Fatty Acid Content and Composition of Freshwater Finfish

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ABSTRACT AND SUMMARY

The fatty acid content and composition of 18 species of freshwater fish filets were determined. The fat content and composition varied with anatomical location. The anterior ventral regions of trout and salmon contained more lipids than the posterior dorsal sections. Marked variations in fatty acid composition between species were observed. Palmitic (C16:0), palmitoleic (C16:1), oleic (C18:1), eicosapentaenoic (C20:5 ω3), and docosahexaenoic (C22:6 ω3) were the most abundant fatty acids. The fatty acids were tabulated according to the number and positions of the double bonds. Significant quantities of ω6 C18:2 and C20:4 fatty acids were found in several species.

INTRODUCTION

Though the present average per capita consumption of fish in the USA is approximately 12 pounds per annum, the potential for increased consumption is marked especially if aquaculture techniques are adopted. Ackman (1) has estimated worldwide production of freshwater species for edible purposes at approximately seven million metric tons per annum. The potential of various freshwater fish species as sources of low fat, high protein food has not yet been fully realized. With the development of this source is the concomitant need for information concerning the chemical composition and nutrient content of various edible species. Such data are required by food scientists to devise optimum processing and storage conditions and by nutritionists to develop suitable dietary formulae.

Of the various components that affect edible quality attributes, the lipids of fish are most important. Lipids may undergo several deteriorative reactions during processing and storage, e.g., hydrolysis and oxidation, and these can adversely affect flavor, odor, color, and texture (2-8). However, knowledge of the lipid content and fatty acid composition of freshwater fish is limited to a few species. Several reviews have revealed the scarcity of quantitative data for freshwater species (7,9-11). In a previous paper we reported the proximate composition, sterol and phospholipid content of 15 species of freshwater fish (12). In the present paper the fatty acid content and composition of 18 species is reported.

MATERIALS AND METHODS

Materials

The smelt, suckers, rainbow, and lake trout were caught in Cayuga Lake, Ithaca, NY, the brook trout were caught locally, and the remaining species of fish analyzed were harvested from Oneida Lake at Bridgeport, NY by personnel of the Cornell Biological Station. All fish were caught during September/October 1975. The fish (Table I) were immediately frozen and stored at −40 C until analyzed. Prior to analysis, the head, tail, fins, viscera, and skin of the fish were removed. Fish filets were obtained by carefully cutting the fish lengthwise along the backbone to obtain maximum amount of flesh without including any bones. The weight of each filet was determined. Because of variations in composition of different sections of the filets depending upon their location (13) the filets were cut into small portions (1 cm^3) and these were mixed before taking samples for analyses.

All chemicals used were reagent grade (Fisher Scientific Co., Rochester, NY), and distilled water was used.

Methods

Lipids: The fish lipids were extracted by the method of Bligh and Dyer (14) with slight modifications. Representative samples of fish filets (30 g) were homogenized in Waring blendor for 2 min with a mixture of methanol (60 ml) and chloroform (30 ml). One volume of chloroform (30 ml) was added to the mixture and after blending for an additional 30 sec distilled water (30 ml) was added. The homogenate was stirred with a glass rod and filtered through Whatman No. 1 filter paper on a Buchner funnel with slight suction. The filtrate was transferred to a separatory funnel. The lower clear phase was drained into a 250 ml round-bottom flask and concentrated with a rotary evaporator at 40 C. The concentrated lipid extract was quantitatively transferred to a vial and made up to a final volume of 20 ml with chloroform. Aliquots (2 ml each) were evaporated in tared vials to constant weight under nitrogen to determine the lipid content. Butylated hydroxytoluene (BHT) at a concentration of 0.05% (of the lipid) was added to the remaining lipid extract, and the extract was stored at −40 C for further analysis.

Fatty acid content: Fatty acid contents of the total lipid extracts were determined by saponification of 50-100 mg of lipid with 10% alcoholic KOH (3 ml) at 85 C for 30 min. After the addition of water (3 ml) the nonsaponifiable materials were thrice extracted with hexane. The residual soaps were acidified to pH 1.5, and the free fatty acids were thrice extracted with hexane. The extracts were pooled, dried in tared vials, and the weight of fatty acids determined. The average results of triplicate analyses are reported for each species. These data were used to calculate the weights of individual fatty acids separated by gas chromatography.

Fatty Acid Analyses

Methylation: Fifteen mg of lipid material containing 0.5 mg of heptadecanoic acid as internal standard was saponified (6 min at 85 C) with 1.0 ml 0.5N KOH in dry methanol. After neutralization with 0.7N HCl, 3 ml of 14% boron trifluoride in methanol was added, and the mixture was heated for 6 min at 85 C to achieve complete methylation. The fatty acid methyl esters were thrice extracted from this salt saturated mixture with hexane (2 ml aliquots) and concentrated to 0.5 ml. Analyses by thin layer chromatography showed that complete methylation was achieved and quantification by gas chromatography revealed recovery rates of 96 ± 2 for methyl heptadecanoate.

Gas chromatography: The content and composition of fatty acid methyl esters (FAME) were analyzed by Hewlett Packard Series 5830A automated gas chromatograph. The temperatures of injection port and detector were 250 and 300 C, respectively. Hydrogen, nitrogen, and air flow rates were 45, 40, and 240 ml/min, respectively.

In order to obtain complete resolution and quantification of all fatty acids, two separate column packings were used under different conditions. For routine analysis of

TABLE I

The Lipid and Fatty Acid Content of Filets of Several Species of Freshwater Fish

Fish species	Lipid content	Fatty acid content[a]
	g/100 g filet	
Bass, Largemouth	1.3	1.0
Bass, Rock (*Ambloplites rupestris*)	0.7 ± 0.2	0.5
Bass, White (*Morone chrysops*)	3.8 ± 0.4	2.1
Bullhead, Brown (*Ictalurus nebulosus*)	2.7 ± 0.3	2.1
Burbot (*Lota lota*)	0.7	0.5
Carp (*Cyprinus carpio*)	2.0	1.7
Crappie, Black (*Pomoxis nigromaculatus*)	1.5 ± 0.8	1.2
Drum, Freshwater (*Aplodinotus grunniens*)	3.2 ± 1.7	2.6
Perch, White (*Morone americanus*)	2.5 ± 1.2	1.7
Perch, Yellow (*Perca flavescens*)	0.8 ± 0.1	0.6
Pike, Northern (*Esox lucius*)	0.7	0.6
Pike, Walleye (*Stizostedion vitreum*)	1.1 ± 0.3	0.8
Salmon (*Salmo salar*)	4.0	3.3
Smelt, American (*Osmerus mordax*)	2.2 ± 0.4	1.5
Sucker, White (*Catostomus commersonni*)	1.9 ± 0.2	1.5
Sunfish, Pumpkinseed (*Lepomis gibbosus*)	0.7 ± 0.2	0.6
Trout, Brook (*Salvelinus fontinalis*)	3.4 ± 1.2	2.7
Trout, Lake (*Salvelinus namaycush*)	7.2 ± 2.6	5.8
Trout, Rainbow (*Salmo gairdneri*)	3.1 ± 1.3	2.3

[a]Average of three determinations.

methyl esters, stainless steel columns (1.9 metre long, 2.16 mm ID) packed with ethylenesuccinate methylsilicone copolymer (EGSS-X) 10% on Gas-Chrom P 100-120 mesh (Applied Science, State College, PA) was used. The temperatures of the columns were 200 C when operated isothermally, or 170 C initially and programmed at 2 C/min to a final temperature of 210 C and held at this temperature until the end of the run when operated with temperature programming. The EGSS column packing, coupled with temperature programming, achieved separation of all fatty acids present except that there was overlapping of C18:3 with C20:1 and of C20:4 with C22:1. These fatty acid peaks were separated and quantified using a column packing of Silar 10 C (Supelco, Bellefonte, PA), 10% coated on Gas-Chrom Q, 100-120 mesh. Dual columns 3.8 meters long, 2.16 mm ID) were operated isothermally at 210 C or temperature programmed from 200 to 240 C at 1 C per min. This succeeded in separating the C18:3 from C20:1 and C20:4ω6 from C22:1. Because C20:1 and C22:1 rarely exceeded 1.5 and 1.0% of total fatty acids, respectively, the Silar 10 C columns were not used for all analyses.

Identification of Fatty Acids

Because of the closeness in molecular weights and presence of various positional isomers, several procedures were used to identify the fatty acid methyl esters (FAME) on chromatograms. Initially a retention timetable for all FAME probably present in freshwater fish was constructed and using this, a tentative identification of unknown chromatographic peaks was possible. First data for a retention timetable were obtained by determining the retention times of standard mixtures of pure FAME; 16:0, 16:1, 18:0, 18:1, 18:2ω6, 18:3ω3, 20:0, 20:1, 20:2ω6, 20:3ω3, 20:4ω6, 20:5ω3, 22:6ω3, and 24:1 (Nu-Chek Prep, Elysion, MN). Then, using a graphical procedure (15), which involved plotting the log of relative retention times against the chain length of homologous series of FAME, four parallel lines were obtained which related molecular structure to retention times for homologues of saturated, monounsaturated, ω6 diunsaturated, and ω3 triunsaturated fatty acids. These lines (Fig. 1) permitted the tentative identification of unknown FAME whose retention times fell on these plots. In addition, separation factors (16) were calculated by dividing the retention time of one FAME by the shorter retention time of an isomeric FAME of the same chain length. Constant separation factors are obtained for FAME with same chain length but differing in the number of double bonds, e.g., C18:3, C18:2, C18:1, and C18:0.

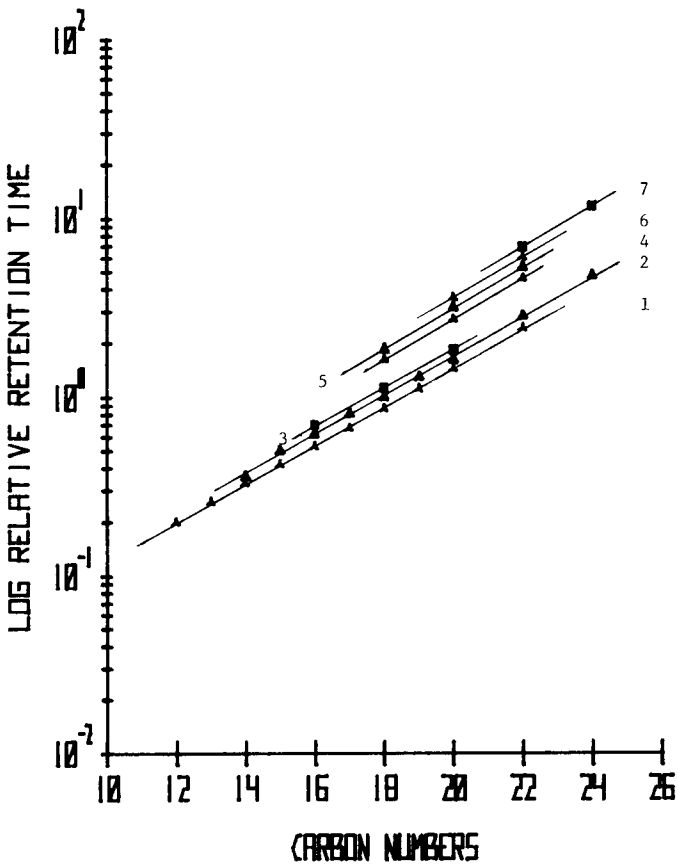

FIG. 1. Plots of the logarithms of the relative retention times against carbon numbers of the homologous isomers of the various families of methyl esters of fatty acids found in freshwater fish. 1–saturated; 2–monoenoic, both ω-7 and ω-9 series; 3–ω-6 dienoic; 4–ω-3 trienoic; 5–ω3 tetraenoic; 6–ω-3 pentaenoic; 7–ω3 hexaenoic fatty acid methyl esters, respectively.

Applying these procedures and using the two different liquid phase column packings EGSS-X and Silar 10 C, most of the FAME in freshwater fish species were identified.

Quantification of Fatty Acids

The areas of the peaks on the chromatograms were

TABLE II

Lipid Content and Fatty Acid Composition of Lipids from Representative Sections of the Filets of Lake Trout (Wt %)

Fatty acid	Section of filet								
	1V	1D	2V	2D	5V	5D	7	8	9
14:0	4.1	3.6	4.3	4.3	3.3	3.4	3.8	3.8	3.4
16:0	15.5	14.9	15.8	16.0	17.7	15.0	15.0	16.0	16.9
16:1	7.8	6.8	8.0	6.8	7.9	7.0	7.8	7.9	7.2
18:0	3.6	4.0	3.9	3.7	3.3	3.0	4.0	4.4	3.7
18:1	24.7	27.6	24.6	24.1	23.6	29.5	23.3	23.2	22.0
18:2ω6	4.9	8.3	4.6	4.6	5.1	4.6	4.4	4.7	4.0
18:3ω3[b]	6.3	4.6	6.4	6.4	5.9	6.0	6.3	5.9	5.8
18:4ω3	2.8	1.5	1.8	2.7	3.2	2.0	3.2	2.5	2.1
20:4ω6[c]	4.0	3.2	4.1	4.1	4.1	4.0	3.7	3.7	4.4
20:4ω3	2.7	2.0	2.8	2.7	2.5	2.5	2.3	2.3	1.8
20:5ω3	5.4	4.6	5.4	5.4	5.3	5.3	4.9	5.0	5.9
22:4ω6	1.2	1.2	1.1	1.5	1.5	1.5	1.4	0.9	1.6
22:5ω6	1.4	1.4	1.3	1.5	1.5	1.4	1.5	1.3	1.5
22:5ω3	3.4	3.5	3.3	3.5	3.5	3.0	3.3	2.9	3.8
22:6ω3	10.0	12.0	9.4	10.9	11.6	11.6	11.7	12.9	15.7
Others[d]	2.2	0.8	3.2	1.8	0.2	1.0	3.4	2.6	0.2
Lipid content (%)	15.7	7.4	15.3	12.7	12.1	7.7	6.4	5.2	5.3

[a]Fish filets were cut into nine equal sections progressing from head to tail, and these were designated as 1 through 9. Some sections were divided to ventral and dorsal tissues which were designated as V and D, respectively.

[b]Includes 1.5-2.0% C20:1.

[c]Includes <1% C22:1.

[d]Includes all fatty acids with wt % below 1%.

TABLE III

Lipid Content and Fatty Acid Composition of Lipids from Representative Sections of Filets of Salmon (Wt %)

Fatty acid	Section[a]										
	2	3	4	6V	6D	7V	7D	8V	8D	9V	9D
14:0	3.1	3.3	3.2	3.4	3.1	3.4	3.2	2.7	3.3	3.1	3.3
16:0	10.4	10.7	10.5	10.1	10.5	10.4	10.6	10.5	11.2	10.9	11.3
16:1	5.4	5.5	5.5	5.5	5.0	6.1	5.0	5.1	5.4	4.8	5.0
18:0	3.9	3.9	3.8	3.9	3.8	3.7	3.9	4.0	3.0	4.0	3.4
18:1	25.3	25.7	26.2	26.6	24.6	27.0	23.3	23.8	23.0	23.3	22.2
18:2ω6	6.5	5.5	5.5	5.7	5.4	5.7	5.3	5.4	4.4	5.2	4.4
18:3ω3[b]	5.5	5.8	5.3	5.7	5.5	5.7	5.7	5.5	5.7	5.4	5.6
18:4ω3	1.9	2.0	1.6	2.0	1.9	2.2	1.7	1.8	1.5	1.7	1.4
20:4ω6[c]	4.9	5.1	5.0	4.9	4.9	4.8	4.6	4.6	4.8	4.9	4.8
20:4ω3	2.1	2.2	2.2	2.1	2.2	2.2	2.2	2.3	2.2	2.0	2.2
20:5ω3	3.9	4.1	3.7	3.4	4.0	3.7	4.2	4.2	4.2	3.8	4.1
22:4ω6	2.2	2.3	2.4	2.5	2.3	2.3	2.1	2.0	2.2	2.0	2.1
22:5ω6	2.5	2.5	2.8	2.9	2.8	2.6	2.6	2.3	2.6	2.5	2.4
22:5ω3	5.0	4.8	5.3	5.5	5.3	4.2	5.4	5.2	5.7	5.4	5.6
22:6ω3	14.8	14.0	14.5	13.4	16.7	12.3	18.9	18.1	19.7	19.7	21.2
Others[d]	2.5	2.7	2.5	2.6	2.1	2.6	1.6	2.3	1.2	1.4	1.1
Lipid content (%)	3.3	3.3	3.9	4.0	2.7	5.7	2.7	3.2	3.2	2.4	2.6

[a]Fish filets were cut into 11 sections of equal weight from head to tail and these were designated as 1 to 10. Some sections were divided to ventral and dorsal sections designated as D and V, respectively.

[b]Includes C20:1 ca. 1.8%.

[c]Includes C22:1 ca. 1.0%.

[d]Includes all fatty acids with wt % below 1%.

integrated electronically by the digital processor. However because several factors may influence detector response (17), area response factors were determined by chromatographing known amounts of standard FAME and plotting peak area vs. weights injected. Thus peak areas obtained by triangulation were corrected for variations in detector response and the percent distribution of each FAME computed.

RESULTS AND DISCUSSION

Prior to quantification of the fatty acids in all the fish species some factors which might affect these data were examined.

Lipids are not distributed uniformly throughout the body of fish (13). Generally the anterior sections of filets are much richer in lipids than sections obtained from the posterior tail region and the ventral portion, especially in the belly flap area, is much richer in lipids than the dorsal region. To determine if this uneven distribution also occurs in freshwater fish, we examined the relative distribution of lipid and of specific fatty acids in different samples of rainbow trout and salmon. If significant variation occurred according to sampling procedure, then this would be a factor in the sampling procedure used.

Filets from lake trout and salmon weighing 300 and 700 g, respectively, were cut vertically into ten sections of equal weight from anterior (head) to posterior (tail) regions. Some sections were further divided into dorsal and ventral segments. The lipid contents and fatty acid composition of these segments were determined as described in the methods section.

In the case of trout filets there was a progressive decrease in lipid content from anterior to posterior section, i.e., from 15.7 to 5.2% (Table II). The ventral portions of the filets also contained much more lipids than the dorsal sections especially in the anterior region. At the posterior end differences between dorsal and ventral regions were much less marked.

The fatty acid composition of the different sections varied slightly. Oleic acid which was the major component was slightly higher in the dorsal anterior region. Docosahexaenoic acid (C22:6) tended to be higher in the dorsal region, and its concentration increased toward the posterior sections (Table II).

The lipid concentration in salmon was much lower than in trout, and the differences in concentrations between anterior and posterior sections were less marked (Table III). The ventral portions of the middle segments showed the highest lipid content. The concentration of oleic acid tended to decrease toward the posterior sections whereas C22:6 noticeably increased. The relative concentration of C22:6 increased as the lipid content decreased which is consistent with the observation of Saddler et al. (18). The other fatty acids were consistent in their distribution throughout the various sections.

To avoid errors because of these differences in distribution of lipids and fatty acids, filets of fish were chopped into small portions (1 cm^3) and these were thoroughly mixed and randomized before sampling for analyses which were done at least in duplicate for all fish samples analyzed.

The lipid contents of fish are summarized in Table I. Within species the filets from larger fish tended to contain more lipids. Statistical analyses according to the sign test (19) revealed that the larger fish contained more lipids (per 100 g filet) than small samples, at a 5% significance level.

Palmitic (C16:0), palmitoleic (C16:1), oleic (C18:1), arachidonic (C20:4), eicosapentaenoic (C22:5), and docosahexaenoic (C22:6) fatty acids were the major component acids in these species of fish (Table IV). There was appreciable variation in fatty acids within species. Appropriate analyses by the sign test showed that the concentration of C16:0 and C18:1 was higher in the larger fish, and C20:4 was greater in small fish samples at the 10% level of significance; C22:6 was higher in smaller fish at the 5% level of significance. Generally higher levels of C16:0, C16:1, and C18:1 occurred in larger fish; whereas C20:4, C20:5, and C22:6 were higher in the smaller fish of the same species. However, the data for certain species, e.g., white sucker and white bass, did not show evidence of these trends. Reiser et al. (20) and Toyomizu et al. (21) previously reported that the fatty acid composition of mullet and rainbow trout vary with size of the fish. Generally for most species analyzed, the intraspecies variations were less than interspecies variations.

Because of these variations and the numerous factors which may influence the lipid content and fatty acid composition of fish (10), we analyzed several samples of freshwater fish of edible size and presented averaged data (Table IV). Data on proximate composition of these fish have been published (12). All species analyzed except the lake trout had a very low lipid content (Table IV). The trout showed much lower lipid levels than the values tabulated by Sidwell et al. (22).

The fatty acid composition of the various species revealed many interspecies differences (Table IV). Palmitic (C16:0), palmitoleic (C16:1), oleic (C18:1), eicosapentaenoic (C20:5ω3), and docosahexaenoic (22:6ω3) were the most abundant fatty acids in all speceis. There was no consistency in the predominance of any one fatty acid, e.g., in rock bass, yellow perch, and northern pike, C22:6 was predominant, in white perch, white bass, and drum—C18:1, in white sucker—C16:1, in sunfish and burbot C16:0 was

TABLE IV

The Average Fatty Acid Composition of Total Lipids from the Filets of Several Species of Freshwater Fish[a] (Wt %)

Fish species	C14:0	C16:0	C16:1ω7	C18:0	C18:1ω9	C18:2ω6	C18:3ω3	C18:4ω3	C20:1ω9	C20:4ω6	C20:4ω3	C20:5ω3	C22:4ω6	C22:5ω6	C22:5ω3	C22:6ω6
Bass, Large Mouth (2)	2.6	18.6	9.3	3.5	17.6	3.0	3.1	1.3	2.0	5.1	1.0	5.0	1.9	1.5	4.5	16.7
Bass, Rock (3)	2.4 ± 0.3	19.3 ± 0.6	9.0 ± 1.3	4.6 ± 0.4	17.8 ± 5.2	2.0 ± 0.1	2.1 ± 0.1	–	–	8.4 ± 2.8	–	4.3 ± 1.1	–	1.8 ± 0.3	3.6 ± 0.0	20.7 ± 3.2
Bass, White (5)	2.6 ± 0.2	17.6 ± 0.8	11.4 ± 0.8	3.0 ± 0.5	29.5 ± 1.5	2.6 ± 0.4	3.3 ± 0.3	1.2 ± 0.2	1.7	4.3 ± 0.3	–	7.1 ± 0.5	–	1.1 ± 0.1	1.4 ± 0.1	10.6 ± 0.8
Bullhead, Brown (7)	2.4 ± 0.2	18.5 ± 1.6	13.8 ± 2.0	2.8 ± 0.7	25.7 ± 4.1	4.4 ± 1.5	5.4 ± 1.4	–	1.1	4.9 ± 0.9	–	7.2 ± 1.9	–	–	2.4 ± 0.9	7.0 ± 1.2
Burbot (6)	–	20.0 ± 0.8	3.8 ± 1.0	6.3 ± 0.6	15.9 ± 0.6	1.1 ± 0.2	tr	–	–	15.8 ± 2.0	–	12.0 ± 1.5	1.1 ± 0.1	1.5 ± 0.3	2.8 ± 0.3	17.1 ± 2.7
Crappie, Black (6)	3.1 ± 0.8	20.3 ± 0.9	11.3 ± 2.7	3.3 ± 0.7	19.6 ± 5.1	3.1 ± 0.3	3.0 ± 0.7	1.1 ± 0.5	–	5.6 ± 1.8	–	4.8 ± 1.6	–	1.4 ± 0.3	4.6 ± 0.7	14.7 ± 4.6
Drum, Freshwater (6)	2.2 ± 0.4	19.5 ± 2.1	16.6 ± 3.0	3.3 ± 0.5	26.4 ± 5.9	3.1 ± 1.0	2.5 ± 2.0	–	1.2 ± 0.4	4.9 ± 2.9	–	5.1 ± 1.4	–	1.1 ± 0.9	2.2 ± 0.6	6.9 ± 4.2
Perch, White (6)	2.7 ± 0.3	18.9 ± 2.2	14.1 ± 2.4	3.1 ± 0.6	25.2 ± 1.7	3.6 ± 0.5	3.5 ± 0.5	1.9 ± 0.5	1.1 ± 0.0	5.1 ± 1.0	–	10.6 ± 0.9	–	–	1.5 ± 0.2	3.6 ± 1.5
Perch, Yellow (10)	2.0 ± 0.4	20.3 ± 1.2	7.9 ± 1.8	4.7 ± 0.7	9.1 ± 1.4	1.6 ± 0.3	1.7 ± 0.6	1.3 ± 0.5	–	7.7 ± 1.1	–	11.5 ± 0.9	1.2 ± 0.4	1.7 ± 0.4	2.5 ± 0.4	26.4 ± 2.0
Pike, Northern (2)	2.1	16.2	5.9	3.8	12.7	4.0	3.0	–	–	7.5	–	6.1	1.1	1.3	3.4	30.7
Pike, Walleye (7)	1.7 ± 0.2	18.9 ± 1.0	9.4 ± 1.7	3.3 ± 0.4	18.8 ± 3.0	2.5 ± 0.4	1.3 ± 0.2	–	–	5.6 ± 1.3	–	8.2 ± 0.8	–	1.8 ± 0.3	1.8 ± 0.3	21.6 ± 2.7
Salmon (1)	2.9	10.7	5.0	3.6	24.5	5.2	5.3	1.5	1.0	5.3	2.3	4.5	2.2	2.3	5.0	17.0
Smelt (6)	4.6 ± 0.2	13.8 ± 0.3	9.0 ± 0.4	1.3 ± 0.1	17.5 ± 1.2	3.6 ± 0.3	4.5 ± 0.2	1.7 ± 0.2	–	3.5 ± 0.3	–	13.3 ± 1.0	–	1.1 ± 0.1	–	22.5 ± 1.8
Sucker, White (5)	2.5 ± 0.7	15.3 ± 1.0	18.8 ± 2.4	2.2 ± 0.6	14.3 ± 2.1	2.7 ± 0.7	2.3 ± 0.6	1.9 ± 0.3	1.2 ± 0.2	4.3 ± 0.4	–	10.3 ± 2.8	–	–	3.4 ± 0.3	14.9 ± 1.3
Sunfish, Pumpkinseed (8)	2.3 ± 0.7	18.8 ± 1.3	7.9 ± 2.5	5.3 ± 0.7	13.2 ± 3.0	2.9 ± 0.6	1.9 ± 0.8	–	1.0 ± 0.2	14.9 ± 2.9	–	7.1 ± 1.6	1.4 ± 0.2	3.0 ± 0.5	3.3 ± 0.5	13.7 ± 2.5
Trout, Brook (8)	3.7 ± 0.2	17.9 ± 1.2	11.2 ± 2.4	4.0 ± 0.4	21.2 ± 3.5	5.5 ± 0.6	6.0 ± 0.6	2.8 ± 0.6	–	4.3 ± 0.4	1.0 ± 0.3	7.1 ± 0.9	–	–	1.6 ± 0.2	9.3 ± 2.8
Trout, Lake (4)	3.4 ± 0.2	13.4 ± 0.9	9.6 ± 1.6	2.7 ± 0.4	29.0 ± 2.3	3.6 ± 0.5	2.9 ± 0.4	1.1 ± 0.3	2.1 ± 0.3	3.8 ± 0.5	1.5 ± 0.3	5.0 ± 0.7	–	1.8 ± 0.3	2.9 ± 0.2	13.4 ± 1.2
Trout, Rainbow (6)	3.5 ± 0.4	13.3 ± 0.5	4.8 ± 0.9	3.8 ± 0.4	18.7 ± 2.7	5.5 ± 0.4	5.9 ± 0.5	2.1 ± 0.4	–	4.4 ± 0.3	2.8 ± 0.3	5.1 ± 0.6	–	2.5 ± 0.5	3.7 ± 0.2	21.0 ± 5.3

[a]The number of fish analyzed given in parentheses. Fatty acids amounting to less than 1% not included. Sucker contained 1.7% C17:1; the C20:4 contains less than 1% C22:1.

TABLE V

Relative Concentrations of Different Groups of Fatty Acids in Filets of Freshwater Fish (Wt %)

Species	Saturated acids	Unsaturated species of fatty acids: Number of double bonds 1	2	3	4	5	6	Families of fatty acids: ω3[a]	ω6	ω7	ω9
		Wt %[b]									
Bass, Largemouth (2))	23.7	29.0	3.0	3.1	7.3	10.0	16.7	31.6	11.5	9.3	19.6
Bass, Rock (3)	26.3	26.8	2.0	2.1	8.4	9.7	20.7	30.7	12.2	9.0	17.8
Bass, White (5)	23.2	42.6	2.6	3.3	4.3	9.5	10.6	23.6	3.7	11.4	29.5
Bullhead (7)	23.7	30.6	4.4	5.4	5.0	9.6	7.0	22.0	9.3	13.8	26.8
Burbot (6)	26.3	19.7	1.1	tr	16.9	16.3	17.1	28.0	19.5	3.8	16.0
Crappie (6)	27.7	30.9	3.1	3.0	6.7	10.8	14.7	28.2	10.1	11.3	19.6
Drum (6)	25.0	44.2	3.1	2.5	5.0	8.3	7.0	16.7	9.1	16.6	27.6
Perch, White (6)	26.7	40.4	3.6	3.5	7.0	12.1	3.6	21.1	8.7	14.1	26.3
Perch, Yellow (10)	27.0	17.0	1.6	1.7	10.2	14.7	26.4	43.5	11.0	7.9	9.1
Pike, Northern (1)	22.1	18.6	4.0	3.0	8.6	10.9	30.7	42.9	12.8	6.0	12.7
Pike, Walleye (7)	23.9	28.2	2.5	1.3	5.6	11.8	21.7	33.0	10.0	9.4	18.8
Salmon (1)	17.2	29.5	5.2	5.3	13.3	11.5	17.0	35.6	15.0	5.0	25.5
Smelt (6)	19.8	26.5	3.6	4.5	5.2	14.4	22.5	42.0	6.2	9.0	17.5
Sucker (5)	21.2	33.1	2.7	2.3	6.2	13.7	15.0	32.8	7.0	18.8	15.5
Sunfish (3)	27.4	21.1	2.9	2.0	16.4	13.4	13.7	26.0	19.4	8.0	14.0
Trout, Brook (8)	25.6	32.4	5.5	6.0	8.1	8.6	9.3	27.8	9.8	11.2	21.2
Trout, Lake (4)	19.5	40.6	3.6	2.9	6.4	9.5	13.4	27.0	9.2	9.6	31.1
Trout, Rainbow (6)	20.6	23.5	5.5	6.0	9.3	11.3	21.0	41.6	9.9	4.8	18.7

[a]ω—Denotes position of first double bond from methyl end of the fatty acid.

[b]Minor fatty acids not included.

predominant. Both of these latter species had a high level of C20:4. The filets of both brook and rainbow trout generally contained higher concentrations of eighteen carbon polyunsaturated fatty acids whereas the lake trout had a high concentration of C18:1.

During biosynthesis in vivo, desaturation occurs between the initial double bond and the carboxyl group, and elongation also occurs at the carboxyl end. Unsaturated fatty acids in fish can be categorized into four families based on the location of the first double bond from the methyl end, e.g., ω7, palmitoleic; ω9, oleic; ω6, linoleic and ω3, linolenic acid families, respectively. The concentrations of fatty acids belonging to these families in freshwater fish vary (Table V). Usually fatty acids of the ω3 family, composed mostly of 20:5ω3 and C22:6ω3 (which are derived by elongation and desaturation of C18:3ω3), are most abundant with the ω9 series usually ranking second in abundance. Compared to marine species of fish (7) freshwater fish usually contain higher levels of the ω6 series, i.e., essential fatty acids. All species of freshwater fish (Table V) contained significant quantities of the ω6 series particularly C18:2 and C20:4. The presence of these and the other polyunsaturated acids emphasize the potential of freshwater fish for use in special low fat diets as suggested by Stansby (13). The ω3 fatty acids, specifically C22:6 may be involved in the prevention of multiple sclerosis (23).

The fatty acid composition of the freshwater fish reported here show marked differences in quantities of polyunsaturated fatty acids, especially C22:6, compared to various European species analyzed by Mangold (24).

Comparison of the fatty acid composition with other published data is redundant because of the numerous factors which can affect both lipid content and fatty acid composition of fish, i.e., origin, age, sex, diet, physiological state, season, geographical source, portion analyzed, etc. (7,10,20,23,25-27).

Interspecies variations in the fat content and composition of freshwater fish have been summarized by Ackman (26), and he reviewed the numerous studies showing effects of location, age, diet, size, and temperature on these components. Worthington and Lovell (27) concluded that the observed variations in fatty acids within cultured carp species, attributable to genotype were small but significant. The major differences were attributed to dietary effects.

The apparent discrepancies between the present and much of the published data on the same species may be explained by the fact that our data pertain solely to skinned filets rather than to whole fish or fish filets with skin. Many fish store triglycerides in liver, and several species which store triglycerides in the muscle deposit them in a layer beneath the skin (7,13,23). Thus differences in published data may also be traced to the portion of the fish analyzed. In the present study the filets analyzed contained low quantities of triglycerides and a relatively high proportion of phospholipids (12). This may account to some extent for the higher concentrations of polyenoic fatty acids found, since phospholipids usually contain significantly higher levels of unsaturated acids.

While knowledge of fatty acid composition per se is useful for comparative purposes, for nutritional evaluation the actual quantities of individual fatty acids are needed (25). Such data can be calculated from Tables I and IV. These data indicate that freshwater fish would be very suitable for inclusion in the formulation of low fat highly polyunsaturated diets.

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