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.

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.
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 function as 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 are two 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 acid content but also due to the 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 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 the individual fish body section.

2. INFLUENCE OF THE PLACE OF BREEDING

According to Çelik et al. [23], the place and method of cultivation affect fish meat quality. Bauer and Schlott [24] concluded from their experiment in Austrian ponds that the
geographical site of carp farming 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 in different regions of Hungary with 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 affects lipids. Tkaczewska et al. [26] studied rainbow trout in various climate regions, even when they were feeding in a similar way and feed there were significant differences in n-3 fatty acids. This leads to the conclusion that the place of cultivation affects the quantity of n-3 fatty acids in the meat lipids of those fish. The impact of breeding conditions is 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 there are regional differences in fatty acid composition of 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 Skalii 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 fish lipids regardless of fish species.

### 3. INFLUENCE OF THE FEEDING

Together with the 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 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 well 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 oil inclusion at levels exceeding 50% of the dietary lipids, significantly reduced content 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] we were supplying 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
shown significant differences between males and females in fat and protein composition and moisture. The body composition of females was of high quality 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 fat content in fillets of common carp 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);
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 CO₂). 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] observed 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/below the lateral line), found the ventral parts significantly fatter (158.1%) than dorsal parts (46.0%). Finally, the study showed that the internal fat lipids were an interesting alternative source of ΣPUFA and, in particular, of ALA, EPA, and DHA. The works mentioned 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 find differences 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 carassius, 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 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 Male | Leuciscus lepidus Female | Salmo trutta macrostigma Male | Salmo trutta macrostigma Female |
|-------------|------------------------|--------------------------|-------------------------------|-------------------------------|
| EPA         | 8.16±0.48              | 8.06±0.65                | 7.88±0.59                     | 6.45±0.43                     |
| DHA         | 23.02±1.14             | 26.01±1.25               | 8.42±0.27                    | 7.38±0.16                    |
| ΣSFA        | 24.83±0.92             | 21.79±1.02               | 25.9±0.67                    | 29.4±0.61                    |
| ΣMUFA       | 27.66±1.13             | 28.23±1.83               | 35.9±0.27                    | 37.5±0.33                    |
| ΣPUFA       | 47.51±1.68             | 49.98±1.71               | 25.4±0.74                    | 22.9±0.24                    |
| Σn-3 PUFA   | 36.08                  | 39.29                    | 25.4±0.74                    | 22.9±0.24                    |
| 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)
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 accessible by the natural way (eating fish) or by taking supplements. Fish oil supplements are usually from marine 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 (feed enriched 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 beneficial and 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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.
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