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FRESHWATER FISH – AN IMPORTANT SOURCE OF N-3 POLYUNSATURATED FATTY ACIDS: A REVIEW

Werner Steffens, Manfred Wirth

Institute of Freshwater Ecology and Inland Fisheries, Department of Fish Culture and Fish Pathology, Berlin, Germany

ABSTRACT. In addition to n-6 fatty acids, n-3 polyunsaturated fatty acids are essential ingredients of the human diet. Many marine fish contain high levels of these fatty acids; however, freshwater fish are also an important source of n-3 fatty acids, especially eicosapentaenoic and docosahexaenoic acids. Generally, there is a balanced relation between n-3 and n-6 fatty acids in freshwater fish. Just as other animals and humans, fish cannot synthesize the essential fatty acids of the n-6 and n-3 series. Thus, these fatty acids must be supplied by the diet, and their original source is plants, particularly phytoplankton. The fatty acid composition of fish is strongly influenced by the lipid pattern of their food. Feeding high energy diets containing high amounts of fish oil in aquaculture results in marketable fish with substantial levels of n-3 polyunsaturated fatty acids. Several investigations have shown that the consumption of freshwater fish has beneficial effects on human health, especially for persons suffering from cardiovascular diseases. This is why freshwater fish is recommended as wholesome food for humans.

Key words: FRESHWATER FISH, FATTY ACIDS, CYPRINIDS, EUROPEAN CATFISH (*SILURUS GLANIS*), RAINBOW TROUT (*ONCORHYNCHUS MYKISS*), VENDACE (*COREGONUS ALBULA*)

INTRODUCTION

Sufficient amounts of n-6 and n-3 fatty acids are essential ingredients of the human diet. Whereas the necessity of a supply of n-6 fatty acids has been well known for a long time (Burr and Burr 1929, Horrobin and Manku 1990), knowledge concerning the enormous importance of n-3 fatty acids is relatively new (Lands 1986, Stansby 1990a, 1990b, Singer 1997, 2000). Both series of these fatty acids are only synthesized *de novo* by plants, thus they must be supplied by the diet. The n-6 series is derived from linoleic acid (LA, C18:2 n-6), and the n-3 series from the α-linolenic acid (ALA, C18:3 n-3). Physiologically more important than these parent fatty acids are their elongated and desaturated derivatives. Specifically, these are arachidonic acid (AA, C20:4 n-6) in

CORRESPONDING AUTHOR: Prof. Dr. habil. Werner Steffens, Eitelsdorfer Str. 32, D-12555 Berlin, Germany, Tel./Fax: +49 30 6561390; e-mail: w.l.steffens@t-online.de

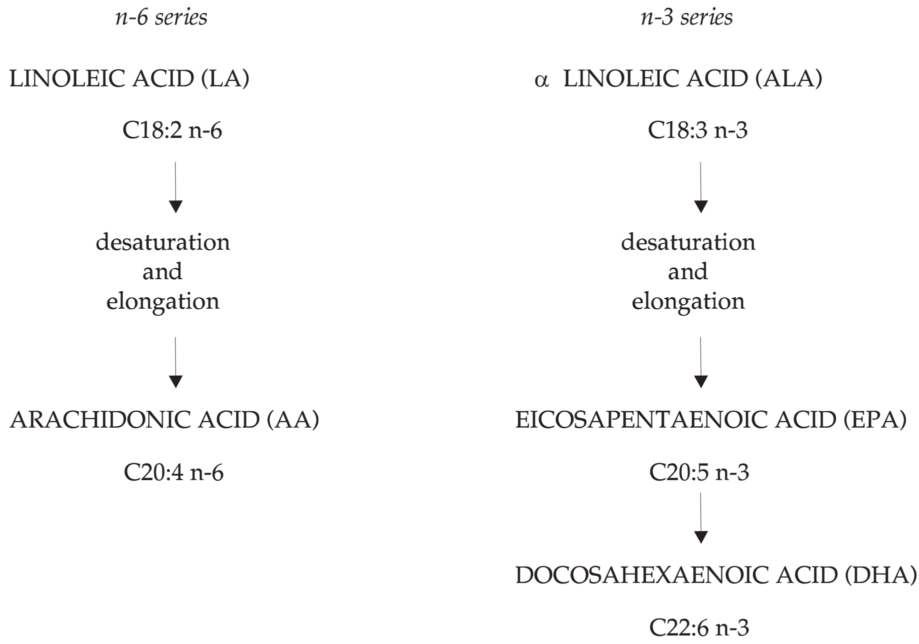

Fig. 1. Pathways in the metabolism of essential fatty acids.

the case of the n-6 series and eicosapentaenoic acid (EPA, C20:5 n-3) and docosahexaenoic acid (DHA, C22:6 n-3) in the case of the n-3 series (Fig. 1).

Essential fatty acids affect the fluidity, flexibility, and permeability of membranes. They are precursors of the eicosanoids and are necessary for maintaining the impermeability barrier of the skin. They are also involved in cholesterol transport and metabolism. Since there are several biochemical interactions between the n-6 and n-3 series, a balanced proportion of these fatty acids in the diet is important for the functioning of animal and human life.

The n-3 polyunsaturated fatty acids have an antiatherosclerotic effect, which is mainly due to:

- the inhibition of synthesis of the vasoaggressive low density lipoproteins (LDL);
- the acceleration of LDL elimination;
- no influence on the vasoprotective high density lipoproteins (HDL) or even enhanced HDL production;
- a decrease in total serum triacylglycerols;
- shifting the eicosanoid balance in favor of the antiaggregatory fraction;

– the reduction of platelet aggregation and prolongation of bleeding time;
– reduction of blood pressure.

There is evidence suggesting that long-chain n-3 polyunsaturated fatty acids also have beneficial effects on diseases other than those of the heart or blood vessels. They include:

– inflammatory diseases (Higgs 1986);
– arthritis (Kremer et al. 1988);
– nephritis (Thais and Stahl 1987);
– lupus erythematosis (Kelley et al. 1985);
– multiple sclerosis (Bates et al. 1989);
– strokes (Hirai et al. 1987);
– cancer (Karmeli 1987);
– skin diseases (Rhodes 1984, Singer and Ständer 1990);
– asthma (Lands 1986).

The beneficial effect of n-3 polyunsaturated fatty acids from marine fish on the prevention or mitigation of atherosclerosis and other diseases is well known. Previous observations on Eskimo food in Greenland suggest that there must be a connection between large amounts of fish eaten there and the low incidence of heart attacks among the inhabitants. In the meantime, many long-term studies performed in different countries are available (see Steffens 1997, 1999, Singer 1997, 2000). All results clearly show that the frequent consumption of fish can reduce the risk of ischemic heart disease and generally can improve the state of health.

FATTY ACID COMPOSITION OF FRESHWATER FISH

The typical fatty acid composition of fish oils results from the fatty acid composition of phytoplankton and other aquatic plants. These fatty acids reach the fish via the food web. Many investigations have shown that the lipids of marine fish species are characterized by low levels of linoleic acid (C18:2 n-6) and linolenic acid (C18:3 n-3) as well as high levels of long-chain n-3 polyunsaturated fatty acids such as eicosapentaenoic (C20:5 n-3) and docosahexaenoic (C22:6 n-3) acids. Because of the low content of n-6 fatty acids in marine fish, the ratio of total n-3 to n-6 fatty acids (the so-called essential fatty acid ratio) is high, ranging between about 5 and 10 (Table 1). Thus, marine fish are recognized a valuable source of n-3 polyunsaturated fatty acids for human nutrition.

TABLE 1

Content of selected fatty acids (%) in several marine fish lipids
(Gruger et al. 1964, Ackman and Eaton 1966, Jangaard et al. 1967)

Fatty acids	Herring, *Clupea harengus*, whole fish lipid	Cod, *Gadus morhua*, liver oil	Mackerel, *Scomber scombrus*, flesh lipid
18:3 n-3	0.3	0.6	1.3
20:5 n-3	7.4	12.9	7.1
22:6 n-3	3.9	12.7	10.8
18:2 n-6	0.7	1.5	1.1
20:4 n-6	0.4	1.4	3.9
Total n-3	14.6	29.1	23.8
Total n-6	1.9	3.7	5.0
n-3/n-6	7.7	7.9	4.7

However, freshwater fish also have a very favourable fatty acid composition and are, therefore, extremely wholesome foodstuffs. The current investigation focused on the following freshwater fish species: silver carp, *Hypophthalmichthys molitrix* (Val.); bighead carp, *Aristichthys nobilis* (Rich.); grass carp, *Ctenopharyngodon idella* (Val.), common carp, *Cyprinus carpio* L.; tench, *Tinca tinca* (L.); European catfish, *Silurus glanis* L.; rainbow trout, *Oncorhynchus mykiss* (Wal.); and vendace, *Coregonus albula* (L.).

SILVER CARP, BIGHEAD CARP, AND GRASS CARP

These fish species feed on phytoplankton, zooplankton, and macrophytes and are rich in n-3 polyunsaturated fatty acids, especially eicosapentaenoic and docosahexaenoic acids (Table 2). The proportion of total n-3 fatty acids varies between 20 and 30% and the n-3/n-6 ratio is about 2 to 3.

TABLE 2

Content of selected fatty acids (%) in silver carp, bighead carp, and grass carp
(Sýkora and Valenta 1978, Mieth et al. 1989a, b)

Fatty acids	Silver carp muscle triacylglycerols	Bighead carp muscle triacylglycerols	Grass carp muscle total lipids
18:3 n-3	7.0	7.8	7.6
20:5 n-3	6.6	10.7	5.1
22:6 n-3	5.7	9.4	8.1
18:2 n-6	4.3	3.3	6.2
20:4 n-6	3.2	3.2	3.0
Total n-3	21.2	30.0	24.0
Total n-6	10.8	9.5	10.5
n-3/n-6	2.0	3.2	2.3

COMMON CARP

Carp reared in ponds exclusively on natural food exhibit a substantial level of total polyunsaturated n-3 fatty acids in the muscle triacylglycerols. Supplementary feeding with wheat results in a lower amount of these essential fatty acids. This is due to the lower proportion of natural food in the diet of the carp which received supplementary grain. On the other hand, feeding dry diets containing fish oil causes high contents of n-3 fatty acids (Table 3). The fatty acid composition reflects, to a large extent, that of the diet. The n-3/n-6 ratio varies between 0.8 and 2.4.

TABLE 3

Content of selected fatty acids (%) in the dorsal muscle triacylglycerols and lipid content of the muscle (% of wet weight) of carp fed different diets (Steffens et al. 1995, Wirth and Steffens 1996)

Fatty acids	Carp reared on natural food in ponds	Carp fed supplementary wheat in ponds	Carp fed dry diet +10% fish oil
18:3 n-3	8.7	5.8	8.5
20:5 n-3	3.3	1.9	7.1
22:6 n-3	1.0	0.4	13.7
18:2 n-6	15.2	10.3	12.8
20:4 n-6	2.2	0.9	0.2
Total n-3	15.1	9.3	34.7
Total n-6	19.5	12.0	14.3
n-3/n-6	0.8	0.8	2.4
Lipid	1.8	3.4	2.2

In another feeding experiment, carp were fed two commercial diets containing similar protein contents of 46.8% (diet I) and 48.4% (diet II), but different lipid levels of 12.9% (diet I) and 23.8% (diet II). The lipid content of the diets was mainly supplied by mackerel oil (diet I) and sandeel oil (diet II). Feeding these diets resulted in high levels of n-3 fatty acids in the muscle triacylglycerols of the fish (Table 4). The n-3/n-6 ratio was 1.3 and 2.3 which was nearly the same as in the diet.

TABLE 4

Content of selected fatty acids (%) in the triacylglycerols of two commercial diets and the dorsal muscle of carp fed these diets (Steffens and Wirth 1995)

Fatty acids	Diet I	Carp muscle fed diet I	Diet II	Carp muscle fed diet II
1	2	3	4	5
18:3 n-3	9.3	13.8	7.4	11.9
20:5 n-3	6.7	2.7	13.8	8.0

cont. **TABLE 4**

1	2	3	4	5
22:6 n-3	11.9	5.6	12.8	9.2
18:2 n-6	11.0	7.9	5.8	3.5
20:4 n-6	7.5	8.8	8.1	9.2
Total n-3	32.1	23.0	39.7	30.8
Total n-6	20.5	17.4	16.3	13.6
n-3/n-6	1.6	1.3	2.4	2.3

TENCH

Muscle triacylglycerols of three groups of fish from ponds were analysed for their fatty acid composition. One group received only natural food, the second one wheat as a supplementary feed, and the third was fed intensively on pellets containing 14% lipid. The tench which received the dry diet showed the highest percentage of n-3 fatty acids (Table 5). They also had a much higher fat content in the muscles than the other two groups (10.2% versus 1.1 and 2.0%).

TABLE 5

Content of selected fatty acids (%) in the muscle triacylglycerols of tench fed different diets (Steffens et al. 1998)

Fatty acids	Tench reared on natural food in ponds	Tench fed supplementary wheat in ponds	Tench fed pellets in ponds
18:3 n-3	7.4	6.3	2.1
20:5 n-3	2.9	3.7	3.8
22:6 n-3	1.2	1.3	6.1
18:2 n-6	9.7	9.4	6.2
20:4 n-6	2.4	1.9	0.6
Total n-3	13.5	14.5	18.4
Total n-6	13.8	12.8	8.5
n-3/n-6	1.0	1.1	2.2

EUROPEAN CATFISH

European catfish were reared until the age of three years in ponds. One group received only natural food (fish), the other group was fed intensively with pellets containing 14% lipid. At the end of the experiment the fatty acid composition of the muscle triacylglycerols of both catfish groups was very similar, and the level of the polyunsaturated fatty acids of the n-3 series, especially eicosapentaenoic and docosahexaenoic acids, was remarkable (Table 6). However, the lipid content of the catfish muscle was very different. The catfish which ingested fish exhibited a much lower lipid content (2.9%) than those which received pellets (11.8%). Therefore, the absolute content of n-3 fatty acids in the meat of the catfish fed pellets was fourfold higher than in that of the other group.

TABLE 6

Content of selected fatty acids (%) in the muscle triacylglycerols of European catfish fed different diets (Füllner and Wirth 1996)

Fatty acids	Catfish fed fish in ponds	Catfish fed pellets in ponds
18:3 n-3	9.5	8.4
20:5 n-3	3.5	4.0
22:6 n-3	7.2	9.3
18:2 n-6	5.4	5.3
20:4 n-6	6.0	6.8
Total n-3	23.1	24.7
Total n-6	14.0	13.4
n-3/n-6	1.7	1.8

RAINBOW TROUT

In an investigation with rainbow trout, this salmonid received the same two commercial diets as the carp in the previous experiment (Table 4). Both rainbow trout groups had higher levels of n-3 fatty acids than the carp (Tables 4 and 7). There were especially high proportions of docosahexaenoic acid in the fish. The essential fatty acid ratio of the fish muscle triacylglycerols is 1.5 and 2.4 and was similar to that of the carp fed the same diet.

TABLE 7

Content of selected fatty acids (%) in the triacylglycerols and lipid content (% of wet weight) of two commercial diets and the dorsal muscle of rainbow trout fed these diets (Steffens et al. 1999)

Fatty acids	Diet I	Rainbow trout muscle fed diet I	Diet II	Rainbow trout muscle fed diet II
18:3 n-3	9.3	11.0	7.4	9.2
20:5 n-3	6.7	3.9	13.8	8.8
22:6 n-3	11.9	11.9	12.8	16.0
18:2 n-6	11.0	8.6	5.8	4.4
20:4 n-6	7.5	10.1	8.1	9.9
Total n-3	32.1	28.7	39.7	36.9
Total n-6	20.5	19.9	16.3	15.7
n-3/n-6	1.6	1.5	2.4	2.4
Lipid	12.9	4.6	23.8	4.9

VENDACE

Vendace is a freshwater fish species that feeds on zooplankton. The fatty acid pattern of the zooplankton and the fish from Lake Arendsee in Germany were analyzed over a period of more than one year. The triacylglycerols of the zooplankton and the vendace were characterized by high levels of n-3 polyunsaturated fatty acids, but some seasonal variations occurred (Table 8). Without doubt, the remarkable proportion of n-3 fatty acids in vendace is the result of high amounts of these fatty acids in zooplankton.

TABLE 8

Content of selected fatty acids (%) in the triacylglycerols of zooplankton and vendace (whole fish without gonads) from Lake Arendsee (Germany) during a period of about 13 months (Wirth and Steffens 1998)

Fatty acids	Zooplankton (n = 12)	Vendace (n = 13)
18:3 n-3	5.9 – 13.8	8.6 – 10.9
20:5 n-3	5.8 – 13.1	5.0 – 7.5
22:6 n-3	7.0 – 12.1	4.7 – 14.0
18:2 n-6	2.3 – 4.8	3.3 – 4.4
20:4 n-6	0.9 – 3.7	2.3 – 3.3
Total n-3	30.6 – 48.4	24.3 – 38.8
Total n-6	6.9 – 12.7	9.0 – 12.6

Like many other investigations (*e.g.*, Sýkora and Valenta 1978, 1979, Vácha and Tvrzická 1994, Hadjinikolova 2004, Jankowska et al. 2004, see also Steffens and Wirth 1997), the current analyses indicated that not only marine fish species but also many freshwater fish are rich in n-3 fatty acids. Surely the level depends on the fatty acid pattern of the diet. Natural feed generally results in high amounts of n-3 fatty acids. In aquaculture the fatty acid composition of the fish reflects, to a large extent, that of the diet (Steffens 1997).

DIETETIC SIGNIFICANCE OF FRESHWATER FISH LIPIDS

Since freshwater fish contain high levels of n-3 polyunsaturated fatty acids they constitute, like marine fish species, a valuable supply of these essential food components. Perhaps, their nutritive quality is even better since the fatty acid composition of freshwater fish is also characterized by high proportions of n-6 polyunsaturated fatty acids, especially linoleic and arachidonic acids (see Tables 2-8). Therefore, the ratio of total n-3 to n-6 fatty acids is much lower for freshwater fish than for marine fish and ranges from about 1 to 3. Unlike marine fish, freshwater fish are able to desaturate and elongate larger quantities of dietary C18 n-6 and C18 n-3 fatty acids to C20 and C22 desaturates.

Efforts to investigate and promote the beneficial effects of freshwater fish on human health were made in Hungary and Germany. In both countries silver carp and bighead carp were used for this purpose. In a test with spontaneously hypertensive rats, which received a diet containing 10% silver carp oil, the development of hypertonia was clearly delayed (Wirth et al. 1990c). After eight experimental weeks, systolic blood pressure was an average of 36 mm lower than in the control animals. This was attended by a reduction in the levels of triacylglycerols and total cholesterol in the blood serum (Table 9). The content of eicosapentaenoic and docosahexaenoic acids in the phospholipids and triacylglycerols of the liver increased. It was also observed that the beneficial effect of silver carp oil on blood pressure, serum lipids, and platelet function is more pronounced than the effect of mackerel oil (Wirth et al. 1990a).

TABLE 9

Blood pressure and serum lipids of spontaneously hypertensive rats fed a diet supplemented with 10% silver carp oil for eight weeks (Wirth et al. 1990c)

	Control group	Test group (+ 10% oil)
Systolic blood pressure (mm Hg)	235 ± 18	199 ± 7
Serum triacylglycerols (mmol l^{-1})	0.97 ± 0.07	0.80 ± 0.10
Serum total cholesterol (mmol l^{-1})	1.06 ± 0.05	0.88 ± 0.07

In a clinical test, fourteen hypertensive patients were put on a two-week diet of 100 g silver carp meat per day (Wirth et al. 1990b, Steffens et al. 1993). This resulted in a significant drop in systolic blood pressure by 15 mm Hg and diastolic pressure by 9 mm Hg (Table 10). In the blood plasma, the level of triacylglycerols was lowered by 0.6 mmol l^{-1}, the HDL-cholesterol increased by 0.26 mmol l^{-1}, while the phospholipid concentration remained constant. However, there were changes in the fatty acid composition of the phospholipids. Whereas the level of arachidonic acid remained unchanged, the concentrations of eicosapentaenoic and docosahexaenoic acids increased by 200 and 30%, respectively.

TABLE 10

Effect of daily administration of 100 g of silver carp meat for two weeks to hypertensive patients on blood pressure and plasma lipids (Wirth et al. 1990b)

	Pre	Post
Systolic blood pressure (mm Hg)	151 ± 9	136 ± 7
Diastolic blood pressure (mm Hg)	94 ± 7	85 ± 7
Triacylglycerols (mmol l^{-1})	1.82 ± 0.86	1.21 ± 0.53
HDL-cholesterol (mmol l^{-1})	1.52 ± 0.39	1.78 ± 0.44
Phospholipids (mg dl^{-1})	223 ± 35	226 ± 40

CONCLUSIONS

1. Investigations in several species of freshwater fish have shown that these species are rich in essential polyunsaturated fatty acids of the n-3 and n-6 series.
2. The n-3/n-6 ratio in the triacylglycerols of frehwater fish is higher than that of marine fish species and varies between 1 to 3.
3. Like marine fish, freshwater fish constitute a healthy addition to the human diet.

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STRESZCZENIE

RYBY SŁODKOWODNE – WAŻNE ŹRÓDŁO WIELONIENASYCONYCH KWASÓW TŁUSZCZOWYCH Z RODZINY N-3

Wielonienasycone kwasy tłuszczowe z rodziny n-3 i n-6 są niezbędnym składnikiem diety człowieka. Nie są one syntetyzowane w organizmie ryb (podobnie, jak i innych zwierząt, w tym człowieka) i muszą być dostarczane z pożywieniem (ich źródłem są rośliny, w szczególności fitoplankton). Wysoki poziom tych kwasów zawarty jest w ciele wielu ryb morskich. Jednakże istotnym źródłem kwasów z rodziny n-3, zwłaszcza kwasów eikozapentaenowego (EPA) i dokozaheksaenowego (DHA), są także ryby słodkowodne. W niniejszym opracowaniu, o charakterze przeglądowym, przeanalizowano profile kwasów tłuszczowych kilku gatunków ryb słodkowodnych, o dużym znaczeniu gospodarczym, takich jak: karp, *Cyprinus carpio*, amur, *Ctenopharyngodon idella*, tołpyga biała, *Hypophthalmichthys molitrix*, tołpyga pstra, *Aristichthys nobilis*, lin, *Tinca tinca*, pstrąg tęczowy, *Onorhynchus mykiss*, sum europejski, *Silurus glanis* i sielawa, *Coregonus albula*. Generalnie u ryb słodkowodnych stosunek kwasów n-3 i n-6 jest zrównoważony. Skład chemiczny kwasów tłuszczowych w ciele ryb jest silnie determinowany rodzajem lipidów w ich diecie. W akwakulturze żywienie ryb wysokoenergetyczną paszą sztuczną, zawierającą znaczne ilości oleju rybiego, wpływa istotnie na jakość mięsa, szczególnie gatunków, u których poziom kwasów tłuszczowych z rodziny n-3 jest znaczny. Dotychczasowe badania wykazały, że spożywanie ryb słodkowodnych korzystnie wpływa na zdrowie człowieka, a zwłaszcza osób cierpiących na schorzenia układu krążenia. W związku z tym w żywieniu człowieka zaleca się, jako zdrową żywność, również ryby słodkowodne.