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The effects of seasonal variation on the fatty acid composition of total lipid, phospholipid, and triacylglycerol in the dorsal muscle of *Capoeta trutta* found in the Tigris River (Turkey)

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Abstract: The effects of seasonal variation on the fatty acid composition of total lipid, triacylglycerol, and phospholipid in the dorsal muscle of *Capoeta trutta* were assessed by gas chromatographic method. A total of 18 different fatty acids were determined in the composition of *C. trutta*. The variations in fatty acid composition of total lipid, triacylglycerol, and phospholipid were recorded throughout the seasons. The total polyunsaturated fatty acids (PUFA) and monounsaturated fatty acids (MUFA) were the most important groups of total lipid. Total saturated fatty acid (SFA) and total MUFA were seen to increase from spring to summer while total PUFA decreased sharply from spring to summer. These seasons corresponded to the beginning and end of the reproduction period, respectively. The major fatty acids of total lipid in all seasons were C16:0, C18:1n-9, C20:4n-6, C20:5n-3, and C22:6n-3. In the present study, n-3/n-6 ratios of total lipid were 3.20, 4.11, 1.69, and 1.45 in spring, summer, autumn, and winter, respectively. MUFA and PUFA were the most important groups of triacylglycerols. Of these, the main fatty acids were found to be C16:0, C16:1n-7, C18:1n-9, and C20:5n-3. PUFA were determined to be the most important group of phospholipids. The major fatty acids identified in the phospholipid group were C16:0, C18:1n-9, C20:5n-3, C22:5n-3, and C22:6n-3 in all seasons. In conclusion, it was shown that the fatty acid compositions in the muscle of *C. trutta* was significantly influenced by the seasons and that, in light of their n-3/n-6 ratios, *C. trutta* should be considered a desirable food in the human diet.

Key words: Seasonal variation, fatty acid composition, total lipid, triacylglycerol, phospholipid, *Capoeta trutta*

Dicle nehrindeki (Türkiye) *Capoeta trutta*'nın dorsal kasındaki total lipit, triaçilgliserol ve fosfolipitin yağ asiti kompozisyonu üzerinde mevsimsel değişimin etkileri

Özet: Total lipit, triaçilgliserol ve fosfolipitin yağ asiti kompozisyonu üzerinde mevsimsel değişimin etkileri gaz kromatografik yöntem ile *Capoeta trutta*'nın dorsal kasında değerlendirildi. *C. trutta*'da 18 farklı yağ asidi saptandı. Total lipit, triaçilgliserol ve fosfolipitin yağ asiti kompozisyonundaki değişiklikler, mevsimler boyunca kaydedildi. Total çoklu doymamış yağ asitleri (PUFA) ve tekli doymamış yağ asitleri (MUFA) total lipitin en önemli gruplarıydı. Total SFA ve MUFA ilkbahardan yaza arttı. Diğer taraftan total PUFA üreme periyodunun sırasıyla başlangıç ve bitimini temsil eden ilkbahardan yaza azaldı. Her mevsimde total lipitin en önemli yağ asitleri C16:0, C18:1n-9, C20:4n-6, C20:5n-3 ve C22:6n-3 idi. Bu çalışmada, total lipitin n-3/n-6 oranları bahar, yaz, sonbahar ve kış mevsimlerinde sırasıyla 3.20, 4.11, 1.69 ve 1.45 idi. MUFA ve PUFA triaçilgliserolün en önemli gruplarıydı. Triaçilgliserolün temel yağ asitleri C16:0, C16:1n-7, C18:1n-9 ve C20:5n-3 olarak bulundu. PUFA fosfolipitin en önemli grubuydu. Tüm mevsimlerde, fosfolipitde tayin edilen en önemli yağ asitleri C16:0, C18:1n-9, C20:5n-3, C22:5n-3 ve C22:6n-3 idi. Araştırma sonucunda, *Capoeta trutta*'nın kasındaki yağ asiti kompozisyonlarının sezonlar tarafından önemli bir şekilde etkilendiği ve n-3/n-6 oranının seviyeleri göz önüne alındığında *C. trutta*'nın insan diyetinde önemli bir besin olduğu gösterildi.

Anahtar sözcükler: Mevsimsel değişim, yağ asit kompozisyonu, total lipit, triaçilgliserol, fosfolipit, *Capoeta trutta*

Introduction

The potential health benefits related to fish consumption are due to the presence of proteins, minerals, and vitamins. Additional health benefits from the consumption of fish or fish oil may be related to polyunsaturated fatty acids (PUFA). Fish oils contain eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), both of which are considered beneficial for human health. These fatty acids are of great importance to humans for the prevention of coronary artery disease (1). Because DHA is a major component of brain, eye retina, and heart muscle, it is considered to be important for brain and eye development as well as the maintenance of good cardiovascular health (2). EPA has also been reported to be useful in brain disorders and cancer treatment (3). It is EPA rather than DHA that is widely known to be involved in the prevention of cardiovascular disease. EPA is the precursor of several messengers regulating metabolism, cellular function (particularly endothelial and platelet function), blood clotting, blood pressure, and cardiac arrhythmia (4). Moreover, recent studies have shown the important role played by n-3 fatty acids in the prevention of autoimmune diseases, cancer, and Alzheimer's diseases (5-7). Arachidonic acid (AA) and EPA can also be oxidatively metabolized into a variety of eicosanoids that act as hormonal substances (8).

Long-chain n-3 PUFA cannot be readily synthesized by human bodies and are mostly obtained through the diet (9). Thus, PUFA, especially the longer-chain n-3 and n-6 PUFA, are considered essential fatty acids. Results from clinical and epidemiological research suggest that EPA and DHA are found mainly in fish and seafood (10). Furthermore, n-3 fatty acids are always present in fish flesh, even in lean fish (11).

Phospholipids (PL) contain a high percentage of PUFA. The absorption of PUFA is influenced by the lipid form in which these fatty acids are eaten (12). In particular, the fatty acid composition of the triacylglycerol (TG) strongly reflects that of the diet, implying that TG acts as a nutritional storage site in the fish body (13).

For these reasons, it is necessary to establish the fatty acid composition of TG and PL in order to estimate the nutritive value of fish. *Capoeta trutta* is an important freshwater fish species distributed especially in Asia (Tigris-Euphrates basin). It is one of the most abundant freshwater fish found in the Tigris River in Turkey. Local people living in southeastern Anatolia consume large quantities of the fish.

In general, the fatty acid composition of fish lipids is influenced by seasonal change, the type of food available, and gonad development (14,15). Although there are many studies on the seasonal changes of many different fish species, no reports have yet been published about the effects of seasonal variations on the fatty acid composition of this important species in the Tigris River. There have been no studies on the fatty acid composition of total lipid, TG, and PL in *C. trutta* lipids. In light of these facts, it seems necessary to carry out a lipid profile study of *C. trutta* in this location. The present study was undertaken to clarify the effects of seasonal variation on the fatty acid composition of total lipid, TG, and PL as well as the n-3/n-6 fatty acids ratio in the dorsal meat of *C. trutta*.

Materials and methods

Sampling

In all seasons, *C. trutta* is one of the most abundant fish in the Tigris and it is of great commercial importance for the people of southeastern Anatolia. The present study was carried out in 2007 and samples were caught from the Tigris River in winter (January), spring (April), summer (July), and autumn (October). The average temperatures for January, April, July, and October were 1.6, 13.7, 31.1, and 17.0 °C, respectively (16).

The samples were kept in ice after being captured and transported to the laboratory. The total length and weight of all individuals were measured. All representative fish (n = 3 at each determination) used in the experiments were approximately the same age and female. The average length of *C. trutta* specimens was 24.10 ± 2.66 cm, and the average weight was 155.2 ± 44.96 g. From each specimen, an edible portion of the dorsal muscle between dorsal fin and the head was excised. This section was then skinned and deboned and the red muscle was trimmed off. The samples were kept at −30 °C prior to analysis. At the beginning of each analysis, the samples were allowed to equilibrate to room temperature and were homogenized in a chloroform/methanol mixture (2/1 v/v).

Lipid extraction and lipid class analysis

Lipids were extracted according to the method described by Bligh and Dyer (17). The PL and TG were fractionated by thin layer chromatography (TLC; 0.25 mm silica Gel 60 F_{254}, Merck). After applying the total lipid extracts, the TLC plates were developed using petroleum ether/diethyl ether/acetic acid (80:20:1 by vol.) and the developed TLC plates were sprayed with 2'7'- dichlorofluorescein (Supelco, Supelco Park, Bellefonte, PA, USA), and PL and TG fractions were identified by corresponding standards. PL and TG fractions were recovered from the TLC plates by scraping off the appropriate bands. Samples containing muscle lipid were transesterified with acidified methanol (18). The fatty acid methyl esters (FAMEs) were extracted from the reaction vials 3 times with hexane and concentrated.

Fatty acid methyl esters (FAMEs) were analyzed by capillary gas chromatography using a Ati Unicam GC-610 equipped with a flame ionization detector (FID), a Unicam 4815 recording integrator, and a fused silica capillary column (Quadrex 007-23, 30 m × 0.25 mm i.d.; 0.25 µm film thickness, Quadrex Corp., New Haven, CT, USA). The carrier gas was nitrogen (flow rate 1 mL/min) and the split ratio was 40:1. The temperature profiles were as follows: initial temperature, 100 °C (initial time, 3 min); heating rate, 5 °C/min; final temperature, 260 °C; injection temperature, 230 °C; and detector temperature, 300 °C.

The FAMEs were identified by comparison of the retention times with those of standard purified fatty acids (Sigma Chemical Co., St. Louis, MO, USA). Results were expressed as FID response area relative percentages. The amount of fatty acids was given as a percentage.

Statistics methods

We used a Kruskal-Wallis non-parametric test for measurements to evaluate the statistical differences across subjects among the 4 seasonal conditions (spring, summer, autumn, and winter). When the Kruskal-Wallis test showed a statistical difference, we used a Mann-Whitney U-test for multiple comparisons to evaluate the statistical significance of the difference between different groups. A rate of $P < 0.05$ was considered statistically significant in all analyses.

Results and discussion

Fatty acid composition of total lipid

Seasonal variations in the fatty acid composition of the total lipid of *C. trutta* are presented in Table 1. We identified and evaluated 18 fatty acids in the muscle lipids of *C. trutta*. In all of the seasons, the major fatty acids in the *C. trutta* were palmitic (C16:0), palmitoleic (C16:1n-7), stearic (C18:0), oleic (C18:1n-9), linoleic (C18:2n-6), linolenic (C18:3n-3), arachidonic (C20:4n-6, AA), eicosapentaenoic (C20:5n-3, EPA), docosapentaenoic (C22:5n-3, DPA), and docosahexanoic acid (C22:6n-3, DHA). It was observed, however, that the fatty acid composition of *C. trutta* varied throughout the seasons.

The high levels of palmitoleic, linoleic, linolenic, and eicosapentaenoic acids are probably caused by very favorable feeding conditions. Palmitic and docosahexaenoic acids are mainly synthesized by fish. Oleic and arachidonic acids can originate from either or both of these sources.

Seasonal variations of the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6, and Σ PUFA) of total lipid in *Capoeta trutta* are shown in Figure 1. The total saturated fatty acid (SFA) and monounsaturated fatty acid (MUFA) were at their highest in summer and it was followed by winter, spring, and autumn. The total SFA percentages of the total lipid extracted from the *C. trutta* ranged from 18.15% to 29.05%. With regard to the ratio of total SFA content, the highest value was found in summer. C16:0 was the major SFA, contributing 59.28% to 69.30% of the total SFA content of the lipids for *C. trutta*. C18:0 was the second major SFA at 2.34% to 4.88%. Similar results have also been reported for other freshwater fish (19-22). The total MUFA percentages of the total lipid extracted from the *C. trutta* ranged from 24.07% to 37.99%. C18:1n-9 was identified as a primary MUFA in the *C. trutta* for all seasons. This fatty acid was found in muscle tissue of *C. trutta* 22.58%, 21.95%, 17.83%, and 13.97% in winter, summer, spring, and autumn, respectively. The highest level

Table 1. Seasonal variations in the fatty acid composition of total lipid in *Capoeta trutta*.

Fatty acid composition	Spring	Summer	Autumn	Winter
C12:0	0.21 ± 0.01a	0.26 ± 0.02b	0.14 ± 0.01c	0.17 ± 0.02ac
C14:0	1.72 ± 0.08a	4.31 ± 0.41b	1.05 ± 0.05c	1.48 ± 0.17ac
C15:0	0.16 ± 0.001a	0.64 ± 0.04b	0.36 ± 0.02c	0.44 ± 0.04d
C16:0	13.12 ± 0.14a	17.22 ± 1.36b	12.18 ±0.51a	16.73 ± 1.09b
C17:0	1.40 ± 0.20a	2.42 ± 0.22b	1.49 ±0.29a	0.44 ± 0.04c
C18:0	2.34 ± 0.63a	4.20 ± 0.30b	2.93 ± 0.60ab	4.88 ± 0.76bc
Σ SFA	18.95	29.05	18.15	24.14
C16:1n-7	8.36 ± 1.34a	14.20 ± 1.93b	8.69 ± 0.70a	8.37 ± 0.70a
C18:1n-9	17.83 ± 1.15a	21.95 ± 1.14b	13.97 ± 0.68c	22.58 ± 0.91b
C20:1n-9	1.35 ± 0.12a	1.84 ± 0.18a	1.41 ± 0.47a	0.61 ± 0.03b
Σ MUFA	27.54	37.99	24.07	31.56
C18:3n-3	3.93 ± 0.63a	2.21 ± 0.16b	1.88 ± 0.24b	4.10 ± 0.50a
C20:5n-3	14.50 ± 1.37a	14.63 ± 0.77a	13.28 ± 0.74a	7.32 ± 0.63b
C22:5n-3	6.30 ± 0.68a	3.56 ± 0.33b	6.20 ± 0.43a	4.71 ± 0.69b
C22:6n-3	16.04 ± 1.05a	6.11 ± 0.22b	14.97 ± 1.02a	10.11 ± 1.19c
Σ n-3	40.77	26.51	36.33	26.24
C18:2n-6	2.53 ± 0.25a	2.50 ± 0.13a	3.76 ± 0.75a	10.29 ± 0.72b
C18:3n-6	0.25 ± 0.05a	0.80 ± 0.05b	0.45 ± 0.05c	1.05 ± 0.05d
C20:2n-6	0.35 ± 0.02a	0.45 ± 0.03b	0.91 ± 0.04c	0.61 ± 0.01d
C20:3n-6	0.20 ± 0.05a	0.23 ± 0.006a	0.94 ± 0.04b	1.05 ± 0.10b
C20:4n-6	9.41 ± 0.69a	2.47 ± 0.35b	15.39 ± 1.03c	5.06 ± 0.85d
Σ n-6	12.74	6.45	21.45	18.06
Σ PUFA	53.51	32.96	57.78	44.30
n-3/n-6	3.20	4.11	1.69	1.45

Values are provided as mean ± S.D. Abbreviations: SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acid. Significant difference at a level of $P < 0.05$ is designated by ‘a’, ‘b’, ‘c’, and ‘d’ (Mann-Whitney U-test); the same letters in different periods indicate no significant difference.

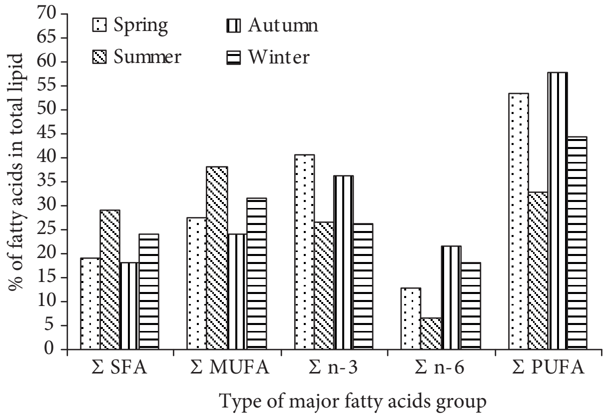

Figure 1. Seasonal variations in the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6, and Σ PUFA) of the total lipid in *Capoeta trutta*. SFA - saturated fatty acids; MUFA - monosaturated fatty acids; PUFA - polyunsaturated fatty acids.

of C18:1n-9 was in winter. Similarly, Guler et al. (21) found that C18:1n-9 was the major MUFA in muscle tissue of zander (*Sander lucioperca*) living in freshwater environments throughout Turkey. C16:1n-7 was identified as the second major MUFA (8.36%–14.20%) in the present study. The high levels of C18:1n-9 and C16:1n-7 have been reported as a characteristic property of freshwater fish oils (23-26).

The total PUFA were highest in autumn, followed decreasingly by spring, winter, and summer. The total PUFA percentages of the total lipid extracted from the *C. trutta* ranged from 32.96% to 57.78%. It was found that in all seasons the predominant fatty acids were C20:5n-3 and C22:6n-3 in PUFA. These findings are very similar to the fatty acid composition results found in previous studies on different species (14,27-29).

Total SFA and total MUFA were also shown to increase from spring to summer. On the other hand, total PUFA decreased sharply from spring (53.51%) to summer (32.96%), seasons that represented the beginning and end of the reproduction period, respectively. This indicates that PUFA may be utilized more for reproduction purposes in this species than is suggested by the reports of Yanes-Roca et al. (30) on PUFA functionality in fish. The spawning period of *C. trutta* occurs in May and June with the reproduction period occurring in March-July (31).

In summer, a high ratio of palmitoleic acid increased the MUFA content and a low level of DHA lowered the PUFA contents of our *C. trutta* specimens. In winter, a high level of linoleic acid increased the PUFA content in this species. The reason for the observed results is likely the feeding habits of the fish. The percentages of PUFA, such as EPA and DHA, in fish muscle are dependent on diet (32,33). Variations in fatty acid composition may be related to changes in the nutritional habits of the fish (34). The low PUFA content in summer may also be attributed to this reason.

The n-3/n-6 ratio is a good index for comparing the relative nutritional value of fish oils. In this study, data show that the n-3/n-6 ratio was 3.20 in spring, 4.11 in summer, 1.69 in autumn, and 1.45 in winter. An increase in the human dietary n-3/n-6 fatty acid ratio is an essential component of the diet to help prevent coronary heart disease and reduce cancer risk by reducing plasma lipids (1). According to the study by Guler et al. on *Sander lucioperca* (21), the ratio of n-3/n-6 fatty acids was 1.49 in spring, 1.45 in autumn, and 1.22 in winter, and the lowest value (0.72) was found in the summer. A high level of n-6 fatty acids lowered the n-3/n-6 ratio found in this freshwater fish during the summer. According to another study done on *Vimba vimba tenalla*, the ratio of n-3/n-6 fatty acids was 1.4 in spring, 1.5 in summer, 1.2 in autumn, and 1.4 in winter (35). Our study revealed that *C. trutta* is a freshwater fish species with a high nutritional value for human consumption due to its high n-3/n-6 ratio.

Fatty acid composition of triacylglycerol

Seasonal variations of the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6, and Σ PUFA) of triacylglycerol (TG) in *Capoeta trutta* are shown in Figure 2. MUFA and PUFA were the most important groups of fatty acids in *C. trutta*. MUFA were highest in summer while the total PUFA were highest in autumn. The percentage of total SFA were the lowest fatty acid group found in *C. trutta* throughout the year. It was observed that the main fatty acids of TG were C16:0 in SFA; C16:1n-7 and C18:1n-9 in MUFA; and C20:5n-3 in PUFA. Shira et al. (13) have reported that the main fatty acids of TG in Japanese and Thai catfish were C16:0, C18:1n-9, and C18:2n-6. The fatty acid composition of TG in *C. trutta* is shown in Table 2.

Table 2. Seasonal variations in the fatty acid composition of triacylglycerol in *Capoeta trutta*.

Fatty acid composition	Spring	Summer	Autumn	Winter
C12:0	0.21 ± 0.01a	0.05 ± 0.006b	0.24 ± 0.01a	0.37 ± 0.02c
C14:0	3.85 ± 0.62a	2.60 ± 0.10ab	2.65 ± 0.57ab	2.49 ± 0.47b
C15:0	0.21 ± 0.02a	0.19 ± 0.02a	0.78 ± 0.01b	0.73 ± 0.02b
C16:0	16.92 ± 1.16a	20.69 ± 1.67b	16.64 ± 0.67a	18.83 ± 1.18ab
C17:0	2.60 ± 0.40a	2.10 ± 0.52a	1.30 ±0.17b	1.72 ± 0.20ab
C18:0	4.28 ± 0.62a	2.19 ± 0.42b	2.44 ± 0.32b	4.85 ± 0.73a
Σ SFA	28.07	27.82	24.05	28.99
C16:1n-7	16.49 ± 1.08a	24.31 ± 1.26b	12.87 ± 1.21c	11.73 ± 0.71c
C18:1n-9	20.97 ± 1.09a	17.04 ± 0.84b	23.40 ± 1.43a	24.15 ± 2.06a
C20:1n-9	1.71 ± 0.17a	1.29 ± 0.14a	1.67 ± 0.26a	0.75 ± 0.01b
Σ MUFA	39.17	42.64	37.94	36.63
C18:3n-3	1.29 ± 0.23a	0.90 ± 0.006b	0.79 ± 0.02b	0.61 ± 0.01b
C20:5n-3	17.77 ± 1.12a	14.40 ± 0.73b	7.41 ± 0.96c	11.00 ± 0.68d
C22:5n-3	3.85 ± 0.77a	1.66 ± 0.44b	3.38 ± 0.22a	4.82 ± 0.75a
C22:6n-3	4.93 ± 0.92a	2.31 ± 0.28b	5.97 ± 0.93a	6.56 ± 0.57a
Σ n-3	27.84	19.27	17.55	22.99
C18:2n-6	3.43 ± 0.44a	3.79 ± 0.22a	9.65 ± 0.85b	5.37 ± 0.46c
C18:3n-6	0.86 ± 0.02a	4.07 ± 0.46b	4.11 ± 0.13b	1.25 ± 0.54a
C20:2n-6	0.21 ± 0.01a	0.23 ± 0.02a	0.91 ± 0.01b	0.77 ± 0.01c
C20:3n-6	0.21 ± 0.01a	0.30 ± 0.01a	2.22 ± 0.21b	2.14 ± 0.18b
C20:4n-6	0.21 ± 0.01a	1.88 ± 0.12b	3.57 ± 0.59c	1.86 ± 0.12b
Σ n-6	4.92	10.27	20.46	11.39
Σ PUFA	32.76	29.54	38.01	34.38
n-3/n-6	5.66	1.88	0.86	2.02

Values are provided as mean ± S.D. Abbreviations: SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acid. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b', 'c', and 'd' (Mann-Whitney U-test); the same letters in different periods indicate no significant difference.

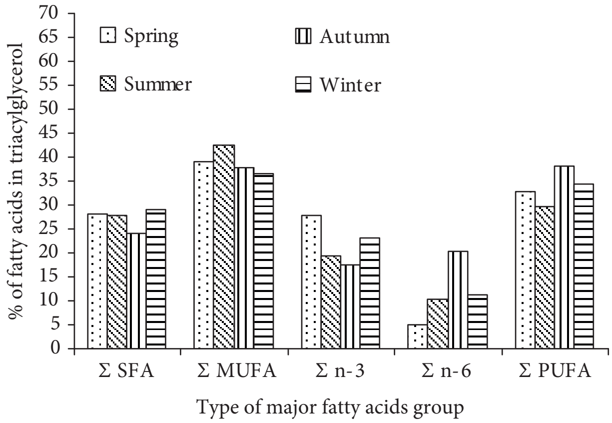

Figure 2. Seasonal variations in the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6, and Σ PUFA) of triacylglycerol in *Capoeta trutta*. SFA - saturated fatty acids; MUFA - monosaturated fatty acids; PUFA - polyunsaturated fatty acids.

It was found that C16:1n-7 was the highest MUFA of triacylglycerols in summer. This fatty acid was also found at high levels in muscle tissues of *C. trutta* which were caught from Atatürk Dam Lake by Kaçar et al (36). In fact, the high ratios of C16:0 and C16:1n-7 fatty acids are common for freshwater fish (37). We think that the C16:1n-7 fatty acid in fish comes from food. The important part of *C. trutta*'s food consists of freshwater algae Oscillatoria and Diatomes (38). These phytoplankton are very rich in terms of C16:1n-7 fatty acid (39), a finding that indicates that the fatty acid content of *C. trutta* is greatly affected by the nutritional intake of the fish.

The proportion of AA in autumn was lower than the proportion of EPA. These fatty acids are the usual precursors of the synthesis of eicosanoids, including prostaglandins and leukotrienes. Eicosanoids derived from AA have negative cardiovascular effects, such as vasoconstrictions and platelet aggregation, while the reverse is true for EPA; vasodilation and antiaggregation are among the positive effects of the latter acid. Various researchers have therefore advised that the consumption of AA in diets must be reduced (10,40).

The percentages of PUFA, such as C20:4n-3 and C22:5n-3, were low in TG. The findings were very similar to the fatty acid compositions found in previous studies on different species (13,41). Levels of C16:0 and C16:1 were highest in summer. Conversely, C18:1n-9 and C20:5n-3 were highest in winter and spring, respectively. The high levels of C18:1 in winter have also been reported in Japanese catfish by Shira et al. (13,41).

The fatty acid composition of TG showed higher percentages of C16:0 and C18:1n-9, which are consumed for energy production (13).

The highest n-3/n-6 ratio of TG was recorded in the spring (5.66). The lowest value was found in the autumn (0.86).

Fatty acid composition of phospholipid

Seasonal variations in the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6 and Σ PUFA) of phospholipid (PL) in *Capoeta trutta* are shown in Figure 3. The fatty acid composition of PL in *C. trutta* captured in different seasons is given in Table 3. PUFA were the most important group of fatty acids in *C. trutta*. Although it was observed that the fatty acid composition varied during the seasons, the major fatty acids identified in the *C. trutta* were C16:0, C18:0, C18:1n-9, C20:4n-6, C20:5n-3, C22:5n-3, and C22:6n-3 in all seasons. Similar results for other fish species have also been reported in the literature (42-45).

The total SFA percentages of the PL extracted from the *C. trutta* ranged from 18.50% to 41.01%. With regard to the ratio of total SFA content, the highest

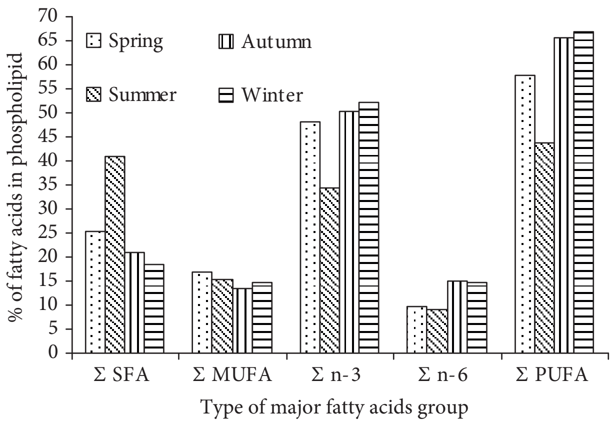

Figure 3. Seasonal variations in the major fatty acid groups (Σ SFA, Σ MUFA, Σ n-3, Σ n-6, and Σ PUFA) of phospholipids in *Capoeta trutta*. SFA - saturated fatty acids; MUFA - monosaturated fatty acids; PUFA - polyunsaturated fatty acids.

Table 3. Seasonal variations in the fatty acid composition of phospholipid in *Capoeta trutta*.

Fatty acid composition	Spring	Summer	Autumn	Winter
C12:0	0.19 ± 0.01a	0.56 ± 0.02b	0.22 ± 0.02a	0.20 ± 0.01a
C14:0	0.80 ± 0.02a	1.33 ± 0.12b	0.67 ± 0.03a	0.16 ± 0.006c
C15:0	1.06 ± 0.08a	1.14 ± 0.11a	0.22 ± 0.03b	0.20 ± 0.02b
C16:0	15.93 ± 1.50a	28.94 ± 2.32b	15.01 ± 1.24a	13.51 ± 1.25a
C17:0	0.99 ± 0.006a	0.28 ± 0.01b	0.89 ± 0.06c	0.39 ± 0.03d
C18:0	6.22 ± 0.33a	8.76 ± 1.11b	4.00 ± 0.99c	4.04 ± 0.61ac
Σ SFA	25.19	41.01	21.01	18.50
C16:1n-7	1.31 ± 0.28a	2.73 ± 0.72 b	2.22 ± 0.23ab	2.94 ± 0.60b
C18:1n-9	14.12 ± 1.02a	12.31 ± 1.30ab	10.78 ± 1.02b	10.97 ± 0.76b
C20:1n-9	1.57 ± 0.34a	0.33 ± 0.006b	0.44 ± 0.03b	0.68 ± 0.02b
Σ MUFA	17.00	15.37	13.44	14.59
C18:3n-3	1.00 ± 0.23a	1.43 ± 0.32a	1.11 ± 0.15a	1.18 ± 0.17a
C20:5n-3	16.76 ± 1.78a	17.42 ± 0.73a	14.02 ± 0.99b	14.22 ± 0.74b
C22:5n-3	9.10 ± 0.80a	3.71 ± 0.16b	10.72 ± 1.54a	10.79 ± 0.92a
C22:6n-3	21.22 ± 1.20a	11.97 ± 1.50b	24.59 ± 2.24ac	26.04 ± 1.30c
Σ n-3	48.08	34.53	50.44	52.23
C18:2n-6	3.70 ± 0.69ab	3.18 ± 0.73ab	2.44 ± 0.21a	4.23 ± 0.25b
C18:3n-6	0.44 ±0.02a	0.35 ± 0.02b	0.44 ± 0.03a	0.58 ± 0.01c
C20:2n-6	0.31 ± 0.02a	0.40 ± 0.02a	2.36 ± 0.28b	0.44 ± 0.01a
C20:3n-6	0.19 ± 0.02a	0.02 ± 0.01a	2.20 ± 0.45b	1.35 ± 0.20c
C20:4n-6	5.09 ± 0.31a	5.14 ± 0.81a	7.67 ± 0.99b	8.08 ± 0.74b
Σ n-6	9.73	9.09	15.11	14.68
Σ PUFA	57.81	43.62	65.55	66.91
n-3/n-6	4.94	3.80	3.34	3.56

Values are provided as mean ± S.D. Abbreviations: SFA - saturated fatty acid; MUFA - monounsaturated fatty acid; PUFA - polyunsaturated fatty acid. Significant difference at a level of $P < 0.05$ is designated by 'a', 'b', 'c', and 'd' (Mann-Whitney U-test); the same letters in different periods indicate no significant difference.

value was found in summer. Of these, C16:0 was the primary saturated fatty acid, ranging from 13.51% to 28.94% in all seasons, with the highest value being observed in summer.

The total MUFA percentages of the PL extracted from the *C. trutta* ranged from 13.44% to 17.00%. For all seasons 18.1 was identified as a primary MUFA in the *C. trutta* (10.78%-14.12%). Similar results for other fish species have also been reported in the literature (42-45).

The total PUFA levels were highest in winter, followed by autumn, spring, and summer. The total PUFA percentages of the phospholipid extracted from the *C. trutta* ranged from 43.62% to 66.91%. For all seasons, the predominant fatty acids in PUFA were found to be C22:6n-3, C20:5n-3, C22:5n-3, and C20:4n-6. In *C. trutta*, the levels of C22:6n-3 and C22:5n-3 were lowest in summer.

With regards to PLs, the highest ratio of n-3/n-6 was measured in the spring (4.94).

Inhamuns and Franco (43) have reported a high level of polyunsaturated fatty acids in phospholipids, including primarily C22:6n-3, C20:4n-6, C18:3n-3, and C20:5n-3.

Miller et al. (46) found increased proportions of C20:4n-6 and C22:6n-3 as a result of cold adaptation while the proportion of saturated fatty acids fell in phospholipid in goldfish. There is no doubt that increases in the PUFA content of phospholipids do occur during adaptation to lower environmental temperatures. The physical properties of the membrane are determined by the phospholipids and the fatty acid composition of phospholipid. The degree of unsaturation of the fatty acids is important in determining the fluidity of the membrane and in providing the correct environment for membrane functions. In fish and other poikilotherms, the degree of unsaturation of the membrane fatty acids is also important in the process of adaptation to different environmental temperatures (47).

Phospholipids are generally considered to be structural or functional lipids, being incorporated to a larger extent in the membrane structure of cellular and subcellular particles. Triacylglycerols are more often storage lipids and reflect the fatty acid composition of the diet to a greater extent than do the phospholipids.

Cold temperatures are normally associated with an increased unsaturation degree in body fat, in particular with a conversion of saturated fatty acids of the biological membrane phospholipids typical of the warm season into the corresponding mono- and dienic fatty acids typical of the cold season. Moreover, the adaptation of lipid metabolism during the cold season implies a concentration increase of long-chain PUFA in the membrane phospholipids (46). This seasonal lipid adaptation is fundamental for animal survival. In fact, the correlation between environmental temperature and PUFA content allows for the preservation of membrane fluidity and, as a consequence, the normal physiological functions of the membranes themselves, independent of the surrounding temperature.

This study has shown that *C. trutta*, as found in the Tigris River in Turkey, is a desirable item in the human diet when the levels of n-3/n-6 ratio are considered. This finding is due to the fact that, when taking into account the benefits to human health, *C. trutta* specimens from the Tigris River appear to be quite nutritious in terms of fatty acid composition and ratio. This study also underlines their commercial importance and notes that the fish will have a greater positive effect on human health because of their higher PUFAs in spring, autumn, and winter.

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