Asian Journal of Fisheries and Aquatic Research

5(4): 1-10, 2019; Article no.AJFAR.54469
ISSN: 2582-3760

Factors Influencing the Lipid Content and Fatty Acids Composition of Freshwater Fish: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author LV wrote the first draft and made the final version of the manuscript. Authors PS and ES managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJFAR/2019/v5i430082
Editor(s):
(1) Dr. Ahmed Karmaoui, Department of Biology, Southern Center for Culture and Sciences, Zagora, Morocco.
Reviewers:
(1) Aba-Toumnou Lucie, University of Bangui, Central African Republic.
(2) Mustapha Aba, Morocco.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54469

Review Article

Received 05 December 2019
Accepted 11 February 2020
Published 21 February 2020

ABSTRACT

Fish farming has a long tradition in Central Europe. Aquaculture is highly developed here and even so, freshwater fish meat consumption is still very low. Freshwater fish meat is an important source of n–3 long-chain polyunsaturated fatty acids (PUFA), principally eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) which have an indisputable effect on human health and prevent the genesis of human coronary disease. Previous researches revealed many aspects affecting the PUFA quantity. In general, the fatty acid composition of fish lipids affects age, seasonal change, nutrition, sex, reproductive cycle, geographical location, etc. This review represents a step towards the characterization of the fatty acid composition of economically important freshwater fish species from different points of view, including the above-mentioned factors and taking into consideration the way of stunning and differences of lipid composition in individual fish body sections.

Keywords: EPA; DHA; meat quality; human health.

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1. INTRODUCTION

The pond farming is an aquaculture technology tightly linked with its surrounding environment, influencing it and being reciprocally influenced by it. The extensive and semi-intensive management systems, typically for Czech pond aquaculture include complex production methods with many important links to the surrounding ecosystem. Finally, these ponds are important ecosystems themselves. Carp (*Cyprinus carpio*, Linnaeus 1758) farming has a long tradition in the Czech Republic, with many ponds originating from early medieval times. Over such a long period, the ponds have become an important part of the countryside. In other European countries has pond farming also long-time tradition, e.g. Poland, Hungary, Austria and Germany.In summary, ponds functionas landscape components, they retain water, and they are irreplaceable for fish production, which means high nutritional quality food production. Even though there are used another systems for fish production (trout farms, recirculation systems) pond farming is most traditional in the Central Europe countries.

High nutritional quality is the most important health benefit of fish meat due to its high content of n–3 polyunsaturated fatty acids, eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3), [1,2]. These highly unsaturated fatty acids (HUFA) are essential for humans and their biosynthesis is limited. Polyunsaturated fatty acids (PUFA), especially n-3 long-chain HUFA (where exactly EPA and DHA belong) found mainly in fish have an indisputable effect on human health, especially, prevention of human coronary disease, a healthy lifestyle and weight reduction [2,3]. There aretwo groups of PUFA: n-3 and n-6. The cardioprotective effects of n-3 PUFA include arrhythmia prevention [4], plasma triacylglycerol reduction [5], vascular relaxation improvement [6], anti-inflammatory responses [7], platelet aggregation inhibition [8], enhancement of plaque stability [9] and antiatherosclerotic effects [10]. Unfortunately, fish meat and fish product consumption is low and the incidence of cardiovascular coronary artery diseases with other lifestyle diseases has an upward trend [11,12]. Block and Pearson [13] present that today´s diet is typical with the increasing quantity of saturated fatty acids (SFA) and n-6 fatty acids from vegetable oils, cereals and products of animal origin rich in fat. Furthermore, not in every country, people consume fish and their products frequently. For example, in the Czech Republic, the annual fish consumption in 2017 was 3.8 kg per capita [14].

Lund [3] states that fish meat is healthy not only thanks to the essential fatty acidcontent but also due tothe favourable composition of proteins, minerals and vitamins. In the water environs, algae are the primary source of n-3 HUFA, which goes through the food chain to fish and humans at the end. Marine fish have a higher content of n-3 HUFA (because of the food chain and faster primary production)and on the other hand, freshwater fish contain a higher proportion of n-6 PUFA, mainly linoleic acid (LA, 18:2n-6) and arachidonic acid (AA, 20:4n-6), [15]. Freshwater non-carnivorous fish species can biosynthesize the n-3 HUFA from α-linolenic acid (ALA, 18:3n-3) and thus these species are an equal source of essential fatty acids to marine fish [16]. And naturally also carnivorous freshwater fish - even lean species (for example pike - *Esox lucius*, Linnaeus 1758) can be in the human diet the source of high-quality fatty acids (PUFA- EPA and DHA).

Fish fat content, type, and quantity of fatty acids influence many factors, these factors include e.g. fish species, size and age of fish, season, water temperature, geographic location. The major factors influencing fatty acids profiles of the freshwater fish flesh are the diet [17,18] and the rearing conditions [19,20]. The fat content and composition vary among different fish species as well as the same species cultured under different conditions [21,22].

Aquaculture has traditionally used products from industrial fisheries, namely, fishmeal and oil, to convert relatively cheap protein and oil into high-value products. Evidently, there exist on many works about freshwater fish meat quality and possible causes of how to, even raise the quality. The aim of this review is to describe thefatty acid composition of economically important freshwater fish species from different points of view, including the above - mentioned factors and taking into consideration the way of stunning and differences of lipid composition in the individual fish body section.

2. INFLUENCE OF THE PLACE OF BREEDING

According to Çelik et al. [23], the place and method of cultivation affectfish meat quality. Bauer and Schlott [24] concluded from their experiment in Austrian ponds that the geographical site of carpfarming influences the composition and quality of carp meat. The mean fat content varied from 2.7 to 6.9% and differed significantly among all three carp farms. But authors admit that fat content should also influence the feeding (mixed feed instead of barley in one farm). Similarly, Varga et al. [25] studied carp from different cultures indifferent regions of Hungarywith identical feeding. They found that environmental factors influence significantly (P = .001) among other fat content. Place of cultivation of rainbow trout (*Oncorhynchus mykiss*, Walbaum 1792) significantly affectslipid saturation. Tkaczewska et al. [26] studied rainbow troutin various climate regions, even when they were feedinga similar way and feed there were significant differences in n-3fatty acids. This leads to the conclusion that the place of cultivation affects the quantity of n-3fatty acids in the meat lipids of those fish. The impact of breeding conditions are not valid only at strictly freshwater fish, in different regions of Turkey was studied European bass (*Dicentrarchus labrax*, Linnaeus 1758), living in seas, coastal waters and rivers, cultivated in three regions. There were statistical differences in SFA, MUFA (monounsaturated fatty acids) and PUFA depending on the farming region [27] but results could influence the natural feed offer.

Also, exist on many studies, which indicate that therearing water temperature influences the biochemical composition of the fish fillet [28,29,30]. Kukačka et al. [31] reported from the laboratory experiment that a gradual and moderate decrease in water temperature resulted in an increase (highly significant) of n-3 fatty acid content, mostly DHA, in carp muscle lipids. This demonstrates that the thermal conditions of the cultivation region (place) affect the fatty acid profile, especially the n-3 fatty acid content in carp muscle. Similar results observed Skalli et al. [32] in European bass and Calabretti et al. [33] in rainbow trout.

From all studies mentioned above, it is clear that the geographic region has a significant influence on the fatty acid composition in fishlipids regardless of fish species.

3. INFLUENCE OF THE FEEDING

Together withthe place or system of cultivation, feeding seems to have the biggest impact on fatty acid composition [34,35]. Fatty acid composition of most common freshwater fish species studied [36]. Fish in the study were from rivers (an extensive type of farming, natural source of food), ponds (a semi-intensive type of farming, natural source of food plus feeding with grains) and aquaculture (an intensive type of farming, feeding with pellets), selected according to the size and processed in the laboratory (left fillet with skin) for fatty acid analyses. The results of Linhartová et al. [36] in the reduced version are in Tables 1 and 2. Results show that fish of the same species have always higher fatty acid content from the more intensive method of breeding (i.e. additional feeding ones) because fish pellets are usually enriched with PUFA.

Common carp is the most important and most frequently cultured species of fish in the Czech Republic. According to the Fish Annual Report [14], the export of living carps was 2322 t, mostly to Germany (646 t), Poland (528 t) and France (285 t). Carps are farming in semi-intensive conditions eating natural feed and cereal feed. This method of farming significantly impacts the increase of fat in the muscles up to 7.62% vs. 4.09% (extensive farming) [37]. Similar results also published [38,39]. Differences in fat and fatty acid content were also evident at rainbow trout farmed in extensive (2.41%) or intensive way (9.78%) [40] and wels catfish *(Silurus glanis*, Linnaeus 1758), 2.97% (extensive breeding) vs. 4.13% (intensive breeding) as well, confirming with studies by Hallier et al. [41].

It is clear that feeding is possible to increase the lipid content and fatty acid composition.Acar and Türker [42] affected the quantity and composition of the fatty acids by adding peanut oil to feeds for rainbow trout. The same effect had additions of palm oil in small doses (<50%) and rapeseed oil for salmon (*Salmo salar*, Linnaeus 1758); [43,44]. Contrarily, palm oilinclusion at levels exceeding 50% ofthe dietary lipids, significantly reducedcontent of 20:5(n-3), 22:6(n-3) and the (n-3):(n-6) PUFA ratio in muscles, resulting in a reduced availability of these essential (n-3) PUFA to the consumer. In a different study [45] weresupplying the palm oil to feed for rainbow trout. The fatty acid profile in trout tissues reflected exactly the fatty acid profile of the feed. Other oils with improving effect are vegetable oils [46] and plant oils [47,48].

4. INFLUENCE OF SEX ON MEAT COMPOSITION

Cakmak et al. [49] found at freshwater chub (*Squalius lepidus*, Heckel 1843) that results had

Table 1. Fatty acid composition (% of identified) of the most common fish species from the extensive/intensive fish farming (Modified from Linhartová et al. [36]; Available from https://doi.org/10.1007/s10499-018-0243-5)

	Extensive farming			Intensive farming		
	Trout	**Tench**	**Carp**	**Trout**	**Catfish**	**Pikeperch**
EPA	1.62±1.00	6.74±0.39	3.55±1.11	2.45±0.31	4.36±1.01	3.05±0.52
DHA	6.85±1.51	5.23±1.18	3.64±1.53	7.54±0.44	8.76±2.28	12.58±1.08
ΣSFA	26.24±5.18	26.42±1.16	24.57±1.19	21.01±1.89	22.25±1.61	21.04±1.36
ΣMUFA	43.17±11.03	38.24±2.87	44.86±3.48	37.22±1.07	37.36±5.23	40.70±2.07
ΣPUFA	30.59±6.13	34.84±3.69	27.61±3.99	41.77±1.61	34.61±2.62	38.26±1.46
Σn-3 PUFA	10.55±3.02	23.7±3.02	14.30±3.95	14.71±0.72	24.48±5.17	20.70±1.25
Σn-6 PUFA	20.04±4.95	11.14±0.84	13.32±2.60	27.06±1.16	11.13±2.71	17.55±1.22
Σn-3 HUFA	9.19±2.48	13.74±1.59	8.85±2.94	11.05±0.77	22.39±6.49	16.99±1.45
EPA+DHA	8.46±2.29	11.96±1.55	7.18±2.42	10.00±0.51	13.12±2.36	15.63±1.38

Abbreviations: DHA, docosahexaenoic fatty acid; EPA, eicosapentaenoic fatty acid; HUFA, highly unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids. Species names: trout, Oncorhynchus mykiss; tench, Tinca tinca; carp, Cyprinus carpio; catfish, Silurus glanis; pikeperch, Sander lucioperca

Table 2. Fatty acid composition (% of identified) of the most common fish species from the semi-intensive fish farming (Modified from Linhartová et al. [36]; Available from https://doi.org/10.1007/s10499-018-0243-5)

	Semi-intensive farming					
	Perch	**Catfish**	**Pike**	**Pikeperch**	**Tench**	**Carp**
EPA	5.49±1.00	3.50±1.15	6.88±0.56	6.35±0.37	5.30±0.03	2.95±2.77
DHA	27.97±2.97	9.76±4.84	21.85±3.93	22.69±1.08	2.96±0.18	1.81±1.62
ΣSFA	31.59±1.07	24.23±1.88	26.71±0.46	22.10±1.02	27.13±0.25	27.62±1.40
ΣMUFA	17.83±1.12	41.61±7.85	22.35±5.35	22.77±1.15	43.15±0.20	52.71±7.75
ΣPUFA	50.57±1.23	28.86±9.83	50.94±5.15	50.05±1.71	29.72±0.19	18.75±7.63
Σn-3 PUFA	37.73±1.70	20.10±6.56	34.61±3.95	38.80±1.48	16.69±0.18	9.58±6.24
Σn-6 PUFA	12.84±0.95	8.77±3.77	16.33±1.91	11.26±0.25	12.73±0.12	9.18±1.85
Σn-3 HUFA	36.25±1.98	15.75±6.33	31.72±4.04	33.45±1.86	9.72±0.27	5.78±5.04
EPA+DHA	33.46±2.14	13.26±5.72	28.73±3.78	29.04±1.42	8.26±0.20	4.77±4.37

Abbreviations: DHA, docosahexaenoic fatty acid; EPA, eicosapentaenoic fatty acid; HUFA, highly unsaturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids. Species names: perch, Perca fluviatilis; catfish, Silurus glanis; pike, Esox lucius; pikeperch, Sander lucioperca; tench, Tinca tinca; carp, Cyprinus carpio

shown significant differences between males and females in fat and protein composition and moisture. The body composition of females was of higherquality than males. Likewise, [50] found at another chub, Mesopotamian pike chub (*Squalius cephalus*, Linnaeus 1758),females, fat quantity higher (15.82) than those of males (12.65; for details see Table 3). By contrast, [51] reported that fatcontent in fillets of common carpis 2.60% in males and only 2.20% in females. Akpinar et al. [52] studied muscle fatty acid component of freshwater brown trout (*Salmo trutta macrostigma*, Duméril 1858) and found that the male and female tissues showed statistical differences in the total MUFA fraction (P = .05); Table 3. Higher levels of EPA and DHA in lipids offreshwater female trout species also established [53,54,55].

A high impact on the fatty acid composition of fish has their reproduction period. Most of the lipids that potentially would bemobilized later, forthe formation and growth of the gonads are stored inmuscle, liver, andabdominal regions before the reproduction period [56]. Morespecifically, mainly the liver stores lipids that will produce the energy required for growth of the gonads and gamete. And, on thecontrary, lipids stored in musclesoffer the energy required for the reproductive activityitself [57].

Table 3. Comparison of males and females in terms of muscle fatty acid composition of total lipid in *Squalius lepidus* (Modified from [49] and *Salmo trutta macrostigma* (Modified from Akpinar et al. [52]; Available from https://doi.org/10.1016/j.foodchem.2008.05.025)

	Leuciscus lepidus		*Salmo trutta macrostigma*	
	Male	**Female**	**Male**	**Female**
EPA	8.16±0.48	8.06±0.65	7.88±0.59[a]	6.45±0.43[b]
DHA	23.02±1.14[a]	26.01±1.25[b]	8.42±0.27	7.38±0.16
ΣSFA	24.83±0.92[a]	21.79±1.02[b]	28.5±0.67[a]	29.4±0.61[b]
ΣMUFA	27.66±1.13	28.23±1.83	35.9±0.27[a]	37.5±0.33[b]
ΣPUFA	47.51±1.68[a]	49.98±1.71[b]		
Σn-3 PUFA	36.08	39.29	25.4±0.74[a]	22.9±0.24[b]
Σn-6 PUFA	11.43	10.69	9.78±0.28	10.1±0.42
Σn-3/n-6	3.15	3.68	2.59±0.37	2.26±0.22

Note: Different letters in the same row and fish indicate significant differences within groups (P = .05)

5. CHOOSING THE RIGHT WAY OF STUNNING AND SUITABLE PART OF THE FISH BODY

It does not exist on any work about the impact of the way of stunning on fatty acid composition in fish muscle. But like [58] present, the choosing of the most suitable method of stunning prior to slaughter is one important step in assuring a good quality of fish as food. Methods of stunning that act quickly and minimize reactions in the fishes are favourable because of both practical and animal welfare reasons. They compared three techniques for anaesthetizing or killing fish (blow on the head or stab in the neck, using electricity and, finally, using CO_2). Investigated fish were carp, eel (*Anquilla anquilla*, Linnaeus 1758) and rainbow trout. Results indicate that fish best anaesthesia is manual with regard to welfare and meat quality parameters (pH values, water-holding capacity and rigor mortis).

Also, the body section matters. Dong et al. [59] studied differences in the physicochemical, microstructural, and textural properties of six sections of the cultured common carp body, including the upper back, lower back, jaw, chest, belly, and tail. Lipids (as sources of fatty acids) were, not uniformly distributed throughout the muscle tissues of common carp. Significantly, higher levels of lipids contained chest (46.2%) and belly sections (jaw 32.1%, belly 45.1%), than the upper back (16.5%), lower back (17.9%) and tail (20.9%). Mráz and Picková [60] observeda similar trend of lipid deposition in common carp muscles and [61] studied fat deposition in silver carp bodies (*Hypophthalmichthys molitrix*, Valenciennes 1844). Separating body into six parts (the cranial, medial and caudal dorsal/ventral part above/belowthe lateral line), found the ventral parts significantly fatter (158.14%) than dorsal parts (46.05%). Finally, the studyshowed that the internal fat lipids were an interesting alternative source of ΣPUFAn-3 and, in particular, of ALA, EPA,and DHA. The worksmentioned and others works [62,63,64] show that the lipid content is very important factor and it can affect the two most required parameters - firmness and juiciness of fish fillets, when higher content of lipids means firm and juicy fillet.

6. POND FISHES VERSUS RIVER FISHES AND THERMAL TREATMENT

Question how thermal treatment influences the content and composition of fatty acids of the freshwater fish answered [65]. The aim of their study was to finddifferences between the pond - farmed fish and river fish in fatty acid content before and after the thermal treatment. The tested mixed sample included meat from these species of freshwater fish: bream (*Abramis brama*, Linnaeus 1758), barbell (*Barbus barbus*, Linnaeus 1758), crucian carp (*Carrassius carrassius*, Linnaeus 1758), catfish (*Ictalurus punctatus*, Rafinesque 1818), tench *(Tinca tinca*, Linnaeus 1758) and silver carp.Total lipid contents of the pond farmed fish and the river Danube fish were 5.63% and 6.70% with a high proportion of unsaturated fatty acids in both cases. Thermal treatment (pasteurization and sterilization) decreased the ratio of PUFA to SFA from 2.53% to 0.58% for the pond - farmed fish and from 2.00% to 0.47% for the river Danube fish (for detailed information see Table 4). Although there were some drop and change in PUFA,the meat of these species of fish considered as “weed white fish” can still be used for fish tins production, suitable, healthy and

Table 4. Fat and fatty acid composition of raw, pasteurized and sterilized pond – farmed fish/Danube fish (% of the total area of the peaks). Modified from Bastić et al. [65] Available from https://doi.org/10.2298/AVB0204259B

Fat	Raw	Pasteurized	Sterilized
Fishpond fish	5.63	5.45	5.12
Danube fish	6.70	6.45	6.45
Saturated FA			
C14:0	0.1 / 0.2	0.2 / 0.1	0.1 / -
C16:0	1.6 / 3.4	3.0 / 0.5	1.7 / 1.1
C18:0	3.0 / 2.0	2.0 / 2.8	3.1 / 2.6
C20:0	0.9 / 1.1	1.8 / 0.9	2.5 / 1.8
Σ SFA	5.6 / 6.7	7.0 / 4.3	7.4 / 5.5
Unsaturated FA			
C16:1	2.3 / 5.3	3.3 / 4.4	3.0 / 4.8
C18:1	40.0 / 39.6	16.4 / 21.0	25.0 / 23.2
C20:1	4.2 / 3.0	1.7 / 1.0	1.4 / 2.2
Σ UFA	46.5 / 47.6	21.4 / 26.4	29.4 / 30.2
Polyunsaturated FA			
C18:2	10.5 / 10.0	1.6 / 1.0	1.9 / 0.6
C18:3	3.0 / 2.3	1.9 / 4.0	2.3 / 1.7
C20:2	0.5 / 1.1	1.6 / 0.2	0.1 / 0.3
C20:3	0.2 / -	0.8 / -	
Σ PUFA	14.2 / 13.4	5.9 / 5.2	4.3 / 2.6
PUFA/SFA	2.53/2.00	0.84/1.21	0.58/0.47

Abbreviations: FA, fatty acid

useful to human nutrition. Bienkiewicz et al. [66] evaluated qualitative changes in lipids of two most popular freshwater farmed fish (rainbow trout and carp) at particular stages of hot smoking process and found that subsequent stages of smoking process resulted in statistically significant losses of EPA and DHA in both fish species. From their results is apparent that smoking fish meat at high temperatures is not suitable method from the aspect of fish meat as healthy food.

7. CONCLUSION

Fish oil is a human nutrition component with great importance. It is easily accessibleby the natural way (eating fish) or by taking supplements. Fish oil supplements are usually frommarine fish. On the other hand, as this work summarizes, freshwater fish can be adequate in fatty acid composition to them. The important role also plays the breeding conditions (when a colder region is for fatty acid production better) and feeding (feedsenriched with various oils). The effect on the number of fatty acids has not only the fish species but also the part of the body. So even lean fish (fat in the muscle is less than 2%, e.g. pike, pike perch – *Sander lucioperca*, Linnaeus 1758) can be in the human diet the source of high-quality fatty acids (PUFA-EPA and DHA). While it is still relevant that eating fish with a higher content of fat in their muscles and/or parts of their body, i.e. richer in fatty acids (mainly PUFA) is beneficialand healthy as prevention of cardiovascular diseases. In future research, the scientists should try to seek effective substitutes to maintain high levels of n-3 HUFA in the flesh of farmed fish or find out which species have the high ability for storing EPA and DHA. And last but not least the better understanding of long chain HUFA biosynthesis would be the subject to specialize in.

This review had to summarize various facts, which can affect the issue of fatty acids in freshwater fish. These summarizing works are important for the inspection of the topic and revealing of themes that are still unresearched.

ACKNOWLEDGEMENT

Authors would like to thank to English native speaker colleague for language revision.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Calder PC, Yaqoob P. Omega-3 polyunsaturated fatty acids and human health outcomes. Biofactors. 2009;35(3): 266–272.
   Available:https://doi.org/10.1002/biof.42
2. Adamkova V, Kacer P, Mraz J, Suchanek P, Pickova J, Kralova Lesna I, et al. The consumption of the carp meat and plasma lipids in secondary prevention in the heart ischemic disease patients. Neuroendocrinol Lett. 2011;32(2):17-20.
3. Lund EK. Health benefits of seafood; is it just the fatty acids? Food Chem. 2013;140 (3):413–420.
   Available:https://doi.org/10.1016/j.foodchem.2013.01.034
4. Leaf A, Kang JX, Xiao YF, Billman GE. Clinical prevention of sudden cardiac death by n-3 polyunsaturated fatty acids and mechanism of prevention of arrhythmias by n-3 fish oils. Circulation. 2003;107(21): 2646-2652.
   Available:https://doi.org/10.1161/01.CIR.0000069566.78305.33
5. Harris WS. n-3 fatty acids and serum lipoproteins: Human studies. Am J Clin Nutr. 1997;65(S5):1611-1616.
6. Goodfellow J, Bellamy MF, Ramsey MW, Jones CJ, Lewis MJ. Dietary supplementation with marine omega-3 fatty acids improve systemic large artery endothelian function in subjects with hypercholesterolemia. JAm Coll Cardiol. 2000;35(2):265-270.
   Available:https://doi.org/10.1016/S0735-1097(99)00548-3
7. Calder PC. n-3 polyunsaturated fatty acids, inflammation and inflammatory diseases. Am J Clin Nutr. 2006;83:1505S-1519S.
8. Harris WS, Miller M, Tighe AP, Davidson MH, Schaefer EJ. Omega-3 fatty acids and coronary heart disease risk: clinical and mechanistic perspectives. Atherosclerosis. 2008;197(1):12-24.
   Available:https://doi.org/10.1016/j.atherosclerosis.2007.11.008
9. Thies F, Garry JMC, Yaqoob P, Rerkasem K,Williams J, Shearman CP, et al. Association of n-3 polyunsaturated fatty acids with stability of atherosclerotic plaques: A randomised controlled trial. Lancet. 2003;361(9356):477-485.
   Available:https://doi.org/10.1016/S0140-6736(03)12468-3
10. Von Schacky C. The role of omega-3 fatty acids in cardiovascular disease. Curr Atheroscler Rep. 2003;5:139-45.
11. Simopoulos AP. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother. 2002;56(8): 365–379.
    Available:https://doi.org/10.1016/S0753-3322(02)00253-6
12. Benjamin EJ, Blaha MJ, Chiuve SE, Cushman M, Das SR, Deo R, et al. Heart disease and stroke statistics. Circulation. 2017;135(10):e146-e603.
    Available:https://doi.org/10.1161/CIR.0000000000000485
13. Block RC, Pearson TA. The cardiovascular implication of omega-3 fatty acids. Fol Cardiol. 2006;13:557–569.
14. Fish Annual Report, Czech Ministry of Agriculture, Prague, Czech. 2017;28.
15. Huynh MD, Kitts DD. Evaluating nutritional quality of pacific fish species from fatty acid signatures. Food Chem. 2009;114(3): 912–918.
    Available:https://doi.org/10.1016/j.foodchem.2008.10.038
16. Tocher DR. Metabolism and functions of lipids and fatty acids in teleost fish. Rev Fish Sci. 2003;11(2):107–184.
    Available:https://doi.org/10.1080/713610925
17. Morris PC. The effects of nutrition on the composition of farmed fish. In: SC Kestin, & PD Warriss (Eds.), Farmed fish quality. Fishing News Books, Oxford. 2001;161–179.
18. Ehsani A, Jasour MS,Khodayari M. Differentiation of common marketable-size rainbow trouts (*Oncorhynchus mykiss*) based on nutritional and dietetic traits: a comparative study. J Appl Anim Res. 2013; 41(4):387-391.
    Available:https://doi.org/10.1080/09712119.2013.783483
19. Steffens W. Effects of variation in essential fatty acids in fish feeds on nutritive value of freshwater fish for humans. Aquaculture. 1997;151(1-4):97–119.
    Available:https://doi.org/10.1016/S0044-8486(96)01493-7
20. Ozogul Y, Ozogul F,Alagoz S. Fatty acid profiles and fat contents of commercially important seawater and freshwater fish species of Turkey: A comparative study. Food Chem. 2007;103(1):217–223.
    Available:https://doi.org/10.1016/j.foodchem.2006.08.009

21. Hara A, Radin NS. Lipid extraction of tissues with a low-toxicity solvent. Anal Biochem 1978;90(1):420–426. Available:https://doi.org/10.1016/0003-2697(78)90046-5
22. Borderias AJ, Sanchez-Alonso I. First processing steps and the quality of wild and farmed fish. J Food Sci. 2011;76 (1):R1–R5. Available:https://doi.org/10.1111/j.1750-3841.2010.01900.x
23. Çelik M, Diler A, Küçükgülmez A. A comparison of the proximate compositions and fatty acid profiles of zander (*Sander lucioperca*) from two different regions and climatic conditions. Food Chem. 2005; 92(4):637–641. Available:https://doi.org/10.1016/j.foodchem.2004.08.026
24. Bauer C, Schlott G. Fillet yield and fat content in common carp (*Cyprinus carpio*) produced in three Austrian carp farms with different culture methodologies. J Appl Ichthyol. 2009;25(5):591–594. Available:https://doi.org/10.1111/j.1439-0426.2009.01282.x
25. Varga D, Hancz C, Horn P, Molnár T, Szabó A. Environmental factors influencing the slaughter value and flesh quality of the common carp in four typical fish farms in Hungary. Acta Aliment Hung. 2013;42(4):495–503. Available:https://doi.org/10.1556/AAlim.42.2013.4.4
26. Tkaczewska J, Kulawik P,Migdal W. The quality of rainbow trout (*Oncorhynchus mykiss*) cultured in various polish regions. Ann Anim Sci. 2015(2);15:527-539. Available:https://doi.org/10.2478/aoas-2014-0087
27. Erdem ME, Baki B, Samsun S. Fatty acid and amino acid compositions of cultured and wild sea bass (*Dicentrarchus labrax* L., 1758) from different regions in Turkey. J Anim Vet Adv. 2009;8(10):1959–1963.
28. Fauconneau B, Chmaitilly J, Andre S, Cardinal M, Cornet J, Vallet JL, et al..Characteristics of rainbow-trout flesh. Chemical-composition and cellularity of muscle and adipose tissues. Sci Aliment. 1993;13(2):173-187.
29. Geri G, Poli BM, Gualtieri M, Lupi P, Parisi G. Body traits and chemical composition of muscle in the common carp (*Cyprinus carpio* L.) as influenced by age and rearing environment. Aquaculture. 1995;129(1-4):329–333. Available:https://doi.org/10.1016/0044-8486(94)00300-D
30. Fauconneau B, Laroche M. Characteristics of the flesh and quality of products of catfishes. Aquat Living Resour. 1996;9(SI): 165–179. Available:https://doi.org/10.1051/alr:1996051
31. Kukačka V, Fialova M,Mareš J. Influence of fish, linseed and rapeseed oil addition to the diet on the fatty acid spectrum of common carp muscle during gradual decrease of environmental temperature. In R. Kopp (Ed.), XI Czech Ichthyological Conference Proceedings of the International Conference. 2008;137-144.
32. Skalli A, Robin J, Le Bayon N, Le Delliou H, Person-Le Ruyet J. Impact of essential fatty acid deficiency and temperature on tissues' fatty acid composition of European sea bass (*Dicentrarchus labrax*). Aquaculture. 2006;255(1-4):223–232. Available:https://doi.org/10.1016/j.aquaculture.2005.12.006
33. Calabretti A, Cateni F, Procida G, Favretto LG. Influence of environmental temperature on composition of lipids in edible flesh of rainbow trout (*Oncorhynchus mykiss*). J Sci Food Agr. 2003;83(14):1493–1498. Available:https://doi.org/10.1002/jsfa.1566
34. Martin JF, Poli JM. Etude des composantes de la qualite´ de la chair du silure glane (*Silurus glanis* L.) 2. Examen sensoriel. La Pisciculture Francaise. 1995; 121:46–50. French.
35. Serot T, Regost C, Arzel J. Identification of odour-active compounds in muscle of brown trout (*Salmo trutta*) as affected by dietary lipid sources. J Sci Food Agr. 2002;82(6):636–643. Available:https://doi.org/10.1002/jsfa.1096
36. Linhartová Z, Krejsa J, Zajíc T, Másílko J, Sampels S, Mráz J. Proximate and fatty acid composition of 13 important freshwater fish species in central Europe. Aquacult Int. 2018;26(2):695-711. Available:https://doi.org/10.1007/s10499-018-0243-5
37. Stancheva M, Merdzhanov A, Dobreva DA, Makedonski L. Common carp (*Cyprinus caprio*) and European catfish (*Sillurus glanis*) from the Danube River as sources of fat soluble vitamins and fatty acids. Czech J Food Sci. 2014;32(1):16–24. Available:https://doi.org/10.17221/31/2013-CJFS

38. Zajic T, Mraz J, Sampels S, Pickova J. Fillet quality changes as a result of purging of common carp (*Cyprinus carpio* L.) with special regard to weight loss and lipid profile. Aquaculture. 2013;400:111–119.
Available:https://doi.org/10.1016/j.aquaculture.2013.03.004
39. Másílko J, Bláha M, Hlaváč D, Vejsada P. The effects of using mechanically modified cereals on the growth, feed conversion, fat content and fillet yield of market size common carp grown in ponds. Turk J Fish Aquat Sc. 2015;15(3): 593–600.
Available:https://doi.org/10.4194/1303-2712-v15_3_02
40. Kose I, Yildiz M. Effect of diets containing sesame oil on growth and fatty acid composition of rainbow trout (*Oncorhynchus mykiss*). J Appl Ichthyol. 2013;29:1318–1324.
41. Hallier A, Serot T, Prost C. Influence of rearing conditions and feed on the biochemical composition of fillets of the European catfish (*Silurus glanis*). Food Chem. 2007;103(3):808–815.
Available:https://doi.org/10.1016/j.foodchem.2006.09.027
42. Acar Ü, Türker A. Response of Rainbow trout (*Oncorhynchus mykiss*) to unrefined peanut oil diets: Effect on growth performance, fish health and fillet fatty acid composition. Aquac Nutr. 2018;24(1):292-299.
Available:https://doi.org/10.1111/anu.12559
43. Bell JG, McEvoy J, Tocher DR, McGhee F, Campbell PJ, Sargent JR. Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (*Salmo salar*) affects tissue lipid compositions and hepatocyte fatty acid metabolism. J Nutr. 2001;131(5):1535–1543.
44. Bell JG, Henderson RJ, Tocher DR, McGhee F, Dick JR, Porter A et al. Substituting fish oil with crude palm oil in the diet of atlantic salmon (*Salmo salar*) affects muscle fatty acid composition and hepatic fatty acid metabolism. J Nutr. 2002;132(2):222–230.
45. Fonseca-Madrigal J, Karalazos V, Campbell PJ, Bell JG, Tocher DR. Influence of dietary palm oil on growth, tissue fatty acid compositions and fatty acid metabolism in liver and intestine in rainbow trout (*Oncorhynchus mykiss*). Aquac Nutr. 2005;11(4):241–250.
Available:https://doi.org/10.1111/j.1365-2095.2005.00346
46. Fountoulaki E, Vasilaki A, Hurtado R, Grigorakis K, Karacostas I, Nengas Iet al. Fish oil substitution by vegetable oils in commercial diets for gilthead sea bream (*Sparus aurata* L.); effects on growth performance, flesh quality and fillet fatty acid profile: recovery of fatty acid profiles by a fish oil finishing diet under fluctuating water temperatures. Aquaculture. 2009; 289(3-4):317–326.
Available:https://doi.org/10.1016/j.aquaculture.2009.01.023
47. Piedecausa MA, Mazón MJ, García BG, Hernández MD. Effects of total replacement of fish oil by vegetable oils in the diets of sharpsnout seabream (*Diplodus puntazzo*). Aquaculture. 2007; 263(1-4):211–219.
Available:https://doi.org/10.1016/j.aquaculture.2006.09.039
48. Nasopoulou C, Zabetakis I. Benefits of fish oil replacement by plant originated oils in compounded fish feeds. A review. LWT Food Sci Technol. 2012;47(2):217–224.
Available:https://doi.org/10.1016/j.lwt.2012.01.018
49. Cakmak O, Altunas A,Ugurcu V, Erdemli HK, Akyol S. Female *Leuciscus lepidus* may be a new alternative for fish oil supplements. J Chem-NY, Art. No. 696303; 2015.
50. Karaton N, Gürel Ínanlı A. The effect of seasonal change on themeat yield and proximate composition of chub (*Squalius cephalus*). Firat University J Sci. 2011;23: 63–69.
51. Arslan A. Microbiological and chemical quality of carp (*Cyprinus carpio* L.) in Keban Lake, Doga. Turk J Vet Anim Sci. 1993;17:251–259.
52. Akpinar MA, Gorgun S, Akpinar AE. A comparative analysis of the fatty acid profiles in the liver and muscles of male and female *Salmo trutta macrostigma*. Food Chem. 2009;112(1):6-8.
Available:https://doi.org/10.1016/j.foodchem.2008.05.025
53. Haliloglu HÍ, Aras NM,Yetim H. Comparison of muscle fatty acids of three trout species (*Salvelinus alpinus*, *Salmo trutta fario*, *Oncorhynchus mykiss*) raised under the same conditions. Turk J Vet Anim Sci. 2002;26(5):1097–1102.

54. Aras NM, Haliloglu HÍ, Ayık Ö, Yetim H. Comparison of fatty acid profiles of different tissues of mature trout (*Salmo trutta labrax*, Pallas, 1811) caught from Kazandere creek in the Coruh region, Erzurum, Turkey. Turk J Vet Anim Sci. 2003a;27(2):311–316.
55. Aras NM, Haliloglu HÍ, Bayır A, Atamanalp M, Sirkecioglu AN. Comparison of the fatty acid composition of different tissues in mature trout (*Salmo trutta macrostigma*, Dumeril, 1858) in Yesildere creek in the Karasu basin. Turk J Vet Anim Sci. 2003b; 27(2):887–892.
56. Kiessling A, Johansson L, Storebakken T. Effects of reduced feed ration levels on fat content and fatty acid composition in white and red muscle from rainbow trout. Aquaculture. 1989;79 (1-4):169–175. Available:https://doi.org/10.1016/0044-8486(89)90458-4
57. Manning NJ, Kime DE. Temperature regulation of ovarian steroid production in the common carp, (*Cyprinus carpio* L.), in vivo and *in vitro*. Gen CompEndocr. 1984; 56:376–388.
58. Marx H, Brunner B, Weinzierl W,Hoffmann R,Stolle A. Methods of stunning freshwater fish: Impact on meat quality and aspects of animal welfare. Z. Lebensmittel-Untersuchung und-Forschung - Food Res Technol. 1997;204(4):282-286. Available:https://doi.org/10.1007/s002170050078
59. Dong XP, Wu Q, Li DY, Wang T, Pan JF, Zheng JJ, Chen GB. Physicochemical, micro-structural, and textural properties of different parts from farmed common carp (*Cyprinus carpio*). Int J Food Prop. 2017; 20(4):946-955. Available:https://doi.org/10.1080/10942912.2016.1190375
60. Mráz J, Pickova J. Differences between lipid content and composition of different parts of fillets from crossbred farmed carp (*Cyprinus carpio*). Fish Physiol Biochem. 2009;35(4):615–623. Available:https://doi.org/10.1007/s10695-008-9291-5
61. Buchtová H, Ježek F. A new look at the assessment of the silver carp (*Hypophthalmichthys molitrix* Val.) as a food fish. Czech Food Sci. 2011;29(5):487-497. Available:https://doi.org/10.17221/392/2010-CJFS
62. Howgate P. Aspects of fish texture. In JG Brennan, KJ Birch, GG Parker (Eds.), Sensory properties of food. London: Applied Science Publishers Ltd. 1977;249–269.
63. Dunajski E. Texture of fish muscle. J Texture Stud. 1979;10:301–318.
64. Hernandez MD, Martinez FJ, Garcia Garcia B. Sensory evaluation of farmed sharpsnout seabream (*Diplodus puntazzo*). Aquacult Int. 2001;9(6):519–529. Available:https://doi.org/10.1023/A:1020513931447
65. Bastić L, Kočovski T, Antonović D,Vidarić D. The meat quality of some freshwater fish – nutritive and technological aspects. Acta Vet (Beograd). 2002;52(4):259-266. Available:https://doi.org/10.2298/AVB0204259B
66. Bienkiewicz G, Tokarczyk G, Czerniejewska–Surma B, Suryn J. Changes in the EPA and DHA content and lipids quality parameters of rainbow trout (Oncorhynchus mykiss, Walbaum) and carp (*Cyprinus carpio* L.) at individual stages of hot smoking. Heliyon. 2019; 5(12). Available:https://doi.org/10.1016/j.heliyon.2019.e02964

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