Food Chemistry 274 (2019) 123–129

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Profile and distribution of fatty acids in edible parts of commonly consumed marine fishes in Chile

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ARTICLE INFO

Chemical compounds studied in this article:
Eicosapentaenoic acid (PubChem CID: 446284)
Docosahexaenoic acid (PubChem CID: 445580)
Omega 3 fatty acids (PubChem CID: 56842239)

Keywords:
Eicosapentaenoic acid
Docosahexaenoic acid
Chilean fishes
Phospholipids
Fatty acid distribution

ABSTRACT

Fatty acid profiles and distribution among lipid classes in the edible parts of seven commonly consumed marine fishes in Chile were investigated. Peruvian morwong, Chilean jack mackerel and Pacific sandperch were found to be the richest sources of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) with 440.2, 343.7 and 313.9 mg EPA + DHA/100 g raw fillet respectively among the studied fishes. DHA was mainly found in the phospholipid fraction in all cases, following EPA the same trend except for Pacific sandperch, Chilean hake (most EPA in triacylglycerols) and Peruvian morwong (most EPA as free fatty acid). A very favorable n-3/n-6 PUFA ratio was found in all studied species, and PUFA/SFA ratios ranged between 0.94 and 1.72, which is desirable to keep a healthy cardiovascular status. This is the first study reporting fatty acid profiles and distribution of commonly consumed marine fishes in Chile.

1. Introduction

Long-chain polyunsaturated fatty acids from the n-3 family (n-3 LCPUFA) are key nutrients whose beneficial effects for the human health are widely known. Eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) are the most recognized n-3 PUFA because of their nutritional and physiological relevance in all life stages (Dyall, 2015; Echeverría, Valenzuela, Hernandez-Rodas, & Valenzuela, 2017; Mozaffarian & Wu, 2012; Swanson, Block, & Mousa, 2012). EPA and DHA are mostly provided to the humans by the diet, being marine foods (fish, microalgae and some crustaceans) the most important sources (Lee, O'keefe, Lavie, & Harris, 2009; Ryckebosch, Bruneel, Muylaert, & Foubert, 2012).

Recommended daily intake of EPA + DHA are between 100 and 250 mg for children up to 10 years, 250 mg for healthy adults and 300 mg for pregnant women (of which at least 200 mg must be DHA), according to the Food and Agriculture Organization (FAO) (Burlingame, Nishida, Uauy, & Weisell, 2009). In Chile, in spite of its large coastal area (more than 6,000 km), there are to date no available data on fatty acid (FA) composition of fishes commonly consumed in the country. In this work, the FA content of edible parts (fillet) of seven commonly consumed fish species in Chile was determined: Chilean hake or "merluza" in Spanish, (*Merluccius gayi gayi*); Pacific pomfret or "reineta" (*Brama australis*); Peruvian morwong or "bilagay" (*Cheilodactylus variegatus*); Pacific sandperch or "blanquillo" (*Prolatilus jugularis*); Chilean jack mackerel or "jurel" (*Trachurus murphyi*); chub mackerel or "caballa" (*Scomber japonicus*) and fine flounder or "lenguado" (*Paralycthis adpersus*).

Some studies have pointed to the higher bioavailability of FA when they are supplied as phospholipids (PL) instead of as triacylglycerols (TAG) (Cook et al., 2016; Michalski et al., 2013; Schuchardt et al., 2011). Because of that, in this work the distribution of FA among different lipid classes in fish fillets was assessed, with a focus on EPA and DHA.

In Chile, only a previous paper reported FA profiles of seven fish species and in Eastern Island (Romero, Robert, Masson, & Pineda, 2000), which is very far from the Chilean continental coast. Furthermore, a recent paper reported the FA composition of by-products extracted from several fishes consumed in Chile (Rincón-Cervera, Villarreal-Rubio, Valenzuela, & Valenzuela, 2017). However, the current paper, to our knowledge, is the first study to characterize FA content and distribution in edible parts (fillets) of Chilean fishes. This is

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https://doi.org/10.1016/j.foodchem.2018.08.113
Received 15 January 2018; Received in revised form 12 July 2018; Accepted 24 August 2018
Available online 25 August 2018
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a prospective study because factors such as water temperature, geographical location, capture season and feed compositions, which are known to modify lipid composition of fishes (Boran, Karaçam, & Boran, 2006; Prato & Biandolino, 2012), were not considered. However, it sheds light on FA composition and distribution of several edible fishes in Chile and can be considered as a starting point to carry out a larger study on n-3 PUFA richness of commonly consumed fishes and other marine products in the country.

2. Materials and methods

2.1. Solvents and reagents

Unless otherwise stated, all solvents and reagents used in this work were purchased from Merck (Darmstadt, Germany).

2.2. Samples

Fishes (four specimens of each studied species) were provided by local fishermen in Coquimbo (Coquimbo Region, Chile) in March 2017. After collection, fishes were sampled as fillets without the skin, which were placed in polyethylene sampling bags and sent frozen to the laboratory where they were kept at −20 °C until analysis.

2.3. Determination of total fat and fatty acid quantification

Samples in their bags were placed in a refrigerator at 4 °C until they were thawed, and then fillets from each fish species were immediately weighed and homogenized in a food processor. Composites were obtained with the freshly minced fillets and aliquots were collected for lipid extraction. Each composited fish sample was processed in triplicate. Lipid extraction was carried out by a modified Folch method according to Cladis, Kleiner, Freiser, and Santerre (2014). Briefly, 5 g composite was weighted and 100 µL of a 50 mg/mL of a methyl tricosanoate solution in *n*-hexane was added as internal standard. After that, 100 mL chloroform:methanol (2:1 v/v) was added and the mixture was homogenized with a Scilogex D160 homogenizer (Connecticut, USA) for 2 min. The mix was sonicated in a water bath for 5 min and then magnetically stirred (250 rpm) in a capped flask for 1 h at room temperature under a nitrogen atmosphere and darkness. Then, the mix was filtered under vacuum and the filtrate was placed in a separatory funnel and rinsed with 30 mL sodium chloride solution (0.9% w/v). The organic layer was collected and filtered through anhydrous sodium sulfate, and the solvent was removed in a rotary evaporator at 35 °C. The residue (extracted lipids) was weighed before further processing. A scheme of the process is shown in Fig. 1.

To determine fatty acid composition, extracted lipids were derivatized to fatty acid methyl esters (FAME) according to a previous work (Rincón-Cervera, Suárez-Medina, & Guil-Guerrero, 2009). Briefly, 25 mg lipids were weighed into test tubes and then 1 mL *n*-hexane was added to each one. FAME were obtained after adding 1 mL of the methylation mixture (methanol:acetyl chloride 20:1 v/v) and heating the closed tubes at 100 °C for 30 min in a hot block. After cooling at room temperature, 1 mL of distilled water was added to each tube, and then they were centrifuged at 3500 rpm for 5 min. The upper hexane layer containing the FAME was collected to be analyzed by gas chromatography coupled with flame ionization detection (GC-FID) (Agilent 6890N with a 7683B autosampler, Agilent Technologies, Santa Clara, CA, USA). Initial oven temperature was set at 140 °C and kept constant for 5 min, then increased at 4 °C/min to 190 °C, then at 1 °C/min to 220 °C and then at 4 °C/min to 240 °C, being temperature kept at 240 °C for 5 min. Nitrogen was used as carrier gas and the split ratio was set at 1:100. Temperature of injector and detector were set at 270 and 260 °C respectively. A Supelco SP-2560 capillary column (100 m × 0.25 mm × 0.2 µm film) was used to carry out the analysis (Sigma-Aldrich). FAMEs were identified according to their respective retention times compared with two known analytical standards (37 component FAME Mix and PUFA mix 3 from Supelco, Sigma-Aldrich).

Fatty acid quantification was carried out using the following equation: $C_{FA} = (m_{IS} \times A_{FA} \times RRF_{FA})/(1.04 \times m_{fish} \times A_{IS})$, where C_{FA} is the concentration of the fatty acid in mg/g, m_{IS} is the weight of the internal standard, A_{FA} is the fatty acid peak area in the GC spectrum, RRF_{FA} is the relative retention factor for each fatty acid (Cladis et al., 2014), 1.04 is the correlation factor between fatty acids and fatty acid methyl esters, m_{fish} is the weight of the fish tissue, and A_{IS} is the internal standard peak area in the GC spectrum.

2.4. Fatty acid distribution among lipid classes

Total lipids were extracted from fish fillets using the same method explained in Section 2.3, using 5 g composite but without adding internal standard. After extracted lipids were weighed, an aliquot (35 mg) was collected and dissolved in 1 mL chloroform. Neutral and polar lipids were isolated passing the sample through a solid-phase extraction (SPE) cartridge containing 1 g silica as stationary phase (Sep-Pak 6 cc, Waters, MA, USA) which was previously conditioned with 10 mL chloroform, and the cartridge was eluted sequentially with 25 mL chloroform containing 1% acetic acid, 25 mL acetone:methanol 9:1 v/v and 25 mL methanol to recover neutral lipids (NL), glycolipids (GL) and phospholipids (PL) respectively (Wang & Wang, 2012) using a pump and a vacuum manifold. Eluates were collected in 100-mL round-bottom glass flasks and solvent was evaporated in a rotary evaporator under vacuum at 40 °C. Then, the residues were collected and weighed. Such residues were developed by Thin Layer Chromatography (TLC) (Silica gel 60 0.5 mm, 20 × 20 cm) from Merck (Darmstadt, Germany) using *n*-hexane:diethylether:acetic acid 70:30:1 v/v/v as mobile phase. After development, the plaques were placed inside a fume hood to remove the residual solvent prior to be revealed with iodine stream in nitrogen. Five bands were found within the NL fraction, which were identified according to their respective retention factors (Rf) as monoacylglycerols (MAG), diacylglycerols (DAG), free fatty acids (FFA), triacylglycerols (TAG) and sterol esters (SE). No other bands apart from those of GL and PL were found in their corresponding lipid fractions, showing that SPE efficiently isolated such fractions. Bands were scrapped off from the TLC plate and derivatized to FAME using the same method previously described in Section 2.3 (Rincón-Cervera et al., 2009) using methyl tricosanoate (0.5 mg) as internal standard (Sigma-Aldrich). Analyses were carried out by GC-FID as previously described.

3. Results and discussion

3.1. Lipid amount and fatty acid content

Lipid content in edible parts of fishes (fillets), expressed on a wet weight basis, ranged from 0.77 g/100 g in fine flounder to 2.31 g/100 g in Pacific sandperch. According to the lipid content, all studied species except Pacific sandperch are classified in the category of lean fish (less than 2% lipid content), whereas Pacific sandperch is regarded as low-fat fish (2–4% lipid content) (Huynh & Kitts, 2009) (as shown in Table 1).

Additionally to its low lipid content, the lowest amounts of saturated FA (SFA), monounsaturated FA (MUFA) and PUFA were found in fillet from fine flounder, with 139.1, 59.4 and 239.9 mg/100 g raw fillet respectively. The highest amount of SFAs and PUFAs were found in Peruvian morwong (543.7 and 617.0 mg/100 g raw fillet respectively) whereas Pacific sandperch was found to be the richest species concerning MUFAs (510.8 mg/100 g raw fillet). Palmitic acid (PA, 16:0) was the most abundant SFA in all studied species, with values ranging from 92.0 to 330.9 mg/100 g raw fillet in fine flounder and Pacific pomfret respectively. Oleic acid (OA, 18:1n9) was the most abundant MUFA in all cases, ranging from 35.6 to 308.9 mg/100 g raw fillet in fine flounder and Pacific sandperch respectively. DHA and EPA were the most abundant PUFA. DHA was found in higher amounts than EPA

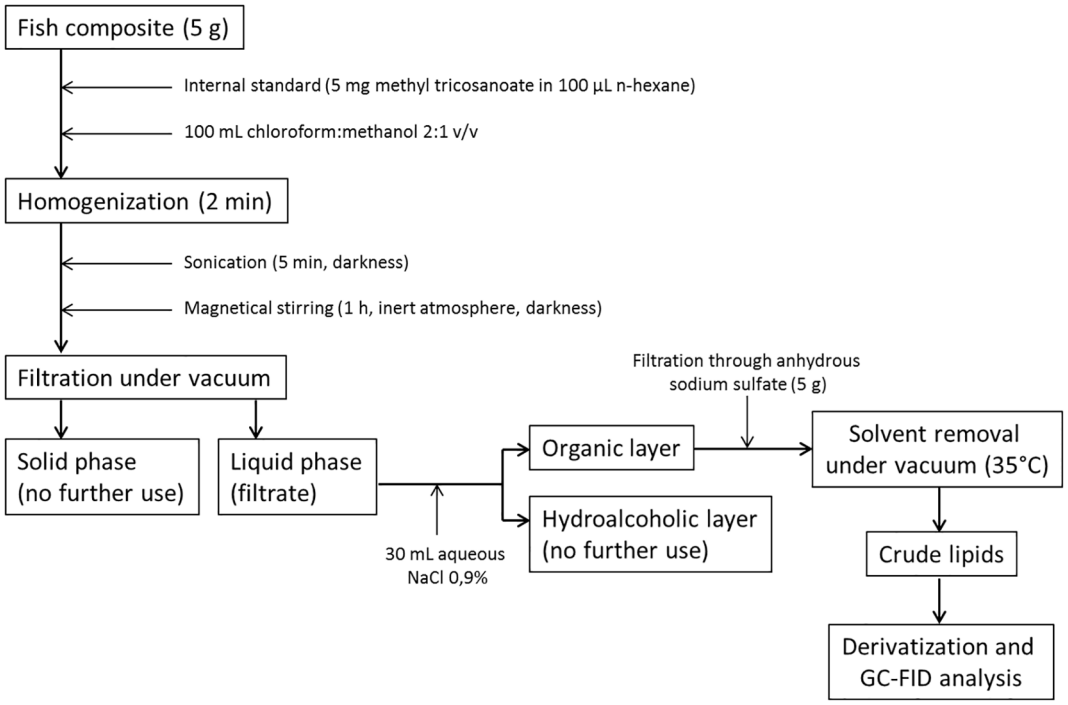

Fig. 1. Process scheme for lipid extraction and fatty acid profiling of fish samples.

in all studied species, with a DHA/EPA ratio ranging from 1.21 in Pacific sandperch (171.9 and 141.9 mg/100 g raw fillet for EPA and DHA respectively) to 10.97 in Pacific pomfret (23.6 and 259.2 mg/100 g raw fillet for EPA and DHA). The lowest and highest amounts of EPA were found in Pacific pomfret (23.6 mg/100 g raw fillet) and Peruvian morwong (144.4 mg/100 g raw fillet) respectively. Concerning DHA, the lowest and highest amounts were found in Chilean hake (148.9 mg/100 g raw fillet) and Peruvian morwong (295.8 mg/100 g raw filet) (Table 1).

According to international recommendations, daily intake of EPA + DHA should reach at least 250 mg for healthy adults. Almost all studied species in this work provide higher amount of EPA + DHA per serving size (100 g), being the richest sources Peruvian morwong and Chilean jack mackerel (440.2 and 343.7 mg EPA + DHA/100 g fillet respectively). Only Chilean hake and fine flounder fillets are below 250 mg. This way, a weekly consumption of 398 g Peruvian morwong, 510 g Chilean jack mackerel and 558 g Pacific sandperch can fulfill the minimal recommended supply of EPA + DHA (1,750 mg/week).

Table 1
Total extracted lipids (g/100 g raw fillet) and amount of each fatty acid (mg/100 g raw fillet) in the studied fish species.

	Peruvian morwong	Pacific pomfret	Chilean hake	Pacific sandperch	Chilean jack mackerel	Chub mackerel	Fine flounder
Total lipids (g/100 g raw fillet)	1.58 ± 0.15	1.50 ± 0.13	1.42 ± 0.09	2.31 ± 0.05	1.59 ± 0.08	1.25 ± 0.11	0.77 ± 0.11
Fatty acid content (mg/100 g raw fillet)							
14:0	55.0 ± 7.4	13.4 ± 2.4	8.2 ± 1.3	65.1 ± 5.3	14.6 ± 1.7	7.6 ± 1.2	7.7 ± 0.3
15:0	8.2 ± 1.2	2.5 ± 0.4	1.5 ± 0.1	12.4 ± 2.2	3.6 ± 0.5	3.4 ± 0.3	1.7 ± 0.0
16:0	325.9 ± 23.1	141.1 ± 12.6	102.8 ± 6.8	314.5 ± 23.1	167.8 ± 11.8	121.8 ± 6.3	92.0 ± 1.0
17:0	9.8 ± 1.4	3.5 ± 0.5	4.0 ± 0.4	13.1 ± 2.1	4.7 ± 0.8	6.1 ± 0.4	1.9 ± 0.2
18:0	134.9 ± 14.4	41.8 ± 4.0	29.3 ± 1.7	102.3 ± 7.4	92.8 ± 9.3	86.0 ± 0.5	35.8 ± 0.6
Σ SFA	533.8 ± 28.3	202.3 ± 13.5	145.8 ± 7.1	507.4 ± 25.0	283.4 ± 15.1	224.9 ± 6.4	139.1 ± 1.2
16:1n-7	95.5 ± 6.8	20.6 ± 1.9	15.0 ± 2.0	119.5 ± 11.7	14.2 ± 2.3	7.7 ± 0.7	10.9 ± 0.2
18:1n-9	225.4 ± 23.6	124.9 ± 10.8	47.0 ± 3.8	308.9 ± 19.1	52.9 ± 6.2	53.6 ± 4.0	35.6 ± 0.3
18:1n-7	75.9 ± 6.7	23.2 ± 3.3	15.5 ± 1.2	63.5 ± 7.6	29.4 ± 3.7	29.9 ± 1.2	10.8 ± 0.2
20:1n-9	11.8 ± 1.3	16.7 ± 1.3	3.4 ± 0.5	18.9 ± 3.0	6.9 ± 1.7	4.6 ± 0.5	2.0 ± 0.1
Σ MUFA	408.6 ± 25.5	185.4 ± 11.5	80.8 ± 4.5	510.8 ± 23.8	103.4 ± 7.8	95.8 ± 4.3	59.4 ± 0.5
18:2n-6	39.1 ± 2.7	5.7 ± 0.8	5.5 ± 0.6	56.0 ± 5.2	11.3 ± 1.8	13.2 ± 2.4	3.6 ± 0.3
20:4n-6	39.8 ± 3.6	9.6 ± 1.0	9.6 ± 0.6	43.0 ± 3.6	20.0 ± 1.7	25.2 ± 0.5	11.2 ± 0.4
18:3n-3	8.5 ± 1.9	1.1 ± 0.2	1.8 ± 0.1	6.9 ± 1.3	3.4 ± 0.6	4.4 ± 0.1	0.9 ± 0.1
18:4n-3	8.7 ± 1.7	0.0 ± 0.0	4.3 ± 0.7	3.8 ± 0.6	3.7 ± 1.1	2.2 ± 0.9	1.4 ± 0.3
20:4n-3	8.3 ± 1.0	2.2 ± 0.3	1.8 ± 0.1	3.7 ± 0.6	4.3 ± 0.7	2.9 ± 0.0	1.2 ± 0.1
20:5n-3 (EPA)	144.4 ± 12.2	23.6 ± 2.7	69.4 ± 4.7	141.9 ± 19.4	63.9 ± 5.7	45.4 ± 0.9	32.2 ± 0.4
22:5n-3	72.3 ± 5.6	9.0 ± 1.0	9.3 ± 0.6	47.5 ± 7.5	29.3 ± 4.1	11.9 ± 0.2	19.7 ± 0.4
22:6n-3 (DHA)	295.8 ± 21.8	259.2 ± 15.1	148.9 ± 8.1	171.9 ± 18.0	279.8 ± 11.2	229.8 ± 9.5	169.7 ± 7.5
Σ PUFA	617.0 ± 26.1	310.5 ± 15.5	250.7 ± 9.5	474.9 ± 28.3	415.8 ± 13.5	334.9 ± 9.9	239.9 ± 7.5
Σ n-6 PUFA	79.0 ± 4.5	15.4 ± 1.2	15.1 ± 0.9	99.0 ± 6.4	31.3 ± 2.5	38.4 ± 2.5	14.8 ± 0.5
Σ n-3 PUFA	538.1 ± 25.7	295.1 ± 15.4	235.5 ± 9.4	375.8 ± 27.6	384.5 ± 13.3	296.5 ± 9.6	225.1 ± 7.5
Σ EPA + DHA	440.2 ± 25.0	282.9 ± 15.4	218.4 ± 9.4	313.9 ± 26.5	343.7 ± 12.6	275.1 ± 9.5	201.9 ± 7.5

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid.

Amounts of n-3 PUFA were much higher than those of n-6 PUFA, thus providing very low n-6/n-3 PUFA ratios, which is highly desirable from a nutritional perspective. This is a common finding in many other marine organism (Prato & Biandolino, 2012), because of the abundance of n-3 LCPUFA (mainly EPA and DHA) in comparison with n-6 PUFA in the marine food web (Prato & Biandolino, 2012; Sargent, Tocher, & Bell, 2002) (Table 1).

Other relevant nutritional indicator is the PUFA/SFA ratio. It has been reported that an excessive SFA intake is not desirable as it is related to an increase of total cholesterol and LDL-cholesterol levels in serum (Calder, 2015). In order to keep a healthy cardiovascular status, values of PUFA/SFA ratio higher than 0.40 are desirable (Ospina-E, Sierra-C, Ochoa, Pérez-Álvarez, & Fernández-López, 2012). In fishes analyzed in this work, PUFA/SFA ratio ranged from 0.94 (Pacific sandperch) to 1.72 (Chilean hake and fine flounder), showing that together with the high n-3 PUFA content, fishes analyzed in this work may contribute to maintain an optimal cardiovascular health. Contrarily to meat, which typically has a PUFA/SFA value of 0.1 (Ospina-E et al., 2012), fish is a more suitable food source concerning the balance between PUFA and SFA.

It is important to consider that fatty acid profile and lipid content in fishes vary depending on the season in which they are caught and their life cycle, among other factors (Huynh & Kitts, 2009; Prato & Biandolino, 2012), and such factors were not considered in this work. As there was no available information about FA composition of marine fishes commonly consumed in Chile, the purpose of this work is to serve as a spearhead to carry out a larger study considering such factors in order to provide relevant nutritional data to promote fish consumption in the country.

3.2. Fatty acid distribution among lipid classes

Five types of neutral lipids (TAG, DAG, MAG, FFA, SE) and two types of polar lipids (GL and PL) containing FA were identified in fish lipids. Most FA in fish lipids were found esterified as TAG in Pacific sandperch, Chilean hake and Peruvian morwong (73.2, 45.5 and 39.0% of total FA respectively), and as PL in fine flounder, Chilean jack mackerel, Pacific pomfret and chub mackerel (65.7, 60.2, 57.0 and 47.9% of total FAs respectively). FA found as FFA ranged from 8.3% of total FA in Pacific sandperch to 30.2% of total FA in chub mackerel. FA esterified as GL were found at higher percentages than 10% only in Chilean jack mackerel (10.2% of total FA) and chub mackerel (11.2% of total FA). The sum of FA esterified as MAG, DAG and SE was lower than 10.0% in all cases (Table 2). It is noticeable the high percentage of FFA found in fish lipids, indicating a large hydrolysis rate of TAG, considering that FFA are hydrolysis products of TAG. Lipases in the fish tissue are still active after the fish is captured, thus hydrolyzing original TAG to FFA and partial glycerides (DAG and MAG) (Lovern & Olley, 1962). It is not relevant from a nutritional point of view as FFA are dispersed into mixed micelles in the human intestinal lumen, bound to soluble lipid-binding proteins in the enterocytes and, after re-esterification, they are secreted into lymph as TAG-rich lipoproteins (Mu & Høy, 2004; Niot, Poirier, Tran, & Besnard, 2009). A high percentage of FFA within the lipid fraction in fish may contribute to reduce the shelf life of the product because FFA are more prone to oxidize than when FA are esterified as TAG or PL (Akoh, 2017). This fact does not affect in first instance to rancid aromas generated by lipid oxidation because long-chain FFA released in muscle foods do not contribute directly to this phenomenon until they are oxidized in a further stage, as it was previously reported (Akoh, 2017). This may happen if fresh fish is not rapidly consumed, but this situation is not usual as then the product loose its organoleptic properties, being unfit and rejected for human consumption.

In order to discuss FA profiles within lipid classes for each fish species, FA were grouped into SFA, MUFA, n-6 PUFA and n-3 PUFA, and only EPA and DHA, which are the focus of the discussion, were considered individually. In almost all studied fish species in this work, DHA proportion in PL is considerably higher than in other lipid classes; DHA proportion in SE is the same as in PL in Chilean hake, and only in fine flounder DHA proportion is higher in SE than in PL (Tables 3 and 4).

To better understand the distribution of each FA or FA group among lipid classes in each fish species, a figure was built representing the amount (in grams) of each FA or FA group in each lipid class for each 100 g FA available in the whole fish lipids. That is, all data are reported on the basis of 100 g FA contained in fish lipids. The major lipid classes found in fish lipids (TAG, PL, FFA) were represented as well as FA available in other classes (MAG, DAG, SE and GL) which were put together because of their low contribution. To do it, data from Tables 2 and 3 or 4 were used. For instance, to calculate the amount (in grams) of DHA available in PL in Pacific sandperch lipids, it has to be considered that 16.0% of total FAs are esterified as PL, that is, 16 g FA as PL/100 g FA in the whole lipids (Table 2). According to Table 3, 33.95% of FA in PL are DHA, that is, 16 g x 33.95/100 = 5.43 g. It means that from each 100 g total FA in Pacific sandperch lipids, 5.43 g are DHA esterified as PL. Doing the same calculation for DHA available in TAG, FFA and other lipid classes, 3.48, 0.62 and 0.43 g DHA were found respectively. It means that there are 9.96 g DHA (5.43 + 3.48 + 0.62 + 0.43) in each 100 g FA contained in Pacific sandperch lipids. It is clear then that DHA is mainly available in the PL fraction in Pacific sandperch lipids (5.43 g out of 9.96 g DHA per 100 g FA). The same calculation was carried out for each FA or FA group and each fish species and results are shown in Fig. 2.

DHA is markedly concentrated in PL in all studied species, especially in fine flounder (20.35 g DHA in PL out of 23.12 g DHA which are contained per 100 g FA in fine flounder lipids from fillet, that is, 88.0% of all DHA is contained in PL), and Pacific pomfret (87.3%), Chilean jack mackerel (85.1%) and chub mackerel (73.5%). This is nutritionally relevant as it has been reported that bioavailability of FA is enhanced when they are provided as PL instead of as TAG (Cook et al., 2016; Ramprasath, Eyal, Zchut, Shafat, & Jones, 2015), and also PUFA are more protected against oxidation (Le Grandois et al., 2010). EPA, however, does not follow the same trend as DHA in all studied species: it is mainly concentrated as PL in chub mackerel (62.7% of total EPA),

Table 2
Fatty acid distribution among lipid classes within the whole lipid fraction extracted from each fish species.

	MAG	DAG	FFA	TAG	SE	GL	PL
FA distribution (g/100 g FA in the whole lipids)							
Pacific sandperch	0.6 ± 0.2	1.3 ± 0.1	8.3 ± 1.9	73.2 ± 2.2	0.1 ± 0.0	0.6 ± 0.1	16.0 ± 1.2
Chilean hake	3.3 ± 0.4	3.8 ± 0.1	14.9 ± 1.4	45.5 ± 4.7	0.6 ± 0.0	2.9 ± 0.6	32.5 ± 2.4
Peruvian morwong	1.8 ± 0.2	2.5 ± 0.2	28.0 ± 1.3	39.0 ± 3.7	1.0 ± 0.6	2.9 ± 0.1	25.0 ± 1.6
Fine flounder	1.2 ± 0.2	1.9 ± 0.2	15.6 ± 1.6	13.4 ± 1.2	0.7 ± 0.3	1.9 ± 0.4	65.7 ± 3.0
Chilean jack mackerel	2.1 ± 0.0	2.5 ± 0.1	15.4 ± 0.8	8.9 ± 0.0	0.1 ± 0.0	10.2 ± 0.0	60.2 ± 1.1
Pacific pomfret	1.5 ± 0.0	1.9 ± 0.1	12.4 ± 0.9	24.3 ± 1.6	0.8 ± 0.0	2.2 ± 0.1	57.0 ± 2.8
Chub mackerel	1.6 ± 0.0	1.9 ± 0.1	30.2 ± 0.5	7.2 ± 1.3	0.1 ± 0.0	11.2 ± 0.1	47.9 ± 1.4

MAG: monoacylglycerols; DAG: diacylglycerols; FFA: free fatty acids; TAG: triacylglycerols; SE: sterol esters; GL: glycolipids; PL: phospholipids.

Table 3
Fatty acid profiles (% of total FA) of the different classes identified in extracted lipids from Pacific sandperch, Chilean hake, Peruvian morwong and fine flounder.

	MAG	DAG	FFA	TAG	SE	GL	PL
Fatty acid profile of each fraction (%)							
Pacific sandperch							
Σ SFA	31.46 ± 1.99	35.79 ± 1.47	55.32 ± 1.11	36.33 ± 0.23	n.d.	29.98 ± 0.92	26.69 ± 1.15
Σ MUFA	17.87 ± 1.09	32.87 ± 1.04	18.15 ± 1.21	38.51 ± 0.69	n.d.	33.81 ± 1.43	10.92 ± 0.56
Σ n-6 PUFA	6.89 ± 0.61	4.79 ± 0.71	3.99 ± 0.51	3.02 ± 0.06	n.d.	7.62 ± 0.81	6.70 ± 0.77
Σ n-3 PUFA	42.18 ± 1.93	26.58 ± 1.21	22.00 ± 1.01	18.43 ± 0.44	n.d.	28.61 ± 1.88	51.94 ± 0.75
EPA	8.92 ± 0.78	10.03 ± 0.51	10.76 ± 0.34	9.29 ± 0.37	n.d.	3.28 ± 0.08	12.71 ± 0.18
DHA	26.78 ± 1.76	11.76 ± 1.07	7.41 ± 0.87	4.76 ± 0.06	n.d.	18.60 ± 1.77	33.95 ± 0.59
Chilean hake							
Σ SFA	48.35 ± 2.16	41.17 ± 1.53	43.35 ± 0.82	39.00 ± 1.71	23.10 ± 0.23	44.31 ± 0.95	39.94 ± 0.18
Σ MUFA	34.59 ± 0.54	35.00 ± 0.51	28.80 ± 0.21	37.85 ± 0.49	24.69 ± 2.12	36.35 ± 0.84	16.01 ± 0.07
Σ n-6 PUFA	2.87 ± 0.65	3.67 ± 0.66	3.82 ± 0.63	2.84 ± 0.40	5.06 ± 0.74	4.13 ± 0.17	2.88 ± 0.06
Σ n-3 PUFA	14.21 ± 1.15	20.15 ± 0.97	24.04 ± 0.73	19.62 ± 1.16	45.66 ± 2.03	15.27 ± 0.72	39.42 ± 0.20
EPA	3.97 ± 0.79	7.95 ± 0.42	12.58 ± 0.52	9.40 ± 0.91	8.98 ± 0.81	2.99 ± 0.22	10.72 ± 0.11
DHA	6.90 ± 0.78	7.56 ± 0.79	7.80 ± 0.47	5.57 ± 0.69	25.01 ± 1.54	10.03 ± 0.22	26.37 ± 0.16
Peruvian morwong							
Σ SFA	43.49 ± 0.31	49.26 ± 0.80	49.23 ± 0.22	47.65 ± 0.91	45.05 ± 1.77	37.85 ± 1.06	49.65 ± 0.44
Σ MUFA	43.73 ± 0.90	43.48 ± 0.52	21.29 ± 0.06	41.50 ± 0.36	41.56 ± 4.48	41.61 ± 0.54	16.38 ± 0.18
Σ n-6 PUFA	6.10 ± 0.41	4.37 ± 0.15	4.69 ± 0.14	2.33 ± 0.16	7.27 ± 1.15	5.52 ± 0.26	3.65 ± 0.09
Σ n-3 PUFA	6.68 ± 0.82	2.88 ± 0.48	24.78 ± 0.57	8.52 ± 0.96	6.13 ± 1.53	15.02 ± 0.82	30.31 ± 1.06
EPA	1.91 ± 0.05	0.92 ± 0.01	9.49 ± 0.25	3.17 ± 0.57	1.38 ± 0.94	1.65 ± 0.12	5.06 ± 0.09
DHA	3.55 ± 0.44	0.68 ± 0.36	10.85 ± 0.52	2.87 ± 0.66	2.65 ± 0.74	10.64 ± 0.67	21.96 ± 1.05
Fine flounder							
Σ SFA	37.54 ± 1.86	47.98 ± 1.99	54.16 ± 1.33	45.27 ± 3.20	11.57 ± 0.23	38.18 ± 1.39	40.56 ± 1.52
Σ MUFA	18.68 ± 1.20	30.27 ± 2.25	23.20 ± 1.86	37.72 ± 1.41	18.61 ± 1.01	31.83 ± 1.36	14.88 ± 0.27
Σ n-6 PUFA	9.08 ± 1.15	6.26 ± 0.52	4.01 ± 0.57	5.44 ± 1.06	5.45 ± 0.08	5.56 ± 0.77	2.77 ± 0.35
Σ n-3 PUFA	34.70 ± 2.14	15.51 ± 0.61	18.64 ± 1.06	11.60 ± 0.95	64.40 ± 0.75	24.43 ± 1.37	39.64 ± 2.13
EPA	4.87 ± 0.59	2.84 ± 0.43	7.25 ± 0.23	3.36 ± 0.57	6.70 ± 0.21	2.67 ± 0.42	4.96 ± 0.32
DHA	21.71 ± 1.79	7.85 ± 0.06	6.37 ± 1.00	5.20 ± 0.53	44.61 ± 0.50	18.43 ± 1.18	30.98 ± 2.10

MAG: monoacylglycerols; DAG: diacylglycerols; FFA: free fatty acids; TAG: triacylglycerols; SE: sterol esters; GL: glycolipids; PL: phospholipids; n.d.: not detected or below the detection limit.

Table 4
Fatty acid profiles (% of total FA) of the different classes identified in extracted lipids from Chilean jack mackerel, Pacific pomfret and chub mackerel.

	MAG	DAG	FFA	TAG	SE	GL	PL
Fatty acid profile of each fraction (%)							
Chilean jack mackerel							
Σ SFA	49.02 ± 1.68	56.61 ± 0.49	55.77 ± 1.59	53.98 ± 1.89	n.d.	34.92 ± 1.50	39.40 ± 1.18
Σ MUFA	23.79 ± 0.63	28.40 ± 0.47	22.25 ± 0.69	34.90 ± 0.30	n.d.	34.70 ± 1.04	9.23 ± 0.20
Σ n-6 PUFA	5.10 ± 0.43	3.62 ± 0.09	3.51 ± 0.19	2.96 ± 0.34	n.d.	5.53 ± 0.15	3.48 ± 0.06
Σ n-3 PUFA	21.97 ± 1.62	11.42 ± 0.17	18.48 ± 1.37	8.17 ± 1.09	n.d.	24.85 ± 0.84	46.28 ± 1.87
EPA	4.67 ± 0.47	2.45 ± 0.13	7.51 ± 0.83	2.29 ± 0.59	n.d.	1.53 ± 0.06	7.80 ± 0.32
DHA	13.32 ± 1.43	6.02 ± 0.10	5.51 ± 0.99	3.32 ± 0.88	n.d.	19.78 ± 0.77	34.19 ± 1.82
Pacific pomfret							
Σ SFA	41.24 ± 2.10	32.06 ± 1.08	41.72 ± 1.52	26.90 ± 0.81	33.71 ± 0.63	28.67 ± 0.51	25.70 ± 0.26
Σ MUFA	34.38 ± 0.38	33.84 ± 0.87	23.35 ± 0.82	42.84 ± 1.21	40.40 ± 0.50	35.05 ± 0.57	12.41 ± 0.10
Σ n-6 PUFA	5.12 ± 0.30	7.45 ± 0.13	3.21 ± 0.01	7.87 ± 0.31	2.89 ± 0.26	5.18 ± 0.10	2.04 ± 0.01
Σ n-3 PUFA	19.26 ± 1.47	26.47 ± 2.30	31.71 ± 2.82	19.13 ± 1.23	23.01 ± 1.24	31.11 ± 0.37	59.86 ± 0.57
EPA	1.12 ± 0.21	2.50 ± 0.47	4.57 ± 0.01	1.12 ± 0.23	2.23 ± 0.20	1.31 ± 0.06	2.84 ± 0.03
DHA	10.09 ± 1.22	14.76 ± 2.23	23.68 ± 2.79	2.32 ± 0.37	12.58 ± 1.17	25.72 ± 0.22	55.66 ± 0.57
Chub mackerel							
Σ SFA	64.57 ± 1.57	56.55 ± 1.61	52.25 ± 1.77	41.60 ± 1.62	n.d.	31.72 ± 1.97	33.98 ± 2.02
Σ MUFA	17.88 ± 0.45	27.38 ± 1.25	22.05 ± 0.45	40.59 ± 2.86	n.d.	32.50 ± 1.10	11.98 ± 0.19
Σ n-6 PUFA	5.56 ± 0.02	7.68 ± 0.39	4.89 ± 0.36	13.40 ± 0.68	n.d.	6.49 ± 0.46	5.30 ± 0.01
Σ n-3 PUFA	12.03 ± 0.46	8.27 ± 0.42	20.70 ± 1.38	4.61 ± 0.26	n.d.	26.26 ± 1.38	44.36 ± 1.13
EPA	2.25 ± 0.21	0.99 ± 0.29	6.19 ± 0.78	1.05 ± 0.06	n.d.	1.66 ± 0.30	7.67 ± 0.50
DHA	8.92 ± 0.01	6.11 ± 0.27	10.01 ± 1.09	2.37 ± 0.04	n.d.	21.25 ± 1.28	33.70 ± 1.01

MAG: monoacylglycerols; DAG: diacylglycerols; FFA: free fatty acids; TAG: triacylglycerols; SE: sterol esters; GL: glycolipids; PL: phospholipids; n.d.: not detected or below the detection limit.

Pacific pomfret (63.0%), Chilean jack mackerel (73.7%) and fine flounder (64.5%), as TAG in Chilean hake (41.9%), Pacific sandperch (68.5%), and as FFA in Peruvian morwong (50.3%). In Peruvian morwong, the richest source of DHA among all studied fish species in this work (295.8 mg DHA/100 g raw fillet), 54.6% of total DHA was contained in the PL fraction, and a considerable proportion of DHA was found as FFA. Only a small proportion (11.1%) of all available DHA was found as TAG (Fig. 2).

Concerning SFA, they are concentrated as TAG in Pacific sandperch (73.3% of total SFA in lipids extracted from the fillet are contained in TAG), Chilean hake (42.5%) and Peruvian morwong 38.4%), and as PL in fine flounder (61.5%), Chilean jack mackerel (55.0%), Pacific

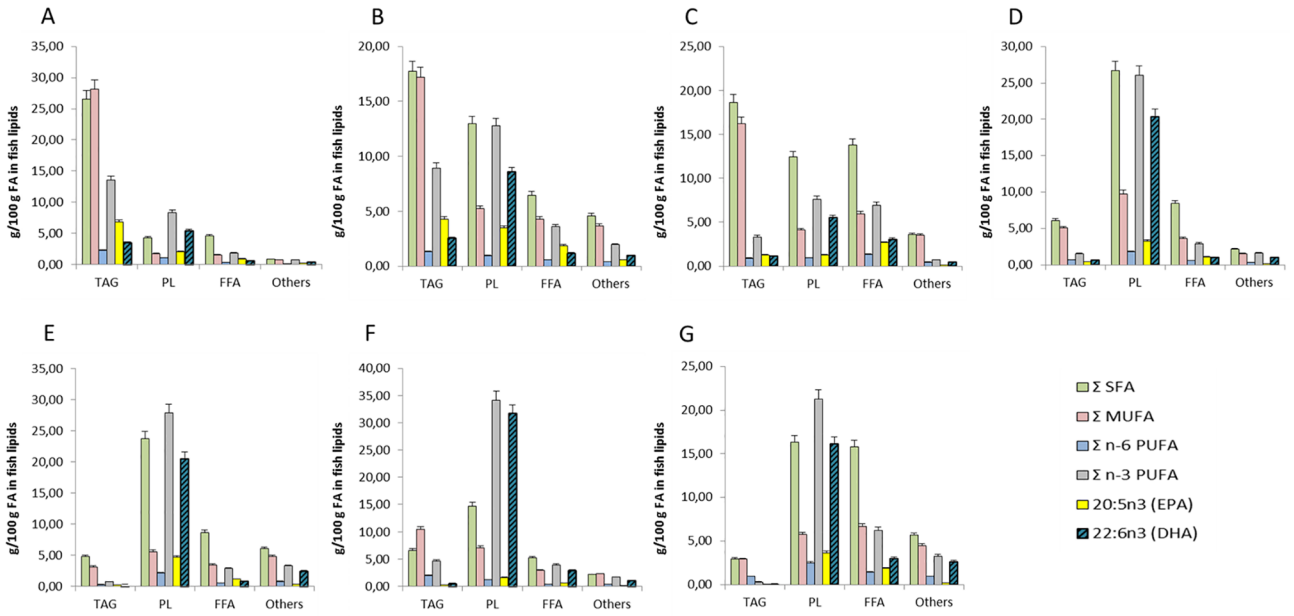

Fig. 2. Distribution of SFAs, MUFAs, n-6 PUFAs, n-3 PUFAs, EPA and DHA (g/100 g total FA in fish lipids) among lipid classes; (A) Pacific sandperch, (B) Chilean hake, (C) Peruvian morwong, (D) Fine flounder, (E) Chilean jack mackerel, (F) Pacific pomfret, (G) Chub mackerel. Σ n-3 PUFA represents all n-3 PUFA quantified in this work, including EPA and DHA. Both n-3 PUFA are shown separately because of their nutritional relevance.

pomfret (51.4%) and chub mackerel (40.0%) (Fig. 2).

Chub mackerel and Peruvian morwong are the two species where the percentages of FA found as FFA were the highest (30.2 and 28.0% respectively of total FAs in the whole lipids from fillets) (Table 2). Most FA in such fraction was composed by SFA, mainly palmitic acid (PA, 16:0) and stearic acid (SA, 18:0), which were the main SFA found in total lipids (Table 1), in agreement with previous studies of marine fishes (Prato & Biandolino, 2012). As PA and SA are saturated long-chain FA, their absorption by the human enterocytes is less efficient as it has been described that the best absorption rate for such FA is as *sn*-2 MAG, and that when they are as FFA, they reach preferably the large intestine to form calcium soap and being excreted (Ramírez, Amate, & Gil, 2001). However, high percentages of PUFA (both n-3 and n-6) were found in the FFA fraction of both fish species: 29.47% PUFA of total FA as FFA in Peruvian morwong and 25.59% PUFA in chub mackerel. This may impact on lipid quality of fillets because PUFA are more prone to oxidative degradation when they are found as FFA than as TAG or PL, as previously discussed in this section.

3.3. Nutritional implications for the Chilean population

In spite of the relevant role for human health of n-3 LCPUFA, especially EPA and DHA, no information concerning how much EPA and DHA is provided by fishes consumed in Chile is currently available. Specific groups of Chilean population such as pregnant women present a very low intake of n-3 LCPUFA (Echeverría et al., 2017), and it has to be considered also that stroke and ischemic heart disease are leading causes of death among Chilean adults (WHO, 2015). Consequently, from a public health perspective, results obtained in this work provide valuable information to develop nutritional strategies focused on specific groups of population in the country.

In this study, fishes were obtained from local fishermen to most accurately reflect as these products are sold in the Chilean market and consumed by the population. As mentioned previously, this methodology has direct relevance for public health, but limits the ability to monitor the quality of products from harvest to analysis. Anyway, this methodology was chosen because the target of the study was to analyze fishes as they are consumed.

Other compounds nutritionally relevant which are usually found in fish such as cholesterol, tocopherols and lipid-soluble vitamins were out of the scope of this study, so further studies are needed to assess the amount of these compounds in fish fillets.

4. Conclusions

This study represents a step towards the characterization of fish species consumed in Chile in terms of their fatty acid profile and availability within lipid classes, thus providing valuable information still not available in the country and showing the current status of commercially-available marine fishes. Analyzed fish species were shown to have low lipid content, high n-3/n-6 PUFA ratios and most DHA supplied as PL, which is desirable from a nutritional point of view. Therefore, regular consumption of fish, such as the studied species, could contribute to efficiently increase the dietary levels of EPA and DHA in the Chilean population, particularly for specific population groups such as pregnant women and the elderly. Further research is recommended to quantify compounds as sterols, tocopherols and lipid-soluble vitamins in edible marine fishes.

Acknowledgements

This work was partially supported by the National Fund for Scientific and Technological Development (FONDECYT) [Grant Number 11160636]. Authors are also grateful to the International Cooperation Program from the National Commission for Scientific and Technological Research [Grant REDES170030] and the Fund for Innovation of the Regional Competitiveness [project FIC-R code 30485950-0].

Conflict of interest

The authors declare no conflict of interest.

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