Available online at www.sciencedirect.com
ScienceDirect
Food Chemistry 108 (2008) 847–852
Food Chemistry
www.elsevier.com/locate/foodchem

Seasonal effects in the nutritional quality of the body structural tissue of cephalopods

Yesim Ozogul [a], Onder Duysak [b], Fatih Ozogul [a,*], Ali Serhat Özkütük [a], Canan Türeli [b]

[a] *Department of Fishing and Fish Processing Technology, Faculty of Fisheries, Cukurova University, 01330 Balcalı, Adana, Turkey*
[b] *Department of Basic Sciences, Faculty of Fisheries, Cukurova University, Adana, Turkey*

Received 7 September 2007; received in revised form 16 October 2007; accepted 21 November 2007

Abstract

The most commonly-consumed cephalopods around the world (the common cuttlefish, *Sepia officinalis*, European squid, *Loligo vulgaris*, common octopus, *Octopus vulgaris* and musky octopus, *Eledone moschata*) were evaluated in terms of seasonal variations in proximate and fatty acid compositions. The arms of the octopuses were used for this study, whereas the mantle of the other species (squids and cuttlefish) were used for the analyses. The lipid contents of species were found to be very low and considered as lean. The lowest lipid content was obtained from *E. moschata* (0.60–0.68%), whereas *L. vulgaris* gave the highest level of lipid (1.34–1.92%) throughout all seasons. Unlike lipid content, protein contents of cephalopods did not change across the seasons. The fatty acid compositions of each species ranged from 28.18% to 35.28% saturated (SFA), 4.36–9.47% monounsaturated (MUFAs) and 43.58–56.55% polyunsaturated acids (PUFAs). The highest proportions of fatty acids in cephalopods were myristic acid (C14:0, 0.96–2.96%), palmitic acid (C16:0, 15.53–25.20%), heptadecanoic acid (C17:0, 1.05–2.56%), stearic acid (C18:0, 4.32–9.96%), oleic acid (*cis*18:1 $n-9$, 1.80–4.29%), *cis*-11-eicosenoic acid (C20:1, 2.07–4.69%), linoleic acid (C18:2 $n-6$, 0.17–1.95%), arachidonic acid (C20:4 $n-6$, 1.48–11.65%), *cis*-5,8,11,14,17-eicosapentaenoic acid (EPA, C20:5 $n-3$, 7.86–16.97%) and *cis*-4,7,10,13,16,19-docosahexaenoic acid (DHA, C22:6 $n-3$, 20.99–39.00%). The results indicated that these cephalopod species are excellent protein sources and very rich in $n-3$ fatty acids.

Keywords: Nutritional quality; Cephalopods; GC

1. Introduction

The cephalopods represent an important economic seafood for human consumption and contribute to 14% of the world fisheries, according to FAO (2004). Due to their nutritional and market value, cephalopod aquaculture has also shown an increase during the past few years (Almansa et al., 2006).

Seafood is generally the main contributor of $n-3$ PUFA in the human diet. Lipids of marine fish species are generally characterised by high levels of long-chain $n-3$ polyunsaturated fatty acids (Steffens, 1997). Among the polyunsaturated fatty acids, EPA (eicosapentaenoic acid, C20:5 $n-3$) and DHA (docosahexaenoic acid, 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 the prevention of coronary heart disease (Conner, 2000; Kinsella, 1987; Mozaffarian, Bryson, Lemaitre, Burke, & Siscovick, 2005). General recommendations for daily dietary intakes of DHA/EPA are 0.5 g for infants, and 1 g/day for adults (Kris-Etherton, Harris, & Appel, 2002). Although cephalopods contain low levels of fat, it is rich in $n-3$ fatty acids (Ozyurt, Duysak, Akamca, & Tureli, 2006; Passi, Cataudella, Di Marco, De Simone, & Rastrelli, 2002; Zlatanos, Laskaridis, Feist, & Sagredos, 2006).

The fatty acid composition of fish reflects the fatty acid composition of their natural foods (Grigorakis, Alexis,

* Corresponding author. Tel.: +90 322 3386084x2961; fax: +90 322 3386439.
E-mail address: fozogul@cu.edu.tr (F. Ozogul).

0308-8146/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2007.11.048

Taylor, & Hole, 2002; Henderson & Tocher, 1987; Van Vliet & Katan, 1990). Diet, location and season are the major factors affecting the fatty acid composition (Gruger, 1967, chap. 1), while seasonal changes in water temperature and nutrients are the major factors affecting composition of fish muscle. From the nutritional point of view, less attention has been paid to the fatty acid profile of cephalopods. Therefore, it is important to determine the level of lipid and fatty acid profile of these species. The current sudy is a comprehensive seasonal comparison of the biochemical composition (protein, lipid, moisture, ash and fatty acids) of four cephalopod species. The most popular and commonly-consumed cephalopods in the Mediterranean sea are the common cuttlefish, *Sepia officinalis* (Cephalopoda, Sepiidae), European squid, *Loligo vulgaris* (Cephalopoda, Loliginidae), common octopus, *Octopus vulgaris* (Cephalopoda, Octopodidae) and musky octopus, *Eledone moschata* (Cephalopoda, Octopodidae).

2. Materials and methods

2.1. Sample preparation

After catching the cephalopods by trawl in spring, autumn and winter (fishing is forbidden in summer), the cephalopod species were immediately iced and transported to the laboratory. These cephalopod species were caught in the eastern Mediterranean sea. The species of cephalopods identified and their mantle length and total weight were measured (Fig. 1). Mean values of mantle lengths and body weights of the captured species were 10.7 ± 2.71 cm and 126 ± 82.3 g for *S. officinalis*, 15.3 ± 4.38 cm and 87.7 ± 66.1 g for *L. vulgaris*, 8.08 ± 1.60 cm and 99.2 ± 49.2 g for *E. moschata*, and 10.3 ± 3.82 cm and 370 ± 448 g for *O. vulgaris.* A minimum of three individuals from each species were gutted, filleted and minced for analyses. Arms of the octopuses were used for this study whereas mantles of the other species (squids and cuttlefish) were used for the analyses.

2.2. FAME analyses

Lipid extraction was made according to the Bligh and Dyer method (1959). Methyl esters were prepared by transmethylation using 2 M KOH in methanol and *n*-heptane, according to the method described by Ichihara, Shibahara, Yamamoto, and Nakayama (1996), with minor modification. Extracted oil (10 mg) was dissolved in 2 ml *n*-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 *n*-heptane layer was taken for GC analysis.

2.3. Gas chromatographic condition

The fatty acid composition was analysed by GC with autosampler (Clarus 500, Perkin Elmer, Norwalk, CT) equipped with a flame ionisation detector and a fused silica capillary column (30 m × 0.32 mm × 0.25 μm BP20; SGE, Ringwood, Australia). The oven temperature was initially 140 °C, for 5 min, rising to 200 °C at a rate of 4 °C/min and then 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 ratio used was 1:100. Fatty acids were identified by comparing the retention times of FAME with the standard 37 component FAME mixture. Two replicate GC analyses were performed and the results were expressed in GC area%, as a mean value ± standard deviation.

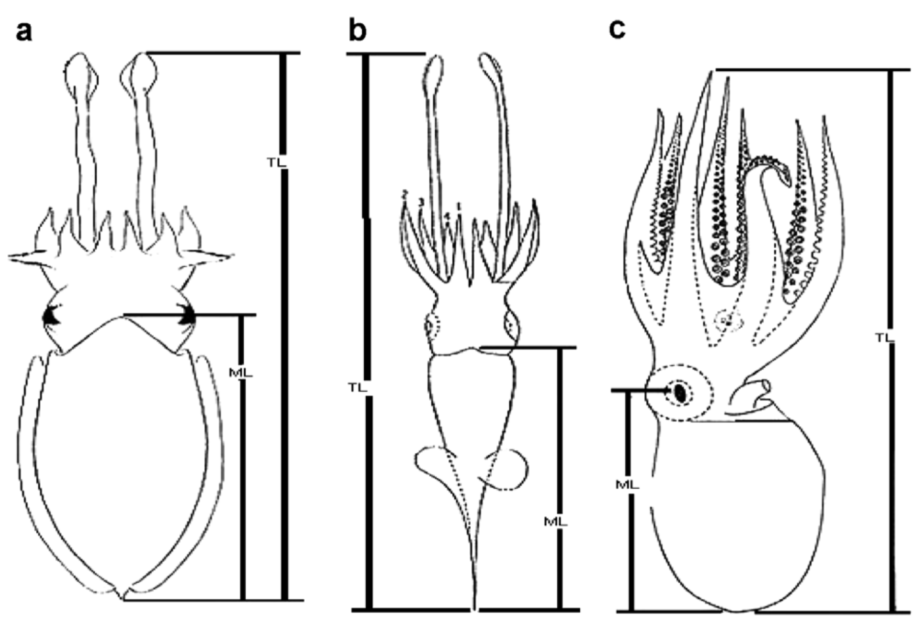

Fig. 1. Total length (TL) and mantle length (ML) of the cephalopods.

2.4. Statistical analysis

For data analysis, each sampling season was subjected to one-way analysis of variance, at the 5% confidence level, using the Duncan multiple range test.

3. Results and discussion

3.1. Proximate composition

Table 1 shows English and taxonomic names of the cephalopods species studied. Table 2 shows the seasonal variations in the proximate compositions of cephalopods. Although all species showed variations in the total lipid content of their body structural tissue throughout all of the seasons, no significant seasonal variation in lipid content was observed in any species apart from *O. vulgaris* ($p < 0.05$). The lowest lipid content was observed for *E. moschata* (0.60–0.68%) whereas *L. vulgaris* gave the highest level of lipid (1.34–1.92%), throughout all seasons. The lipid contents of species were found to be very low and the species were all considered as lean. Similar results were found in cephalopod molluscs (cuttlefish, octopus and squid) by Zlatanos et al. (2006). In general, lipid content of cephalopods was observed to increase in autumn. This may be due to the fact that nutrients in summer and autumn are more abundant than in other seasons. A considerable amount of research has been done on seasonal changes in the lipid level of various species and it was concluded that the major factor affecting the lipid level was the abundance of food (Ackman, 1995; Robards, Anthony, Rose, & Piatt, 1999; Rosa, Nunes, & Sousa Reis, 2002). It has also been indicated that the lipid content of fish changes due to species, gender, geographical origin and season (Rasoarahona, Barnathan, Bianchini, & Gaydon, 2005).

Unlike lipid contents, protein contents of cephalopods did not change throughout all of seasons. Generally, *E. moschata* had the lowest level of protein while *L. vulgaris* gave the highest protein content throughout the year (Table 2). In spring and winter, *L. vulgaris* gave the highest protein level while *S. officinalis* gave the highest level in autumn. *S. officinalis* gave a significantly higher protein content ($p < 0.01$) in autumn than in spring and winter, while the lowest protein content was obtained from *L. vulgaris* ($p < 0.01$) in autumn, compared to spring and winter (Table 2).

The results indicate that these cephalopod species are excellent protein sources and low in fat content. Moisture content of cephalopods significantly fluctuated ($p < 0.01$) across all seasons. Ash contents of cephalopods were also found to be significantly different ($p < 0.05$) throughout all of the seasons, except for *E. moschata* ($p > 0.05$).

Table 1
English and taxonomic names of cephalopod species

Name in English	Scientific name
Common cuttlefish	*Sepia officinalis*
European squid	*Loligo vulgaris*
Common octopus	*Octopus vulgaris*
Musky octopus	*Eledone moschata*

3.2. Fatty acid profiles

Table 3 shows seasonal variations in fatty acid compositions of cephalopods. The results of the fatty acid composition analysis show that cephalopods are very rich in $n-3$ fatty acids. The fatty acid compositions of each species ranged from 28.18–35.28% saturated (SFA), 4.36–9.47%

Table 2
The proximate compositions (%) of edible parts of cephalopods

Name	Composite	Seasons			p
		Spring	Autumn	Winter	
Sepia officinalis	Protein	16.91 ± 0.66^{a}	18.77 ± 0.13^{b}	16.91 ± 0.48^{a}	**
Loligo vulgaris		18.60 ± 0.14^{b}	17.44 ± 0.34^{a}	18.19 ± 0.26^{b}	**
Eledone moschata		12.21 ± 0.62^{a}	14.32 ± 0.36^{ab}	14.50 ± 0.42^{b}	ns
Octopus vulgaris		14.83 ± 0.67^{a}	14.78 ± 1.0^{a}	15.28 ± 0.21^{a}	ns
Sepia officinalis	Lipid	1.01 ± 0.13^{a}	1.52 ± 0.28^{a}	1.29 ± 0.05^{a}	ns
Loligo vulgaris		1.34 ± 0.05^{a}	1.73 ± 0.01^{ab}	1.92 ± 0.26^{b}	ns
Eledone moschata		0.60 ± 0.12^{a}	0.66 ± 0.05^{a}	0.68 ± 0.04^{a}	ns
Octopus vulgaris		0.54 ± 0.03^{a}	0.94 ± 0.09^{b}	0.87 ± 0.05^{b}	*
Sepia officinalis	Moisture	81.02 ± 0.18^{a}	78.02 ± 0.21^{b}	79.51 ± 0.28^{c}	**
Loligo vulgaris		78.51 ± 0.04^{a}	79.41 ± 0.07^{b}	77.91 ± 0.13^{c}	**
Eledone moschata		84.64 ± 0.39^{b}	83.12 ± 0.21^{a}	82.79 ± 0.20^{a}	**
Octopus vulgaris		83.41 ± 0.08^{a}	82.53 ± 0.13^{b}	80.71 ± 1.18^{c}	**
Sepia officinalis	Ash	1.12 ± 0.04^{a}	1.69 ± 0.02^{ab}	2.11 ± 0.64^{b}	*
Loligo vulgaris		1.49 ± 0.01^{ab}	1.26 ± 0.02^{a}	1.95 ± 0.44^{b}	*
Eledone moschata		1.35 ± 0.01^{a}	1.62 ± 0.02^{ab}	1.85 ± 0.33^{b}	ns
Octopus vulgaris		1.17 ± 0.01^{a}	1.69 ± 0.02^{b}	2.06 ± 0.11^{c}	**

Means followed by different letters within the same row are significantly different: $^{**}p < 0.01$, $^{*}p < 0.05$, ns: not significant.

Table 3
Seasonal variation in fatty acid profiles of edible parts of cephalopods

Fatty acids (%)	*S. officinalis*			*L. vulgaris*			*O. vulgaris*			*E. moschata*		
	Spring	Autumn	Winter	Spring	Autumn	Winter	Spring	Autumn	Winter	Spring	Autumn	Winter
C14:0	1.49 ± 0.01^{a}	1.78 ± 0.05^{b}	1.66 ± 0.09^{ab}	1.41 ± 0.05^{a}	2.85 ± 0.14^{b}	2.96 ± 0.07^{b}	1.01 ± 0.07^{a}	1.03 ± 0.01^{a}	1.37 ± 0.12^{a}	2.53 ± 0.88^{a}	0.96 ± 0.04^{a}	1.50 ± 0.07^{a}
C15:0	0.82 ± 0.01^{a}	0.91 ± 0.0^{a}	0.85 ± 0.03^{a}	0.77 ± 0.01^{b}	0.69 ± 0.01^{a}	0.8 ± 0.01^{b}	0.44 ± 0.01^{a}	0.42 ± 0.04^{a}	0.47 ± 0.02^{a}	0.58 ± 0.12^{a}	0.31 ± 0.01^{a}	0.45 ± 0.04^{a}
C16:0	17.61 ± 0.12^{a}	18.95 ± 0.06^{a}	18.04 ± 0.46^{ab}	22.30 ± 0.22^{a}	25.20 ± 0.13^{b}	25.01 ± 0.16^{b}	15.44 ± 0.29^{a}	15.53 ± 0.62^{a}	17.20 ± 0.74^{a}	16.13 ± 0.17^{a}	17.02 ± 0.01^{a}	17.89 ± 1.09^{a}
C17:0	1.57 ± 0.01^{a}	1.51 ± 0.03^{a}	1.52 ± 0.02^{a}	1.47 ± 0.02^{b}	1.05 ± 0.06^{a}	1.15 ± 0.0^{a}	1.94 ± 0.04^{a}	1.96 ± 0.01^{a}	1.80 ± 0.23^{a}	1.69 ± 0.26^{a}	2.54 ± 0.01^{b}	2.56 ± 0.06^{b}
C18:0	7.97 ± 0.02^{a}	7.93 ± 0.22^{a}	8.19 ± 0.02^{a}	5.88 ± 0.06^{c}	4.32 ± 0.16^{a}	5.17 ± 0.03^{b}	8.90 ± 0.09^{a}	9.96 ± 0.14^{a}	8.19 ± 0.78^{a}	8.77 ± 1.40^{a}	9.26 ± 0.12^{a}	8.98 ± 0.14^{a}
C20:0	0.09 ± 0.0^{a}	0.08 ± 0.0^{a}	0.18 ± 0.12^{a}	0.07 ± 0.01^{a}	0.04 ± 0.0^{a}	0.04 ± 0.0^{a}	0.08 ± 0.01^{a}	0.08 ± 0.01^{a}	0.06 ± 0.04^{a}	0.47 ± 0.31^{b}	0.10 ± 0.01^{a}	0.13 ± 0.02^{a}
C22:0	0.27 ± 0.01^{b}	0.15 ± 0.0^{a}	0.12 ± 0.03^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.15 ± 0.1^{b}	0.39 ± 0.05^{a}	0.46 ± 0.09^{a}	0.23 ± 0.05^{a}	0.88 ± 0.12^{b}	0.20 ± 0.01^{a}	0.21 ± 0.08^{a}
∑ SFA	29.80	31.30	30.53	31.83	34.14	35.28	28.18	29.43	29.30	31.04	30.36	31.72
C14:1	0.0 ± 0.0^{a}	0.05 ± 0.01^{b}	0.08 ± 0.01^{b}	0.0 ± 0.0^{a}	0.27 ± 0.02^{c}	0.20 ± 0.01^{b}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.06 ± 0.01^{b}	0.07 ± 0.01^{a}	0.12 ± 0.02^{a}	0.10 ± 0.04^{a}
C15:1	0.16 ± 0.0^{a}	0.12 ± 0.0^{a}	0.12 ± 0.06^{a}	0.03 ± 0.0^{a}	0.07 ± 0.0^{a}	0.07 ± 0.0^{a}	0.0 ± 0.0^{a}	0.08 ± 0.0^{c}	0.04 ± 0.01^{b}	0.05 ± 0.02^{a}	0.08 ± 0.03^{a}	0.08 ± 0.01^{a}
C16:1	0.30 ± 0.01^{a}	0.47 ± 0.03^{a}	0.85 ± 0.08^{b}	0.86 ± 0.02^{b}	0.19 ± 0.01^{a}	0.82 ± 0.01^{b}	0.14 ± 0.03^{a}	0.98 ± 0.04^{b}	1.24 ± 0.4^{c}	2.42 ± 1.01^{a}	0.12 ± 0.02^{a}	0.45 ± 0.08^{a}
C17:1	0.14 ± 0.0^{a}	0.16 ± 0.01^{a}	0.19 ± 0.05^{a}	0.14 ± 0.0^{a}	0.15 ± 0.0^{a}	0.13 ± 0.0^{a}	0.15 ± 0.01^{a}	0.14 ± 0.02^{a}	0.25 ± 0.01^{b}	0.12 ± 0.04^{a}	0.10 ± 0.01^{a}	0.12 ± 0.02^{a}
C18:1 *n*−9	3.48 ± 0.01^{a}	2.61 ± 0.17^{a}	3.32 ± 0.23^{a}	3.45 ± 0.11^{a}	4.29 ± 0.37^{b}	3.61 ± 0.04^{a}	3.52 ± 0.37^{b}	3.68 ± 0.14^{b}	2.24 ± 0.09^{a}	1.93 ± 0.95^{a}	1.89 ± 0.02^{a}	1.8 ± 0.03^{a}
C20:1	3.71 ± 0.03^{a}	3.39 ± 0.08^{a}	3.30 ± 0.04^{a}	4.26 ± 0.03^{b}	2.70 ± 0.08^{a}	2.48 ± 0.01^{a}	4.18 ± 0.06^{b}	4.69 ± 0.07^{b}	3.07 ± 0.18^{a}	3.88 ± 0.76^{a}	2.07 ± 0.04^{a}	2.79 ± 0.80^{a}
C22:1 *n*−9	0.04 ± 0.01^{a}	0.09 ± 0.0^{a}	0.41 ± 0.05^{b}	0.08 ± 0.0^{c}	0.0 ± 0.0^{a}	0.03 ± 0.01^{b}	0.11 ± 0.01^{b}	0.0 ± 0.0^{a}	0.11 ± 0.01^{b}	0.21 ± 0.06^{b}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}
C24:1	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.09 ± 0.03^{b}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.12 ± 0.07^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}
∑ MUFA	7.83	6.89	8.26	8.81	7.75	7.33	8.08	9.47	7.02	8.80	4.36	5.34
C18:2 *n*−6	1.73 ± 0.08^{b}	0.51 ± 0.14^{a}	0.40 ± 0.03^{a}	1.33 ± 0.01^{a}	1.06 ± 0.47^{a}	0.17 ± 0.02^{a}	1.95 ± 0.06^{a}	0.4 ± 0.01^{a}	1.2 ± 0.76^{a}	1.69 ± 0.31^{b}	0.60 ± 0.08^{a}	0.87 ± 0.05^{ab}
C18:3 *n*−6	0.05 ± 0.0^{a}	0.05 ± 0.0^{a}	0.07 ± 0.04^{a}	0.06 ± 0.0^{a}	0.11 ± 0.04^{a}	0.08 ± 0.0^{a}	0.16 ± 0.0^{a}	0.07 ± 0.04^{a}	0.08 ± 0.03^{a}	0.14 ± 0.07^{a}	0.06 ± 0.0^{a}	0.25 ± 0.09^{a}
C18:3 *n*−3	0.06 ± 0.01^{a}	0.05 ± 0.01^{a}	0.12 ± 0.01^{b}	0.06 ± 0.02^{a}	0.05 ± 0.02^{a}	0.05 ± 0.01^{a}	0.16 ± 0.1^{a}	0.18 ± 0.03^{a}	0.11 ± 0.01^{a}	0.16 ± 0.1^{a}	0.11 ± 0.01^{a}	0.15 ± 0.01^{a}
C20:2	0.40 ± 0.01^{a}	0.35 ± 0.0^{a}	0.37 ± 0.05^{a}	0.25 ± 0.01^{a}	0.15 ± 0.01^{a}	0.17 ± 0.09^{a}	0.22 ± 0.0^{a}	0.43 ± 0.04^{a}	0.25 ± 0.09^{a}	0.41 ± 0.06^{a}	0.45 ± 0.01^{a}	0.55 ± 0.06^{a}
C20:3 *n*−6	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.04 ± 0.01^{b}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.07 ± 0.02^{b}	0.11 ± 0.02^{b}	0.0 ± 0.0^{a}
C20:3 *n*−3	0.36 ± 0.01^{a}	0.32 ± 0.0^{a}	0.36 ± 0.06^{a}	0.31 ± 0.02^{b}	0.12 ± 0.01^{a}	0.14 ± 0.01^{a}	0.39 ± 0.02^{a}	0.32 ± 0.03^{a}	0.26 ± 0.04^{a}	0.26 ± 0.04^{a}	0.23 ± 0.04^{a}	0.32 ± 0.09^{a}
C20:4 *n*−6	4.67 ± 0.0^{a}	5.61 ± 0.19^{b}	4.70 ± 0.03^{a}	2.66 ± 0.0^{c}	1.48 ± 0.01^{a}	2.05 ± 0.03^{b}	6.53 ± 0.16^{a}	10.45 ± 0.01^{b}	8.47 ± 1.05^{a}	8.44 ± 2.49^{a}	11.65 ± 0.06^{a}	8.76 ± 1.2^{a}
C20:5 *n*−3	16.03 ± 0.02^{a}	15.44 ± 0.04^{a}	16.13 ± 0.64^{a}	12.05 ± 0.07^{a}	14.31 ± 0.31^{b}	13.78 ± 0.04^{b}	16.97 ± 0.3^{b}	12.23 ± 0.32^{a}	15.85 ± 1.44^{ab}	7.86 ± 0.82^{a}	12.23 ± 0.10^{b}	11.78 ± 0.6^{b}
C22:2	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.07 ± 0.01^{b}	0.13 ± 0.05^{a}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}	0.62 ± 0.05^{b}	0.0 ± 0.0^{a}	0.12 ± 0.02^{a}	3.57 ± 0.08^{b}	0.0 ± 0.0^{a}	0.0 ± 0.0^{a}
C22:6 *n*−3	32.99 ± 0.0^{a}	32.47 ± 0.05^{a}	30.89 ± 1.33^{a}	39.0 ± 0.10^{b}	35.96 ± 0.61^{a}	36.36 ± 0.13^{a}	29.57 ± 0.17^{b}	29.23 ± 0.16^{b}	25.54 ± 1.05^{a}	20.99 ± 1.85^{a}	28.23 ± 0.10^{b}	22.67 ± 0.65^{a}
∑ PUFA	56.27	54.79	53.13	55.85	53.23	52.79	56.55	53.30	51.85	43.58	53.66	45.35
PUFA/SFA	1.88	1.75	1.74	1.75	1.55	1.49	2.00	1.81	1.76	1.40	1.76	1.42
∑*n*−6	6.45	6.17	5.21	4.05	4.01	2.3	8.64	10.92	9.75	10.34	12.42	9.88
∑*n*−3	49.44	48.28	47.5	51.42	50.44	50.33	47.09	41.96	41.76	29.27	40.8	34.92
n−6/*n*−3	0.13	0.12	0.10	0.07	0.07	0.04	0.18	0.26	0.23	0.35	0.30	0.28
DHA/EPA	2.05	2.10	1.91	3.23	2.51	2.63	1.74	2.39	1.61	2.67	2.30	1.92
Unknown	6.1	7.02	8.08	3.51	4.88	4.6	7.19	7.8	11.83	16.58	11.62	17.59

For each species, values in the same row with differing letters are significantly different ($p < 0.05$).

monounsaturated (MUFAs) and 43.6–56.6% polyunsaturated fatty acids (PUFAs). Among the species, the percentages of SFA in *L. vulgaris*, MUFA in *O. vulgaris* and PUFA in *S. officinalis* were found to be higher than others throughout all seasons. The highest proportions of fatty acids in cephalopods were myristic acid (C14:0, 0.96–2.96%), palmitic acid (C16:0, 15.5–25.2%), heptadecanoic acid (C17:0, 1.05–2.56%), stearic acid (C18:0, 4.32–9.96%), oleic acid (*cis*-C18:1 $n-9$, 1.8–4.29%), *cis*-11-eicosenoic acid (C20:1, 2.07–4.69%), linoleic acid (C18:2 $n-6$, 0.17–1.95%), arachidonic acid (C20:4 $n-6$, 1.48–11.65), *cis*-5,8,11,14,17-eicosapentaenoic acid (EPA, C20:5 $n-3$, 7.86–16.97%) and *cis*-4, 7,10,13,16,19-docosahexaenoic acid (DHA, C22:6 $n-3$, 20.99–39.0%). These results are in agreement with previous studies on fatty acids of cephalopods (Ozyurt et al., 2006; Reale et al., 2006; Rosa, Pereira, & Nunes, 2005; Zlatanos et al., 2006). It was also observed that the proportion of these fatty acids changed significantly throughout the seasons (Table 4).

The proportions of $n-3$ PUFAs (ranging from 29.27% for *E. moschata* to 50.44% for *L. vulgaris* in autumn) were higher than those of $n-6$ PUFAs (ranging from 2.30 in winter to 4.01 for *L. vulgaris* in autumn). The UK department of Health recommends a maximum dietary ratio of $n-6/n-3$ of 4.0 (HMSO, 1994). Values higher than the maximum value are harmful to health and may cause cardiovascular diseases (Moreira, Visentainer, de Souza, & Matsushita, 2001). In this study, the ratio of $n-6/n-3$ was found to be much lower than 4. A recommended minimum value of PUFA/SFA ratio is 0.45 (HMSO, 1994), which is lower than those obtained from all species studied. The highest PUFA/SFA ratio was obtained from all species in spring, except *E. moschata*, which had the highest PUFA/SFA ratio in autumn, whereas the lowest values were found in winter for all species, except *E. moschata* (in spring).

Table 4
The results of the analysis of variance on the seasonal variation in the fatty acid composition of cephalopods

Fatty acids (%)	*S. officinalis* (*p*)	*L. vulgaris* (*p*)	*O. vulgaris* (*p*)	*E. moschata* (*p*)
C14:0	ns	**	ns	ns
C15:0	ns	**	ns	ns
C16:0	ns	**	ns	ns
C17:0	ns	**	ns	ns
C18:0	ns	**	ns	ns
C20:0	ns	ns	ns	ns
C22:0	**	**	*	ns
SFA				
C14:1	*	**	**	ns
C15:1	ns	ns	**	ns
C16:1	*	**	**	ns
C17:1	ns	ns	*	ns
C18:1 $n-9$	ns	*	*	ns
C20:1	ns	**	**	ns
C22:1 $n-9$	**	**	**	*
C24:1	ns	ns	ns	ns
MUFA				
C18:2 $n-6$	**	ns	ns	ns
C18:3 $n-6$	ns	ns	ns	ns
C18:3 $n-3$	*	ns	ns	ns
C20:2	ns	ns	ns	ns
C20:3 $n-6$	*	ns	ns	*
C20:3 $n-3$	ns	**	ns	ns
C20:4 $n-6$	**	**	**	ns
C20:5 $n-3$	ns	**	ns	*
C22:2	**	ns	**	**
C22:6 $n-3$	ns	*	*	*
PUFA				

** $p < 0.01$, * $p < 0.05$, ns: not significant.

MUFA have been paid attention during the last decades due to their beneficial effects on cardiovascular heart disease (Kalogeropoulus, Andrikopoulos, & Hassapidou, 2004). Keys et al. (1986) indicated that populations which consumed olive oil had a low rate of CHD, especially Mediterranean countries. Therefore, inclusion of higher dietary MUFA has been suggested by NCEP (2001). The levels of MUFA in this study were found to be low compared to SFA and PUFA, ranging from 4.36% to 9.47%. Consumption of cephalopods would also contribute the intake of MUFA.

Palmitic acid (C16:0) was the primary saturated fatty acid, whereas oleic acid (C18:1 $n-9$) and *cis*-11-eicosenoic acid (C20:1) were the most represented MUFAs. The major fatty acids identified as polyunsaturated fatty acids were eicosapentaenoic acid (EPA, C20:5 $n-3$) and docosahexaenoic acid (DHA, C22:6 $n-3$). These results are supported by the findings of other researchers (Ozyurt et al., 2006; Reale et al., 2006; Zlatanos et al., 2006). The highest proportions of EPA were obtained from *S. officinalis* (16.13) in winter, *O. vulgaris* (16.97) in spring, and *L. vulgaris* (14.31) and *E. moschata* (12.23) in autumn.

A high proportion of DHA was found in all species of cephalopods in this study, compared to fish species (Ozogul & Ozogul, 2007; Özogul, Özogul, & Alagöz, 2007). Three species of cephalopods had the highest DHA in spring (33.0% for *S. officinalis*, 39.0% for *L. vulgaris* and 29.6% for *O. vulgaris*), the exception being *E. moschata* (28.2% in autumn). Although cephalopods contained small amounts of fat, EPA and DHA were found to be high in all species (Kalogeropoulus et al., 2004; Ozyurt et al., 2006; Reale et al., 2006; Zlatanos et al., 2006), increasing the value of cephalopods compared to cultured or wild fish species.

References

Ackman, R. G. (1989). Nutritional composition of fats in seafoods. *Progress in Food and Nutrition Science, 13*, 161–241.

Ackman, R. G. (1995). Composition and nutritive value of fish and shellfish lipids. In A. Ruither (Ed.), *Fish and fishery products* (pp. 117–156). UK: CAB International.

Almansa, E., Domingues, P., Sykes, A., Tejera, N., Lorenzo, A., & Andrade, J. P. (2006). The effects of feeding with shrimp or fish fry on growth and mantle lipid composition of juvenile and adult cuttlefish (*Sepia officinalis*). *Aquaculture, 256*, 403–413.

Bligh, E. C., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology, 37*, 913–917.

Conner, W. E. (2000). Importance of $n-3$ fatty acids in health and disease. *The American Journal of Clinical Nutrition, 17*(1), 171S–175S.

Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (2001). Executive Summary of the Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III). *JAMA, 285*, 2486–2497.

FAO (2004). *The state of world fisheries and aquaculture*. Rome, Italy: FAO Fisheries Department, Food and Agriculture of the United Nations, 153pp.

Grigorakis, K., Alexis, M. N., Taylor, K. D. A., & Hole, M. (2002). Comparison of wild and cultured gilthead sea bream (Sparus aurata): Composition, appearance and seasonal variations. *International Journal of Food Science and Technology, 37*, 477–484.

Gruger, E. H. Jr., (1967). Fatty acid composition. In M. E. Stansby (Ed.), *Fish oils* (pp. 3p). Westport, CT: AVI Publishing Co.

Henderson, R. J., & Tocher, D. R. (1987). The lipid composition and biochemistry of freshwater fish. In R. T. Holman, W. W. Christie, & H. Sprecher (Eds.). *Progress in Lipid Research* (Vol. 26, pp. 281–437). New York: Pergamon Press.

HMSO, UK (1994). *Nutritional aspects of cardiovascular disease (report on health and social subjects No. 46)*. London: HMSO.

Ichihara, K., Shibahara, A., Yamamoto, K., & Nakayama, T. (1996). An improved method for rapid analysis of the fatty acids of glycerolipids. *Lipids, 31*, 535–539.

Kalogeropoulus, N., Andrikopoulos, N. K., & Hassapidou, M. (2004). Dietary evaluation of Mediterranean fish and mollusks pan-fried in virgin olive oil. *Journal of the Science of Food and Agriculture, 84*, 1750–1758.

Keys, A., Menotti, A., Karnonen, M. J., Aravanis, C., Blackburn, H., Buzina, R., et al. (1986). The diet and 15-year death rate in the seven countries study. *American Journal of Epidemiology, 124*, 903–915.

Kinsella, J. E. (1987). *Seafoods and fish oils in human health and disease*. New York: Marcel Dekker.

Kris-Etherton, P. M., Harris, W. S., & Appel, L. J. (2002). Fish consumption, fish oil, omega-3 fatty acids and cardiovascular disease. *Circulation, 106*, 2747–2757.

Moreira, A. B., Visentainer, J. V., de Souza, N. E., & Matsushita, M. (2001). Fatty acids profile and cholesterol contents of three Brazilian Brycon freshwater fishes. *Journal of Food Composition and Analysis, 14*, 565–574.

Mozaffarian, D., Bryson, C. L., Lemaitre, R. N., Burke, G. L., & Siscovick, D. S. (2005). Fish intake and risk of incident heart failure. *Journal of the American College of Cardiology, 45*(12), 2015–2021.

Ozogul, Y., & Ozogul, F. (2007). Fatty acid profiles of commercially important fish species from the Mediterranean, Aegean and Black seas. *Food Chemistry, 100*, 1634–1638.

Özogul, Y., Özogul, F., & Alagöz, S. (2007). Fatty acid profiles and fat contents of commercially important seawater and freshwater fish species of Turkey: A comparative study. *Food Chemistry, 103*, 217–223.

Ozyurt, G., Duysak, O., Akamca, E., & Tureli, C. (2006). Seasonal changes of fatty acids of cuttle fish *Sepia officinalis* L. (Mollusca: Cephalopoda) in the north eastern Mediterranean sea. *Food Chemistry, 95*, 382–385.

Passi, S., Cataudella, S., Di Marco, P., De Simone, F., & Rastrelli, L. (2002). Fatty acid composition and antioxidant levels in muscle tissue of different Mediterranean marine species of fish and shellfish. *Journal of Agricultural and Food Chemistry, 50*, 7314–7322.

Rasoarahona, J. R. E., Barnathan, G., Bianchini, J. P., & Gaydon, E. M. (2005). Influence of season on the lipid content and fatty acid profiles of three tilapia species (*Oreochromsis niloticus*, *O. macrochir* and *Tilapia rendalli*) from Madagascar. *Food Chemistry, 91*(4), 683–694.

Reale, A., Ziino, M., Ottolenghi, F., Pelusi, P., Romeo, V., Condurso, C., et al. (2006). Chemical composition and nutritional value of some marine species from the Egadi Islands. *Chemistry and Ecology, 22*(1), S173–S179.

Robards, D. M., Anthony, J. A., Rose, G. A., & Piatt, J. F. (1999). Changes in proximate composition and somatic energy content for Pacific sand lance (*Ammodytes hexapterus*) from Kachemak. *Journal of Experimental Marine Biology and Ecology, 242*, 245–258.

Rosa, R., Pereira, J., & Nunes, M. L. (2005). Biochemical composition of cephalopods with different life strategies, with special reference to a giant squid, *Architeuthis* sp. *Marine Biology, 146*, 739–751.

Rosa, R., Nunes, M. L., & Sousa Reis, C. (2002). Seasonal changes in the biochemical composition of *Octopus vulgaris*, Cuvier, 1797, from three areas of the Portuguese coast. *Bulletin of Marine Science, 71*, 739–751.

Steffens, W. (1997). Effects of variation in essential fatty acids in fish feeds on nutritive value of freshwater fish for humans. *Aquaculture, 151*, 97–119.

Van Vliet, T., & Katan, M. B. (1990). Lower ratio of $n-3$ to $n-6$ fatty acids in cultured than in wild fish. *American Journal of Clinical Nutrition, 51*, 1–2.

Zlatanos, S., Laskaridis, K., Feist, C., & Sagredos, A. (2006). Proximate composition, fatty acid analysis and protein digestibility-corrected score of three Mediterranean cephalopods. *Molecular Nutrition and Food Research, 50*, 967–970.