Scientific Research and Essays Vol. 5(23), pp. 3776-3780, 4 December, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Fatty acid composition and ω6/ω3 ratio of the pike (*Esox lucius*) muscle living in Eber Lake, Turkey

Sait Bulut

Afyon Kocatepe University, Faculty of Science and Literatures, Biology Department, Afyonkarahisar, Turkey.
E-mail: saitbulut@aku.edu.tr.

Accepted 22 November, 2010

The present study determined variations in total fatty acid composition of pike (*Esox lucius*) in Eber Lake throughout the year, using gas chromatograph (GC). The most predominant fatty acids (SFA) found in pike was palmitic acid (14.78 - 18.13%)(5.38 – 7.99%) and the dominant polyunsaturated fatty acids (PUFA) were docosahexaenoic acids (DHA, 16.04 – 24.29%), linoleic acids (LA, 2.52 – 4.15%), eicosapentaenoic acids (EPA, 5.05 – 8.33%), and arachidonic acids (AA, 4.34 – 9.78%). The total PUFA content was higher than both total SFA and total MUFA throughout the year. While PUFA content was highest in June when lake water and nutrients are most abundant, SFA and MUFA contents were lowest. By months, the ω-3/ω-6 ratio was 3.65, 0.97, 2.73, 2.76 and 3.48 in November, February, April, June and August, respectively. Fatty acid composition in the muscular tissue of pike and ω-3/ω-6 ratio differed according to month and were particularly affected by spawning.

Key words: Pike, *Esox lucius*, fatty acid composition, Eber Lake.

INTRODUCTION

Fish consumption plays an important role in protecting human health and ensuring a balanced diet. Fish is a vital food source, providing fat, protein, minerals and vitamins. Health benefits from the consumption of fish or fish oil may be related to polyunsaturated fatty acids (PUFAs) especially ω-3 PUFAs (Sidhu, 2003). In recent years, this characteristic of fish has been widely researched. previous studies reported that long-term, regular fish consumption, in other words ω-3 PUFA intake, reduces the risk of contracting many diseases, such as cancer, lung diseases, Alzheimer and, in particular, cardiovascular diseases (Simopoulos, 1991; Stone 1996; Cunquer, 2000; Lemaitre et al., 2003). Current health trends indicate that heart diseases are a significant cause of death. Therefore, fish fat – EPA (eicosapentaenoic acids) and DHA (docosahexaenoic acids) intake is recommended by the American Heart Association (AHA) in protecting cardiovascular health (Alasalvar et al., 2002).

EPA and DHA present in fish oils and can not be synthesized by human organisms, they must be intake with foods (Alasalvar et al., 2002). Long chain ω-3 and ω-6 PUFAs are accepted as basic fatty acids and it is known that they are effective in preventing and treating some diseases (Conner, 1997; Kinsella, 1990).

The fatty acid composition of fish may vary depending on diet, temperature, season, type and geographical differences, salinity and spawning periods (Bandarra et al., 1997; Henderson et al., 1987; Leger et al., 1977; Luzia et al., 2003; Shirai et al., 2001). Fatty acid composition differs between herbivorous, carnivorous and omnivorous fish species (Henderson and Tocher, 1987; Brown et al., 1989).

The amount of long-chain unsaturated ω3 fatty acids is higher in the diets of fish species living in cold waters in comparison to fish living in warmer waters. Decrease in water temperature is related to increased unsaturated fatty acids and gives rise to variations in membrane phospholipids (Henderson and Tocher, 1987; Lovell, 1991). The most significant variations in the fatty acid compositions of fish occur during the period of spawning. In that period, particularly stored fats, proteins, minerals and vitamins are mobilized from other parts of the body towards the gonads, thereby favorable concluding reproduction activities (Agren et al., 1987; Cejas et al., 2003). However, the nutritional quality of fish muscles decreases during the period of reproduction (Uysal and Aksoylar, 2005).

The purpose of this study was to determine both the total fatty acid composition,and ω-3/ω-6 ratio variation of pike (*Esox lucius*) living in Eber Lake, one of the most important freshwater lakes existing in Turkey, throughout the year.

MATERIALS AND METHODS

Materials

The *E. lucius* (pike) samples used in this study were meshed from Eber Lake using trammel nets in 2005. Eber Lake is located at 38° 40´N- 31°12´E, at an altitude of 967 m, and has a surface area of between 5200 and 17600 hectares. Eber Lake is surrounded by quite large and thick reedbeds and is rich in vegetative and animal aquatic species. Therefore, it provides an appropriate reproduction, nutrition, sheltering, and accommodation environment for waterfowls. The Lake is also of great importance for migratory and local birds; it renders economic contributions such as agricultural irrigation and fishing for the local community, and reed production (Müezzinoğlu et al., 1992).

Pike (*E. lucius*) is a species of freshwater fish that is widely distributed throughout Europe, Asia and North America (Lorenzoni et al., 2002). It is an economically important fish species and can be found in most freshwaters of Turkey, and is one of the most commonly consumed fish in Turkey.

Its reproduction time is February- March (Geldiay and Balik, 2002). In recent years, the number of pike living in Eber Lake declined due to water pollution, major water scarcity during drought period and the prevalence of *Carassius auratus* species.

Methods

A review of the literature found no previous study conducted on fatty acid composition of Pike living in Eber Lake. The samples analyzed were obtained in November, February, April, June and August. The researchers ensured that the fish (n = 10 at each determination) used in the study were of the same size and age. The netted fish were brought into the laboratory in a cold environment and were frozen at a temperature of -25°C after filleting. Before analyzing, the samples were dissolved at room temperature and homogenized in a mixture (2/1 v/v) of chloroform/methanol.

Fatty acid analysis

Samples of fillets were extracted by the method used by Folch et al. (1957) transesterified with BF_3-methanol (AOAC, 1992). Fatty acid methyl esters (FAMEs) were analyzed using a Agilent 6890N model gas chromatograph (GC), equipped with a flame ionization detector (FID) and fitted with a DB-23 capillary column (60 m, 0.25 mm i.d. and 0.25 mm). Injector and detector temperatures were 250 and 260°C, respectively. Column temperature program was 180°C for 30 min, then increasing at 20°C/min up to 230°C, where it was maintained for 5 min. Carrier gas was helium (2 ml/min) and split ratio was 40:1. Fatty acids were determined by comparing sample peaks according to retention times of the peaks obtained from Supelco (37 mix) standards. GC analyses of each sample were carried out twice.

Statistical analysis

The results are given as means ±SD. The data were analyzed using analysis of variance (ANOVA) at $p<0.05$ significance level, using SPSS 15.0.

RESULTS

Total fatty acid composition of the muscular tissue of pike (*Esox lucius*) is shown in Table 1. In total, 29 different fatty acids were identified in the muscular tissue of pike. The most predominant acids found in all months were C22:6 ω3 (DHA), C16:0, C18:1, C20:5 ω3 (EPA), C20:4 ω6 (AA), C16:1, C18:0, and C18:2 ω6. When analyzing the results, it can be seen that the highest total SFA ratio was for palmitic acid. The highest MUFA ratio was found for oleic acid, with values of 9.053, 11.301, 10.092, 8.623 and 9.856% in November, February, April, June and August, respectively.

PUFAs constitute a great amount of lipids in muscular tissue of pike. By months, while total PUFA ratio varies between 36.62 – 49.65%, DHA (C22:6 ω3), LA (Linoleic acid) (C18:2 ω6), AA (Arachidonic acid) (C20:4 ω6) and EPA (C20:5 ω3) were found in high ratios. Our study reveals that the highest ratio of total fatty acids in the muscular lipids of pike pertains to DHA (24.294%). DHA ratio in pike varied as 22.760% (November), 16.039% (February), 24.294% (June) and 23.050% (August) by months. It decreased at the lowest level in February, the time of reproduction, however it increased in spring.

In the study carried out, EPA and DHA ratios were determined as 5.053 - 8.736% and 16.039 - 24.294% throughout the year, respectively. When the foregoing values are analyzed, it is understood that Pike ω3 is an important source of EPA and DHA.

The ω3/ω6 ratio in PUFA is a significant criterion for fish fats, as a high ration is suggested to have positive benefits for human health. In the present study, ω3/ω6 ratio varied as follows: 3.650 (November), 0.965 (February), 2.730 (April), 2.761 (June) and 3.483 (August).

DISCUSSION

In the present study, major SFA is palmitic acid and other predominant SFA is stearic acid. Palmitic acid has a significant role in the metabolism of fish and is affected by the foods taken (Ackman et al., 1975). Similar results were reported for Pike (Kucska et al., 2006; Jankowska et al., 2008; Kandemir, 2010) and other freshwater fish (Guler et al., 2007; Bulut, 2010; Bulut et al., 2010; Jankowska et al., 2010; Karaçalı et al., 2010).

Previous studies also reported oleic acid as the highest MUFA content in Pike (Kucska et al., 2006; Jankowska et al., 2008; Kandemir, 2010) and other freshwater fish (Guler et al., 2006; Bulut et al., 2011). High levels of oleic, palmitoleic and arachidonic acids are found in freshwater fish (Andrade et al., 1995; Osman et al., 2001).

Table 1. Variations in fatty acids of pike (*Esox lucius*) in Eber Lake (%)*.

Fatty acids	November	February	April	June	August
C12:0***	0.06 ± 0.01 a**	0.04 ± 0.03 a	0.12 ± 0.11 a	0.03 ± 0.01 a	0.06 ± 0.01 a
C13:0	0.04 ± 0.01 a	0.02 ± 0.02 a	0.34 ± 0.48 b	0.02 ± 0.01 a	0.03 ± 0.01 a
C14:0	0.84 ± 0.22 a	0.68 ± 0.22 a	1.19 ± 0.43 b	0.76 ± 0.20 a	0.81 ± 0.17 a
C15:0	1.88 ± 0.17 a	2.16 ± 1.87 b	1.20 ± 0.53 c	1.99 ± 0.27 a	1.76 ± 0.62 a
C16:0	16.61 ± 1.52 a	17.97 ± 1.80 ab	17.43 ± 1.55 ab	14.78 ± 0.69 c	18.13 ± 1.21 b
C17:0	0.59 ± 0.09 a	0.75 ± 0.20 a	0.59 ± 0.11 a	0.58 ± 0.07 a	0.61 ± 0.09 a
C18:0	4.62 ± 0.34 a	5.27 ± 0.78 b	5.09 ± 1.01 b	3.74 ± 1.18 a	4.42 ± 0.57 a
C20:0	0.27 ± 0.05 a	0.11 ± 0.03 b	0.38 ± 0.16 a	0.55 ± 0.16 c	0.32 ± 0.05 a
C21:0	0.70 ± 0.20 a	0.22 ± 0.28 b	0.83 ± 0.63 a	0.73 ± 0.158 a	0.70 ± 0.15 a
C22:0	0.73 ± 0.19 a	0.27 ± 0.40 b	0.08 ± 0.02 b	1.97 ± 4.08 c	1.99 ± 0.40 c
C23:0	0.34 ± 0.17 a	2.67 ± 1.11 b	0.54 ± 0.14 a	0.47 ± 0.09 a	0.73 ± 0.73 a
C24:0	1.18 ± 0.37 a	3.43 ± 0.90 c	1.12 ± 0.21 a	1.64 ± 0.43 a	2.89 ± 5.67 b
∑SFA	**27.87**	**33.58**	**29.06**	**27.28**	**32.46**
C14:1 ω5	0.31 ± 0.05 a	0.56 ± 0.14 b	0.46 ± 0.09 a	0.33 ± 0.04 a	0.36 ± 0.07 a
C15:1 ω6	0.29 ± 0.03 a	0.62 ± 0.13 b	1.95 ± 5.86 c	0.28 ± 0.06 a	0.31 ± 0.06 a
C16:1 ω7	7.99 ± 0.47 a	7.63 ± 1.88 a	6.42 ± 1.85 a	5.38 ± 1.29 b	5.38 ± 1.22 b
C17:1 ω 8	1.11 ± 0.27 a	0.81 ± 0.26 a	0.79 ± 0.34 a	0.90 ± 0.20 a	0.72 ± 0.37 a
C18:1 ω 9	9.05 ± 0.87 a	11.30 ± 1.74 a	10.09 ± 1.42 a	8.62 ± 0.69 a	9.86 ± 1.32 a
C18:1 ω 7	0.19 ± 0.03 a	0.32 ± 0.06 a	0.12 ± 0.12 a	0.17 ± 0.08 a	0.60 ± 1.31 b
C20:1 ω9	0.76 ± 0.16 a	0.83 ± 0.33 a	0.15 ± 0.04 b	0.19 ± 0.06 b	0.21 ± 0.05 b
C24:1 ω9	5.22 ± 0.45 a	3.57 ± 0.59 b	3.98 ± 0.94 b	4.03 ± 0.31 b	3.17 ± 0.38 b
∑MUFA	**24.93**	**25.65**	**22.05**	**19.90**	**20.60**
C18:3 ω3	2.82 ± 0.71 a	0.97 ± 0.67 b	2.69 ± 0.76 a	3.15 ± 0.37 a	3.59 ± 0.56 c
C20:3 ω3	0.38 ± 0.05 a	0.93 ± 0.08 b	0.55 ± 0.06 a	0.68 ± 0.09 a	0.54 ± 0.09 a
C20:5 ω3	8.74 ± 0.97 a	5.05 ± 1.18 c	7.82 ± 0.43 a	8.33 ± 1.38 a	7.06 ± 0.66 b
C22:6 ω3	22.76 ± 1.23 a	16.04 ± 1.51 b	21.44 ± 1.62 a	24.29 ± 1.34 a	23.05 ± 1.32 a
∑ω3	34.70	17.99	32.49	36.45	34.24
C18:2 ω6	3.01 ± 0.53 a	2.52 ± 0.63 a	3.71 ± 0.79 b	4.15 ± 0.73 b	3.85 ± 0.57 b
C18:3 ω6	0.17 ± 0.05 a	0.41 ± 0.56 a	1.03 ± 1.59 b	0.13 ± 0.06 a	0.11 ± 0.02 a
C20:2 ω6	0.33 ± 0.08 a	0.96 ± 0.29 b	0.48 ± 0.28 a	0.44 ± 0.08 a	1.04 ± 1.68 b
C20:4 ω6	5.43 ± 0.75 a	9.78 ± 1.79 c	6.93 ± 0.99 b	7.84 ± 1.37 b	4.34 ± 2.65 a
C22:4 ω6	0.74 ± 0.19 a	0.37 ± 0.10 b	0.78 ± 0.16 a	0.77 ± 0.12 a	0.59 ± 0.34 a
∑ω6	9.50	18.63	11.90	13.20	9.83
∑PUFA	**44.20**	**36.63**	**44.39**	**49.66**	**44.06**
ω-3/ω-6	3.65	0.97	2.73	2.76	3.48
SFA/MUFA	1.12	1.31	1.32	1.37	1.58
SFA/PUFA	0.63	0.92	0.65	0.55	0.74
MUFA/PUFA	0.56	0.70	0.50	0.40	0.47

* Average of two lots analysed. ** Values reported are means ± S.D. *** abc Values for each sample with different superscript letters in the same fraction are significantly different at $P < 0.05$.

In the study conducted by Jankowska et al. (2008), DHA was found as wild Pike (27.96%) and cultured Pike (18.93%). In the study conducted by Kucska et al. (2006), DHA ratios in Pikes fed with 2 different diets were determined as 24.21 and 25.04% Kandemir (2010) found DHA ratio in the different tissues of Pike as 21.25-24.69%. PUFAs of fish (especially DHA) have an important place in the structure and functions of cell. They also play particular roles in nerve cell membranes (Sargent, 1996). Thus, high DHA ratio is a preferred feature for human nutrition and health maintenance.

PUFA ratio in the muscular tissue of Pike is high in the periods when nutrition is favorable but decreases at the lowest level in reproduction periods. Also low water amount and high water temperature in the lake lead to decrease in PUFA ratio. These results support that Pike prefers to accumulate PUFA rather than SFA and MUFA in the period of nutrition; however, PUFA ratio decreases

in reproduction period and right after that (Agren et al., 1987; Cejas et al., 2003).

While PUFA ratio obtained in this study was found higher than the results of Kucska et al. (2006), it was determined lower than the results of Jankowska et al. (2008), the wild Pike, similar to cultured Pike. When freshwater fish are compared to marine fish, it is known that C 16 and C 18 are higher; however, C 20 and C 22 are relatively lower (Ackman, 1967). In addition, EPA and DHA are found in high amounts in freshwater fish (Wang et al., 1990). It can be considered that high DHA ratio fatty acids taken through nutrition may be because of the ability of pike's intermediary metabolism which they can easily convert other fatty acids to the DHA.

In a study conducted by Jankowska et al. (2003), high DHA concentrations were detected in zander (*Sander lucioperca)*. A high ratio of DHA, a fish-based fatty acid, in zander meat content indicates a transformation of PUFAs (18:3) into more unsaturated and long-chain PUFAs (like DHA) independent from nutritional DHA content.

Fish lipid composition is parallel to the lipid content of fish food sources (McKenzie et al., 2000). Carnivorous fish such as pike are rich in long-chain PUFAs. As it is well known, these organisms have long chained PUFA due to their nutrition habits. In the present study, PUFA levels of Pike in Eber Lake were determined as 36.625-49.658% and α-linolenic acid levels as 0.969-3.589%. These results are similar to those reported by Kucska et al. (2006). It was found with higher ratios than in the study conducted by Guler et al. (2007)

Conclusion

During the reproductive period, significant decreases were observed in PUFAs, especially in ω3 fatty acids. When EPA, DHA and ω3 PUFAs are analyzed, it is seen that it would be more beneficial for humans to consume pike during periods outside of the reproduction period. When considering fatty acid composition and ω3 fatty acid ratios of pike living in Eber Lake, it is concluded that they are important sanative food sources for human health.

ACKNOWLEDGEMENT

This study was financed by Afyon Kocatepe University Scientific Research Foundation (BAP) under Project 042.FENED.01.

REFERENCES

Ackman RG (1967). Characteristics of the fatty acid composition and biochemistry of some fresh-water fish oils and lipids in comparison with marine oils and lipids. Comp. Biochem. Phys., 22: 907-922.

Ackman RG, Eaton CA, Linne BA (1975). Differentiation of freshwater characteristics of fatty acids in marine specimens of the Atlantic sturgeon (*Acipenser oxyrhynchus*). Fish. Bull., 73: 838-845.

Agren J, Muje P, Hanninen O, Herranen J, Penttila I (1987). Seasonal variations of lipid fatty acids of Boreal freshwater fish species. Comp. Biochem. Phys., 88: 905-909.

Alasalvar C, Taylor KDA, Zubcov E, Shahidi F, Alexis M (2002). Differentiation of cultured sea bass (*Dicentrarchus labrax*): Total lipid content, fatty acid and trace mineral composition. Food Chem., 79(2): 145-150.

Andrade AD, Rubira AF, Matsushia M, Souza NE (1995). Omega3 fatty acids in freshwater fish from South Brazil. J. Am. Oil Chem. Soc., 72(10): 1207-1210.

AOAC (1992). Fatty acids in encapsulated fish oils and fish oil methyl esters. J. Assoc. Off. Anal. Chem. Int., 72: 140-142.

Bandarra NM, Batista I, Nunes ML, Empis JM, Christie WW (1997). Seasonal changes in lipid composition of Sardine (*Sardina pilchardus*). J. Food Sci., 62(1): 40–42.

Brown AJ, Roberts DCK, Truswell AS (1989). Fatty acid composition of Australian marine finfish: A review. Food Aust., 41(3): 655-666.

Bulut S (2010). The variation of the fatty acid composition in muscle tissue of *Carassius gibelio* living in Seyitler Dam Lake (Afyonkarahisar). J. Food Tech., 5(2): 69-75.

Bulut S, Uysal K, Cemek M, Gok V, Kuş SF, Karaçalı M (2011). Nutritional evaluation of seasonal changes in muscle fatty acid composition of Common carp (*Cyprinus carpio*) in Karamık Lake, Turkey. Int. J. Food Prop. DOI: 10.1080/10942911003664891 2010.

Bulut S, Konuk M, Uysal K, Mert R, Cemek M (2010). Seasonal Variation In The Fatty Acid Composition And Ω6/Ω3 Ratio Of The Pikes (*Esox Lucius*) Muscle Living In Karamik Lake, Turkey. Fresen. Environ. Bull., 19(10): 2227-2231.

Conner WE (1997). The beneficial effects of omega-3 fatty acids:cardiovascular disease and neurodevelopment. Curr. Opin. Lipidol., 8: 1-3.

Cunquer JA (2000). Fatty acid analysis of blood plazma of patient with Alzheimer's disease, other type of dementia, and cognitive impairment. Lipids, 35: 1305-1311.

Cejas JR, Almansa E, Villamandos JE, Badia P, Bolanos A, Lorenzo A (2003). Lipid and fatty acid composition of ovaries from wild fish and ovaries and eggs from captive fish of white sea bream (*Diplodus sargus*). Aquaculture, 216(1-4): 299-313.

Folch J, Lees M, Sloane Stanley GH (1957). A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226: 497-509.

Geldiay R, Balık S (2002). Turkish Freshwater Fish, Ege University, Faculty of Fisheries Publications, p. 532, İzmir, Turkey.

Guler GO, Aktumsek A, Citil OB, Arslan A, Torlak E (2007). Seasonal variations on total fatty acid composition of fillets of zander (*Sander lucioperca*) in Beysehir Lake (Turkey). Food Chem., 103: 1241-1246.

Henderson RJ, Tocher DR (1987). The lipid composition and biochemistry of freshwater fish. Prog. Lipid Res., 26(4): 281-347.

Jankowska B, Zakes Z, Zmijewski T, Szczepkowski M (2003). Fatty acid profile and meat utility of wild and cultured zander, Sander lucioperca (L.). Elect. J. Pol. Agr. Univ. Fish. 6, 1 (Online).

Jankowska B, Zakes Z, Zmijewski T, Szczepkowski M (2008). Fatty acid composition of wild and cultured northern pike (*Esox lucius*). App. Icht., 24: 196-201.

Jankowska B, Zakes Z, Zmijewski T, Szczepkowski M (2010). Fatty acid profile of muscle, liver and mesenteric fat in wild and reared perch (*Perca fluviatilis* L.). Food Chem., 118: 764-768.

Kandemir S (2010). The fatty acid composition and cholesterol and vitamin contents of different muscles of *Esox lucius* (Linnaeus, 1758) living in Lake Ladik. J. Anim. Vet. Adv., 9 (7): 1179-1190.

Karaçalı M, Bulut S, Konuk M, Solak K (2010). Seasonal variations in fatty acid composition of different tissues of mirror carp (*Cyprinus carpio*) in Örenler Dam Lake, Afyonkarahisar-Turkey. Int. J. Food Prop. DOI: 10.1080/10942910903556454.

Kinsella JE, Lokesh B, Stone RA (1990). Dietary n_3 polyunsaturated fatty acids and amelioration of cardiovascular disease: possible mechanisms. Am. J. Clin. Nutr., 52(1): 1-28.

Kucska B, Pal L, Müller T, Bodis M, Bartos A, Wagner L, Husveth F, Bercsenyi M (2006). Changing of fat content and fatty acid profile of reared pike (*Esox lucius*) fed two different diets. Aquac. Res.,

37: 96-101.
Leger C, Bergot P, Lukuet P, Flanzy J, Meurot J (1977). Specific distribution of fatty acids in the triglycerides of rainbow trout adipose tissue: Influence of temperature. Lipids, 12(7): 538-543.
Lemaitre RN, King IB, Mozaffarian D, Kuller LH, Tracy RP, Siscovick DS (2003). n3 polyunsaturated fatty acids, fatal ischemic heart disease, and nonfatal myocardial infarction in older adults: The Cardiovascular Health Study. Am. J. Clin. Nutr., 77(2): 319-325.
Lorenzoni M, Corboli M, Dörr AJM, Mearelli M, Giovinazzo G (2002). The growth of pike (*Esox lucius* L., 1758) in Lake trasimeno (Umbria, Italy). Fish. Res., 59: 239-246.
Lovell RT (1991). Nutrition of aquaculture species. J. Anim. Sci., 69(10): 4193-4200.
Luzia LA, Sampaio GR, Castellucci CMN, Torres EAFS (2003). The influence of season on the lipid profiles of five commercially important species of Brazilian fish. Food Chem., 83(1): 93-97.
McKenzie DJ, Piraccini G, Piccolella M, Steffensen JF, Bolis CL, Taylor EW (2000). Effects of dietary fatty acid composition on metabolic rate and responses to hypoxia in the European eel (*Anguilla anguilla*). Fish Physiol. Biochem., 22(4): 281-296.
Müezzinoğlu A, Küçükgül EY, Sponza D, Karagündüz A, Azbar N (1992). Environmental Issues on Eber Lake and Bolvadin District. Eber Lake and the Environment Symposium, pp. 1-8, Bolvadin, Turkey.
Osman H, Suriah AR, Law EC (2001). Fatty acid composition and cholesterol content of selected marine fish in Malaysian waters. Food Chem., 73(1): 55-60.
Sargent JR (1996). Origins and functions of egg lipid. In NR Bromage, RJ Roberts (Eds.), Broodstock management and egg and larval quality (pp. 353–372). Oxford: Blackwell.
Shirai N, Suzuki H, Tokairin S, Wada S (2001). Spawning and season affect lipid content and fatty acid composition of ovary and liver in Japanese catfish (*Silurus asotus*). Comp. Biochem. Phys., B 129(1): 185-195.
Sidhu KS (2003). Health benefits and potential risks related to consumption of fish or fish oil. Regul. Toxicol. Pharm., 38(3): 336-344.
Simopoulos AP (1991). Omega-3 fatty acids in health and disease and in growth and development, a review. Am. J. Clin. Nutr., 54: 438-463.
Stone J (1996). Fish consumption, fish oil, lipids and coronary hearty disease. Am. Heart Assoc., 94: 2337-2340.
Uysal K, Aksoylar MY (2005). Seasonal variations in fatty acid composition and the n6/n3 fatty acid ratio of pikeperch (*Sander lucioperca*) muscle lipids. Ecol. Food Nutr., 44: 23-35.
Wang YJ, Miller LA, Perren M, Addis PB (1990). Omega-3 fatty acids in lake superior fish. J. Food Sci., 55(1): 71-73.