/n-3 Ratios in Fish and Seafood

Nutritional analysis of fatty acids can be classifed as qualitative and quantitative. Qualitative analysis of fatty acids produces data regarding their composition in the form of percentages of total fatty acids (% of total fatty acids). Meanwhile, quantitative analysis is able to quantify the actual amount (weight) of each fatty acid, presenting in the food. Quantitative data are often presented in the form of weight of the fatty acid per weight of food or fat (e.g., mg/g oil) (Aziz *et al*. 2013).

The two important classes of essential fatty acids, which are not interconvertible, are n-3 and n-6 FAs. The ratio between n-3 and n-6 is a very useful index for comparing the nutritional value of fish lipid due to their healthy effects on the human organism (Khoddami *et al*. 2009**).** The ratio of n-3/n-6 in total lipids of marine fish species changes mostly between 5 and 19.5 (Abedi&Sahari 2014; Olgunoglu&Artar 2016).The ratio of n-3/n-6 in total lipids of freshwater fishes changes mostly between 0.5 and 4 (Saglık *et al*. 2003; Abedi&Sahari 2014; Güler *et al*. 2008). Medical experts recommend that n-3:n-6 are present in the diet at an optimal ratio of around 1:3 to 1:5. Currently, in the developed world the ratio is nearer 1:10 to 1:20. The amount of PUFAs/SFAs (Saturated Fatty Acids) and the ratio of n-6/n-3 is known to be of nutritional importance as it is the key index for balanced synthesis of eicosanoids in the body. In order to prevent cardiovascular disease, the ratio of PUFAs/SFAs consumed should be less than 0.45 and within the PUFAs, and the n-6/n-3 ratio should not exceed 4.0 (Juszczak&Szymczak 2009; Abedi&Sahari 2014; Olgunoglu&Artar 2016).

2.4. n-3 Fatty Acids in Some Fish Species

Depending on their fat content, the fish species are classified as lean (up to 2% fat), medium fat (2-7% fat), fat (7-15% fat), and very fat (over 15% fat) (Tang *et al*. 2009). The fat content of a fish species varies depending on the season, if it is sexually mature and spawning and what the fish eats. In farmed fish, the fat content is strongly dependent on what feed it receives. In most cases, the amount of n-3 fatty acids is related to the total fat content of the species. The darker fleshed fish species (such as herring, salmon, mackerel and bluefish) in general contain a higher total fat content than the leaner, lighter colored flesh species, such as cod, flounder, and pollock. In fact, all fish species contain EPA and DHA, but the quantities of these substances vary greatly among and within the species according to environmental variables such as the temperature, salinity, season, life stage, diet and habitat, but also depending of that whether the fishes are herbivorous, omnivorous or carnivorous (Cengiz *et al*. 2010; Querques *et al*. 2011). Thus, dietary intake of EPA and DHA from fish and shellfish is strongly dependent on the species consumed (Mahaffey *et al.* 2011**).** Fatty acid compositions of different parts (head, tail, fins, and skin = HTFS, liver, viscera, and muscle tissue) of five commercially important fish species from the Persian Gulf (*Scomberomorus commersoni*, *Thunnus tonggol*, *Euthynnus affinis*, *Scomberomorus guttatus*, and *Dussumieria acuta*) as good sources of n-3 PUFAs were studied. The richest sources of n-3 were HTFS in *S. guttatus* and *S. commersoni*, liver in *S. guttatus*, total body of *D. acuta*, liver of *E. affinis* and *T. tonggol*, followed by viscera of *E. affinis* (Sahari *et al*. 2013)

The levels of EPA and DHA in seawater fish are higher than those in freshwater fish (Tang *et al*. 2009). The saturated and monounsaturated fatty acids are generally abundant in fish from warm or temperate regions, whereas PUFAs show higher levels in fish from cold regions (Dhaneesh *et al*. 2012)**.** In fact, the content of fatty acid in the fish tissues reflects the fatty acid content of their diet.

Some studies have shown that the farmed fish contain more fat and a lower percentage of n-3 fatty acids than the wild fish (Hardy 2003). However, the farmed fish shows more constant rates of EPA and DHA synthesis, probably because the feed is controlled and balanced throughout the farming period (Moussa *et al.* 2014). Li&Hu (2009) investigated the n-3 PUFAs content in common commercially available wild and cultured freshwater fishes. Four species of wild and cultured freshwater fishes—crucian carp, mandarin fish, silver fish, and snakeheaded fish—were studied. Long-chain n-3 fatty acid contents in cultured samples were higher than in the wild, except for EPA, and DHA for mandarin fish; DHA for silver fish and ALAs for snakeheaded fish were higher in the wild fish compared to the cultured fish. Consequently, main aquatic species that have been shown to have n-3 PUFAs include fishes, shrimps and shellfishes. The contents of n-3 fatty acids in some fish species are presented in Table 1.

Table 1. n-3 Fatty Acids Content in Fish and Seafood /100 g portion

Fish Species	Source	ALA (g)	EPA (g)	DHA (g)	Total	References
Mossul bleak (*Alburnus mossulensis*)	Freshwater	2.07	1.54	3.97	7.58	Cengiz *et al*. 2010
Barb (*Barbus rajonorum*)	Freshwater	1.87	13.39	26.89	42.15	
Sangal (*Carasobarbus luteus*)	Freshwater	5.90	6.87	11.97	24.74	
Kawar (*Leuciscus lepidus)*	Freshwater	2.70	6.52	27.08	36.30	
Shebhe-nazy (*Acanthobrama marmid*)	Freshwater	2.64	7.97	10.75	21.36	
Large-mouthed barb (*Cyprinion macrostomus*)	Freshwater	1.40	20.15	22.19	43.74	
Abu mullet (*Liza abu*)	Freshwater	2.13	0.65	0.72	3.5	
Picarel (*Spicara smaris*)	Marine	-	9.26	18.44	27.70	
European hake (*Merluccius merluccius*)	Marine	1.79	4.60	14.53	20.92	Olgunoglu & Artar 2016
Black-bellied angler (*Lophius budegassa*)	Marine	0.42	2.03	14.92	17.37	
Blackbelly rosefish (*Helicolenus dactylopterus*)	Marine	0.72	3.65	16.95	21.32	
Shortnose greeneye (*Chlorophthalmus agassizi*)	Marine	0.68	3.31	14.62	18.61	
Gilthead seabream (*Sparus aurata*)	Marine	-	0.02	0.13	0.15	Saglık *et al*. 2003
Sea bass *(Dicentrarchus labrax)*	Marine	-	0.26	0. 41	0.67	
Carps (*Cyprinus carpio*)	Freshwater	0.70	4.83	6.66	12.19	Güler *at al*. 2008
Shabut (*Barbus grypus*)	Freshwater	0.89	3.22	12.83	16.94	Olgunoglu *et al*.2011
Mesopotamian catfish *Silurus triostegus*	Freshwater	2.19	2.92	4.22	9.33	Olgunoglu, 2013
Spiny eel, (*Mastacembelus mastacembelus*)	Freshwater	2.65	1.76	9.36	13.77	Olgunoglu 2011
Anchovy (*Engraulis encrasicolus*)	Marine	1.56	10.24	20.05	31.85	Gencay &Turhan 2016
Yellowtail catfish *Pangasius pangasius*	Freshwater	1.13	2.45	0.23	3.81	Asmah *et al*. 2014
Long tail shad *(Hilsa (clupea) macrura*)	Marine	5.98	11.83	5.96	23.77	
Rainbow Trout (*Oncorhynchus mykiss*)	Freshwater	2.96	7.18	5.39	15.53	Çelik *et al*. 2008
Thornback ray *Raja clavata*	Marine	0.63	1,52	12.21	14.36	Turan *et al*. 2007
Pike *Esox lucius*	Freshwater	1.93	8.11	22.72	32.76	Bulut *et al*. 2010
Pintado *Pseudoplatystoma corruscans*	Freshwater	3.0	0.5	2.8	6.3	Tanamati *et al*. 2009
Pacu *Piaractus mesopotamicus*	Freshwater	1.9	0.7	1.9	4.5	
Pearl Mullet *Chalcalburnus tarichi*	Freshwater	0.77	5.25	8.09	14.11	Mısır *et al*., 2013
Atlantic bonito *Sarda sarda*	Marine	-	8.12	21.52	29.64	Mısır *et al*. 2014
Spotless shad *Alosa immaculata,*	Marine	3.9	5.48	18.08	27.46	Mısır *et al*. 2016
Salmon *Salmo salar*	Marine	4.27	4.18	6.81	15.26	Luczyñska *et al.* 2014

Fish Species	Source	ALA (g)	EPA (g)	DHA (g)	Total	References
Cod *Gadus morhua*	Marine	0.31	16.38	26.97	43.66	
Common sole *Solea solea*	Marine	0.17	19.00	12.34	31.51	
European flounder *Platichthys flesus*	Marine	0.99	9.50	6.67	17.16	
Catfish (*Clarias gariepinus*)	Freshwater	1.91	4.67	8.88	15.46	
Nile tilapia (*Oreochromis niloticus*)	Freshwater	1.36	0.60	5.32	7.28	
Pangasius (*Pangasianodon hypophthalmus*)	Freshwater	0.82	0.78	2.46	4.06	
European Eel (*Anguilla anguilla*)	Freshwater	0.7	3.4	2.3	6.40	Ghazali *et al.* 2013
Vimba (*Vimba vimba tenella*)	Freshwater	2.12	5.27	6.67	14.06	Kalyoncu *et al.,* 2009
Sardine (*Sardina pilchardus*)	Marine	-	10.67	20.83	31.50	Zlatanos &Laskaridis 2007
Picarel (*Spicara smaris*)	Marine	-	9.26	18.44	27.70	
Giant red shrimp (*Aristaeomorpha foliacea*)	Marine	-	12.41	9.56	21.97	Olgunoglu *et al.* 2015
Jinga shrimps (*Metapenaeus affinis*)	Marine	-	13.54	8.28	21.82	Dinçer& Aydin 2014
Warty Crab (*Eriphia verrucosa*)	Marine	0.4	7.87	4.39	12.66	Kaya *et al.* 2009
Swimming crab (*Portunus trituberculatus*)	Marine	0.53	15.74	15.63	31.90	He *et al*. 2017
Blue Swimming Crab (*Portunus pelagicus*)	Marine	1.85	6.12	7.88	15.85	Jahaheri *et al*. 2016
Atlantic spider crab (*Maja brachydactyla*)	Marine	-	22.10	12.53	34.63	Marques *et al.*2010
Chinese mitten crab (*Eriocheir sinensis*)	Freshwater	2.42	2.17	2.85	7.44	Chen *et al*. 2007
Blue crab (*Callinectes sapidus*)	Marine	1.70	8.41	5.30	15.41	Çelik *et al*., 2004
Brown crab (*Cancer pagurus*)	Marine	-	21.5	11.32	32.85	Barrento *et al*. 2016
King Crab (*Lithodes santolla*)	Marine	1.42	17.1	11.00	29.52	Risso&Carelli 2012
Danube crayfish (*Astacus leptodactylus*)	Freshwater	1.02	22.29	7.77	31.08	Öksüz& Mazlum 2016
Caviar from (*Huso huso)*	Marine	1.71	0.77	2.63	5.11	Abbas& Hrachya 2015
Caviar from (*Mugil cephalus*)	Marine	-	7.29	5.36	12.65	Olgunoglu & Olgunoglu 2011
Oyster (*Crassostrea gigas)*	Marine	-	20.21	7.63	27.84	Dagorn *et al*. 2016
Mangrove Oyster (*Crassostrea rhizophorae*)	Marine	3.5	8.75	4.87	17.12	Martino& Cruz 2004

ALA = alpha linolenic acid (18:3n-3), EPA = eicosapentaenoic acid (20:5n-3), DHA = docosahexaenoic acid (22:6n-3)

2.5. n-3 Fatty Acids in Algae

The algae obtain energy from the lightand can produce valuable metabolites, for example, antimicrobials, antioxidants, and PUFAs (Abedi&Sahari 2013). Therefore, the only organisms that are able to easily produce EPA and DHA are marine algae. A recent commercial development of the current century has been the production of oils, rich in DHA and EPA, from micro-algae. These algal oils are already established for use in infant formula and are now increasingly being used in health supplements and enriched food products. Currently, the most common micro-algae, used for the production of DHA-rich algal oil and biomass, are from the marine members of the families *Thraustochytriaceae* and *Crypthecodiniaceae* (Winwood 2013).

2.6. Recommendations for EPA and DHA intake

Many countries have suggested daily EPA and DHA intake levels ranging from 500 mg/day in France to 1-2 g/day in Norway. In the USA, the adequate intakes for adults have been set at 1.6 g n-3 fatty acids (ALAs) per day for men, 1.1 g/day for women respectively, and 17 g n-6 fatty acids (LA) per day for men (19–50 years of age), 12 g/day for women (19–50 years of age) respectively (Candela *et al*. 2011; www.nutri-facts.org). As regards international organizations, the World Health Organization (WHO) recommends the consumption of between 0.3-0.5 g/day, while the International Society for the Study of Fatty Acids and Lipids (ISSFAL) advocates 500 mg/day, and the North Atlantic Treaty Organization (NATO) recommends 800 mg/day. The American Heart Association and Academy of Nutrition and Dietetics recommend an intake of two 4-ounce servings of fish, preferably fatty fish, per week (especially, n-3 fatty acids can be found in fatty fish, such as salmon, tuna, anchovies and sardines, other marine life such as algae). This amount of fish intake correlates roughly to 500 mg of EPA and DHA per day (Candela *et al*. 2011; Watters *et al*. 2012).

It is significant to maintain an appropriate balance of n-3 and n-6 PUFAs in the diet, as these two substances work together to prevention of coronary heart disease and possibly other chronic diseases. The n-3 fatty acids, help reduce inflammation, and most n-6 fatty acids tend to promote inflammation. An inappropriate balance of these essential fatty acids contributes to the development of disease whereas a proper balance helps maintain and even improve health (Simopoulos 2010; Mirajkar *et al*. 2011). Intake of omega-3 fatty acids is much lower at the present time because of the decrease in fish consumption and the industrial production of animal feeds rich in grains containing omega-6 fatty acids, leading to production of meat rich in omega-6 and poor in omega-3 fatty acids (Simopoulos, 2004). Therfore, the diets of Western countries tend to contain 11 to 30 times more omega-6 than omega-3 fatty acids. In contrast, the current Mediterranean diet is made up of a healthier and more appropriate balance between n-3 and n-6 fatty acids (Dhikav *et al*. 2004).

3. Conclusion

The results, presented in the current review, indicated the importance and role of fish consumption in terms of including high PUFAs values in human nutrition, due to the lowering of cardiovascular diseases. Also, the great variety in the fatty acids content in different fish species is confirmed.

References

Abbas, E. M. & Hrachya, G. H. (2015), Fatty acid composition of caviar and liver from cultured great sturgeon (*Huso huso*). International Food Research Journal. **22**(3),1083-1086.

Abedi, E. & Sahari, M.A. (2014). Long-chain polyunsaturated fatty acid sources and evaluation of their nutritional and functional properties. Food Science & Nutrition. **2**(5),443–463.

Abeywardena, M.Y., & Patten, G.S. (2011). Role of ω 3 Longchain Polyunsaturated Fatty Acids in Reducing Cardio- Metabolic Risk Factors Endocrine, Metabolic & Immune Disorders - Drug Targets. **11**(3):232-246.

Asmah, R., Sumaiyah, S.A., & Nurul, S. R. (2014). Comparison of protein, total fat, and omega-3 fatty acids content in yellowtail catfish (*Pangasius pangasius*) and long tail shad (Hilsa (clupea) macrura) in raw and pressurized fish. International Food Research Journal. **21**(6),2147-2153.

Aziz, N.A., Azlan A., Ismail, A., Alinafah, S.M. & Razman, M.R. (2013). Quantitative Determination of Fatty Acids in Marine Fish and Shellfish from farm Water of Straits of Malacca for Nutraceutical Purposes. BioMed Research International. Article ID 284329 12p.

Barrento, S., Marques, A., Teixeira B., Mendes, R., Bandarra N., Pires P. V. & Nunes M.L. (2016). Chemical composition, cholesterol, fatty acid and amino acid in two populations of brown crab *Cancer pagurus*: Ecological and human health implications. Journal of Food Composition and Analysis. **23**, 716–725.

Bratu, A., Mihalache M., Hanganu A., Chira N.-A, Todaşcă M. C. & Roşca S. (2013). Quantitative determination of fatty acids from fish oils using GC-MS method and H-NMR Spectroscopy. U.P.B. Sci. Bull., Series B. **75**(2): 23-32.

Bulut, S., Konuk, M., Uysal, K., Mert, R. & Cemek, M. (2010). Seasonal Varıation in the Fatty Acid Composition and ω6/ω3 ratio of the pike (*Esox lucius*) Muscle Living in Karamık Lake, Turkey. Fresenius Environmental Bulletin. **19**(10), 2227-2231.

Candela, C.G., López, L.M.B., Kohen, V.L. (2011). Importance of a balanced omega 6/omega 3 ratio for the maintenance of health. Nutritional recommendations. Nutr. Hosp. **26**(2):323-329.

Cengiz, E.I., Ünlü, E., & Başhan, M. (2010). Fatty acid composition of total lipids in muscle tissues of nine freshwater fish from the River Tigris (Turkey). Turk. J. Biol. **34**,433-438.

Chang CY., Ke D.S, & Chen J.Y. (2009). Essential Fatty Acids and Human Brain. Acta Neurol Taiwan. **18**:231-241.

Chen, De W., Zhang M. &Shrestha, S. (2007). Compositional characteristics and nutritional quality of Chinese mitten crab (*Eriocheir sinensis*). Food Chemistry. **103**, 1343–1349.

Çelik, M., Türeli, C., Çelik, M., Yanar, Y., Ünal E. & Küçükgülmez A. (2004). Fatty acid composition of the blue crab (*Callinectes sapidus* Rathbun, 1896) in the north eastern Mediterranean Food Chemistry. **88**,271–273.

Çelik, M., Gökçe M.A., Başusta N., Küçülgülmez A., Taşbozan O. & Tabakoğlu Ş.S. (2008), Nutritional Quality of Rainbow Trout (*Oncorhynchus Mykiss*) Caught From The Atatürk Dam Lake in Turkey, Journal of Muscle Foods. **19**,50–61.

Dagorn, F., Couzinet-Mossion A., Kendel, M., Beninger, P.G., Rabesaotra V., Barnathan, G., Wielgosz-& Collin, G. (2016). Exploitable Lipids and Fatty Acids in the Invasive Oyster Crassostrea gigas on the French Atlantic Coast. Mar. Drugs. **14**,104.

Drevon, C.A. Omega-3 (2009). fatty acids - metabolism and mechanisms of action of essential fatty acids Möller's orig.indd.

Dhaneesh, K.T. Noushad, K.M. &Kumar, T.T.A. (2012). Nutritional Evaluation of Commercially Important Fish Species of Lakshadweep Archipelago, India. Nutritional Quality of Fishes of Lakshadweep Sea. **7**(9);1-7.

Dhikav, V., Anand, K. S. & Sudha R. (2004). Omega-3 Polyunsaturated Fatty Acid and Cardiovascular Disorders JIACM. **5**(2),182-1855.

Dinçer, M.T., & Aydın, İ. (2014). Proximate composition and mineral and fatty acid profiles of male and female jinga shrimps (*Metapenaeus affinis*, H. Milne Edwards, 1837). Turk. J. Vet. Anim. Sci. **38**,1-7.

Etherton, P.M.K., Harris, W.S. & Appel, L.J. (2002). Fish Consumption, Fish Oil, Omega-3 Fatty Acids, and Cardiovascular Disease. Circulation. **19**,2747-2757. DOI: 10.1161/01.CIR.0000038493.65177.94

FAO, (2014). Committee on Fisheries Fish Trade and Human Nutrition COFI: FT/XIV/2014/4 Bergen,Norway, 24–28 February 2014 (http://www.fao.org/3/a-az998e.pdf)

Fischer, S. & Glei, M. (2015). Health aspects of regular consumption of fish and omega-3-fatty acids. Ernahrungs Umschau. **62**(9),140–151 DOI: 10.4455/eu.2015.02.

Fotuhi M., Mohassel P. & Yaffe K. (2009). Fish consumption, long-chain omega-3 fatty acids and risk of cognitive decline or Alzheimer disease:a complex association. Nature Clinical Practice Neurology. 5 (3): 140-152. doi:10.1038/ncpneuro1044.

Gencay, G. & Turhan, S. (2016). Proximate Composition and Nutritional Profile of the Black Sea Anchovy (*Engraulis encrasicholus*) Whole Fish, Fillets, and By-Products. Journal of Aquatic Food Product Technology. **25**(6),864–874.

Ghazali, N., Boussoufa, D., Navarro, J.C. & El Cafsi, M. (2013). Lipid and fatty acid variations in muscle tissues of the 'yellow' stage of the European eel (*Anguilla anguilla*) during short-term adaptation to freshwater and seawater under food deprivation. Marine and Freshwater Behaviour and Physiology. **45**(6),385–395.

Güler, G.O., Kiztanir, B., Aktümsek, A., Citil, O.B. & Özparlak, H. (2008). Determination of the seasonal changes on total fatty acid composition and ω3/ω6 ratios of carp (Cyprinus carpio L.) muscle lipids in Beysehir Lake (Turkey). Food Chemistry. **108**,689–694.

Hardy, R.W. (2003). Farmed Fish & Omega-3 Fatty Acids.Aquaculture Magazine. March/April.

He, J., Xuan, F., Shi H., Xie J., Wang, W., Wang, G. & Xu W. (2017). Comparison of nutritional quality of three edible tissues of the wild-caught and pond-reared swimming crab (*Portunus trituberculatus*) females. - Food Science and Technology. **75**,624-630.

Hossain, M.A. (2001). Fish as Source of n-3 Polyunsaturated Fatty Acids (PUFAs), Which One is Better-Farmed or Wild? Advance Journal of Food Science and Technology. **3**(6):455-466.

http://chemistry.tutorvista.com/biochemistry/omega-3-fatty-acids.html 03.12.2016

IFFO, International Fishmeal and Fish Oil Organisation, The importance of dietary EPA & DHA omega-3 fatty acids in the health of both animals and humans. Datasheet http://www.iffo.net/system/files/75_0.pdf. 31.01.2017

Javaheri, B. M., Velayatzadeh, M., Roomiani, L. & Khoramabadi, A. (2016). Effect of sex and tissue on fatty acid composition in the meat of Blue Swimming Crab (*Portunus pelagicus*) from the Persian Gulf. Iran Iranian Journal of Fisheries Sciences. **15**(2),818-826.

Juszczak, L.P. & Szymczak, K.K. (2009). Fatty acid profiles and Fat Contents of Commercially Important fish from Vistula Lagoon. Pol. J. Food Nutr. Sci. **59**(3),225-229.

Kalyoncu, L., Kissal, S., Aktumsek, A. (2009). Seasonal changes in the total fatty acid composition of Vimba, *Vimba vimba tenella* (Nordmann, 1840) in Egˇirdir Lake, Turkey Food Chemistry. **116**,728–730.

Kandemir, Ş. & Polat N. (2007). Seasonal Variation of Total Lipid and Total Fatty Acid in Muscle and Liver of Rainbow Trout (*Oncorhynchus mykiss* W., 1792) Reared in Derbent Dam Lake. Turkish Journal of Fisheries and Aquatic Sciences. **7**, 27-31.

Kaya, Y., Turan, H. & Erdem, E. (2009). Determination of Nutritional Quality Crab (*Eriphia verrucosa* Forsskal, 1775). Journal of Animal and Veterinary Advances. **8**(1):120-124.

Khoddami, A., Ariffin, A.A. Bakar, J. & Ghazali, H.H. (2009). Fatty Acid Profile of the Oil Extracted from Fish Waste (Head, Intestine and Liver) (*Sardinella lemuru*) World Applied Sciences Journal. **7**(1), 127-131.

Li, D. & Hu, X. (2009). Fish and its multiple human health effects in times of threat to sustainability and affordability: are there alternatives? APJCN **218**,553–563.

Ljubojevic, D., Trbovic, D., Lujic, J. Bjelic-Cabrilo, O., Kostic D., Novakov, N. & Cirkovic, M. (2013). Fatty Acid Composition of Fishes from Inland Waters. Bulgarian Journal of Agricultural Science. **19**(1),62–71.

Łuczyńska, J., Paszczyk, B., Borejszo, Z. & Tarkowski, Ł. (2012). Fatty Acid Profi le of Muscles of Freshwater Fish from Olsztyn Markets Pol. J. Food Nutr. Sci. **62**(1),51-55.

Luczyñska J., Paszczyk B., Luczyñski, M.J. (2014). Fatty acid profiles in marine and freshwater fish from fish markets in northeastern Poland. Arch. Pol. Fish. **22**,181-188.

Maggie, B. & Covington, M.D. (2004). Omega–3 Fatty Acids. American Family Physician. **70**(1):133–140.

Mahaffey, K.R., Sunderlan, E.M., Chan, H.M., Choi, A.L., Grandjean, P., Mariën, K., Oken, E., Sakamoto, M., Schoeny, R., Weihe, P., Yan, C.H. & Yasutake, A. (2011). Nutrition Reviews. **69**(9):493–508. doi:10.1111/j.1753-4887.2011.00415.x

Manus, A. Mc. & Hunt, W. (2013). Consumption of omega-3 fatty acids and women's health. OA Women's Health. 1(2):11.

Martino, R.C. & Maria da Cruz. G. (2004). Proximate Composition and Fatty Acid Content of the Mangrove Oyster Crassostrea rhizophorae Along the Year Seasons. Brazilian Archives of Biology and Technology. **47**(6):955-960.

Marques, A., Teixeira, B., Barrento, S., Anacleto, P., Carvalho, M.L. & Nunes, M.L. (2010). Chemical composition of Atlantic spider crab Maja brachydactyla: Human health implications. Journal of Food Composition and Analysis. **23**,230–237.

Mısır, G.B., Kutlu, S. & Çibuk, S. (2013). Determination of Total Lipid and Fatty Acid Composition of Pearl Mullet (*Chalcalburnus tarichi*, Pallas 1811). Turkish Journal of Fisheries and Aquatic Sciences. **13**,777-783.

Mısır, G.B., Tufan, B. & Köse, S. (2014). Monthly variation of total lipid and fatty acid contents of Atlantic bonito, *Sarda sarda* (Bloch, 1793) of Black Sea. International Journal of Food Science and Technology. **49**,2668–2677.

Mısır, G.B., Tufan, B. & Köse, S. (2016). Variations in Total Lipid and Fatty Acid Contents of Edible Muscle, Liver, and Roes of Spotless Shad, *Alosa immaculata*, During Catching Season in Black Sea. Journal of Aquatic Food Product Technology. **25**(1),2-14.

Mirajkar, R.N., Jamadar, S.A., Patil, A.V. & Mirajkar, N.S., (2011). Omega 3 Fatty Acids- Clinical Implications. International Journal of ChemTech Research. **3**(2),724-732

Moussa, El R. W.H., Shereen, A.N., Manal, A., Mehanni, A.H.E. & Rasha, A.E. (2014). Nutritional Value and Fatty Acid Composition of Household Cooking on Fish Fatty Acids Profile Using Atherogenicity and Thrombogenicity Indices. J. Food Chem. Nutr. **2**(1),27-41.

Oehlenschläger, J. & Rehbein, H. (2009). Basic facts and figures, Chapter 1. Fishery Products Quality, safety and authenticity Edited by Hartmut Rehbein and Jörg Oehlenschläger. 1-18.

Olgunoglu, İ.A. (2011). Determination of the fundamental nutritional components in fresh and hot smoked spiny eel (*Mastacembelus mastacembelus*, Bank and Solander, 1794) Scientific Research and Essays. **6** (31),6448-6453.

Olgunoglu, İ.A. & Olgunoglu, M.P. (2011). Concentrations of metal contaminants, vitamin and mineral in waxed caviar from *Mugil cephalus* (L.,1758). African Journal of Agricultural Research. **6(**4):1041-1046.

Olgunoglu, İ.A., Olgunoglu, M.P. & Artar, E. (2011). Seasonal Changes in Biochemical Composition and meay yieald of Shabut (*Barbus grypus*, Heckel 1843). Iranian Journal of Fisheries Sciences. **10**(1),183-189.

Olgunoglu, İ.A. (2013). Seasonal Variation of The Fatty Acid Composition In The Muscle Of Mesopotamian Catfish (*Silurus Triostegus*, Heckel, 1843) From Atatürk Dam Lake (Turkey, Adiyaman). Advences in Food Sciences. **35**(3),126-130.

Olgunoglu, I.A., Artar, E. & Göçer, M. (2015). Comparison of Fatty Acid Profiles of Male and Female Giant Red Shrimps (*Aristaeomorpha foliacea* Risso, 1827) obtained from Mediterranean Sea. Ital. J. Food Sci. **27**,432-435.

Olgunoglu, I.A. & Artar, E. (2016). The Fatty Acid Profiles in the Muscle Tissues of Four Benthic Fish Species from Northeastern Mediterranean Sea of Turkey. Research Journal of Biotechnology. 2016. 11(9):71-74.

Osendarp, S.J.M. (2011). The role of omega-3 fatty acids in child development. OCL, **18**(6):307-313.

doi :10.1684/ocl.2011.0417

Osibona, A.O, Kusemiju, K. & Akande, G.R. (2009). Fatty acid composition and amino acid profile of two Freshwater species, African catfish (*Clarias gariepinus*) and tilapia (*Tilapia zillii*). African Journal of Food Agriculture Nutrition and Development. **9**(1):608-621.

Querques, G., Forte, R. & Souied, E.H. (2011). Retina and Omega-3 Journal of Nutrition and Metabolism. Article ID 748361, 12 p.

Öksüz, A. & Mazlum, Y. (2016). Determination of Proximate Composition and Fatty Acid Profiles of *Astacus leptodactylus* Eschscholtz, 1823 in Turkish Freshwater Resources. Crustaceana. **89**(10):1135-1147.

Richardson A.J. (2003). The importance of omega-3 fatty acids for behaviour, cognition and mood Scandinavian. J. Ntr. **47**(2): 92-98.

Risso, S. & Carelli, A.A. (2012). J Nutrient Composition of Raw and Cooked Meat of Male Southern King Crab (*Lithodes santolla* Molina, 1782). Journal of Aquatic Food Product Technology. **21**,433–444.

Saglık, S., Alpaslan, M., Gezgin, T., Çetintürk, K., Tekinay, A. & Güven, K.C. (2003). Fatty acid composition of wild and cultivated gilthead Seabream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*). Eur. J. Lipid Sci. Technol. **105**,104–107.

Sahari, M.A, Farahani, F., Soleimanian Y. & Mokhlesi A. (2013). n-3 Fatty Acid Distribution of Commercial Fish Species Components J Am Oil Chem Soc. **90**:1167–1178.

Simopoulos, A.P. (2004). Omega-3 Fatty Acids and Antioxidants in Edible Wild Plants. Biol. Res. **37**, 263-277

Simopoulos A.P. (2010). The omega-6/omega-3 fatty acid ratio: health implications. OCL, **17**:267-275. http://dx.doi.org/10.1051/ocl.2010.0325.

Simopoulos, A.P. (2016). An Increase in the Omega-6/Omega-3 Fatty Acid Ratio Increases the Risk for Obesity. Nutrients. **8**(128),1-17.

Singh, M. (2005). Essential Fatty Acids, DHA and Human Brain. Indian Journal of Pediatrics. **72**,239-242.

Soltan, S.S.A.M. (2012) The Effects of Varieties Sources of Omega-3 Fatty Acids on Diabetes in Rats. Food and Nutrition Sciences, 3, 1404-1412. http://dx.doi.org/10.4236/fns.2012.310184.

Suvarna, B.S. (2008). Secrets of omega-3 oil. Kathmandu University Medical Journal. **6**(3),23,406-411.

Tanamati, A, Stevanato, F.B., Visentainer, J.E.L., Matsushita, M., Evelázio de Souza N. & Visentainer, J.V. (2009). Fatty acid composition in wild and cultivated pacu and pintado fish. Eur. J. Lipid Sci. Technol. **111**,183–187.

Tang, H.G., Chen ,L.H., Xiao, C.G. & Wu, T X. (2009). Fatty acid profiles of muscle from large yellow croaker (*Pseudosciaena crocea* R.) of different age. J. Zhejiang Univ Sci B. **10**(2):154-158.

Turan, H., Sönmez, G. & Kaya, Y. (2007). Fatty acid profile and proximate composition of the thornback ray (*Raja clavata*, L. 1758) from the Sinop coast in the Black Sea. Journal of FisheriesSciences.com. **1**(2),97-103.

Visentainer, J.V., Noffs, M.D'A., Carvalho Patricia de O., Almeida, V., & Vivian, D.E. (2007). Lipid Content and Fatty Acid Composition of 15 Marine Fish Species from the Southeast Coast of Brazil. J. Amer. Oil Chem. Soc. **84**,543.

Watters, C., Iwamura, S., Ako, H. & Deng, D.F. (2012). Nutrition Considerations in Aquaculture: The Importance of Omega-3 Fatty Acids in Fish Development and Human Health. Foods and Nutrition. FN-11. Published by the College of Tropical Agriculture and Human Resources (CTAHR).

Winwood, R.J. (2013). Recent developments in the commercial production of DHA and EPA rich oils from micro-algae. OCL **20**(6) D604.

www.nutri-facts.org. 27.11.2016. (http://www.nutri-facts.org/content/dam/nutrifacts/pdf/Nutrients-pdf/Essential_Fatty_Acids.pdf)

Zlatanos, S. & Laskaridis, K. (2007). Seasonal variation in the fatty acid composition of three Mediterranean fish– sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicholus*) and picarel (*Spicara smaris*). Food Chem. **103**,725–728.