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Characterization of Mexican Fishes According to Fatty Acid Profile and Fat Nutritional Indices

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The fatty acid profile of crevalle jack was compared with that of Atlantic bluefin tuna, Atlantic Spanish mackerel, red snapper, and Nile tilapia. Crevalle jack and Atlantic Spanish mackerel showed similarities in their fatty acid profiles, with the saturated fatty acid > monounsaturated fatty acid > polyunsaturated fatty acid pattern. Atlantic bluefin tuna and red snapper followed a similar pattern to each other, with the polyunsaturated fatty acid > saturated fatty acid > monounsaturated fatty acid pattern, and the pattern for Nile tilapia was saturated fatty acid > monounsaturated fatty acid ≈ polyunsaturated fatty acid. In winter, the DHA+EPA content of crevalle jack (493.2 mg/100 g fillet) was 37% lower than Atlantic bluefin tuna and Atlantic Spanish mackerel, 35% higher than for the red snapper, and 2.8 fold higher than for the Nile tilapia. The best nutritional indices were for Atlantic bluefin tuna > red snapper > Atlantic Spanish mackerel > crevalle jack > Nile tilapia.

Keywords: Fatty acid composition, Fat nutritional indices, *Caranx hippos*, *Thunnus thynnus*, *Scomberomorus maculatus*, *Lutjanus campechanus*, *Oreochromis niloticus*.

INTRODUCTION

Fish consumption is recommended because of several nutritional benefits[1]—low in total fat and rich in protein, contains a number of essential minerals (selenium, iodine, magnesium, zinc, calcium, iron, phosphorous, potassium, sodium, cobalt, and fluorine) and several beneficial

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vitamins (B1, B2, B6, B12, A, D, E). Specifically, fish contains a higher amount of polyunsaturated fatty acids (PUFA), especially n-3 PUFA, compared with other protein sources, such as milk, meat and eggs, that have a high content of saturated fatty acids (SFA) or n-6 PUFA. The consumption of n-3 PUFA aids in the reduction of plasma cholesterol and triacylglycerol levels,[2] which suggests that it can also serve as a mechanism in the protection against cardiovascular disease (CVD), such as the prevention of cardiac arrhythmias, decrease in platelet aggregation, stabilization of atherosclerotic plaque, decrease in thrombosis, and reduction of blood pressure.[3] Despite the fact that CVD is a multifactor disease, fish consumption could have a beneficial effect against CVD risk factors, such as atherosclerosis, thrombosis and high plasma cholesterol. Furthermore, n-3 PUFA are essential for mental and visual function; their intake has been associated with a decreased risk of Alzheimer's disease, dementia, depression, and attention deficit hyperactivity disorder.[4] For that reason, it is necessary to describe the fatty acid (FA) composition of fish products.

Some health effects of fish species can be discerned by investigating the quality indices in relation to the type and content of FAs (e.g., the index of atherogenicity [IA], the index of thrombogenicity [IT] and the hypocholesterolemic to hypercholesterolemic FAs ratio [HH]).[5,6] These indices provide an overview of the fat nutritional quality when considering groups of FAs and their relationship to different diseases.

Although fish products are well known for their health value, not all fish species offer the same benefits. In Mexico, there is a large variety of marine and freshwater fish species, but not all are exploited, because of ignorance of their features. Specifically, the crevalle jack (*Caranx hippos*) is a specie of interest because of the lack of analytical data for FA composition, as indicated following a review of the Mexican food composition tables.[7]

Crevalle jack is a coastal species found in tropical and subtropical zones worldwide. It is distributed in the eastern Atlantic, from Portugal to Angola, including the western Mediterranean. It is also distributed in the western Atlantic, from Nova Scotia, Canada, and the northern Gulf of Mexico to Uruguay, including the Greater Antilles.[8] It is a cheap species that is commonly used as a game fish, in public aquariums, and human consumption, but the FA profile during different seasons and its nutritional indices have not yet been reported. In this work, the FA composition of crevalle jack was compared over three seasons with Atlantic bluefin tuna (AB tuna) and Atlantic Spanish mackerel (AS mackerel), which are good sources for n-3 PUFA; in the second part of the work, the last species were compared in winter with Nile tilapia and red snapper, which are important commercial fish species in Mexico. Data were analyzed to evaluate the fat nutritional quality of the five fish species by calculating the PUFA to SFA ratio, the IA, the IT, and the HH ratio. Additionally, a comparison of nutritional indices was also conducted between the Mexican species with other important species from around the world, in order to show nutritional characteristics of Mexican species.

MATERIALS AND METHODS

Biological Fish Material

Crevalle jack (*Caranx hippos*), AB tuna (*Thunnus thynnus*), AS mackerel (*Scomberomorus maculatus*), red snapper (*Lutjanus campechanus*), and Nile tilapia (*Oreochromis niloticus*) were purchased at La Nueva Viga Market in Mexico City, which is one of the largest fish markets in the world. Nile tilapia (average mass, 495.6 ± 27.0 g) were obtained from a farm; crevalle jack (average mass, 758.2 ± 73.5 g), AB tuna (average mass, 146.1 ± 28.4 kg), AS mackerel (average mass, 582.5 ± 44.3 g), and red snapper (average mass, 1013.3 ± 143.1 g) were from the Gulf of Mexico. AB tuna and AS mackerel are pelagic species, whereas red snapper is a reef-associated species that remains within a relatively small area.[9]

Whole specimen with excellent physical properties were acquired from various vendors. The quality of chilled fish was assessed by a visual inspection of eyes, gills, skin, and scales. All samples were immediately placed on ice, kept cold, transported in polystyrene boxes, and maintaining at 0.0 ± 0.5°C until analysis. A total of 11 fillets per species per season were analyzed. Crevalle jack, AB tuna, and AS mackerel fillets were sampled during the summer (June to August 2011), autumn (October to December 2011), and winter (February and March 2012); 11 fillets of red snapper and Nile tilapia were sampled in winter (February 2012). A total of 121 samples were analyzed. Each fillet from an individual specimen was ground in a food processor; the obtained homogeneous mass was used for the analyses described below.

Fat Content

Total lipid content was extracted from the ground fillet according to Folch et al.[10] using a chloroform–methanol solution (2:1, mL:mL) and recovering the lipids in a Rotavapor at 43°C. The extract was used to quantify both the total fat and the FA composition.

FA Analysis

Aliquots of the total lipid extract were used to prepared fatty acid methyl esters (FAMEs) by method 2.301 of IUPAC.[11] The FAMEs profile was determined in triplicate for each sample and was based on the experimental procedure described by Hernández-Martínez et al.[12] using a PerkinElmer Clarus 500 gas chromatograph equipped with a flame ionization detector and a Rtx-2330 capillary column (105 m length; 0.25 mm internal diameter; 0.20 mm film thickness; Restek, Bellefonte, USA).

Data were processed using the TotalChrom Software of PerkinElmer. The FAMEs were identified by comparison of their retention time with those of a marine standard mix (Restek 35066). FA quantification was carried out by calculating the percentage peak area to obtain the percentage of FAMEs, then to calculate the percentage of total FAs the conversion factors of the AOAC 996.06 method were used.[13] The amount of FA in mg/100 g of edible portion (fillet) was also calculated.

The estimated limits of detection (LOD) and limits of quantification (LOQ) for the individual FAMEs components on the gas chromatography were between 0.093 and 1.669 mg/mL, and 0.309 and 5.565 mg/mL, respectively, and they were calculated according to Miller and Miller.[14] The LOD of an analyte may be described as that concentration which gives an instrument signal significantly different from the "blank" or "background" signal. The LOQ is the lower limit for precise quantitative measurements.[14]

Fat Nutritional Indices

The FA composition was used to determine three nutritional indices, which attributed different weights to FAs depending on the different contribution of these to the promotion or prevention of pathological phenomena. The IA and the IT were calculated according to Ulbricht and Southgate,[5] and the HH ratio, according to Santos-Silva et al.[6] using the following formulae:

$$IA = \frac{[C12:0 + (4 * C14:0) + C16:0]}{MUFA + n-6PUFA + n-3PUFA}$$

$$IT = \frac{(C14:0 + C16:0 + C18:0)}{\left[(0.5 * MUFA) + (0.5 * n-6PUFA) + (3 * n-3PUFA) + \left({n-3PUFA}/{n-6PUFA}\right)\right]}$$

$$HH = \frac{(C18:1c\ n-9 + C18:2n-6 + C20:4n-6 + C18:3n-3 + C20:5n-3 + C22:5n-3 + C22:6n-3)}{(C14:0 + C16:0)}$$

To calculate the nutritional indices, the FAs concentrations were expressed as mg/100 g of fillet. The values of HH are expected to be as high as possible, and IA and IT as low as possible.

Statistical Analysis

Significant differences between FAs and nutritional indices among species and seasons were determined by one-way analysis of variance (ANOVA) at a 5% significance level ($p < 0.05$) using Tukey's test. The analyses were performed with Minitab Statistical Software, version 16.1.0 (State College, PA, USA).

RESULTS AND DISCUSSION

Chemical Composition

The mean lipid content of crevalle jack, AB tuna, AS mackerel, red snapper, and Nile tilapia was 3.25, 3.32, 6.60, 1.64, and 1.03 g/100 g of fillet, respectively. The complete chemical composition of crevalle jack, AB tuna, and AS mackerel can be seen in the work of Hernández-Martínez et al.[15]

FA Content

Twenty FAs in fish fillets were identified and compared among different species. The most abundant FA identified in fish species were: palmitic acid (C16:0), stearic acid (C18:0), palmitoleic acid (C16:1 n-7), oleic acid (C18:1 n-9), eicosatrienoic acid (C20:3 n-3), eicosapentaenoic acid (EPA, C20:5 n-3), and docosahexaenoic acid (DHA, C22:6 n-3), these seven FA were in the highest proportions of total FA. The average percentage of main FAs in crevalle jack, AB tuna, AS mackerel, red snapper, and Nile tilapia was 88.65, 92.88, 87.53, 77.21, and 94.86%, respectively. The less abundant FAs (C14:0, C14:1, C18:1 n-7, C18:2, C18:3, C20:0, C20:1, C20:2, C22:1, C22:0, C24:0, C20:4, C24:1) individually had a percentage between 0.02 to 4.97% of total FAs.

The FA profile of crevalle jack, AB tuna, and AS mackerel is shown in Table 1. The total SFA in marine species ranged from 33.77 to 46.95% of total FAs. Similar results were reported for 12 marine fish species from the Black Sea.[16] In all species, SFA was mainly composed of C16:0 (20.73–31.93%) and C18:0 (7.22–13.66%).

The total SFA showed significant differences ($p < 0.05$) between the seasons only for crevalle jack and AS mackerel. Crevalle jack showed statistically the same SFA percentage as AS mackerel in autumn and winter. The SFA values could be explained by the metabolic necessities of crevalle jack and AS mackerel; Murillo et al.[17] suggest that SFA and MUFA are used as metabolic sources of energy for related species as *Caranx caballus* and *Scomberomorus sierra*.

The monounsaturated fatty acids (MUFA) ranged from 14.47 to 36.22%. The major MUFA was the oleic acid (C18:1 n-9). It ranged from 17.98 to 25.96% of the total FAs in the crevalle jack and AS mackerel and in lower proportions, from 10.16 to 20.74%, in the AB tuna. The total MUFA showed significant differences ($p < 0.05$) between the seasons in all species. Among the species, the AS mackerel showed the highest MUFA contents throughout seasons (33.06–36.22%) followed by the crevalle jack (27.64–30.33%).

The total PUFA ranged from 17.42 to 50.76% of total FAs. The PUFA was mainly composed of C20:3 n-3, EPA and DHA. The DHA and EPA were predominant (67.05–88.25%) among the total PUFA. The AB tuna showed the highest PUFA content (50.76–34.45%) followed by the crevalle jack (26.05–28.06%). These marine species showed an EPA+DHA content greater than 13.2% of the total FAs.

TABLE 1
Fatty acid composition (% of total fatty acids) in crevalle jack, AB tuna, and AS mackerel fillets by season

	Crevalle jack			*AB tuna*			*AS mackerel*		
Fatty acids	*Summer*	*Autumn*	*Winter*	*Summer*	*Autumn*	*Winter*	*Summer*	*Autumn*	*Winter*
	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11	n = 11
C14:0	2.24 ± 0.10 ^{c}	3.02 ± 0.05 ^{b}	2.48 ± 0.11 ^{c}	0.30 ± 0.06 ^{d}	2.28 ± 0.09 ^{c}	0.47 ± 0.16 ^{d}	3.48 ± 0.23 ^{s}	3.02 ± 0.20 ^{b}	3.28 ± 0.42 ^{ab}
C16:0	24.54 ± 0.13 ^{de}	30.12 ± 0.81 ^{ab}	28.19 ± 1.19 ^{bc}	21.94 ± 0.29 ^{ef}	24.40 ± 0.63 ^{de}	20.73 ± 2.05 ^{f}	20.68 ± 2.83 ^{f}	31.93 ± 1.69 ^{a}	26.44 ± 0.40 ^{cd}
C18:0	13.66 ± 0.70 ^{a}	9.90 ± 0.79 ^{cd}	12.89 ± 0.43 ^{ab}	12.76 ± 3.06 ^{ab}	8.82 ± 0.36 ^{cd}	11.51 ± 0.09 ^{abc}	7.22 ± 1.22 ^{d}	10.72 ± 0.72 ^{bc}	9.26 ± 0.24 ^{cd}
C20:0	0.74 ± 0.06 ^{e}	0.34 ± 0.10 ^{f}	1.53 ± 0.09 ^{c}	0.57 ± 0.09 ^{ef}	1.17 ± 0.18 ^{cd}	0.59 ± 0.07 ^{ef}	2.10 ± 0.37 ^{b}	0.81 ± 0.17 ^{de}	3.94 ± 0.05 ^{a}
C22:0	0.05 ± 0.00 ^{bc}	0.08 ± 0.01 ^{bc}	0.35 ± 0.11 ^{a}	0.02 ± 0.02 ^{c}	0.09 ± 0.01 ^{bc}	0.22 ± 0.18 ^{ab}	0.19 ± 0.01 ^{abc}	0.15 ± 0.01 ^{bc}	0.20 ± 0.03 ^{ab}
C24:0	0.37 ± 0.05 ^{ab}	0.43 ± 0.15 ^{ab}	0.59 ± 0.04 ^{a}	0.35 ± 0.20 ^{abc}	0.32 ± 0.06 ^{abc}	0.25 ± 0.20 ^{bc}	0.10 ± 0.03 ^{c}	0.32 ± 0.08 ^{abc}	0.22 ± 0.05 ^{bc}
ΣSFA	41.60 ± 0.82 ^{bc,B}	43.89 ± 1.54 ^{ab,AB}	46.03 ± 1.79 ^{ab,A}	35.95 ± 3.55 ^{d,A}	37.07 ± 1.15 ^{cd,A}	33.77 ±2.01 ^{d,A}	33.77 ± 3.60 ^{d,B}	46.95 ± 2.32 ^{a,A}	43.34 ± 0.35 ^{ab,A}
C14:1	1.83 ± 0.04 ^{a}	0.70 ± 0.04 ^{c}	0.64 ± 0.05 ^{cd}	0.19 ± 0.17 ^{g}	0.94 ± 0.03 ^{b}	0.36 ± 0.04 ^{f}	0.57 ± 0.02 ^{cde}	0.48 ± 0.07 ^{ef}	0.48 ± 0.03 ^{def}
C16:1 n-7	4.12 ± 0.11 ^{c}	5.73 ± 0.39 ^{ab}	4.45 ± 0.74 ^{bc}	1.02 ± 0.17 ^{e}	4.35 ± 0.18 ^{c}	2.76 ± 1.23 ^{d}	5.75 ± 0.47 ^{a}	6.72 ± 0.32 ^{a}	6.56 ± 0.13 ^{a}
C18:1 n-9	20.70 ± 0.44 ^{d}	19.86 ± 0.69 ^{de}	17.98 ± 0.62 ^{e}	10.35 ± 0.43 ^{f}	20.74 ± 0.68 ^{cd}	10.16 ± 0.09 ^{f}	22.70 ± 1.39 ^{bc}	25.96 ± 1.50 ^{a}	24.05 ± 0.63 ^{ab}
C18:1 n-7	1.84 ± 0.08 ^{bc}	2.32 ± 1.63 ^{abc}	2.69 ± 0.09 ^{ab}	2.16 ± 0.58 ^{bc}	1.06 ± 0.07 ^{c}	1.52 ± 0.01 ^{bc}	1.70 ± 0.31 ^{bc}	1.05 ± 0.15 ^{c}	3.61 ± 0.26 ^{a}
C20:1 n-9	0.29 ± 0.03 ^{de}	0.59 ± 0.09 ^{b}	0.32 ± 0.04 ^{cde}	0.08 ± 0.01 ^{f}	0.41 ± 0.02 ^{cd}	0.09 ± 0.01 ^{f}	1.36 ± 0.11 ^{a}	0.44 ± 0.03 ^{c}	0.24 ± 0.07 ^{e}
C22:1	0.07 ± 0.02 ^{b}	0.15 ± 0.02 ^{b}	0.35 ± 0.11 ^{a}	0.08 ± 0.02 ^{b}	0.17 ± 0.01 ^{b}	0.22 ± 0.18 ^{ab}	0.08 ± 0.01 ^{b}	0.07 ± 0.01 ^{b}	0.20 ± 0.03 ^{ab}
C24:1	1.51 ± 0.04 ^{a}	0.71 ± 0.28 ^{bc}	1.21 ± 0.25 ^{ab}	0.64 ± 0.07 ^{bc}	0.81 ± 0.05 ^{abc}	0.37 ± 0.07 ^{c}	0.90 ± 0.11 ^{abc}	0.91 ± 0.28 ^{abc}	1.08 ± 0.15 ^{abc}
ΣMUFA	30.35 ±0.31 ^{bc,A}	30.06 ± 1.53 ^{bc,A}	27.64 ± 1.14 ^{c,B}	14.47 ± 1.30 ^{d,B}	28.48 ± 0.89 ^{c,A}	15.47 ±1.45 ^{d,B}	33.06 ± 1.82 ^{ab,B}	35.62 ± 1.96 ^{a,AB}	36.22 ± 0.54 ^{a,A}
C18:2 n-6	1.11 ± 0.08 ^{cde}	0.88 ± 0.04 ^{def}	1.43 ± 0.07 ^{b}	1.16 ± 0.19 ^{bcd}	1.31 ± 0.28 ^{bc}	0.80 ± 0.10 ^{ef}	1.86 ± 0.10 ^{a}	0.72 ± 0.06 ^{f}	1.01 ± 0.10 ^{cdef}
C18:3 n-3	0.40 ± 0.06 ^{bc}	0.42 ± 0.07 ^{bc}	0.76 ± 0.05 ^{a}	0.14 ± 0.01 ^{d}	0.43 ± 0.08 ^{bc}	0.14 ± 0.01 ^{d}	0.33 ± 0.06 ^{c}	0.54 ± 0.06 ^{b}	0.49 ± 0.07 ^{b}
C20:2 n-6	0.28 ± 0.02 ^{b}	0.19 ± 0.02 ^{bcd}	0.24 ± 0.01 ^{bcd}	0.73 ± 0.14 ^{a}	0.27 ± 0.03 ^{b}	0.16 ± 0.01 ^{bcd}	0.26 ± 0.04 ^{bc}	0.15 ± 0.01 ^{cd}	0.14 ± 0.01 ^{d}
C20:3 n-3	3.63 ± 0.06 ^{d}	2.47 ± 0.07 ^{e}	5.77 ± 0.50 ^{b}	9.78 ± 0.69 ^{a}	2.88 ± 0.02 ^{e}	4.65 ± 0.14 ^{c}	3.09 ± 0.18 ^{de}	2.42 ± 0.18 ^{e}	4.72 ± 0.08 ^{c}
C20:4 n-6	0.25 ± 0.07 ^{c}	0.17 ± 0.07 ^{c}	0.53 ± 0.07 ^{a}	0.17 ± 0.01 ^{c}	0.17 ± 0.01 ^{c}	0.21 ± 0.02 ^{c}	0.18 ± 0.04 ^{c}	0.37 ± 0.02 ^{b}	0.37 ± 0.01 ^{b}
C20:5 n-3	2.49 ± 0.10 ^{e}	4.28 ± 0.11 ^{c}	2.48 ± 0.23 ^{e}	4.50 ± 0.65 ^{c}	5.37 ± 0.21 ^{b}	4.52 ± 0.09 ^{c}	9.27 ± 0.61 ^{a}	4.13 ± 0.40 ^{cd}	3.34 ± 0.16 ^{d}
C22:6 n-3	19.90 ± 1.01 ^{cd}	17.64 ± 0.66 ^{d}	15.14 ± 1.36 ^{de}	33.10 ± 3.83 ^{b}	24.01 ± 1.97 ^{c}	40.28 ± 1.34 ^{a}	18.18 ± 1.12 ^{d}	9.08 ± 3.37 ^{f}	10.38 ± 0.58 ^{ef}
ΣPUFA	28.06 ± 1.13 ^{cd,A}	26.05 ± 0.83 ^{de,A}	26.34 ± 2.16 ^{d,A}	49.58 ± 4.82 ^{a,A}	34.45 ± 1.91 ^{b,B}	50.76 ± 1.10 ^{a,A}	33.17 ± 1.87 ^{bc,A}	17.42 ± 3.84 ^{f,B}	20.44 ± 0.80 ^{ef,B}
DHA+EPA	22.39 ± 1.12 ^{de,A}	21.92 ± 0.76 ^{e,A}	17.62 ± 1.56 ^{ef,B}	37.61 ± 4.47 ^{b,B}	29.39 ± 2.11 ^{c,C}	44.80 ± 1.30 ^{a,A}	27.45 ± 1.65 ^{cd,A}	13.21 ± 3.78 ^{f,B}	13.71 ± 0.74 ^{f,B}
n-3 PUFA	26.43 ± 1.12 ^{cd}	24.81 ± 0.78 ^{de}	24.14 ± 2.05 ^{de}	47.52 ± 5.16 ^{a}	32.70 ± 2.03 ^{b}	49.59 ± 1.21 ^{a}	30.88 ± 1.78 ^{bc}	16.18 ± 3.89 ^{f}	18.92 ± 0.85 ^{ef}
n-6 PUFA	1.64 ± 0.11 ^{cd}	1.24 ± 0.06 ^{de}	2.20 ± 0.15 ^{a}	2.06 ± 0.34 ^{ab}	1.75 ± 0.28 ^{bc}	1.17 ± 0.12 ^{e}	2.29 ± 0.13 ^{a}	1.25 ± 0.08 ^{de}	1.52 ± 0.09 ^{cde}

SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Mean values with different superscript letters in the same row differ significantly in the Tukey's test (p < 0.05); Lowercase letters indicate significant differences among species and seasons. Capital letters indicate significant differences among seasons for a particular species.

Among the n-6 PUFA, linoleic acid (C18:2 n-6) was the most abundant, ranging from 0.72 to 1.86% of total FAs and arachidonic acid (C20:4 n-6) was the next most abundant, ranging from 0.17 to 0.53%. The n-6 PUFA were very low compared with n-3 PUFA. Percentages of PUFA and n-3 PUFA showed no significant differences ($p < 0.05$) among studied seasons for crevalle jack, whereas significant differences were observed for AB tuna and AS mackerel. These differences could be due to the intake and accumulation of FAs which depend upon multiple factors, such as diet, accumulation, and distribution of FA among fish tissues, the consumption of FA during spawning season, and migration.[18]

Results showed that PUFA concentrations for crevalle jack were constant probably due to a constant FAs sources and geographic location, even though the analysis was carried out in samples collected during the spawning season (March–September).[19] In the case of AS mackerel, the higher percentage of DHA+EPA was found in summer which is the spawning season (July–September)[20] and the lower percentages were found in autumn and winter seasons. These latter results can be attributed to the reduction of FAs reservoirs after the spawning. Similar results can be observed in other fish species.[21] These results can also be due to migration behavior, since AS mackerel migrates from south to north in spring–summer and in opposite direction in autumn–winter.[20]

In the case of AB tuna, results showed significant differences ($p < 0.05$) of DHA+EPA among the studied seasons, with the higher percentage in winter. These differences can be attributed to multiple factors: (1) n-3 PUFA are constituents of the cellular membrane phospholipids, which are needed especially during the low temperature season to maintain the membrane fluidity and membrane protein function;[17,21] (2) due to the intake of phytoplankton and carnivorous diet of the fish;[22] another less important factor is the spawning season which occurs for each individual every 2 to 3 years, but for the specie as a whole, every year.[23]

Regarding red snapper and Nile tilapia, the percentage of SFA, MUFA, PUFA, n-3 PUFA, n-6 PUFA, and DHA+EPA based on the total FA were 40.06, 13.43, 46.51, 45.61, 0.90, and 40.26% and 51.29, 24.37, 24.33, 19.97, 4.37, and 12.93%, respectively. Red snapper and Nile tilapia were sampled in winter only, because more levels of PUFA were expected since fish in a cold region or season have higher amounts of PUFA to provide the lower water temperature adaptation.[21,24] However, results in Table 1 show that for crevalle jack and mackerel, winter was not the season with the highest percentage of PUFA, as was expected, indicating that cold temperature season is not the only factor for the increase of n-3 PUFA concentration in these species.[21,25] Mourete et al.[22] mentioned that the most important factor for the increase of PUFA is the fish diet.

When FA results are expressed as mg/100 g of fillet instead of the percentage of total FA, a rather different pattern emerges. Thus, Table 2 shows the winter FA content of crevalle jack, AB tuna and AS mackerel, red snapper, and Nile tilapia, as mg/100 g of fillet. It is observed in Table 2 that the crevalle jack and the AB tuna statistically had the same PUFA content; also no significant differences were observed ($p < 0.05$) in the n-3 PUFA and DHA+EPA contents for AS mackerel and AB tuna.

The n-3 PUFA amount increased, respectively, in the AS mackerel, AB tuna, crevalle jack, and red snapper, which are marine species, unlike the Nile tilapia that showed a lower content. The marine fish species exhibit an EPA+DHA content as high as 364.88 mg/100 g of fillet. Because of the high fat content of the AS mackerel (5.62 g/100 g of fillet), it provided statistically the same DHA+EPA content, approximately 0.8 g/100 g fillet, as the AB tuna whose fat content was lower (2.17 g/100 g fillet), although it had the highest DHA+EPA percentage of the total FAs. The red snapper, which has a similar PUFA percentage as AB tuna, in the quantitative analysis (mg per 100 g of fillet) showed a smaller PUFA content because of its low fat content (1.64 g/100 g fillet). The results confirm the importance of analyzed total lipid content and the FA composition in the evaluation of nutritional quality.

The winter DHA+EPA content of the crevalle jack was approximately 37% lower than for the AB tuna and AS mackerel species, which are best known for their high n-3 PUFA content. However, the crevalle jack was 35% higher than for the red snapper, and it was 2.8 fold higher than for the Nile tilapia (Table 2), although the last two species are more popular for consumption than crevalle jack.

Fat Nutritional Indices

There is a large variety of consumable fish species that provide different health benefits. These benefits can be evaluated using the fat quality indices. For example, foods that have a PUFA to SFAs (P/S) ratio above 0.45 are considered desirable,[26] because of their potential to reduce cholesterol in the blood. In this study, the P/S ratios ranged from 0.59 in the Nile tilapia to 1.40 in the AB tuna (Fig. 1). This ratio can be used as an indicator to compare the fat nutritional quality of fish. However, other nutritional indices calculated for the five species may better emphasise the nutritional quality of lipids because they take into account the functional effects of the different FAs.[27] The indices were calculated for FA content per 100 g of fillet. Figure 1 shows the comparison of the fat quality index per species for each season.

TABLE 2
Fatty acid composition (mg/100 g of fillet) in crevalle jack, AB tuna, AS mackerel, red snapper, and Nile tilapia fillets in winter

Fatty acids	*Crevalle jack*	*AB tuna*	*AS mackerel*	*Red snapper*	*Nile tilapia*
	n = 11	n = 11	n = 11	n = 11	n = 11
Fat content ^{A}	2.92 ± 1.39 ^{b}	2.17 ± 0.60 ^{bc}	5.62 ± 1.25 ^{a}	1.64 ± 0.44 ^{cd}	1.03 ± 0.10 ^{d}
C14:0	81.78 ± 20.13 ^{b}	37.30 ± 9.65 ^{c}	176.94 ± 23.79 ^{a}	9.88 ± 2.18 ^{d}	40.86 ± 4.98 ^{c}
C16:0	666.50 ± 201.17 ^{b}	360.65 ± 115.48 ^{c}	1143.33 ± 296.33 ^{a}	303.70 ± 67.10 ^{c}	241.90 ± 29.48 ^{c}
C18:0	282.09 ± 86.64^{b}	184.76 ± 45.15 ^{c}	416.90 ± 90.09 ^{a}	143.51 ± 31.71 ^{cd}	78.07 ± 9.51 ^{d}
C20:0	18.96 ± 5.49 ^{b}	9.22 ± 5.79 ^{cd}	68.78 ± 12.42 ^{a}	2.00 ± 0.44 ^{d}	15.59 ± 1.90 ^{bc}
C22:0	9.43 ± 3.30 ^{b}	4.45 ± 2.01 ^{c}	15.76 ± 2.88 ^{a}	0.88 ± 0.20 ^{d}	1.87 ± 0.23 ^{cd}
C24:0	14.94 ± 4.38 ^{a}	5.51 ± 1.68 ^{b}	16.53 ± 6.84 ^{a}	2.32 ± 0.51 ^{b}	2.12 ± 0.26 ^{b}
ΣSFA	1073.71 ± 313.77 ^{b}	620.19 ± 152.62 ^{c}	1838.24 ± 399.42 ^{a}	462.29 ± 102.14 ^{c}	380.41 ± 46.35 ^{c}
C14:1	19.60 ± 6.04 ^{b}	10.28 ± 4.95 ^{c}	29.62 ± 5.50 ^{a}	6.04 ± 1.33 ^{c}	8.53 ± 1.04 ^{c}
C16:1 n-7	141.81 ± 47.61 ^{b}	67.62 ± 29.03 ^{c}	277.41 ± 36.68 ^{a}	22.25 ± 4.92 ^{d}	53.24 ± 6.49 ^{cd}
C18:1 n-9	414.19 ± 145.74 ^{b}	187.92 ± 66.35 ^{b}	962.32 ± 243.29 ^{a}	98.45 ± 21.75 ^{c}	78.08 ± 9.51 ^{c}
C18:1 n-7	58.26 ± 12.91 ^{b}	23.88 ± 5.76 ^{b}	157.85 ± 96.31 ^{a}	21.25 ± 4.69 ^{b}	39.08 ± 4.76 ^{b}
C20:1 n-9	48.69 ± 17.48 ^{b}	20.72 ± 10.46 ^{c}	81.57 ± 13.72 ^{a}	4.30 ± 0.95 ^{d}	13.59 ± 1.66 ^{cd}
C22:1	16.23 ± 9.26 ^{b}	18.34 ± 8.80 ^{b}	37.51 ± 6.02 ^{a}	3.92 ± 0.87 ^{c}	16.72 ± 2.04 ^{b}
C24:1	27.49 ± 9.27 ^{b}	8.27± 2.46 ^{c}	49.10 ± 6.61 ^{a}	7.30 ± 1.61 ^{c}	7.20 ± 0.88 ^{c}
ΣMUFA	726.28 ± 234.62 ^{b}	353.02 ± 111.28 ^{c}	1595.39 ± 370.75 ^{a}	164.80 ± 34.51 ^{c}	216.44 ± 26.37 ^{c}
C18:2 n-6	35.20 ± 10.97 ^{b}	18.59 ± 8.36 ^{c}	52.99 ± 7.16 ^{a}	7.37 ± 1.63 ^{d}	24.02 ± 2.93 ^{c}
C18:3 n-3	38.41 ± 11.13 ^{b}	12.11 ± 7.90 ^{cd}	54.83 ± 8.86 ^{a}	5.32 ± 1.18 ^{d}	17.16 ± 2.09 ^{c}
C20:2 n-6	9.25 ± 2.99 ^{b}	5.22 ± 2.21 ^{c}	15.26 ± 3.31 ^{a}	2.33 ± 0.52 ^{d}	2.52 ± 0.31 ^{cd}
C20:3 n-3	97.70 ± 29.66 ^{b}	58.81 ± 14.22 ^{c}	144.65 ± 31.75 ^{a}	53.27 ± 11.77 ^{c}	35.34 ± 4.31 ^{c}
C20:4 n-6	45.79 ± 14.00 ^{b}	15.95 ± 5.43 ^{cd}	63.35 ± 8.73 ^{a}	6.07 ± 1.34 ^{d}	17.74 ± 2.16 ^{c}
C20:5 n-3	99.08 ± 30.79 ^{b}	107.48 ± 40.77 ^{b}	217.01 ± 29.98 ^{a}	74.14 ± 14.73 ^{b}	38.90 ± 4.74 ^{c}
C22:6 n-3	399.70 ± 105.70 ^{b}	677.30 ± 160.73 ^{a}	569.62 ± 162.64 ^{a}	290.74 ± 48.86 ^{b}	90.25 ± 11.00 ^{c}
ΣPUFA	725.13 ± 191.02 ^{b}	895.45 ± 194.47 ^{b}	1119.70 ± 200.29 ^{a}	439.26 ± 79.37 ^{c}	225.93 ± 27.53 ^{d}
DHA+EPA	493.18 ± 133.78 ^{b}	784.78 ± 171.33 ^{a}	786.62 ± 185.11 ^{a}	364.88 ± 63.19 ^{b}	129.15 ± 15.74 ^{c}
n-3 PUFA	634.89 ± 164.54 ^{b}	855.71 ± 186.63 ^{a}	986.11 ± 185.95 ^{a}	423.48 ± 75.93 ^{c}	181.65 ± 22.13 ^{d}
n-6 PUFA	90.24 ± 27.20 ^{b}	41.37 ± 14.39 ^{c}	133.60 ± 17.75 ^{a}	15.78 ± 3.49 ^{d}	44.28 ± 5.40 ^{c}

^{A}Fat content is expressed as g/100 g of fillet; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; Mean values with different superscript letters in the same row differ significantly in the Tukey's test (p < 0.05).

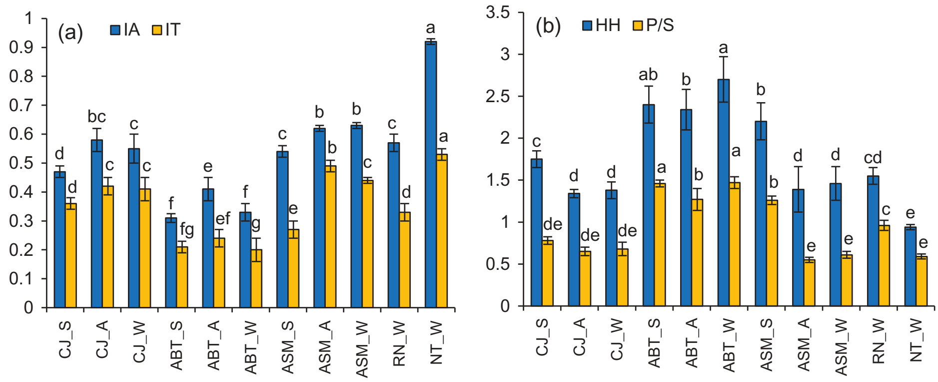

FIGURE 1 A: IA, index of atherogenicity; IT, index of thrombogenicity; B: HH, hypocholesterolemic to hypercholesterolemic fatty acid ratio; P/S, polyunsaturated to saturated fatty acids ratio from Crevalle jack (CJ), Atlantic bluefin tuna (ABT) and Atlantic Spanish mackerel (ASM), Nile tilapia (NT) and red snapper (RN), in summer (S), autumn (A), or winter (W). Values are expressed as the mean ± SD (n = 11). Bars represent standard deviation (n = 11). Mean values with different letters differ significantly in the Tukey's test (p < 0.05).

The HH ratio considers the specific effects of FAs on cholesterol metabolism. Higher values of this ratio are desirable. The IA and IT indices are related to pro- and antiatherogenic and pro- and antithrombogenic FAs;[27] the lower the values of both indices, the better the protective potential for CVDs. In a global assessment, crevalle jack, AB tuna, and AS mackerel had their best fat nutritional indices in the summer (Fig. 1). The lowest AI were for AB tuna < crevalle jack < red snapper < AS mackerel < Nile tilapia; the lowest TI were for AB tuna < red snapper < crevalle jack, AS mackerel < Nile tilapia; and the highest HH were for AB tuna < AS mackerel < red snapper < crevalle jack < Nile tilapia.

The average nutritional indices for all seasons (summer, autumn, and winter) for Crevalle jack, AB tuna, and AS mackerel, and those for red snapper and nile tilapia for winter (only season considered for these two species) are shown in Table 3. To compare the average nutritional quality of the studied species with respect to other reported species,[27–35] in this work the (IA+IT) to HH ratio was introduced as a general index; the lowest values expressed a better balance between nutritional indices (Table 3). Table 3 summarize all data available in the literature concerning nutritional indices regardless the season. It is worth mentioning that some nutritional indices in Table 3 were calculated from the original data reported by the different authors. According to Table 3, AB tuna showed the best nutritional indices followed by red snapper, AS mackerel, crevalle jack, and Nile tilapia. Other marine and freshwater samples analyzed by several authors are shown in Table 3; in overall terms, the nutritional indices of marine fish were better than freshwater species, and the analyzed oceans offer species with diverse nutritional quality. It is observed that the same species can produce different nutritional indices. Many researchers have reported that the amounts and types of FAs are affected by seasonal changes, species, gender, size, feed intake, geographic location, sexual changes, water temperature, and salinity.-[21,25] Comparing the crevalle jack with other species, it was evaluated in an acceptable manner. Additionally, crevalle jack is an economical species. Among all the species studied, it is the cheapest, with an average monthly wholesale cost of \$1.40 USD per kg, whereas the AB tuna, red snapper, AS mackerel, and Nile tilapia have costs of \$14.95, \$6.92, \$3.55, and \$2.08 USD per kg,[36] respectively. There is a relationship between cost and fat nutritional indices; however, in terms of the DHA+EPA content, there is no relationship because AS mackerel had the highest content followed by AB tuna, crevalle jack, red snapper, and Nile tilapia (Table 3). According to the recommended daily EPA + DHA intake of 500 mg[37] or 250 mg,[38] for the primary prevention of CVDs, the consumption of 120 g of fresh crevalle jack provides 592 mg, which exceeds both recommendations.

TABLE 3
Comparison of nutritional quality indices in fillet of freshwater and marine fish species

Species	*Total fat %*	*P/S*	*IA*	*IT*	*HH*	*(IA+IT)/HH*	*DHA+EPA (mg/100 g fillet)*	*Origin*
Atlantic salmon (*Salmo salar*) [a]	16.47	1.75	0.37	0.25	3.48	0.18	1509	North Atlantic Ocean
Silver scabbardfish (*Lepidopus caudatus*) [b]	0.40	1.44	0.37	0.21	2.60	0.22	82	North Atlantic Ocean
AB tuna (*Thunnus thynnus*) [c]	3.98	1.40	0.35	0.22	2.47	0.23	1078	Gulf of Mexico
Mahi mahi (*Coryphaena hippurus*) [a]	0.85	1.39	0.40	0.25	2.69	0.25	156	North Pacific Ocean
Ray (*Raja* spp.) [b]	0.20	1.43	0.40	0.23	2.19	0.29	57	North Atlantic Ocean
Meagre (*Argyrosomus regius*) [d]	2.97	1.48	0.47	0.23	2.36	0.30	678	Fish farm, Ansedonia
Atlantic bonito (*Sarda sarda*) [e]	8.41	1.45	0.53	0.22	2.46	0.30	2340	Eastern Black Sea
Tuna yellowfin (*Thunnus albacares*) [f]	2.2-4.6	1.10	0.43	0.27	1.97	0.36	178	Arabian Sea
Red snapper (*Lutjanus campechanus*) [a]	1.26	1.30	0.53	0.26	2.12	0.37	253	North Atlantic Ocean
Tuna yellowfin (*Thunnus albacares*) [a]	0.98	1.07	0.50	0.32	2.06	0.39	161	North Atlantic Ocean
Hake (*Merluccius merluccius*) [b]	0.70	0.95	0.51	0.30	1.92	0.42	194	North Atlantic Ocean
Malabar red snapper (*Lutjanus argentimeculatus*) [i]	1.37	1.30	0.63	0.22	1.86	0.46	234	Straits of Malacca
Mackerel (*Scomberomorus cavalla*) [g]	1.96	1.18	0.48	0.24	1.56	0.46	801	South Atlantic Ocean
Kingfish (*Scomberomorus commerson*) [h]	3.85	0.81	0.74	0.12	1.82	0.47	1159	Gulf of Oman and Arabian Sea
Spanish mackarel (*Scromberomorus guttatus*) [i]	1.05	0.97	0.68	0.22	1.75	0.52	98	Straits of Malacca
Red snapper (*Lutjanus campechanus*) [c]	1.64	0.96	0.57	0.33	1.55	0.58	365	Gulf of Mexico
AS mackerel (*Scomberomorus maculatus*) [c]	6.60	0.81	0.60	0.40	1.68	0.60	1212	Gulf of Mexico
Red grouper (*Epinephelus morio*) [a]	0.95	1.02	0.62	0.40	1.68	0.61	100	Gulf of Mexico, North Atlantic Ocean
Crevalle jack (*Caranx hippos*) [c]	3.25	0.70	0.54	0.40	1.49	0.63	567	Gulf of Mexico
Spanish mackerel (*Scomberomorus maculatus*) [a]	3.82	0.63	0.59	0.48	1.66	0.65	563	Gulf of Mexico, North Atlantic Ocean
Sixbar grouper (*Epinephelus fasciatus*) [i]	3.46	0.92	0.77	0.28	1.44	0.73	299	Straits of Malacca
Jarupensém (*Surubim lima*) [j]	11.19	0.40	0.53	0.94	1.80	0.82	95	Miranda River, Brazil
Tilapia (family: Cichlidae; tribe: tilapiini) [a]	2.47	0.67	0.64	0.77	1.67	0.85	76	Fish farm, USA
Sardines (*Opisthonema oglinum*) [g]	9.03	1.47	0.60	0.20	0.87	0.92	3690	South Atlantic Ocean
Spot (*Leiostomus xanthurus*) [a]	11.65	0.43	0.76	0.64	1.12	1.25	949	North Atlantic Ocean
Jaú (*Paulicea luetkeni*) [j]	10.44	0.27	0.62	1.00	1.30	1.25	118	Miranda River, Brazil
Pangasius (*Pangasius hypophthalmus*) [a]	1.21	0.38	0.79	1.24	1.50	1.36	17	Fish farm, USA
Moonfish (*Trachinotus blochii*) [i]	6.89	0.96	1.28	0.38	1.19	1.39	299	Straits of Malacca

(*continued*)

TABLE 3
(*Continued*)

Species	*Total fat %*	*P/S*	*IA*	*IT*	*HH*	*(IA+IT)/HH*	*DHA+EPA (mg/100 g fillet)*	*Origin*
Nile tilapia (*Oreochromis niloticus*) [c]	1.03	0.59	0.92	0.53	0.94	1.54	129	Fish farm, State of Mexico
Barbado (*Pinirampus pirinampu*) [j]	7.30	0.23	0.79	1.18	1.14	1.73	91	Miranda River, Brazil
Indian mackarel (*Rastrelliger kanagurta*) [i]	1.8	0.32	1.25	0.74	0.84	2.36	77	Straits of Malacca
Japanese threafin bream (*Nemipterus japonicus*) [i]	2.7	0.66	1.40	0.51	0.78	2.45	552	Straits of Malacca

P/S: polyunsaturated to saturated fatty acids ratio; IA: index of atherogenicity; IT: index of thrombogenicity; HH: hypocholesterolemic to hypercholesterolemic fatty acid ratio; DHA: docosahexaenoic acid (C22:6 n-3); EPA: eicosapentaenoic acid (C20:5 n-3);

[a]Calculated from Cladis et al.;[28]
[b]Afonso et al.;[29]
[c]Present work;
[d]Martelli et al.;[30]
[e]Misir et al.;[31]
[f]Al-Busaidi et al.;[32]
[g]Fernandes et al.;[33]
[h]Calculated from Khan et al.;[34]
[i]Calculated from Aziz et al.;[35]
[j]Ramos et al.[27]

CONCLUSION

The present study showed that AB tuna and red snapper had the best nutritional values of P/S ratio, IA, IT, and HH. However, in terms of the DHA+EPA content, AB tuna and AS mackerel were better options, followed by crevalle jack, red snapper, and Nile tilapia. The nutritional indices indicated that crevalle jack is an adequate source of "healthy" FAs because it is an economical source of DHA+EPA, with 592 mg/120 g of fresh fillet in winter. Additionally, it has an advantage over other species because it has a stable chemical composition of PUFA throughout the analyzed seasons.

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