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Comparative study of fat content, profile and quality of fatty acid in three species of Carangidae of southwestern Mediterranean

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Abstract

This work focuses on the study of three pelagic fish species of the same genus, caught from the south-western coasts of the Mediterranean. It concerns lipid content, fatty acid profile and nutritional quality (atherogenic index, thrombogenicity index, ratio between hypocholesterolemic and hypercholesterolemic fatty acids and n6-to-n3 ratio) of *Trachurus trachurus*, *Trachurus mediterraneus* and *Trachurus picturatus*. Lipid extraction and esterification were carried out on the flesh of each species, and fatty acid methyl esters were analysed using gas chromatography-mass spectrometry. The obtained results show that lipid content mean values vary between 2.87 and 5.06%, saturated fatty acids contents range from 37.51 to 53.23%, monounsaturated fatty acids content range from 29.24 to 37.65% and polyunsaturated fatty acids content range from 9.11 to 33.24% according to species. Also, the different mean values of indexes describing the nutritional quality vary significantly depending on species. That confirms the good quality of studied species and their importance for human nutrition and health, hence the urgent need to preserve their stocks.

Introduction

Currently, people have been interested in their nutrition and look for selecting healthful foods for their diets. Fishing products, especially fish, are ranked first among these foods, dint of their richness in proteins and fatty acids. Fish oil is of greatest importance in terms of nutrition physiology (Celik, 2008) and its importance for human health has been extensively described and proven (Ruxton *et al.*, 2007). The polyunsaturated fatty acids (PUFA) contained in fish oil are the main contributors to these properties, more specifically, those belonging to the omega-3 family such as eicosapentaenoic (EPA, C20:5n3) and docosahexaenoic (DHA, C22:6n3) acids.

Omega-3 long-chain fatty acids play an important role in prevention of cardiovascular diseases owing to their anti-thrombotic, anti-arrhythmic and anti-inflammatory properties (Huang *et al.*, 2005; Morales-Medina *et al.*, 2016). They also have beneficial effects on high blood pressure, brain development, depression, diabetes and cancer in children (Simopoulos, 2002; Tapiero *et al.*, 2002), contribute to the improvement of mitochondrial functions and inflammation in obese people (Borja-Magno *et al.*, 2023) and exert an important neuroprotective effect (Neto *et al.*, 2022). Also, DHA is one of the components of the ocular retina, brain and myocardium. It plays an essential role in the development of the eyes and the brain, thus ensuring good cardiovascular health (Ward and Singh, 2005). Moreover, EPA is also useful in anxiety cases and cancer treatment (Fenton *et al.*, 2000; Neto *et al.*, 2022). People that consume between 0.5 and 0.7 g day^{-1} of DHA have a lower incidence of heart troubles. However, their deficiency leads to some disorders such as poor eyesight, dermatoses and anaemia (Celik, 2008). The general recommendation for daily DHA/EPA intake is 1 g day^{-1} for adults and 0.5 g for infants (Kris-Etherton *et al.*, 2002). Pelagic fish are considered to be one of the main sources of these fatty acids, and are generally known for their high fat content (Passi *et al.*, 2002).

On the eastern Algerian coasts, the genus *Trachurus* is represented by three species: horse mackerel *Trachurus trachurus*, Mediterranean horse mackerel *Trachurus mediterraneus* and blue-jack mackerel *Trachurus picturatus* (Derbal and Kara, 2001). These are very important pelagic fish in terms of economic interest and biomass in the Mediterranean and throughout the world. On a local scale, production of combined species of *Trachurus* genus was estimated at 45% of total pelagic fish production between 2010 and 2020 in Jijel city. Besides that, they are highly appreciated and requested by consumers because of their high organoleptic value.

The geographical location is one of the factors influencing the fatty acid composition of fish (Winston and Di Giulio, 1991). The species of the *Trachurus* genus are characterized by more or less different geographical distribution areas. *Trachurus trachurus* is characterized by a wide distribution on the continental shelf and the edge of the slope in the Atlantic Ocean; the coasts of South Africa and the sub-tropical and tropical seas (the Norwegian Sea, the North Sea, the Mediterranean Sea, the Sea of Marmara and the Black Sea). *Trachurus mediterraneus* is present in the North-East Atlantic, from the Bay of Biscay to Mauritania, in the Black Sea and especially in the Mediterranean. However, it is absent in the Levantine basin. *Trachurus picturatus* is a cosmopolitan, common in the Adriatic, in the eastern and western Mediterranean, and in the eastern Atlantic, from the Bay of Biscay to Mauritania (Bauchot, 1987). Also, according to Winston and Di Giulio (1991), the fatty acid profile of fish generally, and of PUFA especially, is related to dietary. The horse mackerel feeds mainly on small crustaceans, but also on small fish such as sardines and anchovies (Rahmani *et al.*, 2020). However, the Mediterranean horse mackerel is mostly piscivorous, it feeds on sardines and anchovies, but also sometimes on small crustaceans. The young individuals target only crustaceans (Bensalem, 1988). Blue-jack mackerel feeds mainly on crustaceans such as copepods and zooplankton and mesopelagic fish (Bauchot and Paras, 1980; Bauchot, 1987; Battaglia *et al.*, 2020).

The fatty acid profile of fish species has been the subject of several studies over the last two decades. On the northern coasts of Mediterranean, *T. trachurus* fatty acid profile was studied in the Alborán Sea by Morales-Medina *et al.* (2016), and on the Italian coasts by Passi *et al.* (2002), Orban *et al.* (2011) and Giandomenico *et al.* (2023). Fernandez-Jover *et al.* (2007) was interested in *T. mediterraneus* on the North-West Mediterranean coasts. Turan *et al.* (2007) were also interested by the same species in the Black Sea. Furthermore, the fatty acid composition of *T. picturatus* in Mediterranean was targeted only by Zlatanos and Sugredos (1993) on the Greece coast. However, on the South-West coasts of the Mediterranean, these three species have never been studied from the point of view of their biochemical composition despite their great economic interest and their importance for human health.

This study aims to provide original data on lipid content, fatty acid profile and nutritional quality of three pelagic species: *T. trachurus*, *T. mediterraneus* and *T. picturatus*, in the coast of Jijel, eastern of Algeria. The results to be obtained will make it possible to determine the biochemical status of these three species in the region studied. They will also help guide consumer choice.

Materials and Methods

Sampling

A total of 90 specimens of three species from genus *Trachurus*, caught mainly by pelagic trawls and having commercial and similar sizes ($N_{T.\ trachurus} = 30$, $TL_{T.\ trachurus} = 19 \pm 0.6$ cm, $TW = 51.35 \pm 7.66$ g; $N_{T.\ mediterraneus} = 30$, $TL_{T.\ mediterraneus} = 19 \pm 0.5$ cm, $TW = 55.85 \pm x\ 7.81$; $N_{T.\ picturatus} = 30$, $TL_{T.\ picturatus} = 19 \pm 0.6$ cm, $TW = 54.17 \pm 8.74$ g), were collected during October of 2022 from Jijel Bay on the South-western Mediterranean of Algeria (36°49′39.1″N 5°45′58.8″E), via wholesalers and fishmongers (Figure 1). (N) means the sample size of each species, the total length (TL) was measured to the nearest mm, and the total weight (TW) was recorded to the nearest g.

Sample preparation

After capture, the samples were kept in ice and transported to the laboratory. Only the fillets were taken after removing the skin and the head of the eviscerated fish. Afterwards, the fillets of every ten individuals for each species were independently crushed as a paste (the total weight of the meat obtained by species: 1109.4 g for *T. trachurus*; 1225.85 g for *T. mediterraneus* and 1189.57 g for *T. picturatus*), using a warring blender with a variable transformer (VWR Scientific, Norwalk, CA, USA). The chemical analysis was therefore carried out in three biological replicates per species ($n = 3$), separately.

Lipid extraction

For each subsample of the three species, an amount of 20 g of crushed fillets were homogenized with 100 ml of methanol (grade AA), using the waring blender. Next, 40 ml of double distilled water and 50 ml of chloroform ($CHCl_3$) were added, and the obtained mixture was homogenized again for 2 min using always the warring blender. Then, 50 ml of double distilled water and 50 ml of chloroform were added, and homogenization was applied again for 30 s. After that, 100 ml of the mixture were centrifuged in glass tubes (3300 × g, 10°C). The decanted liquids were collected by filtration through Whatman No. 1 filter paper in glass funnels, and kept separately. The resulting solids were newly extracted by adding 20 ml of 1:1 (v/v) chloroform: methanol; both resulting extracts were combined and transferred into a separate funnel, which is a device facilitating the separation of two liquids. The chloroform layer was passed through a layer of 2.5 cm of anhydrous sodium sulphate using Whatman No. 1 filter paper, in a funnel. The last step consists of removing the solvents from the tared flask by using a rotary evaporator under vacuum (Heidolph model VV2000), at 40°C (Folch *et al.*, 1957). To avoid the risk of contamination, the glassware was washed carefully after each use, with hot water and detergent, then rinsed with acetone.

Estimation of lipid content

The content of lipids in the sample of each species was calculated according to the following formula (Guil-Guerrero *et al.*, 2011):

$$\text{Lipids content}(\%) = \frac{\text{amount of extracted lipids(g)}}{\text{weight of original sample(g)}} \times 100$$

Where the weight of extracted lipids was calculated as follows:

$$\text{Weight of lipids} = (\text{weight of container} + \text{extracted lipids}) - \text{weight of container(g)}$$

Transesterification

The main objective of this step is to extract fatty acid methyl esters (FAMEs) and increase their volatility in the extracts to be analysed. For that, 20 mg of each oil sample were mixed with 20 ml of a solution of methanol and acetyl chloride (20:1, v/v) and 20 ml of hexane, according to Rodríguez-Ruiz *et al.* (1998). The mixture was heated under stirring at 100°C during 30 min, and cooled afterwards in room temperature. Afterward, 20 ml of water were added and the FAMEs were extracted in a layer of hexane. Three extractions with hexane were made on the same extract to ensure maximal recovery of FAMEs (Guil-Guerrero *et al.*, 2011).

Fatty acid analysis

FAMEs were analysed using an Agilent gas chromatography system (model GC-2030). An Rtx-5MS capillary column (28 m long, with an inner diameter of 0.25 mm and a film thickness of 0.25 µm) was employed for the separation of fatty acids. The column

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Figure 1. Map showing study area in Eastern Algerian coast.

temperature was initially set to 70°C for 1 min after injection, then increased at a rate of 7°C min^{-1} to reach 170°C, which was maintained for 55 min. Subsequently, the temperature was raised at a rate of 10°C min^{-1} to 230°C and held at this final temperature for 33 min. Helium served as the carrier gas, set at a split ratio of 1:20. The injector and detector temperatures were maintained at 250 and 350°C, respectively, with an injection volume of 1 µl.

FAME chromatogram peaks were identified by comparing their retention times with recognized FAME standards. Each fatty acid's concentration was determined by calculating its peak area relative to the total peak area, and the results were reported as a percentage of each fatty acid in the total lipids.

Nutritional quality of fatty acids

Nutritional quality of studied species fillets was verified by calculating the values of the atherogenic index (AI), thrombogenic index (TI), hypocholesterolemic-to-hypercholesterolemic ratio (HH) and n6-to-n3 ratio, as following (Ulbricht and Southgate, 1991; Santos-Silva *et al*., 2002):

$$\mathrm{AI} = (\mathrm{C12{:}0} + 4 \times \mathrm{C14{:}0} + \mathrm{C16{:}0}) / \left(\sum\nolimits^{\mathrm{MUFA}} + \sum\nolimits^{\mathrm{PUFA}}\right)$$

$$\mathrm{TI} = \Big[(\mathrm{C14{:}0} + \mathrm{C16{:}0} + \mathrm{C18{:}0}) / (0.5 \times \sum\nolimits^{\mathrm{MUFA}}) + (0.5 \times \sum\nolimits^{n} 6\mathrm{PUFA}) + \left(3 \times \sum\nolimits^{n} 3\mathrm{PUFA}\right) + (\omega 3/\omega 6)\Big]$$

$$\mathrm{HH} = (\mathrm{C18{:}1}n9 + \mathrm{C18{:}2}n6 + \mathrm{C20{:}4}n6 + \mathrm{C18{:}3}n3 + \mathrm{C20{:}5}n3 + \mathrm{C22{:}5}n3 + \mathrm{C22{:}6}n3) / (\mathrm{C14{:}0} + \mathrm{C16{:}0})$$

$$n6\text{-to-}n3 \text{ ratio} = n6/n3$$

For each species, the calculation of the indices was carried out in three biological repetitions, separately. AI assesses the possibility of a food or substance to reduce blood fat content, and TI evaluates the capacity of a food or substance to inhibit platelet activity, contributing to blood clot formation (Iwamoto *et al*., 2019). Generally, low values of these indices reflect a protective effect against cardiovascular diseases, while high ones may reflect the opposite (Turan *et al*., 2007; Grigorakis *et al*., 2011). These indices are based on the fatty acid composition of foods and are useful to choose the good diet for heart health (Grigorakis, 2007). Moreover, HH is strongly dependent on cholesterol metabolism, and high HH values are considered to be beneficial for human health (Ramos Filho *et al*., 2010). Also, the high n6-to-n3 ratio is an index of the lipid quality and is considered as an element of nutritional relevance (Orban *et al*., 2011).

Statistical analysis

The SPSS 23 software package was used for statistical analysis, and significant differences were considered at $\rho < 0.05$. The statistical comparison of the lipid content between the studied species was made by the ANOVA test. An overall comparison of the composition of saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and PUFA in the three species was carried out by the MANOVA test. The ANOVA test was also used to compare the SFA, MUFA and PUFA contents, as well as to compare each of the AI, TI, HH indices and the n6-to-n3 ratio separately between species.

Results

Lipid content

The obtained results show that the mean values of lipid content in *T. trachurus*, *T. mediterraneus* and *T. picturatus* are 5.06% (SD = 0.16), 2.87% (SD = 0.18) and 2.82% (SD = 0.15), respectively, where SD represents the standard deviation. Statistical comparison of these means, using ANOVA test, indicates significant differences between species ($F = 176.84$, $\rho < 0.05$) (Table 1).

Fatty acid profile

The study of fatty acid profile in horse mackerel, Mediterranean horse mackerel and blue-jack mackerel caught from the study area, reveals the presence of each of the SFA (35.1–53.23%), MUFA (29.24–37.65%) and PUFA (9.11–33.24%) in the muscle of all species (Table 2). Overall statistical comparison, using MANOVA test, shows significant differences ($F = 2631.31$, $\rho <$

Table 1. Lipid contents (g\100 g muscle of fish) of *Trachurus trachurus*, *Trachurus mediterraneus* and *Trachurus picturatus*

Species	*T. trachurus*	*T. mediterraneus*	*T. picturatus*
Lipid contents	5.06 ± 0.16^{a}	2.87 ± 0.18^{b}	2.82 ± 0.15^{b}

Data are means of triplicate determinations ± standard deviation: the different letters indicate significant differences between species; error bars, standard deviations.

Table 2. Fatty acids composition in *Trachurus trachurus*, *Trachurus mediterraneus* and *Trachurus picturatus* (% of total fatty acids)

Fatty acids	*T. trachurus*	*T. mediterraneus*	*T. picturatus*
C14:0	3.25 ± 0.02	3.1 ± 0.02	1.81 ± 0.01
C15:0	0.86 ± 0.01	0.96 ± 0	0.54 ± 0
C16:0	19.51 ± 0.03	32.06 ± 0.17	21.1 ± 0.23
C17:0	1.07 ± 0.01	1.44 ± 0.01	1.09 ± 0.01
C18:0	7.81 ± 0.03	12.36 ± 3.94	12.02 ± 0.02
C19:0	0.26 ± 0.01	–	–
C20:0	0.39 ± 0	0.52 ± 0	0.58 ± 0.02
C22:0	1.95 ± 0	0.52 ± 0	–
C24:0	–	–	0.37 ± 0.01
∑SFA	**35.1 ± 6.34**	**53.23 ± 11.14**	**37.51 ± 7.4**
C16:1n7	5.29 ± 0.02	5.32 ± 0.01	3.85 ± 0.07
C17:1	–	0.42 ± 0.01	–
C18:1n9	24.89 ± 0.26	30.39 ± 0.17	22.74 ± 0.10
C20:1n6	1.6 ± 0	1.52 ± 0.01	1.64 ± 0.03
C24:1n9	1.03 ± 0	–	1.01 ± 0.02
∑MUFA	**32.81 ± 0.25**	**37.65 ± 0.16**	**29.24 ± 0.1**
C18:2n6	1.62 ± 0.04	1.27 ± 0.04	1.29 ± 0.04
C20:2n11	–	–	0.33 ± 0
C18:3n3	2.03 ± 0.03	0.43 ± 0	1.19 ± 0.05
C20:4n6	1.07 ± 0	–	1.44 ± 0.07
C20:5n3 (EPA)	7.34 ± 0.06	1.89 ± 0.04	6.59 ± 0.08
C22:5n3	0.49 ± 0	–	0.77 ± 0
C22:6n3 (DHA)	19.55 ± 0.12	5.52 ± 0.05	21.63 ± 0.08
∑PUFA	**32.1 ± 0.11**	**9.11 ± 0.11**	**33.24 ± 0.07**

∑SFA, total saturated fatty acid; ∑MUFA, total monounsaturated fatty acid; ∑PUFA, total polyunsaturated fatty acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid. Data are means of triplicate determinations ± standard deviation.

0.05), in the composition of the main FAMEs groups in the three species studied.

Fatty acid profile of T. trachurus

Trachurus trachurus is composed mainly of SFA (35.1%), of which the most abundant fatty acids are palmitic acid (19.51%), stearic acid (7.81%) and myristic acid (3.25%). MUFA constitutes 32.81% of total fatty acids, mainly split into oleic acid (24.89%) and palmitoleic acid (5.29%). Moreover, PUFA represent 32.1% of fatty acids, with 19.55% of DHA and 7.34% of EPA. Statistical comparison between SFA, MUFA and PUFA fractions using the ANOVA test showed significant differences ($F = 21.50$, $\rho < 0.05$) in the same species.

Fatty acid profile of T. mediterraneus

The mean fatty acid composition of *T. mediterraneus* was found to be 53.23% of SFA, 37.65% of MUFA and 9.11% of PUFA (ANOVA: $F = 249.98$, $\rho < 0.05$). The majority fatty acids in the SFA class are palmitic acid, stearic acid and myristic acid, corresponding to 32.06, 12.36 and 3.1%, respectively. In the MUFA class, the most abundant acids are oleic acid and palmitoleic acid, corresponding to 30.39 and 5.32%, respectively. PUFA is the class least represented by this species, with only 9.11%, distributed essentially over 5.52% of DHA and 1.89% of EPA.

Fatty acid profile of T. picturatus

Trachurus picturatus is composed of 37.51% SFA, 29.24% MUFA and 33.24% PUFA (ANOVA: $F = 60.20$, $\rho < 0.05$). A large proportion of SFA is represented by palmitic acid (21.10%) and stearic acid (12.02%). Oleic acid constitutes 22.74% and palmitoleic acid accounts for 3.85% of total MUFA. Also, DHA is the major component of PUFA, followed by EPA, with proportions corresponding respectively to 21.63 and 6.59% (Figure 2A).

The three studied species are rich in SFA, MUFA and PUFA, with percentages varying from one species to another. Statistical comparison of the contents of these main fatty acid classes according to species reveals significant differences (ANOVA: $F_{SFA} = 32.17$, $\rho_{SFA} < 0.05$, $F_{MUFA} = 1602.69$, $\rho_{MUFA} < 0.05$ and $F_{PUFA} = 56547.28$, $\rho_{PUFA} < 0.05$) (Figure 2B).

Nutritional quality of fatty acids

The average values of the AI, TI, HH and n6-to-n3 ratio are 0.50, 0.26, 2.50 and 0.15 in *T. trachurus*; 0.95, 0.97, 1.12 and 0.36 in *T. mediterraneus* and 0.45, 0.30, 2.43 and 0.14 in *T. picturatus*, respectively (Table 3). These values varied significantly among species (ANOVA: $F_{AI} = 26746.06$, $\rho_{AI} < 0.05$; $F_{TI} = 222$, $\rho_{TI} < 0.05$; $F_{HH} = 26746.06$, $\rho_{HH} < 0.05$ and $F_{n6\text{-to-}n3} = 19832.85$, $\rho_{n6\text{-to-}n3} < 0.05$).

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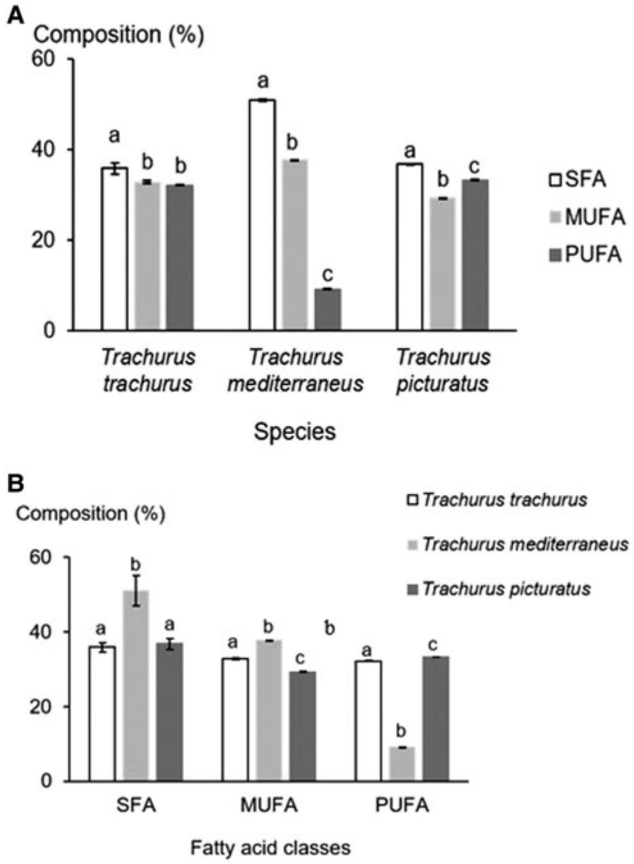

Figure 2. Intra (A) and interspecific (B) comparison of principal fatty acid classes in *Trachurus trachurus*, *Trachurus mediterraneus* and *Trachurus picturatus*: the different letters indicate significant differences between species, considering each species separately (A); and between fatty acid classes considering each class separately (B); SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid and error bars, standard deviations.

Discussion

Lipid content

The highest lipid content value was recorded in *T. trachurus* (5.06%), while the lowest one was estimated in *T. picturatus* (2.82%). Our results differ from those obtained in other regions, which can be explained by many factors, such as: feeding habits (Lee and Lip, 2003), species (Mohanty *et al*., 2019), stage of development (Costa *et al*., 2018), geographic origin, environmental factors, fishery period, reproductive season, etc. (Winston and Di Giulio, 1991). Thus, the extraction method can influence the yield of lipid content: Morales-Medina *et al*. (2016), Nougueira *et al*. (2013) and Turan *et al*. (2007) used the AOAC official methods (1980, 1990, 2006) respectively. Fernandez *et al*. (2007) carried out the extraction of fatty acids by ethyl ether, using a laboratory extractor. Orban *et al*. (2011) followed the method of Bligh and Dyer (1959) and Zlatanos and Sugredos (1993) carried out the extraction by anhydrous sodium sulphate and *n*-hexane using Soxhlet. The chloroform-based Folch approach that we used achieves very high extraction efficiency compared to several other methods (Pilecky *et al*., 2024).

The spawning period extends from January to May for *T. trachurus* (Ciccone *et al*., 2013; Gherram *et al*., 2018), from May to August for *T. mediterraneus* (Viette *et al*., 1997; Demirel and Yüksek, 2013) and from January to March for *T. picturatus* (Neves *et al*., 2022). The sampling period of the three species coincides with the gonadal rest stage, which minimizes the effect of the reproductive season on the obtained results. Comparing with previous studies, lipid content in *T. trachurus* ranges from 2.10% (Orban *et al*., 2011) to 4.90% (Morales-Medina *et al*., 2016) in the north-western Mediterranean where it is 2.36% in *T. mediterraneus* (Fernandez-Jover *et al*., 2007), while it is 1.13% in the Black Sea (Turan *et al*., 2007). In *T. picturatus*, it is 1.70% in the Aegean Sea (Zlatanos and Sugredos, 1993) and 1.87% in the north-east Atlantic (Nogueira *et al*., 2013). The aforementioned values are all lower than the obtained results on the south-western Mediterranean coast, confirming the effect of geographical location on lipid content in fish (Winston and Di Giulio, 1991).

Additionally, fish are classified by Haard (1992) as following: high-fat (lipid content ≥8%), medium-fat (4% ≤lipid content <8%), low-fat (2% ≤lipid content <4%) and lean (lipid content <2%). Based on these intervals, our results indicate that *T. trachurus* is medium-fat fish, contrary to *T. mediterraneus* and *T. picturatus* which are considered as low-fat fish. Fatty acids are key organic components of fish, serving as important energy sources for growth, reproduction and locomotion (Tocher, 2003). They are also essential to animal and human nutrition due to their role in essential physiological processes.

Table 3. Nutritional quality assessment of *Trachurus trachurus*, *Trachurus mediterraneus* and *Trachurus picturatus*

Nutritional indices	*T. trachurus*	*T. mediterraneus*	*T. picturatus*
AI	0.50 ± 0[a]	0.95 ± 0[b]	0.45 ± 0[c]
TI	0.26 ± 0[a]	0.97 ± 0.08[b]	0.30 ± 0[a]
HH	2.50 ± 0.02[a]	1.12 ± 0[b]	2.43 ± 0.02[c]
n6 – to – n3 ratio	0.15 ± 0[a]	0.36 ± 0[b]	0.14 ± 0[a]

AI, atherogenic index; TI, thrombogenicity index; HH, hypocholesterolemic-to-hypercholesterolemic ratio and *n*6-to-*n*3 ratio.
Data are means of triplicate determinations ± standard deviation: the different letters indicate significant differences between indices for each species.

Fatty acid profile

The results obtained for the main FAMEs groups confirm that the fatty acid profile differs from one species to another. *Trachurus trachurus* is considerably richer in SFA than in both MUFA and PUFA. These results vary in comparison with those obtained in Alboran Sea (SFA: 32.8%, MUFA: 29.6% and PUFA: 36.2% or DHA and EPA present together 27.9%) by Morales-Medina *et al*. (2016) and on the Italian coast (SFA: 37.55%, MUFA: 24.49% and PUFA: 32.69%, where DHA and EPA represent 20.85 and 5.29% respectively) by Orban *et al*. (2011). Results concerning the composition of FAMEs in *T. mediterraneus* differ from those found by Turan *et al*. (2007) in the Black Sea (SFA: 25.9%, MUFA: 28.2% and PUFA: 27.9% of which 21.7% correspond to DHA and EPA as one), and Fernandez-Jover *et al*. (2007) (SFA: 36.04–36.10%, MUFA: 14.62–17.39% and PUFA: 45.98–49.28% of which 32.56–36.61% correspond to EPA and 5.83–6.18% correspond to DHA) in two localities in the North-West Mediterranean. In the case of *T. picturatus*, Nogueira *et al*. (2013) recorded in the North-East Atlantic, 33.67% SFA, 26.11% MUFA and 40.22 PUFA with 4.10% EPA and 28.46% DHA. Thus, Zlatanos and Sugredos (1993) found, in the same species, 5.9% EPA and 9.5% DHA in the Aegean Sea (Table 4).

The highest SFA and MUFA values were recorded in *T. mediterraneus*. These are mainly palmitic and oleic acids. Palmitic acid is a long-chain SFA often found in many kinds of fats and dietary oils. Although excessive consumption of SFA is generally associated with negative effects on cardiovascular health, it is

Table 4. Comparison of lipid content (g\100 g muscle of fish) and fatty acid profile (g\100 g fatty acid) of *T. trachurus*, *T. mediterraneus* and *T. picturatus* in different areas

Species	Lipid content	SFA	MUFA	PUFA	EPA	DHA	Study area	Source
T. trachurus	4.9	32.8	29.6	36.2	27.9		Alboran Sea	Morales-Medina *et al.* (2016)
	2.10	37.55	24.49	32.69	5.29	20.85	Italian coast	Orban *et al.* (2011)
	5.06	35.1	32.81	32.1	7.34	19.55	S-W Mediterranean	Present study
T. mediterraneus	1.13	25.9	28.2	27.9	21.7		Black Sea	Turan *et al.* (2007)
	2.36	36.10	14.62	49.28	6.18	32.56	Alicante (N-W Mediterranean)	Fernandez-Jover *et al.* (2007)
	2.36	36.04	17.39	45.98	5.83	36.61	Villajoyosa (N-W Mediterranean)	
	2.87	53.23	37.65	9.11	1.89	5.52	S-W Mediterranean	Present study
T. picturatus	1.7	37.1	32.1	30.8	5.9	9.5	Aegean Sea	Zlatanos and Sugredos (1993)
	1.87	33.67	26.11	40.22	4.10	28.46	N-E Atlantic	Nogueira *et al.* (2013)
	2.82	37.51	29.24	33.24	6.95	21.63	S-W Mediterranean	Present study

SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; DHA, docosahexaenoic acid and EPA, eicosapentaenoic acid.

important to note that the total fatty acid composition, including unsaturated fatty acids, is also important in assessing the overall impact of fish oil on health (Agostoni *et al.*, 2015). However, oleic acid or omega-6 is known for its various beneficial impacts on humans, including the modulation of inflammatory markers, gastrointestinal functions, insulin sensitivity, blood pressure and even various cancers (Van der Merwe *et al.*, 2013). Nevertheless, *T. trachurus* and *T. picturatus* are richer in PUFA than *T. mediterraneus*. DHA and EPA are omega-3 fatty acids that are associated with multiple human health benefits. These results illustrate the specificity of these two species and the crucial role they could play in a healthy diet to prevent various pathologies (Kugo *et al.*, 2016).

The correlation coefficients obtained from analysing the lipid content of the studied species in relation to their SFA, MUFA and PUFA reveal weak linear relationships among the pairs of variables ($r_{(\text{lipid content, SFA})} = -0587$; $r_{(\text{lipid content, MUFA})} = -0067$ and $r_{(\text{lipid content, PUFA})} = 0446$). This suggests that the fatty acid profile of each species is independent of its lipid content.

The differences recorded in fatty acid profile, in *T. trachurus*, *T. mediterraneus* and *T. picturatus*, compared to previous studies, can be explained by differences in geographical location and environmental factors, notably the availability and quality of ingested prey. Celik *et al.* (2005) reported that the fatty acid composition of a freshwater species caught from lakes of different water temperatures was different. PUFA amounts of the same fish species caught from the lakes of lower temperatures were much higher than those of higher temperatures. According to Winston and Di Giulio (1991), the fatty acid profile of fish generally, and of PUFA especially, is species-specific and is related to many factors, such as environmental and dietary factors. Due to the differences in extraction methods and solvents used in previous studies, we can primarily attribute the variations observed in fatty acid profiles to these technical factors.

Nutritional quality of fatty acids

Ulbricht and Southgate (1991) developed AI and TI to evaluate the fatty acid profile of a food or dietary product and its impact on human cardiovascular health, especially concerning the prevention or promotion of coronary heart disease (Valfré *et al.*, 2003). In this study, the lowest AI value was recorded in *T. picturatus* (0.45), while the lowest TI ones were found in *T. trachurus* (0.26) and *T. picturatus* (0.30). These values indicate that these two species have a significant protective effect against cardiovascular diseases compared to *T. mediterraneus* of the Eastern Algeria. Compared to the other study areas, the values of AI and TI obtained in this study in T. trachurus (0.5 and 0.26, respectively) and T. picturatus (0.45 and 0.30, respectively) are lower. Concerning T. trachurus, AI and TI were estimated at 0.87 and 0.51, respectively, in central Mediterranean of (Giandomenico *et al.*, 2023) and at 0.33 and 1.83 in the southern Adriatic coast of Italy (Orban *et al.*, 2011). Also, Nogueira *et al.* (2013) estimated these indices for *T. picturatus* in Northeastern Atlantic at 0.57 for AI and 1.07 for TI. However, the same index values obtained in this study are higher (AI = 0.95 and TI = 0.97) in *T mediterraneus* compared to those recorded in Alboran Sea (AI = 0.61 and TI = 0.22) (Morales-Medina *et al.*, 2016), and in two localities of southern Spain (Villajoyosa: AI = 0.47, TI = 0.21; Alicante: AI = 0.52, TI = 0.23) (Fernandez *et al.*, 2007). The lower the values of the AI and TI indices, the healthier the food and richer in fatty acids with high nutritional properties (Giandomenico *et al.*, 2023).

Moreover, *T. trachurus* represents the highest HH value (2.50), followed by *T. picturatus* (2.43) and *T. mediterraneus* (1.12). That indicates the high nutritional importance of *T. trachurus* compared with the other studied species, concerning cholesterol metabolism. The value obtained in *T. trachurus* is higher than those estimated in southeastern Adriatic coast of Italy (1.83) by Orban *et al.* (2011) and in central Mediterranean of Italy (1.44) by Giandomenico *et al.* (2023). Thus, Nogueira *et al.* (2013) found a lower value of the same index in *T. picturatus* (1.38) in northeastern Atlantic. Nevertheless, *T. mediterraneus* represents a lower value compared to those estimated in Alboran Sea (1.74) by Morales-Medina *et al.* (2016), and in two localities of southern Spain (Villajoyosa: 2.40, Alicante: 2.16) (Fernandez *et al.*, 2007).

The n6-to-n3 ratio values indicate that *T. trachurus* and *T. picturatus* represent significantly lower values (0.15 and 0.14, respectively) compared to *T. mediterraneus* (0.36). Compared to previous studies, *T. trachurus* represents a more or less different value of this ratio compared to what Orban *et al.* (2011) and Giandomenico *et al.* (2023) found on the Italian coasts (0.13 and 0.25, respectively). Concerning *T. mediterraneus* and *T.*

picturatus, the values found in this study are lower than those estimated on the northwestern coast of Mediterranean by Morales-Medina *et al.* (2016) (0.04) and Fernandez *et al.* (2007) (0.12–0.13) for *T. mediterraneus*, and by Nogueira *et al.* (2013) on the northeastern Atlantic (0.08) for *T. picturatus*. A ratio n6-to-n3 of 3:1 to 4:1 might prevent many diseases characteristic of the diet based on animal proteins (Anses, 2011). Likewise, according to Simopoulos (2010), a n6-to-n3 ratio of 1:1–2:1 appears to be consistent with research on evolutionary aspects of diet, neurodevelopment and genetics.

The obtained values of different indices show that the studied species have not the same importance as a healthy food. *Trachurus trachurus* is the best for cholesterol metabolism, *T. picturatus* is advisable for the prevention of cardiovascular diseases, and *T. mediterraneus* is ranked the best in terms of its omega-3 and 6 content, which makes it beneficial for nutrition and neurodevelopment. These differences between species are highly related to the differences in their fatty acid profiles. Despite these recorded differences, they are all essential for human health and are suggested to be included in human diet on a regular basis.

Data. The data that support the findings of this study are available from the corresponding author, R. Mohdeb, upon reasonable request.

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