Biological Trace Element Research
https://doi.org/10.1007/s12011-019-01925-x

Trace Elements and Fatty Acid Profile of *Argyrosomus regius* (Asso, 1801) from Mediterranean Aquaculture

Nellya Amoussou[1] · Michel Marengo[1,2,3] · Eric Dominique Henry Durieux[3,4] · Caroline Douny[5] · Marie-Louise Scippo[5] · Sylvie Gobert[1,2]

Received: 18 June 2019 / Accepted: 1 October 2019

Abstract

Although *Argyrosomus regius* (Asso, 1801) counts among the most appreciated and increasingly consumed fish species in Europe, little information is available on its flesh quality. This research concerns both healthy aquatic resource diversification and good nutritional quality. It is the first study to evaluate the quality of *A. regius* flesh from Mediterranean aquaculture. It aims to assess the concentration of 19 trace elements and to determine the fatty acid profile of this fish farmed in the Mediterranean Sea and to discuss human exposure risks. The nutritional intake of oligoelements (selenium (Se), zinc (Zn), and chromium (Cr)) and the mean concentrations of contaminants (arsenic (As), barium (Ba), cadmium (Cd), lead (Pb), and tin (Sn)) in *A. regius* muscles are, respectively, above and below recommended regulatory standards set by the international legislation. Additionally, the low fat content in its muscle mass and its high level of docosahexaenoic acid (C22: 6 *n*-3; DHA) and, to a lesser extent, eicosapentaenoic acid (C20: 5 *n*-3; EPA) confers satisfying nutritional qualities. This study allowed to conclude that meager can be considered as a source of seafood with good nutritional qualities for human health.

Keywords Contamination · Trace elements · *Argyrosomus regius* · Fatty acids · Human health

Introduction

Fisheries and aquaculture represent significant resources for hundreds of millions of people around the world, whether as food, income, or livelihoods [1]. The average global fish consumption per year has now reached a record of 20 kg, reflecting the high potential of fish production to participate in global food security [2]. But in recent years, despite the constant increase in world aquaculture production, EU countries have shown a decrease in water species production that involves almost all the raised species. Among the factors penalizing EU fish production, we should highlight a decrease in demand and the presence on the market of competitively priced foreign products. While fish consumption contributes to the intake of compounds such as trace elements (TEs) and fatty acids (FA) which can be essential to the normal physiological functioning of the body, it can also be a vector involved in physiopathological processes [3].

TEs are defined as any element characterized by an average concentration of less than 1 mg kg^{-1} [4]. They are minerals present in biological fluids in very small quantities [5]. In this paper, we will consider as TE any element, whether metallic or not, present in such concentrations. They can be essential (e.g., Cr, Cu, Fe, Li, Mn, Mo, Se, Zn) or non-essential (e.g., Ag, Al, As, Ba, Bi, Cd, Pb, Sb, Sn, U, V). Non-essential elements can become extremely toxic [6] due to their persistence, their high toxicity [7], and their tendency to bioaccumulate [8]. In this way, they could induce adverse effects such as renal dysfunction, lung disease, liver failure, and/or chronic damages to the peripheral nervous system [9]. Therefore, it is important to estimate their composition in food and especially in marine fish which are widely consumed by humans.

✉ Michel Marengo
michel.marengo@stareso.com

1 Centre MARE, Laboratoire d'Océanologie, Université de Liège, Sart-Tilman, B6c, 4000 Liège, Belgium

2 STAtion de REcherche Sous-marines et Océanographiques (STARESO), 20260 Calvi, France

3 UMR 6134 CNRS-UCPP Sciences pour l'Environnement, Université de Corse Pascal Paoli, 20250 Corse, France

4 UMS 3514 CNRS-UCPP Plateforme marine Stella Mare, Université de Corse Pascal Paoli, 20620 Biguglia, France

5 Faculté de Médecine vétérinaire, Laboratoire d'Analyse des Denrées Alimentaires, Université de Liège, Avenue de Cureghem 10, Bât B43B, Sart-Tilman, BE-4000 Liège, Belgium

Published online: 17 October 2019

Among the essential nutritional contributions to humans, the family of lipids is also considered as essential to the development and functioning of the human body. Fish lipids are well known to be rich in long-chain *n*-3 polyunsaturated fatty acids, especially eicosapentaenoic acid (EPA or C20:5 *n*-3) and docosahexaenoic acid (DHA or C22:6 *n*-3 DHA) which play a vital role in the human nutrition [10]. They are called semi-essential because they can be synthesized by the human body only in small amounts and thus may have to be supplied at least in part by the diet. When they are not present in sufficient quantities in the diet, they could be at the origin of important disorders [11], in particular cardiovascular disorders [12, 13]. In view of all the above, a convenient knowledge of the level of TEs and the nutritional value of FA appears as essential.

Argyrosomus regius (Asso, 1801) commonly known as "meager" is a carnivorous fish species that can be found along the Atlantic coast of Europe [14], the East African coast, and the Mediterranean Sea and the Black Sea. It is an emerging species regarding the diversification of European aquaculture due to its attractive and competitive biological attributes. These include its zootechnical performance [15] with a fast growth rate of ~ 1 kg per year in temperatures between 17 and 21 °C, its resistance to diseases [16], its low feed conversion ratio of 0.9–1.2, its good flesh quality [17] including low fat content and excellent taste, and finally, its high economic value [18]. With 14,000 tons per year, it is one of the most produced fish in the Mediterranean region [19, 20].

In view of all these characteristics, meager seems to be an ideal candidate for aquaculture. However, there are only a few studies available on the ecotoxicology and the nutritional composition of meager in the Mediterranean Sea. Studies of TE contamination of meager flesh have already been discussed in the Gironde estuary [21] and in Portugal [6]. Studies regarding its nutritional composition were also conducted in Portugal [17], Italy [22], Spain [23], and Greece [14].

The present study aims (i) to determine the concentrations of 19 TEs in the muscle of *A. regius* produced in the Mediterranean Sea; (ii) to estimate the weekly intake of these trace elements; (iii) to characterize the quality of the fatty acids; and (iv) to evaluate the potential risks related to its consumption.

Material and Methods

Area of Study and Sample Collection

Thirty cultured specimens of *Argyrosomus regius* (Asso, 1801) were purchased from a fish farm located on the Corsican coast in December 2016. The method of slaughter was by immersion in ice-cold water (hypothermia). The exact location of the farm cannot be provided in order to preserve anonymity, complying with the wishes of the fish farmers.

Corsica is considered as a reference zone in the Mediterranean due to the quality of its waters and the low fishing pressure [24]. The surroundings of the island represent an ideal area to monitor the quality of the flesh (fatty acid composition, survey, and changes in the concentration of contaminants related to the development of coastal areas).

The average length and weight for the 30 sampled individuals were 65 ± 4 cm and 3.04 ± 0.33 kg, respectively. A sample of dorsal white muscle (the most commonly consumed part of the fish) of average weight 12.81 ± 1.83 g (wet weight (ww)) was taken from each fish. Tissues were frozen at − 20 °C until analysis in the laboratory.

Trace Elements

Analysis

Before TE analysis, samples were thawed and cleaned with ultrapure water (MilliQ). Samples were mineralized using Teflon digestion vessels, in a closed microwave digestion lab station (Ethos D, Milestone Inc.), using hydrogen peroxide and nitric acid as reagents (Suprapur grade, Merck). Overall, 19 TEs (Ag, Al, As, Ba, Bi, Cd, Cr, Cu, Fe, Li, Mn, Mo, Pb, Sb, Se, Sn, U, V, Zn) were analyzed by inductively coupled plasma mass spectrometry using dynamic reaction cell technology (ICP-MS ELAN DRC II, Perkin-Elmer according to [25]. The trace element detection limits in mg kg^{-1} dry weight were as follows: Ag = 0.0024; Al = 0.1400; As = 0.0200; Ba = 0.0039; Bi = 0.0028; Cd = 0.0054; Cr = 0.0137; Cu = 0.0400; Fe = 0.9000; Li = 0.0090; Mn = 0.0100; Mo = 0.0041; Pb = 0.0273; Sb = 0.0200; Se = 0.1900; Sn = 0.0090; U = 0.0002; V = 0.0033; Zn = 0.1000. Analyses were performed according to the method described in [25]. The purity of the chemicals used was verified by running a number of chemical blanks and no evidence of contamination was found. Analytical quality control was achieved using Certified Reference Materials (CRM) including DOLT-3: dogfish liver, NIST 1566b: oyster tissue, NIST 1577c: bovine liver, and NIST 2976: mussel tissue. The results obtained on the Certified Reference Materials were consistent with the certified values for all TEs. For each TE, detection limit (LD) and quantification limit (LQ) were calculated, depending on their specific blank distribution [26] and both were expressed in milligrams of element per kilogram of wet weight (mg kg^{-1} ww) [24].

Risk Evaluation

Risk of TE (only available for Al, Cd, and Sn) intake was estimated for a 70-kg person and was calculated considering the respective levels found in *A. regius* and a weekly consumption rate of 427 g (defined for European population) [2]. The estimated monthly intake (EMI, mg kg^{-1} body weight) and estimated weekly intake (EWI, mg kg^{-1} body weight) have been calculated [27–30]. EMI values for the Cd [31] and EWI for the other elements were determined using the following equations:

$$\mathrm{EMI} = (\mathrm{Cm} \times \mathrm{IRm})/\mathrm{BW}$$
$$\mathrm{EWI} = (\mathrm{Cm} \times \mathrm{IRw})/\mathrm{BW}$$

Cm represents the TE concentration in fish (mg kg^{-1}), IRm the monthly ingestion rate (kg), IRw the weekly ingestion rate (kg), and BW the body weight (kg). In order to assess public health risks, these calculated intakes were compared with the provisional tolerable intake. Monthly (PTMI) and provisional tolerable weekly intake (PTWI) recommended by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) [30]. These latter indices provide safe exposure levels used to estimate the amount of contaminants that could be ingested over a lifetime without appreciable risk [32].

According to the regulatory guidelines established by the FAO/WHO Expert Committee on Food Additives, the PTMI of Cd was set at 25 μg kg^{-1} body weight $week^{-1}$ [33, 34]. PTMI of Cd for a 70-kg person represents 1750 μg $week^{-1}$ [29]. In addition, we calculated and compared the daily ingestion of various TEs (Al, Cd, and Sn). In order to discriminate contamination levels according to meager origin, data from this study (farmed meager) were compared with the available data in literature (wild meager) considering the concentrations of six trace elements (As, Cd, Cu, Fe, Pb, and Zn).

Fatty Acids

To determine the fatty acid (FA) content, fifteen samples of fish muscle were analyzed. Lyophilized samples were finely ground with a pestle before weighing about 1 g of material in 50 ml Falcon tubes. The fat content of the weighed material was then extracted with a mixture of solvents, followed by saponification-methylation of the FA and gas chromatography coupled with mass spectrometry analysis (GC-MS).

Extraction

The extraction protocol was adapted according to [35]. A volume of 10 ml of an acetone/hexane (50/50) mixture was added to each tube containing the muscle of the fish. Each tube was vortexed before being placed in a rotative agitator for 1 h. Then, 5 ml of water was added and samples were vortexed and centrifuged (10 min, 3700*g*). The organic phase was transferred into a new tube. The extraction procedure was repeated a second time with 5 ml of hexane. Both organic phases were combined and 5 ml of it was poured in dry weighed tubes. The solvent was evaporated to dryness in an oven at 60 °C overnight. Fat content was finally determined by weighing the tubes and the samples were stored at − 80 °C until saponification of the fat.

Saponification and Methylation of the Fat

The fatty acid profile of fish muscle was determined by analysis of the fatty acid methyl esters (FAME) by gas chromatography-mass spectrometry (GC-MS) according to [36]. The method involves the saponification and methylation of the fat extracted from fish samples, in the presence of an internal standard (nonadecanoic acid, C19:0), followed by two extractions with hexane. Fatty acid methyl esters were separated on a Focus GC gas chromatograph (Thermo Fisher Scientific) on a CP-Sil88 column for FAME (Varian, 100 m × 0.25 mm, 0.2 mm) and analyzed with an ion trap PolarisQ mass spectrometer (Thermo Fisher Scientific). The GC parameters were as follows: inlet at 250 °C, splitless injection, helium as carrier gas at 1.5 ml/min; temperature program − 55 °C for 1 min, followed by an increase of 5 °C/min to 180 °C, then 10 °C/min to 200 °C, 200 °C for 15 min, then a rise of 10 °C/min to 225 °C, and 225 °C for 14 min; the total run time was 59.50 min; injection volume was 1 μl. The peaks were identified by comparing their mass spectrum and retention times with those of the corresponding standards. The mass spectrum conditions were as follows: transfer line at 250 °C; ion source at 220 °C; collision energy at 35 eV, positive ionization mode. Fatty acid methyl esters were detected using selected ion monitoring (SIM) mode in five segment windows. In each chromatographic run, different ions were monitored for each analyzed fatty acid, which allowed detecting and quantifying *m/z* 101 and 143 for saturated fatty acids (SFA), and 79 and 91 for monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), respectively. The respective sums of SFA, MUFA, and PUFA were expressed as the percentage of the total fatty acids.

Meager Nutritional Contribution

The nutritional intake of meager consumption was estimated by taking into account concentrations of essential trace elements (Fe, Cr, Cu, Mn, Mo, Se, and Zn) and the sum of fatty acids (EPA and DHA).

Fish consumption in the Mediterranean is about 20 kg per capita per year, which represents 60 g of fish per capita per day. The nutritional contribution was calculated based on the formula of [17].

$$\%\mathrm{NC} = [(C \times M) \div (\mathrm{DRI})] \times 100$$

where C is the mean concentration of the mineral or contaminant (mg kg^{-1}); M is the meal portion consumed (kg).

Dietary reference intake (DRI) values were established by the European Food Safety Authority [37] and the national academies, engineering, and medicine [38].

Regarding EPA and DHA, the recommended intake preventing cardiovascular disease ranges from 250 to 500 mg/day for the sum of the 2 fatty acids [37] .

Statistical Analysis

Data were analyzed using R and XLSTAT software [39]. Descriptive statistics (mean, standard deviation, minimum and maximum) were applied. All TE data were checked beforehand, for goodness of fit to a normal distribution with Shapiro-Wilk test and homogeneity of variance using a Bartlett test. Data were natural log-transformed in order to better meet the assumptions of standard parametric statistical test, to reduce the effect of outliers on skewed data distribution, and to bring elemental concentrations within the same range. TE concentrations that were found to be below their analytical LD were considered as half of the LD value during data statistical treatment. The correlation analysis is a useful tool for analyzing similarities between paired data and is widely used in trace metal data analysis [40]. Spearman correlations were used to investigate the relationship between TE levels (inter-elementary correlations), setting a p value for significance at 0.05.

Results

Trace Elements

The respective mean concentrations of TEs in the meager muscle tissues are presented in Table 1. Variance analysis showed a large variability ($p < 0.05$) between element concentrations (Fig. 1) with concentrations ranging from < LD (Ag, U, and V) to 4.5 ± 0.7 mg kg^{-1} ww (Zn). The distribution pattern in TE concentrations follows the sequence Zn > Fe > Al > Sb > Cu > Se > As > Mn > Sn > Ba > Li > Cr > Pb > Mo > Cd > Bi > V > U > Ag with considerably higher concentrations of zinc (Zn) and iron (Fe). In contrast, concentrations of U, V, and Bi were very low and below the ICP-MS detection limit.

Various degrees of correlations, both negative and positive, were found between the elements (Table 2). For instance, positive correlations ($p < 0.001$) were found between Ba-Al (r = 0.75), Zn-Fe (0.78), Zn-Cu ($r = 0.79$), and Fe-Cu ($r = 0.93$), while Sn-Pb concentrations showed a negative correlation ($p < 0.05$).

Average levels of some non-essential trace elements (in mg kg^{-1}ww) from meager muscles of the study correspond to As 0.240, Ba 0.019, Cd 0.001, Pb 0.004, and Sn 0.063. They were always below (corresponding respectively to 2, 95, 0.05, 0.3, and 250).

Table 1 Mean and standard deviation (mean ± SD) and range (minimum and maximum values) of trace element (essential and non-essential) concentrations (mg kg^{-1} wet weight) in the muscle of meager

	Trace element	Mean ± SD	Min	Max
Essential	Fe	2.8 ± 1.8	0.9	8.5
	Cr	0.011 ± 0.008	0.002	0.041
	Cu	0.29 ± 0.20	0.11	1.00
	Li	0.017 ± 0.005	0.010	0.034
	Mn	0.16 ± 0.30	0.04	1.50
	Mo	0.001 ± 0.000	0.001	0.002
	Se	0.273 ± 0.025	0.220	0.361
	Zn	4.5 ± 0.7	3.4	6.7
Non-essential	Ag	< LD	< LD	< LD
	Al	0.54 ± 0.63	0.08	2.38
	As	0.240 ± 0.055	0.136	0.369
	Ba	0.019 ± 0.019	0.004	0.070
	Bi	< LD	< LD	0.001
	Cd	0.001 ± 0.002	< LD	0.011
	Pb	0.004 ± 0.003	< LD	0.014
	Sb	0.448 ± 0.438	0.095	1.677
	Sn	0.063 ± 0.070	0.001	0.266
	U	< LD	< LD	0.001
	V	< LD	< LD	0.002

The PTWI values recommended by the expert committee on food additives (joint FAO/WHO Expert Committee on Food Additives) [29] were used to compare the estimated weekly intakes of TEs in this study (Table 3). The As, Cd, Cr, Cu, Fe, Pb, Sn, and Zn intakes that were calculated taking into account the mean contamination levels constituted only 9.8%, 0.09%, 0.10%, 0.01%, 0.05%, 0.31%, 0.01%, and 0.39%, respectively, of the PTWI kg^{-1}, indicating that consumption of such seafood can be considered safe.

Fatty Acids

Results for fatty acid (FA) composition of *A. regius* are presented in Table 4. The analysis revealed that the average muscle lipid content was 1.1 ± 0.9%, ranging from 0.4 to 3.0% ($n = 15$).

The fatty acid contribution (Fig. 2) shows that polyunsaturated FA (PUFA) counts for 55.5% of the total fatty acids, compared with SFA (26.8%) and MUFA (17.7%). This heat map shows that the dominant fatty acids were C16:0 (palmitic acid), C14:0 (myristic acid), C18:0 (stearic acid), C16:1 (palmitoleic acid), C18:1 (oleic acid), C18:2 n-6 (linoleic acid), C20:5 n-3 (eicosapentaenoic acid (EPA)), and C22:6 n-3 (docosahexaenoic acid (DHA)). More precisely, palmitic acid (C16:0), myristic acid (C14:0), and stearic acid (C18:0) were

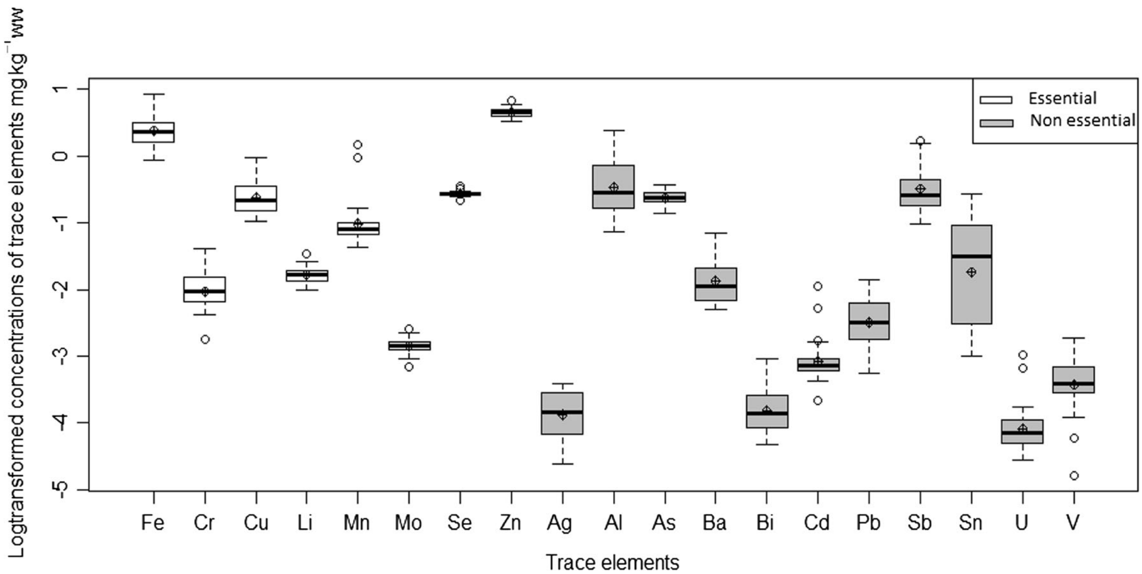

Fig. 1 Boxplot of the 19 trace elements in the muscles of *Argyrosomus regius* caught in Corsica

the major saturated FA (SFA) followed by the monounsaturated FA oleic acid (C18:1). Indeed, these 3 predominant SFA constituted approximately 98% of the total SFA content of the lipids contained in the meager muscle tissue.

Among the polyunsaturated FA, the *n*-3 series (∑ *n*-3 = 42.5%) were predominant compared with the *n*-6 series. They are mainly represented by DHA (23.7 ± 6.3%) and EPA (11.5 ± 1.7%), which together represented at least 64% of all PUFA. Related indices (*n*-3/*n*-6; EPA/DHA) used to assess the nutritional value of the muscle lipid fraction are also shown in Table 4. The *n*-3/*n*-6 and EPA/DHA ratios indicate the proportion of fatty acid in *n*-3 relative to that in *n*-6 contained in the fish lipids. For meager, ratios correspond to 3.3 ± 0.6% (*n*-3/*n*-6) and 0.5 ± 0.2% (EPA/DHA). Therefore, both *n*-3/*n*-6 and EPA/DHA ratios were favorable in terms of nutritional value in the meager muscle.

Potential Benefits of Meager Consumption

Essential element concentrations could vary, depending on the sex. The dietary reference intake (DRI) of some elements can be different between male and female (e.g., Fe, Table 5). Most contributing essential TEs are selenium (Se = 191%), followed by zinc (Zn = 22%) and chromium (Cr = 17%). The results also revealed that meager consumption may provide 71% of the recommended daily intake of essential fatty acids (EPA + DHA).

Discussion

In this paper, the contamination level (non-essential TEs) and the quality (essential TEs and fatty acid composition) of *Argyrosomus regius* muscle from aquaculture has been assessed.

Trace Elements

The concentration levels of essential TEs (Zn > Fe > Cu > Mn) in meager muscle found in this study are similar to those described in the literature [41]. Mean Zn concentration (4.5 ± 0.7 mg kg^{-1} ww) is also consistent with data measured in fish from conventional aquaculture (5.3 ± 0.4 mg kg^{-1} ww) [17]. Zn levels in fish muscle depend on several parameters such as sex [24], diet [6], and the type of food [42]. In addition, the results of this study (Table 5) are in agreement with those of [17] and confirm that meager is a good source of essential elements such as Se, highly recommended for the prevention of cardiovascular disease and the optimization of life span [43].

Unlike essential metals, biological functions of Pb, Cd, V, and U remain unknown. Moreover, these elements could be harmful for living organisms even at low concentration [44]. However, in this study, concentrations for Pb and Cd elements were much lower than the limits established by European legislation and the food safety regulations namely 0.3 mg kg^{-1} and 0.050 mg kg^{-1}, respectively ([45] and its amendments).

Results suggest a large difference in the TE composition between farmed and wild meager. Indeed, the comparison of TE concentration measure in our farmed meager with those found in meager from the natural environment [45] showed that muscles of wild fish may contain up to 50, 44, 35, 5, and 4 times more Cd, As, Pb, Zn, and Fe, respectively. In contrast to farmed fish, the high trace element content in wild fish may be influenced by many exogenous factors (e.g., food sources, spatial distribution) reflecting environmental conditions [46].

Table 2 The Pearson correlation matrix between trace element concentrations (inter-relationship) and fish weight in the muscle of meager

TEs	Ag	Al	As	Ba	Bi	Cd	Cr	Cu	Fe	Li	Mn	Mo	Pb	Sb	Se	Sn	U	V
Ag																		
Al	0.25																	
As	0.17	0.32																
Ba	0.18	0.75***	0.21															
Bi	0.50	0.18	0.10	−0.11														
Cd	0.13	0.07	0.04	0.01	−0.16													
Cr	0.21	0.08	−0.07	0.13	0.16	−0.03												
Cu	0.16	0.01	0.17	0	0.01	0.26	0.01											
Fe	0.15	0.17	0.11	0.16	−0.01	0.23	0.07	0.93***										
Li	0.14	0.30	−0.29	0.65*	−0.22	0.09	0.07	0.25	0.35									
Mn	−0.04	0.27	0.10	0.65*	−0.25	−0.11	0.04	0.05	0.12	0.65*								
Mo	0.17	0.12	−0.08	0.13	0.03	0.39	0.01	0.56	0.62*	0.36	0.04							
Pb	0.28	0.44	0.21	0.44	−0.04	0.48	−0.08	0.23	0.23	0.39	0.08	0.27						
Sb	0.15	0.55	0.31	0.73***	−0.11	0.32	0.11	0.07	0.15	0.32	0.12	0.13	0.57					
Se	−0.31	−0.10	−0.06	−0.38	0.03	0	−0.01	0.10	−0.01	−0.38	−0.43	−0.01	0.09	−0.16				
Sn	0.09	−0.25	−0.28	−0.25	0.18	−0.54	0.03	−0.19	−0.16	−0.24	−0.05	−0.06	−0.59	−0.51	−0.18			
U	0.11	0.44	−0.09	0.78***	−0.16	−0.06	0	0	0.10	0.79***	0.88***	0.07	0.17	0.28	−0.50	−0.07		
V	0.44	0.65*	0.20	0.72**	−0.03	0.11	0.26	0.06	0.19	0.54	0.45	0.12	0.30	0.48	−0.55	−0.17	0.61	
Zn	0.11	0.19	0.23	0.27	−0.06	0.38	0.15	0.78***	0.79***	0.32	0.19	0.62*	0.49	0.37	0.16	−0.39	0.09	0.16

*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Table 3 Intake estimation for trace elements in meager. Provisional tolerable monthly intake (PTMI-1 kg) in μg/week/kg body weight. Provisional tolerable monthly intake (PTMI-70 kg) in μg/week/70 kg body weight is followed by an asterisk (*). Provisional tolerable weekly intake (PTWI-1 kg) in μg/week/kg body weight. Provisional tolerable weekly intake (PTWI-70 kg) in μg/week/70 kg body weight. Estimated monthly intakes (EMI) in μg/week/70 kg body weight is followed by an asterisk (*). Estimated weekly intakes (EWI) in μg/week/70 kg body weight

Elements	PTMI*-1 kg/PTWI-1 kg	PTMI*-70 kg/PTWI-70 kg	EMI*/EWI
Al	2000	140,000	0.003320318
Cd	25*	1750*	0.000812088*
Sn	14,000	980,000	0.0003843

Considering the trophic level, the diet, and the spatial distribution of the meager, it is important to mention its potential exposure to the trace elements including mercury (Hg) (not analyzed in this study). Mercury is one of the most persistent metal contaminant [47]. Due to its high affinity for thiol groups (present in key peptides and proteins), Hg accumulation can cause deleterious effect [48] and ultimate mortality [49]. The mean Hg concentrations in meager muscle determined by [50, 51] correspond to 0.255 mg kg^{-1} and 0.251 mg kg^{-1}, respectively. They are above recommended regulatory standards for human health. However, in contrast to previous data that showed high concentrations of Hg in *A. regius* muscles, a recent study by [52] revealed that under heat stress, meager would be weakly concentrated in mercury, which would induce a relatively moderate effect of the contaminant on human health. The fact that meager is a very resilient species that adapts easily to environmental changes [53] may explain these lower effects following exposure.

In our study, correlation analysis between TEs was conducted (Table 2). Various degrees of mutual correlations were found between Ba-Al, Zn-Fe, Zn-Cu, and Fe-Cu. Consistently to our results, many studies reported positive inter-correlations among these same TEs [54, 55]. These inter-correlations between the different elements may result from the similar accumulation behavior and/or may reflect a common source of occurrence [56].

According to [57], meager is also a good source of selenium (Se). Se is essential for the normal functioning of enzymes that protect brain and endocrine tissues from oxidative damage [58]. In addition, selenium has a natural mercury antagonistic effect that may neutralize the symptoms of high exposure to this contaminant [51].

Fatty Acids

Lipids play an important role in fish development and metabolism by the production of energy and essential fatty acids [59, 60]. Overall, measured lipid content values correspond to other data found for this species [61] which confirm that lipid contents of *A. regius* are very different from the other European species (in particular sea bass, gilthead sea bream, and trout), in which higher percentages of fat (from 2 to 5 times) occur [62–66]. The farming condition (organic aquaculture) could have influenced the diet and consequently increased this low lipid content in the meager muscle [67].

Total saturated fatty acid (SFA) content of meager was higher than MUFA. SFA is probably used by meager SFA for energy production and its high levels may result from a lipogenic activity [68]. Similar results have been reported

Table 4 The fatty acid profile in the muscle of the meager grown in Corsica (% of total fatty acids). Values are mean ± SD and expressed as g/100 g (for total lipids) or as percentages of total fatty acids (for fatty acids)

Fatty acids	Mean ± SD	Min	Max
Capric acid (C10:0)	0.3 ± 0.0	LOQ	0.4
Lauric acid (C12:0)	LOQ	LOQ	LOQ
Tridecyl acid (C13:0)	LOQ	LOQ	LOQ
Myristic acid (C14:0)	2.2 ± 1.3	0.6	4.5
Palmitic acid (C16:0)	17.1 ± 3.9	12.3	24.9
Heptadecanoic acid (C17:0)	0.4 ± 0.1	LOQ	0.7
Stearic acid (C18:0)	6.9 ± 1.7	4.4	10.9
Arachidic acid (C20:0)	0.3 ± 0.0	LOQ	0.3
Docosanoic acid (C22:0)	LOQ	LOQ	LOQ
Lignoceric acid (C24:0)	LOQ	LOQ	LOQ
∑ Saturated fatty acids (SFA)	26.8		
Palmitoleic acid (C16:1), *n*-7	2.9 ± 1.7	1.1	6.3
Heptadecenoic acid (C17:1), *n*-7	0.8 ± 0.5	LOQ	1.8
Oleic acid (C18:1), *n*-8	14.0 ± 3.9	11.5	24.7
∑ Monounsaturated fatty acids (MUFA)	17.7		
Linoleic acid (C18:2), *n*-6	10.1 ± 1.3	8.0	11.3
Gamma linolenic acid (C18:3), *n*-6	0.4 ± 0.2	LOQ	0.6
Eicosadienoic acid (C20:2), *n*-6	0.5 ± 0.1	LOQ	0.6
Arachidonic acid (C20:4), *n*-6	2.6 ± 1.1	1.1	4.5
Alpha linolenic acid (C18:3), *n*-3	1.2 ± 0.8	0.5	3.0
Octadecatetraenoic acid (C18:4), *n*-3	0.4 ± 0.2	LOQ	0.7
di-Homo-ɣ-linolenic acid (C20:3), *n*-3	0.7 ± 0.1	LOQ	0.7
Eicosapentaenoic acid (C20:5; EPA), *n*-3	11.5 ± 1.7	6.8	13.7
Docosapentaenoic acid (C22:5), *n*-3	5.6 ± 1.1	3.9	7.8
Docosahexaenoic (C22:6; DHA), *n*-3	23.8 ± 6.3	13.9	34.1
∑ Polyunsaturated fatty acids (PUFA)	55.5		
EPA + DHA	0.3		
∑ *n*-3	42.5		
∑ *n*-6	13.0		
n-3/*n*-6 ratio	3.3 ± 0.6	1.1	4.1
EPA/DHA ratio	0.5 ± 0.2	0.3	0.9
Total lipids	1.0 ± 0.43	0.5	1.8

LOQ inferior to the lower limit of quantification (0.1% of total fatty acids)

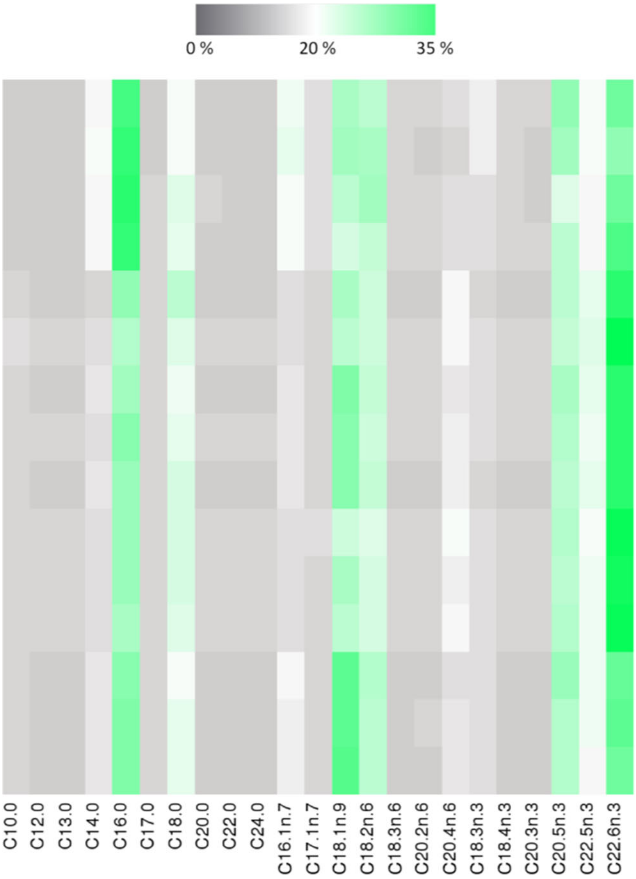

Fig. 2 Heat map representing the relative abundance (%) of fatty acids in the in the muscle of meager

previously for the European sea bass [10, 69, 70]. Although significant amounts of MUFA and SFA were found, PUFA were the main fraction in all samples, suggesting that SFA and MUFA could promote the improvement of PUFA muscle deposition [71]. These results agree with those from [17].

Among the PUFA, *n*-3 series were 3 times more abundant than *n*-6 series (ratio *n*-3:*n*-6 > 1). Overall, *n*-6 FA were present in lower quantities than other FA groups in meager muscle. The amount of *n*-6 FA in farmed fish could be related to the feed ingredients [61, 69]. Due to their reduced capacity for chain elongation and desaturation, *n*-6 FA accumulate largely unchanged in the lipids of marine fish [70]. That situation seems to be a characteristic common to most marine fishes, in particular, meager [23]. They contain lower quantities of SFA compared with PUFA [72]. This study revealed that the most abundant *n*-3 PUFA in muscle tissue were DHA and EPA. They are vital constituents for cell membrane structure and function [54, 55, 68]. These results were in accordance with those of [17, 67] for the same species. Indeed, meager was shown to have a rich PUFA content, particularly DHA [73]. So, the higher levels of PUFA in phospholipids indicate their preferential incorporation.

The *n*-3/*n*-6 and EPA/DHA ratios are useful indicators for comparing the nutritional value of nutritional resources [74]. High ratios of *n*-3/*n*-6 play an important role in human health as these prevent and reduce human cardiovascular diseases [36, 75], which represent the second cause of death in France after cancer [76]. Indeed, *n*-3 PUFA reduces cardiac frequency [62, 63], (improves vascular function, reduces plasma 20-hydroxyeicosatetraenoic acid and blood pressure in patients with chronic kidney disease) [77]. Furthermore, in the present study, it prevents human coronary diseases [78], increases sensitivity to insulin [79], and reduces arterial stiffness [80]. Inadequate dietary levels of PUFA can lead to different kinds of skeletal malformations, an excess of PUFA accelerated osteoblast differentiation, leading to a

Table 5 Nutritional contribution (%) of meager in terms of essential elements and EPA and DHA, taking into account a meal of 60 g

	Adult consumers	DRI (mg)	*C* (mg/kg)	*M* (kg)	% NC
Essential elements					
Fe	Male	8	2.815	0.385	14
	Female	18	2.815	0.385	6
Cr	Male/female	0.025	0.011	0.385	17
Cu	Male/female	0.9	0.285	0.385	12
Mn	Male	1.8	0.161	0.385	3
	Female	2.3	0.161	0.385	3
Mo	Male/female	0.045	0.001	0.385	1
Se	Male/female	0.055	0.273	0.385	191
Zn	Male	11	4.519	0.385	16
	Female	8	4.519	0.385	22
n-3 Fatty acids					
EPA + DHA	Male/female	250–500	3230	0.055	71

DRI dietary reference intake, *C* mean concentration of the element, *M* meal portion consumed, *NC* nutritional contribution supernumerary vertebra [81]. Furthermore, it was found that the *n*-3/*n*-6 ratio was high. These values are similar to those found by Alasalvar et al., in cultured European sea bass. Similarly to the *n*-3/*n*-6 ratio, the EPA/DHA ratio was high (1:1). A high ratio has also been detected in the muscle of sea bass and sea bream fed on diets with high proportions of vegetable oils in [82]). Therefore, both *n*-3/*n*-6 and EPA/DHA ratios were high in terms of nutritional value in the meager muscle. Consequently, meager can be a considerable source of essential fatty acids. Indeed, this study shows that up to 71% of the daily recommended intake for semi-essential fatty acids (EPA + DHA) can be covered by the consumption of 20 kg of meager per capita per day.

Conclusion

In this paper, we analyzed the concentrations of 19 TEs (essential and non-essential) and characterized the profile of the fatty acids in the muscle tissue of *Argyrosomus regius* from Mediterranean organic aquaculture. Analytical data for non-essential TEs obtained from this study are below regulatory standards and thus suggest that farmed meager in the Mediterranean Sea/Corsica presents no risk for human health. Regarding fatty acids, the high level of PUFA, more specifically EPA and DHA (semi-essential fatty acids), found in this fish species compared with those reported in other marine species, shows that meager is a significant source of polyunsaturated fatty acids. Additionally, high nutritional content in selenium was found in muscle tissue. Although in this study, mercury analysis was not taken into account, in view of all the above, we conclude that meager can be considered as a source of seafood with good nutritional properties for human health. This does not exclude a permanent and effective monitoring of their production in order to guarantee sustainable healthy foods.

Funding Information This research was funded by the "Agence de l'eau Rhône Méditerranée Corse" and the "Collectivité de Corse" (CdC), as part of STARECAPMED project research.

References

1. FAO (2018) La situation mondiale des pêches et de l'aquaculture 2018 (SOFIA): atteindre les objectifs de developpement durable. Food & Agriculture Org, Rome
2. FAO (2016) La situation mondiale des pêches et de l'aquaculture 2016: contribuer à la sécurité alimentaire et à la nutrition de tous. FAO, Rome (I)
3. Watanabe T, Kiron V, Satoh S (1997) Trace minerals in fish nutrition. Aquaculture 151:185–207. https://doi.org/10.1016/S0044-8486(96)01503-7
4. Dallinger R, Prosi F, Segner H, Back H (1987) Contaminated food and uptake of heavy metals by fish: a review and a proposal for further research. Oecologia 73:91–98. https://doi.org/10.1007/BF00376982
5. World Health Organization (1996) Trace elements in human nutrition and health. World Health Organization, Geneva
6. Carvalho ML, Santiago S, Nunes ML (2005) Assessment of the essential element and heavy metal content of edible fish muscle. Anal Bioanal Chem 382:426–432. https://doi.org/10.1007/s00216-004-3005-3
7. Cresswell T, Smith REW, Nugegoda D, Simpson SL (2014) Comparing trace metal bioaccumulation characteristics of three freshwater decapods of the genus Macrobrachium. Aquat Toxicol 152:256–263. https://doi.org/10.1016/j.aquatox.2014.04.015
8. Tarley CRT, Coltro WKT, Matsushita M, de Souza NE (2001) Characteristic levels of some heavy metals from Brazilian canned sardines (Sardinella brasiliensis). J Food Compos Anal 14:611–617. https://doi.org/10.1006/jfca.2001.1028
9. Yu M-H, Tsunoda H, Tsunoda M (2016) Environmental toxicology: biological and health effects of pollutants. CRC Press, Boca Raton
10. García Mesa S, Suárez MD, Cervera R, et al (2014) Time course of muscle fatty acid composition of cultured meagre (Argyrosomus regius) during the first sixteen months of a cage culture. 65: https://doi.org/10.3989/gya.049813
11. SanGiovanni JP, Chew EY (2005) The role of omega-3 long-chain polyunsaturated fatty acids in health and disease of the retina. Prog Retin Eye Res 24:87–138. https://doi.org/10.1016/j.preteyeres.2004.06.002
12. Manson JE, Bassuk SS, Lee I-M et al (2012) The VITamin D and OmegA-3 TriaL (VITAL): rationale and design of a large randomized controlled trial of vitamin D and marine omega-3 fatty acid supplements for the primary prevention of cancer and cardiovascular disease. Contemp Clin Trials 33:159–171. https://doi.org/10.1016/j.cct.2011.09.009
13. Mozaffarian D, Katan MB, Ascherio A et al (2006) Trans fatty acids and cardiovascular disease. N Engl J Med 354:1601–1613. DOI. https://doi.org/10.1056/NEJMra054035
14. Grigorakis K, Fountoulaki E, Vasilaki A et al (2011) Lipid quality and filleting yield of reared meagre (Argyrosomus regius): lipid quality & filleting yield of reared meagre. Int J Food Sci Technol 46:711–716. https://doi.org/10.1111/j.1365-2621.2010.02537.x
15. Kružić N, Mustać B, Župan I, Čolak S (2016) Meagre (Argyrosomus regius Asso, 1801) aquaculture in Croatia. Croat J Fish 74:14–19. https://doi.org/10.1515/cjf-2016-0003
16. Foata J, Quilichini Y, Torres J, Pereira E, Spella MM, Mattei J, Marchand B (2009) Comparison of arsenic and antimony contents in tissues and organs of brown trout caught from the river Presa polluted by ancient mining practices and from the river Bravona in Corsica (France): a survey study. Arch Environ Contam Toxicol 57: 581–589. https://doi.org/10.1007/s00244-009-9300-4
17. Costa S, Afonso C, Bandarra NM et al (2013) The emerging farmed fish species meagre (Argyrosomus regius): how culinary treatment affects nutrients and contaminants concentration and associated benefit-risk balance. Food Chem Toxicol 60:277–285. https://doi.org/10.1016/j.fct.2013.07.050
18. Monfort MC (2010) Present market situation and prospects of meagre (*Argyrosomus regius*), as an emerging species in Mediterranean aquaculture. Food and Agriculture Organization of the United Nations, Rome
19. Faliex E, Da Silva C, Simon G, Sasal P (2008) Dynamic expression of immune response genes in the sea bass, Dicentrarchus labrax, experimentally infected with the monogenean Diplectanum aequans. Fish Shellfish Immunol 24:759–767. https://doi.org/10.1016/j.fsi.2008.02.011
20. Antonelli L, Foata J, Quilichini Y, Marchand B (2016) Influence of season and site location on European cultured sea bass parasites in Corsican fish farms using indicator species analysis (IndVal). Parasitol Res 115:561–568. https://doi.org/10.1007/s00436-015-4772-9

21. Durrieu G, Maury-Brachet R, Girardin M et al (2005) Contamination by heavy metals (Cd, Zn, Cu, and Hg) of eight fish species in the Gironde estuary (France). Estuaries 28:581–591. https://doi.org/10.1007/BF02696069
22. Martelli R, Parisi G, Lupi P et al (2013) Effect of rearing system on body traits and fillet quality of meagre (Argyrosomus regius, Asso 1801) chilled for a short time. Ital J Anim Sci 12(4):e30. https://doi.org/10.4081/ijas.2013.e88
23. García Mesa S, Suárez MD, Rincón Cervera MA et al (2014) Time course of muscle fatty acid composition of cultured meagre (Argyrosomus regius) during the first sixteen months of a cage culture. Grasas Aceites 65:e006. https://doi.org/10.3989/gya.049813
24. Gobert S, Pasqualini V, Dijoux J et al (2017) Trace element concentrations in the apex predator swordfish (Xiphias gladius) from a Mediterranean fishery and risk assessment for consumers. Mar Pollut Bull 120:364–369. https://doi.org/10.1016/j.marpolbul.2017.05.029
25. Richir J, Luy N, Lepoint G et al (2013) Experimental in situ exposure of the seagrass Posidonia oceanica (L.) Delile to 15 trace elements. Aquat Toxicol 140–141:157–173. https://doi.org/10.1016/j.aquatox.2013.05.018
26. Currie LA (1999) Nomenclature in evaluation of analytical methods including detection and quantification capabilities:(IUPAC Recommendations 1995). Anal Chim Acta 391:105–126. https://doi.org/10.1016/S0003-2670(99)00104-X
27. FAO (2008) Report of the tenth session of the Scientific Advisory Committee. General Fisheries Commission for the Mediterranean (GFCM). Nicosia, Cyprus, 22–26 October 2007.FAO Fisheries Report No. 856. Rome, FAO. pp 1–144
28. FAO/WHO (2011) Evaluation of certain food additives and contaminants: seventy-third [73rd] report of the Joint FA
29. European Food Safety Authority (EFSA) Panel on Contaminants in the Food Chain (CONTAM) (2011) Statement on tolerable weekly intake for cadmium. EFSA J 9(2):1975. https://doi.org/10.2903/j.efsa.2011.1975
30. JECFA (2011) Safety evaluation of certain food additives and contaminants/prepared by the seventy-third meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA); Geneva pp 305–380
31. Song Y, Wang Y, Mao W et al (2017) Dietary cadmium exposure assessment among the Chinese population. PLoS One 12:e0177978
32. Chamannejadian A, Sayyad G, Moezzi A, Jahangiri A (2013) Evaluation of estimated daily intake (EDI) of cadmium and lead for rice (Oryza sativa L.) in calcareous soils. Iran J Environ Health Sci Eng 10:28. https://doi.org/10.1186/1735-2746-10-28
33. FAO/WHO (2013) Evaluation of certain food additives and contaminants: seventy-seventh report of the Joint FAO/WHO Expert Committee on Food Additives. World Health Organization, Geneva
34. Chunhabundit R (2016) Cadmium exposure and potential health risk from foods in contaminated area, Thailand. Toxicol Res 32:65–72. https://doi.org/10.5487/TR.2016.32.1.065
35. Stefanov I, Vlaeminck B, Fievez V (2010) A novel procedure for routine milk fat extraction based on dichloromethane. J Food Compos Anal 23:852–855. https://doi.org/10.1016/j.jfca.2010.03.016
36. Douny C, El Khoury R, Delmelle J et al (2015) Effect of storage and cooking on the fatty acid profile of omega-3 enriched eggs and pork meat marketed in Belgium. Food Sci Nutr 3:140–152. https://doi.org/10.1002/fsn3.197
37. EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA) (2010) Scientific opinion on dietary reference values for fats, including saturated fatty acids, polyunsaturated fatty acids, monounsaturated fatty acids, trans fatty acids, and cholesterol. EFSA J 8. https://doi.org/10.2903/j.efsa.2010.1461
38. Food and Nutrition Board (2004) Dietary reference intakes (DRIs): recommended intakes for individuals. Inst Med US Natl Acad Wash DC
39. Addinsoft (2019) XLSTAT statistical and data analysis solution. Long Island, NY, USA
40. Chen M, Ma LQ, Harris WG (1999) Baseline concentrations of 15 trace elements in Florida surface soils. J Environ Qual 28:1173–1181. https://doi.org/10.2134/jeq1999.00472425002800040018x
41. Rakocevic J, Sukovic D, Maric D (2018) Distribution and relationships of eleven trace elements in muscle of six fish species from Skadar Lake (Montenegro). Turk J Fish Aquat Sci 18:647–657. DOI. https://doi.org/10.4194/1303-2712-v18_5_01
42. Harlioğlu AG, Yilmaz Ö, Oray IK, Aydin S (2016) A comparison of fatty acid, cholesterol and vitamin composition in sea bass [*Dicentrarchus labrax* (Linnaeus, 1758)] and sea bream [*Sparus aurata* (Linnaeus, 1758)] from three cage farm areas: Antalya and Muğla (Turkey) and İskele (Northern Cyprus). J Appl Ichthyol 32:577–582. https://doi.org/10.1111/jai.13036
43. Zhang L, Zeng H, Cheng W-H (2018) Beneficial and paradoxical roles of selenium at nutritional levels of intake in health span and longevity. Free Radic Biol Med 127:3–13. https://doi.org/10.1016/j.freeradbiomed.2018.05.067
44. Bodin N, Lesperance D, Albert R et al (2017) Trace elements in oceanic pelagic communities in the western Indian Ocean. Chemosphere 174:354–362. https://doi.org/10.1016/j.chemosphere.2017.01.099
45. Chaguri MP, Maulvault AL, Costa S et al (2017) Chemometrics tools to distinguish wild and farmed meagre (*Argyrosomus regius*). J Food Process Preserv 41:e13312. https://doi.org/10.1111/jfpp.13312
46. Orban E, Nevigato T, Lena GD et al (2003) Differentiation in the lipid quality of wild and farmed seabass (Dicentrarchus labrax) and gilthead sea bream (Sparus aurata). J Food Sci 68:128–132. https://doi.org/10.1111/j.1365-2621.2003.tb14127.x
47. Korbas M, MacDonald TC, Pickering IJ et al (2011) Chemical form matters: differential accumulation of mercury following inorganic and organic mercury exposures in zebrafish larvae. ACS Chem Biol 7:411–420. https://doi.org/10.1021/cb200287c
48. Mieiro C, Ahmad I, Pereira M et al (2010) Antioxidant system breakdown in brain of feral golden grey mullet (Liza aurata) as an effect of mercury exposure. Ecotoxicology 19:1034–1045
49. Coccini T, Randine G, Candura SM et al (2000) Low-level exposure to methylmercury modifies muscarinic cholinergic receptor binding characteristics in rat brain and lymphocytes: physiologic implications and new opportunities in biologic monitoring. Environ Health Perspect 108:29–33. https://doi.org/10.1289/ehp.0010829
50. Di Lena G, Casini I, Caproni R et al (2017) Total mercury levels in commercial fish species from Italian fishery and aquaculture. Food Addit Contam Part B 10:118–127. https://doi.org/10.1080/19393210.2017.1281353
51. Afonso C, Costa S, Cardoso C et al (2015) Evaluation of the risk/benefit associated to the consumption of raw and cooked farmed meagre based on the bioaccessibility of selenium, eicosapentaenoic acid and docosahexaenoic acid, total mercury, and methylmercury determined by an in vitro digestion model. Food Chem 170:249–256. https://doi.org/10.1016/j.foodchem.2014.08.044
52. Sampaio E, Lopes AR, Francisco S et al (2018) Ocean acidification dampens physiological stress response to warming and contamination in a commercially-important fish (Argyrosomus regius). Sci Total Environ 618:388–398. https://doi.org/10.1016/j.scitotenv.2017.11.059
53. Monfort M-C (2010) Present market situation and prospects of meagre (*Argyrosomus regius*), as an emerging species in Mediterranean aquaculture. Stud Rev-Gen Fish Comm Mediterr
54. Pourang N, Nikouyan A, Dennis J (2005) Trace element concentrations in fish, surficial sediments and water from northern part of

the Persian Gulf. Environ Monit Assess 109:293–316. https://doi.org/10.1007/s10661-005-6287-9

55. Rejomon G, Nair M, Joseph T (2010) Trace metal dynamics in fishes from the southwest coast of India. Environ Monit Assess 167:243–255. https://doi.org/10.1007/s10661-009-1046-y
56. Kojadinovic J, Potier M, Le Corre M et al (2007) Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. Environ Pollut 146:548–566. https://doi.org/10.1016/j.envpol.2006.07.015
57. Cardoso C, Bandarra N, Lourenço H et al (2010) Methylmercury risks and EPA+ DHA benefits associated with seafood consumption in Europe. Risk Anal Int J 30:827–840. https://doi.org/10.1111/j.1539-6924.2010.01409.x
58. Ralston NV, Ralston CR, Raymond LJ (2016) Selenium health benefit values: updated criteria for mercury risk assessments. Biol Trace Elem Res 171:262–269. https://doi.org/10.1007/s12011-015-0516-z
59. Navarro JC, McEvoy LA, Amat F, Sargent JR (1995) Effects of diet on fatty acid composition of body zones in larvae of the sea bass Dicentrarchus labrax: a chemometric study. Mar Biol 124:177–183. https://doi.org/10.1007/BF00347121
60. Hunt AÖ, Özkan F, Engin K, Tekelioğlu N (2011) The effects of freshwater rearing on the whole body and muscle tissue fatty acid profile of the European sea bass (Dicentrarchus labrax). Aquac Int 19:51–61. https://doi.org/10.1007/s10499-010-9340-9
61. Piccolo G, Bovera F, De Riu N et al (2016) Effect of two different protein/fat ratios of the diet on meagre (*Argyrosomus regius*) traits. Ital J Anim Sci 7:363–371. https://doi.org/10.4081/ijas.2008.363
62. Orban E, Ricelli A, Paoletti F, et al (1996) Nutritional and organoleptic quality characteristics of sea bream (Sparus aurata) fillets from different rearing systems. pp 331–334
63. Orban E, Ricelli A, Di Lena G, et al (1999) Quality differences in sea bass (Dicentrarchus labrax) from intensive and extensive rearing systems. pp 180–181
64. Lanari D, Poli BM, Ballestrazzi R et al (1999) The effects of dietary fat and NFE levels on growing European sea bass (Dicentrarchus labrax L.). Growth rate, body and fillet composition, carcass traits and nutrient retention efficiency. Aquaculture 179:351–364. https://doi.org/10.1016/S0044-8486(99)00170-2
65. Poli B, Parisi G, Zampacavallo G et al (2003) Preliminary results on quality and quality changes in reared meagre (Argyrosomus regius): body and fillet traits and freshness changes in refrigerated commercial-size fish. Aquac Int 11:301–311
66. Ballestrazzi R, Rainis S, Maxia M (2006) The replacement of fish oil with refined coconut oil in the diet of large rainbow trout (Oncorhynchus mykiss). Ital J Anim Sci 5:155–164. https://doi.org/10.4081/ijas.2006.155
67. Alasalvar C, Taylor KDA, Zubcov E et al (2002) Differentiation of cultured and wild sea bass (Dicentrarchus labrax): total lipid content, fatty acid and trace mineral composition. Food Chem 79:145–150. https://doi.org/10.1016/S0308-8146(02)00122-X
68. Gisbert E, Villeneuve L, Zambonino-Infante JL et al (2005) Dietary phospholipids are more efficient than neutral lipids for long-chain polyunsaturated fatty acid supply in European sea bass Dicentrarchus labrax larval development. Lipids 40:609–618. https://doi.org/10.1007/s11745-005-1422-0
69. Krajnović-Ozretic M, Najdek M, Ozretić B (1994) Fatty acids in liver and muscle of farmed and wild sea bass (Dicentrarchus labrax L.). Comp Biochem Physiol A Physiol 109:611–617. https://doi.org/10.1016/0300-9629(94)90200-3
70. Fuentes A, Fernández-Segovia I, Serra JA, Barat JM (2010) Comparison of wild and cultured sea bass (Dicentrarchus labrax) quality. Food Chem 119:1514–1518. https://doi.org/10.1016/j.foodchem.2009.09.036
71. Valenzuela R, Echeverria F, Ortiz M, Rincón-Cervera MÁ, Espinosa A, Hernandez-Rodas MC, Illesca P, Valenzuela A, Videla LA (2017) Hydroxytyrosol prevents reduction in liver activity of Δ-5 and Δ-6 desaturases, oxidative stress, and depletion in long chain polyunsaturated fatty acid content in different tissues of high-fat diet fed mice. Lipids Health Dis 16:64–16. https://doi.org/10.1186/s12944-017-0450-5
72. Petursdottir AL, Farr SA, Morley JE et al (2008) Effect of dietary n-3 polyunsaturated fatty acids on brain lipid fatty acid composition, learning ability, and memory of senescence-accelerated mouse. J Gerontol A Biol Sci Med Sci 63:1153–1160. https://doi.org/10.1093/gerona/63.11.1153
73. Martelli R, Zotte AD, Bonelli A et al (2013) Macronutrient and fatty acid profiles of meagre (Argyrosomus regius) fillets as influenced by harvesting time and boiling. 9. https://doi.org/10.4081/ijas.2013.e30
74. Simopoulos AP (2002) The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomed Pharmacother 56:365–379. https://doi.org/10.1016/S0753-3322(02)00253-6
75. Takahashi M, Ando J, Shimada K et al (2017) The ratio of serum n-3 to n-6 polyunsaturated fatty acids is associated with diabetes mellitus in patients with prior myocardial infarction: a multicenter cross-sectional study. BMC Cardiovasc Disord 17. https://doi.org/10.1186/s12872-017-0479-4
76. Directorate for Research, Studies, Assessment and Statistics of Ministry of Health (France)/ the national public health agency (2017) Report on the French Population Health, 2017. In: Executive summary: overview and highlights. DREES, Paris
77. Barden AE, Burke V, Mas E et al (2015) n-3 Fatty acids reduce plasma 20-hydroxyeicosatetraenoic acid and blood pressure in patients with chronic kidney disease. J Hypertens 33:1947–1953. https://doi.org/10.1097/HJH.0000000000000621
78. Sorice M, Tritto FP, Sordelli C et al (2015) N-3 polyunsaturated fatty acids reduces post-operative atrial fibrillation incidence in patients undergoing “on-pump” coronary artery bypass graft surgery. Monaldi Arch Chest Dis 76. https://doi.org/10.4081/monaldi.2011.196
79. Flachs P, Rossmeisl M, Kopecky J (2014) The effect of n-3 fatty acids on glucose homeostasis and insulin sensitivity. Physiol Res 63(Suppl 1):S93–S118
80. Pase MP, Grima NA, Sarris J (2011) Do long-chain n-3 fatty acids reduce arterial stiffness? A meta-analysis of randomised controlled trials. Br J Nutr 106:974–980. https://doi.org/10.1017/S0007114511002819
81. Villeneuve LA, Gisbert E, Moriceau J et al (2006) Intake of high levels of vitamin A and polyunsaturated fatty acids during different developmental periods modifies the expression of morphogenesis genes in European sea bass (Dicentrarchus labrax). Br J Nutr 95:677–687. https://doi.org/10.1079/BJN20051668
82. Grigorakis K (2007) Compositional and organoleptic quality of farmed and wild gilthead sea bream (Sparus aurata) and sea bass (Dicentrarchus labrax) and factors affecting it: a review. Aquaculture 272:55–75. https://doi.org/10.1016/j.aquaculture.2007.04.062