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Fatty acid profiles and fat contents of commercially important seawater and freshwater fish species of Turkey: A comparative study

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Abstract

The fat content and fatty acid compositions of edible muscle of commercially important seawater and freshwater fish species were investigated. The fatty acid compositions of seawater fish species were found to be 25.5–39.4% saturated (SFA), 13.2–29.0% monounsaturated (MUFAs) and 25.2–48.2% polyunsaturated acids (PUFAs), whereas the fatty acid compositions of freshwater fish from Lake Seyhan consisted of 28.0–34.6% saturated (SFA), 10.7–22.7% monounsaturated (MUFAs) and 23.2–43.7% polyunsaturated acids (PUFAs). The proportions of *n*3 PUFAs of seawater fish (ranging from 22.6 for waker to 44.2% for blue fish) were higher than those of *n*3 PUFAs of freshwater fish (ranging from 11.5% for North African catfish to 28.4% for zander). However, the levels of *n*6 PUFAs of seawater fish (ranging from 0.43% for blue fish to 14.4% for sea bass) were lower than those of *n*6 PUFAs of freshwater fish (ranging from 5.27% for kutum to 16.8% for tench). The results showed that fatty acid profiles of most freshwater fish are basically comparable to those of seawater fish as sources of PUFAs.

Keywords: Fatty acids; GC; Seawater fish; Freshwater fish; EPA; DHA

1. Introduction

Lipids of marine fish species are generally characterized by low levels of linoleic acid (18:2*n*6) and linolenic acid (18:3*n*3) and high levels of long-chain *n*3 polyunsaturated fatty acids (Steffens, 1997). Among the polyunsaturated fatty acids, eicosapentaenoic acid (EPA, C20:5*n*3) and docosahexaenoic acid (DHA, C22:6*n*3) are the dominant *n*3 fatty acids in marine fish (Ackman, 1989). These fatty acids are of great importance to humans for prevention of coronary artery disease (Conner, 2000; Kinsella, 1987; Simopoulos, 1991; Mozaffarian, Bryson, Lemaitre, Burke, & Siscovick, 2005). Since DHA is a major component of brain, eye retina and heart muscle, DHA has been considered as important for brain and eye development and also good cardiovascular health (Ward & Singh, in press). EPA has also been reported to be useful in brain disorders and cancer treatment (Fenton, Hibbeln, & Knable, 2000). Fish lipids are a good source of EPA and DHA. However, pregnant and nursing mothers have been recommended that EPA content should be low because it causes bleeding (Ward & Singh, in press). The western diet contains high levels of omega-6 and low levels of C18ω-3 PUFAs which is considered to be an unbalanced diet. Populations which consume 0.5–0.7 g/day DHA have a lower incidence of heart disease. General recommendation for daily intakes of DHA/EPA is 0.5 g for infants and 1 g/day for adults and patients with heart disease (Kris-Etherton, Harris, & Appel, 2002).

Compared to marine fish, freshwater fish contain high levels of C18 PUFA and low levels of the *n*3 EPA and DHA (Ackman, 1967). Freshwater fish are generally characterized by high levels of *n*6 PUFA, especially linoleic acid (18:2*n*6) and arachidonic acid (20:4*n*6). Since freshwater

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fish contain lower proportions of long-chain *n*3 PUFA than marine fish (Rahman, Huah, Hassan, & Daud, 1995), the ratio of total *n*3 to *n*6 fatty acids is much higher for marine fish than freshwater fish, varying from 5 to 10 or more.

The fatty acid composition of marine fish oils results from the fatty acid composition of their natural foods (Grigorakis, Alexis, Taylor, & Hole, 2002; Henderson & Tocher, 1987; Van Vliet & Katan, 1990). Indeed, the fatty acid composition of different individual fish of the same species can vary because of diet, location, gender and environmental conditions (Gruger, 1967). It has been found that water temperature affects the fatty acid composition of fish lipids. As the temperature decreases, the proportion of unsaturated fatty acids in phospholipids and neutral lipids increases (Farkas, Csengeri, Majoros, & Oláh, 1980).

Considerable amounts of research have been carried out on rearing conditions for their effects of diet on fatty acid profiles of fish flesh. The results showed that the fatty acid composition of fish reflects that of the diet (Castline & Buckley, 1980; Cowey, 1993; Steffens, 1997; Watanabe & Takeuchi, 1976; Watanabe, 1982). Waagbo, Sandnes, Torrisen, Sandvin, and Lie (1993) fed salmon with three dietary levels of ω-3 PUFA's, resulting in an increase levels of ω-3 fatty acids in their tissue content. Therefore, freshwater fish can be as good as seawater fish species in terms of a source of essential fatty acids.

The objective of this study was to investigate the differences between seawater and freshwater fish species in fat composition and fatty acid profile.

2. Materials and methods

2.1. Sample preparation

Nine seawater fish species of commercial importance were chosen and purchased from the local fish market. These are *Epinephelus aeneus* (waker), *Trigla lucerna* (tub gurned), *Merlangius merlangus* (whiting), *Scomber scombrus* (mackerel), *Pomatomus saltator* (blue fish), *Sparus auratus* (sea bream), *Dicentrarchus labrax* (sea bass), *Siganus rivulatus* (marbled spinefoot), *Sarda sarda* (Atlantic bonito). On the other hand, freshwater fish species were caught in Seyhan Dam Lake in Adana, which is located in the southern part of Turkey. These are *Clarias gariepinus* (North African catfish), *Cyprinus carpio* (common carp), *Siluris glanis* (wels catfish), *Tinca tinca* (tench), *Rutilus frisii* (kutum), *Sander lucioperca* (zander). Fish were 1 or 2 days post-capture on arrival at the laboratory in ice. A minimum of 5 individuals from each species were gutted, filleted and muscle tissue (edible muscle) was minced for analyses.

2.2. FAME analyses

Lipid extraction followed the Bligh and Dyer method (1959). Methyl esters were prepared by transmethylation using 2M KOH in methanol and *n*-heptane according to the method as described by Ichihara, Shibahara, Yamamoto, and Nakayama (1996) with minor modification. Extracted lipids (10 mg) were dissolved in 2 ml heptane followed by 4 ml of 2 M methanolic KOH. The tube was then vortexed for 2 min at room temperature. After centrifugation at 4000 rpm for 10 min, the heptane layer was taken for GC analyses.

2.3. Gas chromatographic condition

The fatty acid composition was analysed by GC Clarus 500 with autosampler (Perkin Elmer, USA) equipped with a flame ionization detector and a fused silica capillary SGE column (30 m × 0.32 mm, ID × 0.25 μm, BP20 0.25 UM, USA). The oven temperature was 140 °C, held 5 min, raised to 200 °C at a rate of 4 °C/min and to 220 °C at a rate of 1 °C/min, while the injector and the detector temperature were set at 220 °C and 280 °C, respectively. The sample size was 1 μl and the carrier gas was controlled at 16 psi. The split used was 1:100. Fatty acids were identified by comparing the retention times of FAME with a standard 37 component FAME mixture (Supelco). Two replicate GC analyses were performed and the results were expressed in GC area % as a mean value and ± standard deviation.

3. Results and discussion

Table 1 shows the fat content of a range of seawater and freshwater species. While the lipid content of seawater species ranged from 1.01 ± 0.12% for blue fish to 12.4 ± 0.45% for sea bream, the lipid contents of freshwater species were between 0.39 ± 0.06% for zander to 3.21 ± 0.22% for North African catfish. The lipid content of fish changes due to species, diet,gender, geographical origin and season (Rasoarahona, Barnathan, Bianchini, & Gaydou, 2005).

Tables 2 and 3 give % as a mean value of 30 FA for seawater and freshwater species, respectively. The fatty acid

Table 1
The fat contents of fish species

	Lipid content (%)
Seawater fish species	
Epinephelus aeneus (waker)	2.14 ± 0.02
Trigla lucerna (tub gurned)	1.59 ± 0.37
Merlangius merlangus (whitting)	1.20 ± 0.04
Scomber scombrus (mackerel)	1.16 ± 0.13
Pomatomus saltator (blue fish)	1.01 ± 0.12
Sparus auratus (sea bream)	12.4 ± 0.45
Dicentrarchus labrax (sea bass)	3.02 ± 0.03
Siganus rivulatus (marbled spinefoot)	1.21 ± 0.10
Freshwater fish species	
Clarias gariepinus (North African catfish)	3.21 ± 0.22
Cyprinus carpio (common carp)	0.88 ± 0.11
Siluris glanis (wels catfish)	0.54 ± 0.06
Tinca tinca (tench)	0.61 ± 0.03
Rutilus frisii (kutum)	1.52 ± 0.22
Sander lucioperca (zander)	0.39 ± 0.06

n:5.

Table 2
Fatty acids profiles of seawater fish species

Fatty acids (%)	*Epinephelus aeneus* Waker	*Trigla lucerna* Tub gurned	*Merlangius merlangus* Whiting	*Scomber scombrus* Mackerel
C12:0	0.06 ± 0.06	0.15 ± 0.01	0.06 ± 0.01	0.06 ± 0.02
C13:0	0.04 ± 0.01	0.02 ± 0.0	0.04 ± 0.0	0.05 ± 0.01
C14:0	3.59 ± 0.13	2.71 ± 0.03	2.89 ± 0.16	2.19 ± 0.1
C15:0	0.53 ± 0.01	0.47 ± 0.01	0.72 ± 0.02	0.57 ± 0.01
C16:0	25.5 ± 0.73	20.2 ± 0.02	19.4 ± 0.46	14.5 ± 0.1
C17:0	0.70 ± 0.01	0.76 ± 0.01	0.78 ± 0.01	0.78 ± 0.01
C18:0	6.47 ± 0.1	5.55 ± 0.0	5.10 ± 0.02	7.17 ± 0.15
C20:0	0.67 ± 0.02	0.22 ± 0.0	0.23 ± 0.01	0.27 ± 0.02
C22:0	0.24 ± 0.02	0.11 ± 0.05	0.10 ± 0.01	0.14 ± 0.01
C23:0	0.18 ± 0.04	1.33 ± 0.05	2.57 ± 0.14	2.57 ± 0.01
C24:0	0.18 ± 0.02	0.08 ± 0.01	0.14 ± 0.0	0.13 ± 0.02
∑SFA	38.0	30.3	29.6	25.9
C14:1	0.10 ± 0.0	0.21 ± 0.0	0.04 ± 0.01	0.05 ± 0.01
C15:1	0.08 ± 0.0	0.11 ± 0.01	0.07 ± 0.0	0.04 ± 0.02
C16:1	9.44 ± 0.18	7.63 ± 0.01	4.09 ± 0.09	2.85 ± 0.14
C17:1	0.17 ± 0.16	0.56 ± 0.01	0.50 ± 0.0	0.31 ± 0.01
C18:1*n*9	14.1 ± 0.99	20.2 ± 0.36	14.2 ± 0.22	10.5 ± 0.30
C20:1	0.18 ± 0.04	0.20 ± 0.03	0.17 ± 0.01	0.46 ± 0.09
C22:1*n*9	0.06 ± 0.01	0.08 ± 0.03	0.05 ± 0.0	0.10 ± 0.08
C24:1	0.07 ± 0.04	0.10 ± 0.0	0.09 ± 0.01	0.0 ± 0.0
∑MUFA	24.2	29.0	19.2	14.3
C18:2*n*6	1.34 ± 0.02	0.74 ± 0.01	1.75 ± 0.71	3.46 ± 0.13
C18:3*n*6	0.30 ± 0.01	0.10 ± 0.0	0.24 ± 0.01	0.39 ± 0.0
C18:3*n*3	0.67 ± 0.06	0.32 ± 0.01	0.74 ± 0.04	0.72 ± 0.03
C18:4*n*3	0.08 ± 0.01	0.04 ± 0.0	0.06 ± 0.01	0.09 ± 0.01
C20:2*cis*	0.36 ± 0.03	0.30 ± 0.01	0.29 ± 0.02	0.32 ± 0.03
C20:3*n*6	0.22 ± 0.01	0.10 ± 0.0	0.07 ± 0.0	0.12 ± 0.0
C20:3*n*3	3.29 ± 0.06	3.02 ± 0.02	1.77 ± 0.02	2.88 ± 0.08
C20:4*n*6	0.32 ± 0.17	0.15 ± 0.0	0.10 ± 0.01	0.13 ± 0.01
C20:5*n*3	4.23 ± 0.04	5.46 ± 0.03	6.33 ± 0.06	4.74 ± 0.05
C22:2*cis*	0.08 ± 0.04	0.08 ± 0.05	0.07 ± 0.05	0.16 ± 0.06
C22:6*n*3	14.4 ± 0.53	17.0 ± 0.16	28.2 ± 0.53	35.2 ± 0.76
∑PUFA	25.2	27.3	39.6	48.2
PUFA/SFA	0.66	0.90	1.33	1.85
∑*n*6	2.18	1.09	2.16	4.1
∑*n*3	22.6	25.9	37.1	43.6
*n*6/*n*3	0.096	0.042	0.058	0.094
DHA/EPA	3.39	3.12	4.45	7.41
Unidentified	12.6	13.4	11.7	11.6
	Pomatomus saltator Blue fish	*Sparus auratus* Sea bream	*Dicentrarchus labrax* Sea bass	*Siganus rivulatus* Marbled spinefoot
C12:0	0.0 ± 0.0	0.04 ± 0.0	0.02 ± 0.0	0.52 ± 0.01
C13:0	0.01 ± 0.01	0.03 ± 0.0	0.01 ± 0.0	0.02 ± 0.01
C14:0	1.47 ± 0.06	4.49 ± 0.27	3.23 ± 0.04	4.30 ± 0.04
C15:0	0.54 ± 0.04	0.52 ± 0.03	0.34 ± 0.0	0.40 ± 0.01
C16:0	19 ± 0.33	16.1 ± 0.33	15.5 ± 0.04	26.7 ± 0.21
C17:0	0.78 ± 0.04	0.36 ± 0.01	0.40 ± 0.01	0.47 ± 0.01
C18:0	7.44 ± 0.12	3.11 ± 0.04	3.72 ± 0.04	5.39 ± 0.06
C20:0	0.16 ± 0.0	0.27 ± 0.01	0.19 ± 0.0	0.15 ± 0.02
C22:0	0.04 ± 0.0	0.41 ± 0.01	2.12 ± 0.02	0.05 ± 0.03
C23:0	0.11 ± 0.01	0.23 ± 0.01	0.31 ± 0.01	1.29 ± 0.01
C24:0	0.14 ± 0.01	0.0 ± 0.0	0.06 ± 0.01	0.11 ± 0.02
∑ SFA	29.7	25.5	25.9	39.4
C14:1	0.0 ± 0.0	0.10 ± 0.01	0.03 ± 0.0	0.04 ± 0.0
C15:1	0.03 ± 0.04	0.09 ± 0.01	0.06 ± 0.0	0.06 ± 0.0
C16:1	2.47 ± 0.06	7.25 ± 0.21	5.04 ± 0.04	5.61 ± 0.03
C17:1	0.33 ± 0.01	0.28 ± 0.01	0.25 ± 0.0	0.19 ± 0.0

(*continued on next page*)

Table 2 (*continued*)

Fatty acids (%)	*Pomatomus saltator* Blue fish	*Sparus auratus* Sea bream	*Dicentrarchus labrax* Sea bass	*Siganus rivulatus* Marbled spinefoot
C18:1*n*9	9.58 ± 0.49	20 ± 0.18	15.9 ± 0.08	9.86 ± 0.45
C20:1	0.73 ± 0.07	0.14 ± 0.01	3.21 ± 0.04	0.28 ± 0.01
C22:1*n*9	0.09 ± 0.01	0.13 ± 0.12	0.07 ± 0.01	0.04 ± 0.01
C24:1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.05 ± 0.07
∑MUFA	13.2	28.0	24.6	16.1
C18:2*n*6	1.43 ± 0.37	7.46 ± 0.07	14.0 ± 0.09	2.01 ± 0.01
C18:3*n*6	0.26 ± 0.01	0.17 ± 0.0	0.19 ± 0.0	0.55 ± 0.01
C18:3*n*3	0.38 ± 0.08	1.22 ± 0.03	1.61 ± 0.05	0.89 ± 0.01
C18:4*n*3	0.0 ± 0.0	0.39 ± 0.51	0.02 ± 0.0	0.04 ± 0.01
C20:2*cis*	0.26 ± 0.01	0.20 ± 0.01	0.65 ± 0.0	0.12 ± 0.03
C20:3*n*6	0.10 ± 0.0	0.12 ± 0.01	0.14 ± 0.0	0.98 ± 0.0
C20:3*n*3	3.36 ± 0.07	0.41 ± 0.05	0.89 ± 0.03	7.68 ± 0.11
C20:4*n*6	0.07 ± 0.0	0.40 ± 0.02	0.08 ± 0.0	0.18 ± 0.04
C20:5*n*3	4.35 ± 0.16	6.77 ± 0.13	7.02 ± 0.03	4.33 ± 0.05
C22:2*cis*	0.0 ± 0.0	0.0 ± 0.0	0.04 ± 0.05	0.02 ± 0.03
C22:6*n*3	36.1 ± 0.38	17.4 ± 0.71	14.7 ± 0.21	11.7 ± 0.15
∑ PUFA	46.3	34.5	39.3	28.5
PUFA/SFA	1.56	1.35	1.52	0.72
∑*n*6	0.43	8.15	14.4	3.72
∑*n*3	44.2	26.2	24.2	24.6
*n*6/*n*3	0.009	0.31	0.59	0.15
DHA/EPA	8.30	2.56	2.08	2.69
Unidentified	10.8	12.0	10.3	16.0

n: 3.

compositions of seawater fish species were found to be 25.5–39.4% saturated (SFA), 13.2–29.0% monounsaturated (MUFAs) and 25.2–48.2% polyunsaturated acids (PUFAs), whereas the fatty acid compositions of freshwater fish consisted of 28.0–34.6% saturated (SFA), 10.7–22.7% monounsaturated (MUFAs) and 23.2–43.8% polyunsaturated acids (PUFAs). Among those, those occuring in the highest proportions of seawater fish species were myristic acid (C14:0, 1.47–4.49%), palmitic acid (C16:0, 14.5–26.7%), palmitoleic acid (C16:1, 2.47–9.44%), stearic acid (C18:0, 3.11–7.44%), oleic acid (C18:1*n*9*cis*, 9.58–20.2%), linoleic acid (C18:2*n*6, 0.74–14.0%), *cis*-11, 14, 17-eicosatrienoic acid (C20:3*n*3, 0.41–7.68%), *cis*-5, 8, 11, 14, 17-eicosapentaenoic acid (EPA, C20:5*n*3, 4.23–7.02%) and *cis*-4, 7, 10, 13, 16, 19-docosahexaenoic acid (DHA, C22:6*n*3, 11.7–36.1%). These results are in agreement with previous studies on FA of other species (Chen, Chapman, Wei, Porteir, & O''Keefe, 1995; Luzia, Sampaipo, Castellucci, & Torres, 2003; Ozogul & Ozogul, 2007). However, major fatty acids of freshwater fish species were myristic acid (C14:0, 0.19–2.11%), palmitic acid (C16:0, 15.9–20.5%), palmitoleic acid (C16:1, 2.51–10.9%), heptadecanoic acid (C17:0, 0.45–1.47%), stearic acid (C18:0, 5.63–14.8%), oleic acid (C18:1*n*9*cis*, 3.46–15.9%), linoleic acid (C18:2*n*6, 1.48–6.98%), linolenic acid (C18:3*n*3, 0.62–3.36%), *cis*-8, 11, 14-eicosatrienoic acid (C20:3*n*6, 2.29–14.0%), *cis*-5, 8, 11, 14, 17-eicosapentaenoic acid (EPA, C20:5*n*3, 2.10–13.8%) and *cis*-4, 7, 10, 13, 16, 19-docosahexaenoic acid (DHA, C22:6*n*3, 6.72–24.8%). It was observed that the proportion of C14:0 and C22:6*n*3 were higher in seawater fish than freshwater fish species. However, the levels of fatty acids C17:0 and C20:3*n*6 were found to be higher in freshwater fish than seawater fish. C20:3*n*3 (*cis*-11, 14, 17-eicosatrienoic acid) was not detected in any freshwater fish.

The proportions of PUFAs-*n*3 of seawater fish (ranging from 22.6% for waker to 44.2% for blue fish) were higher than those of PUFAs-*n*3 of freshwater fish (ranging from 11.5% for North African catfish to 28.4% for zander). However, the levels of PUFAs-*n*6 of seawater fish (ranging from 0.43% for blue fish to 14.4% for sea bass) were lower than those of PUFAs-*n*6 of freshwater fish (ranging from 5.27 for kutum to 16.8% for tench). Similar results were found by Rahman et al. (1995) and Vlieg and Body (1988). Among the seawater fish species studied, the highest ratio of *n*6/*n*3 was found to be 0.59 for sea bass followed by 0.31 for sea bream while the lowest value was obtained from blue fish (0.009). As for freshwater fish, the highest ratio of *n*6/*n*3 was obtained from North African catfish (1.0) and common carp (0.91). Kutum and zander gave the lowest values (0.21 and 0.46, respectively). The ratios of *n*6/*n*3 found in this study were lower in both seawater and freshwater fish than the value (4.0 at maximum) recommended by UK Department of Health (HMSO, 1994). Values higher than the maximum value are harmful to health and may promote cardiovascular diseases (Moreira, Visentainer, de Souza, & Matsushita, 2001).

A minimum value of PUFA/SFA ratio recommended is 0.45 (HMSO, 1994), which was lower than those obtained from all freshwater and seawater fish species studied.

Table 3
Fatty acids profile of freshwater fish species

Fatty acids (%)	*Clarias gariepinus* North African catfish	*Cyprinus carpio* Common carp	*Siluris glanis* Wels catfish	*Tinca tinca* Tench
C12:0	0.82 ± 0.03	0.4 ± 0.0	0.09 ± 0.03	0.2 ± 0.18
C13:0	0.40 ± 0.01	0.19 ± 0.0	0.04 ± 0.01	0.0 ± 0.0
C14:0	2.11 ± 0.01	1.28 ± 0.02	1.12 ± 0.16	0.19 ± 0.17
C15:0	0.72 ± 0.05	0.67 ± 0.0	0.6 ± 0.04	0.40 ± 0.01
C16:0	18.2 ± 0.01	15.9 ± 0.3	18.1 ± 0.04	17.6 ± 0.25
C17:0	1.37 ± 0.04	1.47 ± 0.04	1.06 ± 0.02	0.82 ± 0.01
C18:0	5.63 ± 0.04	6.18 ± 0.27	6.84 ± 0.08	6.09 ± 0.04
C20:0	0.29 ± 0.01	0.19 ± 0.0	0.21 ± 0.03	0.11 ± 0.01
C22:0	0.11 ± 0.01	0.31 ± 0.02	0.19 ± 0.04	0.12 ± 0.01
C23:0	0.18 ± 0.04	1.33 ± 0.05	2.57 ± 0.14	2.57 ± 0.01
C24:0	0.0 ± 0.0	0.0 ± 0.0	0.06 ± 0.08	0.0 ± 0.0
∑SFA	29.8	28.0	30.9	28.1
C14:1	0.06 ± 0.01	0.08 ± 0.0	0.02 ± 0.01	0.0 ± 0.0
C15:1	0.05 ± 0.01	0.03 ± 0.01	0.01 ± 0.0	0.06 ± 0.02
C16:1	6.41 ± 0.0	3.69 ± 0.03	3.37 ± 0.27	2.51 ± 0.0
C17:1	0.13 ± 0.01	0.23 ± 0.01	0.58 ± 0.03	0.38 ± 0.2
C18:1*n*9	15.9 ± 0.11	9.54 ± 0.01	11.6 ± 0.47	7.48 ± 0.11
C20:1	0.12 ± 0.0	0.18 ± 0.01	1.48 ± 0.47	0.21 ± 0.03
C22:1*n*9	0.04 ± 0.01	0.06 ± 0.0	0.06 ± 0.04	0.10 ± 0.01
C24:1	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
∑MUFA	22.7	13.8	17.1	10.7
C18:2*n*6	6.98 ± 0.0	6.39 ± 0.14	2.50 ± 0.28	2.18 ± 0.06
C18:3*n*6	0.19 ± 0.01	0.25 ± 0.02	0.21 ± 0.06	0.10 ± 0.01
C18:3*n*3	2.23 ± 0.04	3.36 ± 0.28	1.22 ± 0.11	0.93 ± 0.02
C18:4*n*3	0.48 ± 0.04	0.4 ± 0.01	0.52 ± 0.10	0.23 ± 0.02
C20:2*cis*	0.06 ± 0.0	0.12 ± 0.01	0.12 ± 0.02	0.12 ± 0.01
C20:3*n*6	3.73 ± 0.04	9.16 ± 0.17	9.41 ± 0.9	14.0 ± 0.12
C20:4*n*6	0.67 ± 0.01	0.46 ± 0.14	0.45 ± 0.27	0.51 ± 0.14
C20:5*n*3	2.10 ± 0.01	5.86 ± 0.07	2.76 ± 0.08	8.71 ± 0.0
C22:2*cis*	0.08 ± 0.02	0.09 ± 0.08	0.10 ± 0.04	0.16 ± 0.0
C22:6*n*3	6.72 ± 0.25	8.21 ± 0.07	14.8 ± 1.05	16.8 ± 0.04
∑ PUFA	23.2	34.3	32.0	43.8
PUFA/SFA	0.78	1.23	1.04	1.56
∑*n*6	11.6	16.3	12.6	16.8
∑*n*3	11.5	17.8	19.3	26.7
*n*6/*n*3	1.0	0.91	0.65	0.63
DHA/EPA	3.2	1.40	5.34	1.93
Unidentified	24.3	24.0	20.0	17.4

Fatty acids (%)	*Rutilus frisii* Kutum	*Sander lucioperca* Zander
C12:0	0.04 ± 0.0	0.02 ± 0.01
C13:0	0.0 ± 0.0	0.0 ± 0.0
C14:0	1.95 ± 0.12	0.86 ± 0.06
C15:0	0.89 ± 0.09	0.41 ± 0.0
C16:0	16.0 ± 0.08	20.5 ± 0.22
C17:0	0.45 ± 0.01	0.71 ± 0.01
C18:0	14.8 ± 0.08	6.81 ± 0.13
C20:0	0.29 ± 0.01	0.24 ± 0.01
C22:0	0.0 ± 0.0	0.05 ± 0.01
C23:0	0.22 ± 0.02	2.07 ± 0.04
C24:0	0.0 ± 0.0	0.13 ± 0.01
∑SFA	34.59	31.8
C14:1	0.05 ± 0.0	0.03 ± 0.01
C15:1	0.14 ± 0.01	0.0 ± 0.0
C16:1	10.9 ± 0.75	3.08 ± 0.02
C17:1	0.51 ± 0.04	0.55 ± 0.01
C18:1*n*9	3.46 ± 0.04	9.67 ± 0.08

(*continued on next page*)

Table 3 (*continued*)

Fatty acids (%)	*Rutilus frisii* Kutum	*Sander lucioperca* Zander
C20:1	0.47 ± 0.13	0.39 ± 0.02
C22:1*n*9	0.26 ± 0.01	0.08 ± 0.02
C24:1	0.0 ± 0.0	0.0 ± 0.0
∑MUFA	15.8	13.8
C18:2*n*6	1.48 ± 0.16	1.62 ± 0.16
C18:3*n*6	0.30 ± 0.04	0.21 ± 0.01
C18:3*n*3	1.01 ± 0.09	0.62 ± 0.01
C18:4*n*3	0.22 ± 0.03	0.09 ± 0.03
C20:2*cis*	0.39 ± 0.04	0.13 ± 0.04
C20:3*n*6	2.29 ± 0.11	11.1 ± 0.25
C20:4*n*6	1.20 ± 0.08	0.22 ± 0.14
C20:5*n*3	13.8 ± 0.02	3.59 ± 0.06
C22:2*cis*	0.06 ± 0.08	0.08 ± 0.02
C22:6*n*3	9.97 ± 1.16	24.8 ± 0.04
∑PUFA	30.7	42.4
PUFA/SFA	0.89	1.33
∑*n*6	5.27	13.1
∑*n*3	25.0	28.4
*n*6/*n*3	0.21	0.46
DHA/EPA	0.72	6.89
Unidentified	18.9	12.1

PUFA/SFA ratio among seawater fish ranged from 0.66 for waker to 1.85 for mackerel whereas PUFA/SFA ratio among freshwater fish ranged from 0.78 for North African catfish to 1.56 for tench. Palmitic acid (C16:0) was the primary saturated fatty acid contributing 56–68% and 46–65% of the total saturated fatty acid (SFA) content of lipids for seawater and freshwater fish species, respectively. Oleic acid (C18:1$n-9$) was the primary MUFAs accounting for 58–74% of total MUFAs for seawater fish while it contributes 22–70% of total MUFAs for freshwater fish. The major fatty acids identified as polyunsaturated fatty acids of seawater fish were eicosapentaenoic acid (EPA, C20:5*n*3) and docosahexaenoic acid (DHA, C22:6*n*3), *cis*-11, 14, 17-eicosatrienoic acid (C20:3*n*3) and linoleic acid (C18:2*n*6). However, the major polyunsaturated fatty acids of freshwater fish found were linoleic acid (C18:2*n*6), linolenic acid (C18:3*n*3), EPA (C20:5*n*3), *cis*-8,11,14-eicosatrienoic acid (C20:3*n*6), DHA (C22:6*n*3).

Among the seawater fish species, the highest EPA were obtained from sea bream and tub gurned, accounting for 20% of total PUFAs. The high proportion of DHA was found with blue fish (78%), mackerel (73%), and whiting (71% of total PUFAs) whereas sea bass (37%) and marbled spinefoot (41%) gave lower DHA content among seawater fish species. For freshwater fish, kutum gave the highest EPA (40% of total PUFAs), followed by tench (20% total PUFAs). A maximum value of DHA was obtained from zander and wels catfish (58% and 46% of total PUFAs, respectively). In this study, EPA and DHA were found to be high in all fish species, increasing the value of wild these fish species compared to cultured fish species (Ackman & Takeuchi, 1986; Chen et al., 1995; Rahman et al., 1995). Compared with freshwater fish, marine fish contain higher levels of PUFAs especially DHA and EPA as found in this study. However, both seawater and freshwater fish were good sources of EPA and DHA.

It was observed that seawater species contained high level of *n*3 series, ranging from 22.6% for waker to 44.2% for blue fish (Table 2) whereas the level of *n*3 series of freshwater fish ranged from 11.5% for North African catfish to 28.4% for zander (Table 3). Rasoarahona et al. (2005) studied fatty acid profiles of wild tilapia species from Madagastar and they indicated that wild tilapias contain *n*3 series of fatty acids and contribute *n*3 fatty acids intake of population. The level of *n*6 series of seawater fish was found to be low, ranging from 0.43% for blue fish and 14.4% for sea bass. However, the content of *n*6 series of freshwater fish were found to be high. The highest value was obtained from 16.8% for tench, followed by 16.3% for common carp and 13.1% for zander. Among *n*6 series of fatty acids, freshwater fish contain higher levels of C18:2*n*6 and C20:3*n*6 than seawater species. Differences in fatty acids of marine and freshwater fishes should not only be considered with respect to species habitat but also based on their natural diet especially whether a species is herbivorous, omnivorous or carnivorous (Sargent, Bell, Bell, Henderson, & Tocher, 1995). Apart from that, size, age, reproductive status of fish, environmental conditions, especially water temperature influence lipid content and fatty acid composition of fish muscle to a certain extent (Ackman, 1989; Gruger, 1967; Saito, Yamashiro, Alasalvar, & Konno, 1999).

Although there is a differences in lipid content and fatty acid composition of seawater and freshwater fish species,

this study exhibits that fatty acid profiles of freshwater fish are comparable to those of seawater fish as sources of PUFAs.

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