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Cyprinids as a Valuable Source of Essential Fatty Acids for Human Health: A Review[1]

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Abstract. Cyprinids are important objects of world aquaculture production. Many contain high levels of essential fatty acids of the n-6 and especially the n-3 series which have anti-atherosclerotic efficacy. Phytoplankton is the original source of these fatty acids, and the fatty acid composition of the fish is markedly influenced by the lipid pattern of the food. Freshwater fish such as cyprinids are able to desaturate and elongate greater quantities of dietary C 18 n-6 and n-3 polyunsaturated fatty acids (PUFA) to C 20 and C 22 desaturates. Cyprinids feeding on plankton, e. g., silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*), are rich in eicosapentaenoic acid and docosahexaenoic acid. But lipids of grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) are also characterized by considerable contents of n-3 PUFA. Clinical tests hve proven that consumption of cyprinids has beneficial effects on human health, especially for persons with cardiovascular diseases.

Cyprinid culture has increased continuously during the last years, and cyprinids represent 70% of world aquaculture fish production which was 9,417,153 tonnes in 1992 (FAO 1994). Thus consumption of cyprinids is of crucial importance for human nutrition especially in several Asian countries.

The most important cyprinid fish species are silver carp, grass carp, common carp and bighead carp (Table 1) which can be reared successfully in warmwater ponds in polyculture. However, many other cyprinid species are also interesting from the economic point of view.

Significance of essential fatty acids

Two types of essential fatty acids, the n-6 series and the n-3 series, cannot be synthesized by animals or humans and must be supplied in the diet (Horrobin and Manku 1990). Both can be metabolized by the same enzyme sequence (Fig. 1).

Essential fatty acids are required for the normal structures (fluidity, flexibility, permeability) of the membranes and act as precursors of the eicosanoids such as prostaglandins, thromboxanes and leucotrienes. They are involved in cholesterol transport and disposal, and are responsible for

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maintaining the impermeable barrier of the skin, and for regulating permeability in the gut. Since n-6 and n-3 fatty acids interfere with each other's metabolism, neither of them should be consumed in excess.

Whereas the necessity of supply of n-6 fatty acids is well known and undisputed (Horrobin and Manku 1990), knowledge of the significance of n-3 fatty acids became generally accepted in recent years (Lands 1986; Stansby 1990a, 1990b).

Table 1. World aquaculture production (t) of important cyprinid species 1992 (FAO 1994).

Silver carp (*Hypophthalmichthys molitrix*)	1,616,613
Grass carp (*Ctenopharyngodon idella*)	1,252,728
Common carp (*Cyprinus carpio*)	1,022,887
Bighead carp (*Aristichthys nobilis*)	786,604

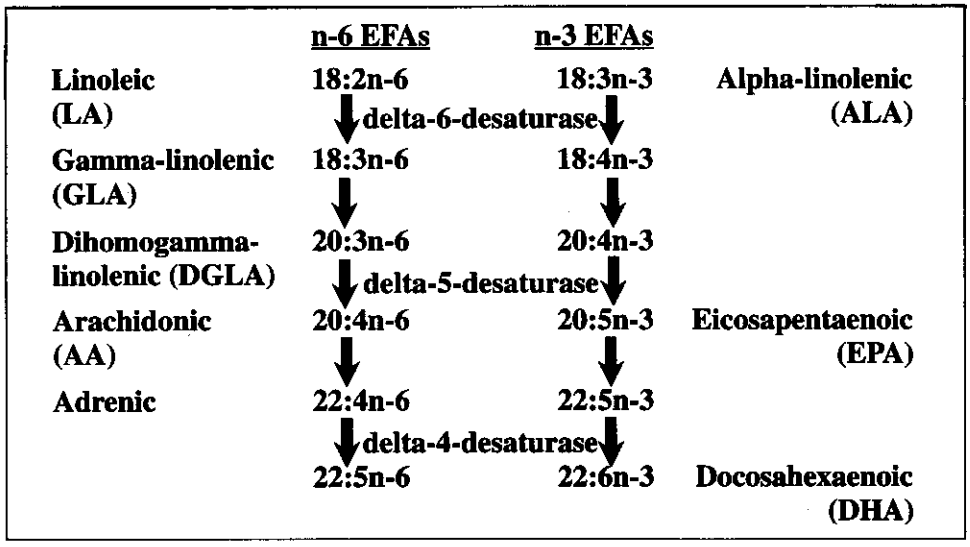

Fig 1. Metabolic pathways of the n-6 and n-3 fatty acids.

Today there is no doubt that polyunsaturated n-3 fatty acids have anti-atherosclerotic efficacy (Herold and Kinsella 1986, Pigott and Tucker 1987, Singer 1994, Steffens 1995). This is especially based on

- inhibition of synthesis of the vasoaggressive low density lipoproteins (LDL),
- acceleration of LDL elimination,
- non-influence on vasoprotective high density lipoproteins (HDL) or even enhanced HDL production,
- decrease in total serum triglycerides,
- shifting the eicosanoid balance in favor of the anti-aggregatory fraction,
- reduction of platelet aggregation and prolongation of bleeding time; and
- reduction of blood pressure.

However, several investigations have shown that long-chain n-3 polyunsaturated fatty acids (PUFA) may also have beneficial effects on diseases other than those of the heart and blood vessels, e.g., inflammatory diseases, arthritis, nephritis, Lupus erythematosis, multiple sclerosis, strokes, cancer, skin diseases and asthma.

Fatty Acid Levels in Cyprinid Fish Species

Fish lipids are a significant source of essential fatty acids which have its origin in phytoplankton and reach fish via the food web (Steffens 1989). Lipids of marine fish species are characterized by low levels of linoleic acid (18 : 2 n-6) and linolenic acid (18 : 3 n-3) as well as high levels of long-chain n-3 polyunsaturated fatty acids, especially eicosapentaenoic acid (EPA, 20 : 5 n-3) and docosahexaenoic acid (DHA, 22 : 6 n-3). The ratio of total n-3 to n-6 fatty acids is high, varying between 5 and more than 10.

Freshwater fish, on the other hand, generally contain higher levels of C18 PUFA, but also substantial concentrations of EPA and DHA. In addition the fatty acid composition of freshwater fish is characterized by high proportions of n-6 PUFA, especially linoleic acid and arachidonic acid (AA, 20 : 4 n-6). Therefore the ratio of total n-3 to n-6 fatty acids ranges from 1 to 4.

Unlike marine fish species, freshwater fish are able to desaturate and elongate greater quantities of dietary C18 n-6 and n-3 PUFA to C20 and C22 desaturates (Henderson and Tocher 1987, Sargent et al. 1989).

Cyprinids such as silver carp and bighead carp, which feed on phyto- and zooplankton, are abundant in n-3 PUFA (Table 2). But there are also considerable amounts of arachidonic acid (Steffens et al. 1993).

Muscle lipids of the grass carp, (e.g., an important species for aquaculture which feeds on macrophytes (e.g., filamentous algae, water-weeds and grass), contain high levels of EPA and DHA (Table 3).

The fatty acid composition of the common carp is influenced to a great extent by the fatty acid composition of the feed (Table 4). Compared to supplementary wheat, natural food results in higher levels of essential fatty acids in the muscle triglycerides (Table 5).

Investigations concerning the fatty acid composition of a number of European cyprinids have shown that most of them contain considerable levels of essential fatty acids, especially n-3 PUFA (Table 6 and 7). However, there are differences which may depend on species, nutrition and environmental conditions.

Beneficial Effects of Cyprinid Lipids on Human Health

Experiments to take advantage of the favorable fatty acid composition of cyprinid lipids were carried out in Hungary (Farkas et al. 1987, Joó et al. 1988, Csengeri et al. 1989) and Germany (Steffens et al. 1989, 1991; Wirth et al. 1990b, 1992) with silver carp and bighead carp.

Table 2. Fatty acid composition (%) of the triglycerides of the dorsal and ventral muscle of silver carp and bighead carp (Mieth et al. 1989a, 1989b)

Fatty acids	Silver carp (*Hypophthalmichthys molitrix*)		Bighead carp (*Aristichthys nobilis*)	
	Dorsal muscle	Ventral muscle	Dorsal muscle	Ventral muscle
14 : 0	4.5	5.0	2.4	2.8
16 : 0	15.4	15.6	10.8	11.4
16 : 1	10.5	11.2	9.1	9.6
18 : 0	3.2	3.4	2.5	2.6
18 : 1 n - 9	24.8	27.2	27.0	24.5
18 : 2 n - 6	4.3	4.4	3.1	3.5
18 : 3 n - 3	7.0	6.9	7.8	7.8
20 : 1 n - 9	2.5	2.6	2.8	3.7
20 : 4 n - 6	3.3	3.1	3.3	3.1
20 : 5 n - 3	6.6	6.6	10.7	10.8
22 : 1 n - 9	2.9	2.9	3.1	3.1
22 : 5 n - 6	1.4	1.3	1.2	1.2
22 : 5 n - 3	2.0	1.9	2.1	2.0
22 : 6 n - 3	6.0	5.3	9.9	8.9
Σ n - 3	21.6	20.7	30.5	29.5
Σ n - 6	11.0	10.5	9.7	9.3
n - 3 / n - 6	2.0	2.0	3.1	3.2

Table 3. Fatty acid composition (%) of the total lipids of white and red muscle, liver and brain of grass carp (Sýkora and Valenta 1978).

Fatty acids	White muscle	Red muscle	Liver	Brain
16 : 0	18.6	17.4	19.5	18.4
16 : 1	10.9	13.2	8.5	10.1
18: 0	4.9	3.0	3.9	3.9
18 : 1 n - 9	22.9	26.4	25.4	23.3
18 : 2 n - 6	6.0	6.4	5.1	6.1
18 : 3 n - 3	5.4	9.9	7.2	7.8
20 : 4 n - 6	2.4	3.6	4.3	3.9
20 : 5 n - 3	6.4	3.8	5.0	5.1
22 : 5 n - 3	2.5	2.2	2.6	2.0
22 : 6 n - 3	10.2	6.0	11.6	12.1
Σ n - 3	24.9	23.0	27.2	27.8
Σ n - 6	9.9	11.0	10.6	11.7
n - 3 / n - 6	2.5	2.1	2.6	2.4

Table 4. Fatty acid composition (%) of the muscle triglycerides of common carp (125 - 160 g) fed different diets for 84 d (Steffens et al. 1995).

Fatty acids	Basal diet (control)	Basal diet + 10% corn germ oil	Basal diet + 10% sunflower oil	Basal diet + 10% fish oil	Basal diet + 10% rapeseed oil
14 : 0	1.9	0.9	0.9	4.2	0.9
16 : 0	15.1	10.1	8.1	12.4	7.7
16 : 1	6.2	2.4	2.2	4.9	2.4
18 : 0	1.9	1.1	2.0	1.0	1.0
18 : 1 n - 9	30.0	23.4	24.1	18.9	45.1
18 : 2 n - 6	22.3	51.6	50.9	12.8	25.0
18 : 3 n - 3	5.2	3.1	3.3	8.5	9.8
18 : 4 n - 3	0.5	0.2	tr	3.5	0.2
20 : 4 n - 6	1.3	0.7	1.0	0.2	1.3
20 : 5 n - 3	3.0	1.3	1.3	7.1	1.2
22 : 5 n - 3	1.1	0.4	0.4	1.9	0.5
22 : 6 n - 3	7.0	2.9	2.8	13.7	2.7
Σ n - 3	16.8	7.9	7.8	34.7	14.4
Σ n - 6	25.1	53.9	53.7	14.3	27.4
n - 3 / n - 6	0.7	0.1	0.1	2.4	0.5

Table 5. Fatty acid composition (%) of the muscle triglycerides of market-size carp (> 1,000 g) reared on the basis of natural food only or fed supplementary wheat.

Fatty acids	Carp reared on the basis of natural food	Carp fed supplementary wheat
16 : 0	15.9	20.5
16 : 1	11.7	9.8
18 : 1 n - 9	27.8	39.2
18 : 2 n - 6	15.2	10.3
18 : 3 n - 3	8.7	5.8
20 : 4 n - 6	2.2	0.9
20 : 5 n - 3	3.3	1.9
22 : 6 n - 3	1.0	0.4
Σ n - 3	15.3	9.3
Σ n - 6	19.4	12.0
n - 3 / n - 6	0.8	0.8

In a test with spontaneously hypertensive rats, which received a diet containing 10% silver carp oil, systolic blood pressure was lowered and levels of triglycerides and total cholesterol were reduced in blood serum after 8 weeks (Wirth et al. 1990c).

In a comparative experiment, the beneficial effect of silver carp oil containing a higher level of arachidonic acid was more pronounced than the effect of mackerel oil on blood pressure, serum lipids and platelet function (Wirth et al. 1990a, 1992).

In a clinical test, 14 hypertensive patients were put on a 2-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 decreased levels of triglycerides in the blood plasma, and increased HDL-cholesterol, while phospholipid concentration remained constant (Table 8).

Table 6. Fatty acid composition (%) of the total lipids of the white muscle of several European cyprinid species (Sýkora and Valenta 1978, 1979).

Fatty acids	Rudd (*Scardinius erythrophthalmus*)	Gudgeon (*Gobio gobio*)	Dace (*Leuciscus leuciscus*)	Chub (*Leuciscus cephalus*)	Bleak (*Alburnus alburnus*)	Zanthe (*Vimba vimba*)
16 : 0	18.3	21.2	15.5	20.6	20.2	17.2
16 : 1	4.0	6.2	11.3	2.7	7.9	10.1
18 : 0	5.3	7.5	3.9	4.7	4.4	4.4
18 : 1 n - 9	12.3	15.1	20.4	12.0	28.2	33.2
18 : 2 n - 6	5.3	3. 9	5.3	2.7	9.7	6.3
18 : 3 n - 3	5.4	6.2	1.4	4.1	5.1	5.8
20 : 4 n - 6	6.6	8.3	3.0	7.7	5.1	2.1
20 : 5 n - 3	15.8	8.3	9.5	9.3	3.0	4.4
22 : 5 n - 3	3.9	2.2	4.3	3.4	1.9	1.2
22 : 6 n - 3	18.3	13.3	12.0	25.7	6.5	7.1
Σ n - 3	43.9	30.5	28.2	42.9	17.4	19.4
Σ n - 6	12.7	14.0	9.3	11.5	15.9	9.8
n - 3 / n - 6	3.5	2.2	3.0	3.7	1.1	2.0

Table 7. Fatty acid composition (%) of the lipids of several European cyprinid species (Vácha and Tvrzická 1994).

Fatty acids	Tench (*Tinca tinca*)	Bream (*Abramis brama*)	Roach (*Rutilus rutilus*)	Asp (*Aspius aspius*)	Crucian carp (*Carassius carassius*)	Barb (*Barbus barbus*)
16 : 0	17.4	21.6	19.8	15.7	21.2	17.2
16 : 1	16.2	7.3	12.9	12.8	14.6	9.1
18 : 0	2.1	7.2	3.5	3.5	4.5	5.9
18 : 1 n - 9	23.3	32.4	22.7	35.8	27.1	18.3
18 : 2 n - 6	5.2	9.7	8.5	2.4	2.7	2.5
18 : 3 n - 3	10.8	1.3	9.3	3.2	4.8	3.3
20 : 4 n - 6	2.4	3.9	1.2	2.4	1.3	5.1
20 : 5 n - 3	4.7	2.0	3.2	3.6	4.0	6.7
22 : 5 n - 3	1.4	0.7	0.9	1.6	1.2	2.5
22 : 6 n - 3	3.5	3.7	3.2	6.5	4.2	15.8
Σ n - 3	24.5	8.7	19.8	17.6	17.4	31.2
Σ n - 6	8.8	15.1	10.5	5.6	4.7	8.9
n - 3 / n - 6	2.8	0.6	1.9	3.1	3.7	3.5

Table 8. Effect of daily administering of 100 g meat of silver carp for 2- weeks to hypertensive patients on blood pressure (mm Hg) and plasma lipids ($mmol \cdot l^{-1}$) (Wirth et al. 1990b).

	Pre	Post
Systolic blood pressure	151± 9	136 ± 7*
Diastolic blood pressure	94 ± 7	85 ± 7
Triglycerides	1.82 ± 0.86	1.21 ± 0.53*
HDL-cholesterol	1.52 ± 0.39	1.78 ± 0.44*
Phospholipids	223 ± 35	226 ± 40

* Difference significant ($P < 0.05$)

Lipids of many cyprinid species exhibit high levels of essential fatty acids, particularly n-3 PUFA. In general there is a balanced ratio of n-3 to n-6 fatty acids. Plankton-feeding species such as silver carp and bighead carp, and also grass carp, and common carp are especially valuable sources of these indispensable fatty acids. Experiments with hypertensive rats and clinical tests have confirmed the beneficial effects of cyprinid fish species in preventing cardiovascular diseases. Thus, cyprinids can be recommended as wholesome food for humans.

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