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RESEARCH PAPER

Lipid and Fatty Acid Composition of Wild Almaco Jack *Seriola rivoliana* at Two Maturation Stages

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Abstract

Almaco jack (*Seriola rivoliana)* is an emergent marine finfish that presents high market value. In order to study the feasibility of the exploitation of this marine resource for human consumption the evaluation of the nutritional characteristics of this species has attracted the attention of the scientific community. The lipid characteristics and fatty acid composition were evaluated in muscle, liver and gonad tissues of wild Almaco jack from Atlantic Ocean at two different maturation stages. According to results, the lipid content was found higher at pre-spawning stage (21.78 - 36.17%) and highest proportion being exhibited in the liver. Palmitic acid was predominant among the saturated fatty acids (35.42 - 47.80%) and oleic acid was detected as the main monounsaturated acid (25.26 - 36.55%). Higher amounts of *ω3* polyunsaturated fatty acids (PUFAs) were identified in gonads of resting females, of which more than 84% was accounted by docosahexaenoic acid (12.62%). Muscle and liver of resting females presented the highest ω3/ω6 ratios. The Hypocholesterolemic/Hypercholesterolemic index was higher in gonads of both maturation stages (0.97 and 1.05). The results showed that wild Almaco jack at resting stage were a better source of oleic acid and ω3 PUFAs and that liver and gonads present good nutritional by-products.

Keywords: Lipids, fatty acid profile, maturation stages, Hypocholesterolemic/Hypercholesterolemic index.

Introduction

In the next five years, world per capita fish food consumption is projected to reach 20.6kg, up from nearly 19kg in 2010-12 (OECD-FAO 2013). Fish and other types of seafood constitute an important source of protein worldwide, comprising for more than 3 billion people, up to 20 percent of the average per-capita intake of animal protein (FAO 2014). Additionally, they are also sources of other important nutrients, such as lipids and fatty acids, including the long-chain polyunsaturated fatty acids (PUFAs) eicosapentaenoic acid/docosahexaenoic acid (EPA/DHA) (Fernandes *et al*., 2014). These fatty acids, namely EPA and DHA, are associated in human diet with the prevention or attenuation of cardiovascular diseases, inflammatory events and various types of cancers (Memon, Talpur, Bhanger, & Balouch, 2011; Fernandes *et al*., 2014;) and an average daily consumption of 250 mg of EPA/DHA per day has been recommended (USDA and HHS 2010).

The growing demand for fish and seafood and current discussion on its benefits and risks (Santerre, 2008; Violette, 2008), seconded by a lack of scientific studies with clear conclusions about fish nutritional value, dictates the need to present literature about fish nutritional value and to find new seafood products. In the urban societies, where fish is usually consumed in lower amounts, the most consumed part is the fish muscle, or more commonly the *fillet*. Liver and gonads are not usually commercially exploited and are discarded. It is important to address investigation towards these alternative sources, not only for increasing the profitability of the by-products of the fishing industry, but also for the possibility of finding nutritionally important PUFA-oils, with higher quality than traditional ones (Nogueira, Fernandes, Fernandes, & Cordeiro, 2016).

Seriola rivoliana (Almaco jack; pacific yellowtail), is a circumtropical species that occurs in the Indian Ocean, Pacific Ocean and Atlantic Ocean (such as Azores and Madeira) (Barreiros, Morato, Santos, & Borba, 2003). As with other *Seriola* species, this species is considered one of the emergent marine finfish species for aquaculture and fisheries due to their fast growth (Roo *et al*., 2014). Often destined to the demanding sushi markets, almaco jack may reach high market values of around $13 per kg (Bairagi *et al*, 2016). Published works of Almaco jack

are very limited and are mainly focused on broodstock management and reproduction in captivity (Saito, 2012; Roo, Fernández-Palacios, Schuchardt, Hernández-Cruz, & Izquierdo, 2015). There is a lack of information relating wild Almaco jack biological traits and nutritional value as a source of lipid and fatty acids for human consumption.

This work aimed to compare and evaluate the nutritional potential of Almaco jack by-products (liver and gonads) as a source of lipid and fatty acids for human consumption.

Materials and Methods

Chemicals

Methanol, BHT, heptane, as well as the standard samples that used were supplied by Sigma Aldrich (St. Louis, MO). Chloroform, dichloromethane, acetone and potassium chloride were supplied by VWR (Radnor, PA), while ethyl acetate was supplied by Merck (Darmstadt, Germany). All of the aforementioned chemicals used in this work have an analytical grade.

Fish Material and Sampling Procedure

Wild Almaco jack fish (n = 17) were directly obtained from fishermen in the Atlantic North (Madeira Archipelago) between August and September of 2012 (Table 1) and kept on ice (0-4ºC) for a maximum period of 36h, until landing. Once fish were brought to laboratory, all specimens were examined for individual meristic identification and morphometric data was collected (Table 1). Subsequently, all fish were eviscerated and sex as well as gonadal maturity stage was determined through macroscopic and microscopic examination. The microscopic histological analysis was performed in order to validate the macroscopic scale, using Ramos (1986) histological technique. The gonads were fixed with glutaraldehyde in 0,1M sodium cacodylate buffer (pH 7.4), dehydrated through different ethanol concentrations and embedded in resin (methacrylate). Gonads were sectioned at 5µm thickness and stained with Loffler's methylene blue solution. A LEICA DMLB microscope, LEICA EC 3 camera and LEICA Application suite software were used for image acquisition.

Maturation stages were performed using a six stage scale: 0-Immature; I-Maturing virgin or Resting; II-Developing; III–Pre-spawning; IV-Spawning; V-Spent (adapted from Holden & Raitt 1974).

Muscle samples (10 g) were collected from the dorsal side, directly under the dorsal fin and above the lateral line. Liver (5 g) and gonad (5 g) samples were also collected for later lipid and fatty acid determination. Samples were kept at –20 ºC for a period no longer than three months after homogenization and pooling according to collection date, gender and maturity stage and. All pooled samples (n = 4) were freeze dried at –60 ºC and 0.1 mbar in a Savant freeze-dryer. Samples were considered dried when the residual water content was less than 0.4% (w/w), using a Gibertini Eurotherm electronic moisture balance (Gibertini Elettronica, Novate Milanese MI, Italy).

Gonads were examined and weighed for determination of the gonadosomatic index [*GSI* % = (gonad mass/body mass) × 100]. Hepatosomatic index [*HIS* %= (liver mass/body mass) × 100] which is a common metrics of reproductive allocation and reproductive condition in fisheries biology was determined for each specimen.

Total Lipid and Lipid Classes

The lipid content was determined according to Bligh & Dyer (1959) and described in Fernandes, Fernandes, Andrade & Cordeiro (2016). Around 100 mg of lyophilized sample was weighted and 3 mL of a solution containing methanol/chloroform/BHT (2:1:0.01%) and 400 µL of saturated solution of potassium chloride were added. Then, 2 mL of chloroform and 2 mL of distilled water were added and the mixture placed under agitation for 20 min. The organic phase was collected and the solvent removed using a rotary evaporator at 40 ºC. The lipid content was determined gravimetrically and the results expressed in percentage of dry weight (DW). The experimental error was estimated to be below 5%. The samples were made in triplicate and stored at -20 ºC until further analysis.

Fatty Acids Analysis

Total lipid extracts were analysed for their fatty acid composition as fatty acid methyl esters (FAMEs) as previously described by Lepage & Roy (1986), modified by Cohen, Vonshak & Richmond (1988). Briefly, the fatty acids were converted to FAMEs by adding a mixture of ethyl acetate-methanol (1:19 v/v) to total lipid aliquots that were after submitted at 80 ºC for 1 h. FAMEs were analysed by gas chromatography (Agilent HP 6890) equipped with a mass selective detector (Agilent 5973) and a fused silica capillary column SupelcowaxTM 10 (30 m x 0.25 mm inner diameter, 0.25 µm film thickness) from Supelco. The chromatographic conditions were: initial temperature, 40 ºC for 5 min; temperature gradient, 2 ºC min^{-1}; final temperature, 250 ºC for 5 min; injector temperature, 260 ºC; transfer-line temperature, 260 ºC; split ratio, 1:100. Helium was used as the carrier gas with a flow of 1.0 mL min^{-1}.

The FAMEs were identified through comparison of retention times and mass spectra obtained with two standard samples: "bacterial acid methyl esters CP mix" and "Supelco 37 component FAME mix" and spectra library Wiley-NIST. To quantify the FA of the fish sample it was used heneicosanoic acid as an

Table 1. Site collection and morphometric data of wild Almaco jack female at two maturation stages. Gonadosomatic Index (GSI) and Hepatosomatic Index (HSI) are also presented

	Collection date	Site	Body weight (g)	Eviscerated weight (g)	Total Length (mm)	Fork length (mm)	Body Height (mm)	Body Depth; (mm)	Gonad weight; (g)	Liver weight (g)	GSI	HSI
Pre-spawning	24-08-2011	Selvagens	4465	4138	740	645	199	85	81	61	1.81	1.37
	24-08-2011	Selvagens	4810	4453	742	653	194	86	83	83	1.73	1.73
	24-08-2011	Desertas	4982	4529	788	679	189	94	90	75	1.81	1.51
	24-08-2011	Desertas	4944	4486	760	660	195	86	82	80	1.66	1.62
	20-09-2011	Selvagens	6274	5609	825	720	211	93	259	109	4.13	1.74
	20-09-2011	Selvagens	7858	7072	864	768	220	86	354	142	4.50	1.81
	20-09-2011	Selvagens	3584	3274	678	585	189	82	170	49	4.74	1.37
	20-09-2011	Selvagens	6277	5727	829	725	197	107	295	99	3.11	1.58
	20-09-2011	Desertas	5390	4949	761	664	195	91	153	102	2.84	1.89
			5398 ± 1249[a]	4915 ± 1098[a]	776 ± 57[a]	678 ± 54[a]	199 ± 10[a]	90 ± 8[a]	174 ± 104[a]	89 ± 28[a]	2.93 ± 1.27[a]	1.62 ± 0.18[a]
Resting	24-08-2011	Selvagens	3694	3427	671	583	185	78	24	40	0.66	1.09
	24-08-2011	Selvagens	3414	3181	678	570	180	78	27	31	0.78	0.91
	24-08-2011	Selvagens	5058	4759	759	662	203	90	31	51	0.61	1.00
	24-08-2011	Selvagens	3260	3106	662	584	180	70	15	30	0.45	0.92
	24-08-2011	Selvagens	4103	3883	711	625	188	90	24	43	0.58	1.05
	24-08-2011	Desertas	3282	2977	650	572	181	76	22	38	0.67	1.15
	30-08-2011	Selvagens	5571	5084	770	671	211	88	58	53	1.04	0.94
	30-08-2011	Selvagens	5294	4801	772	667	194	82	40	73	0.76	1.38
			4210 ± 958[a]	3902 ± 860[a]	709 ± 51[a]	618 ± 45[a]	190 ± 12[a]	82 ± 7[a]	30 ± 14[b]	45 ± 14[b]	0.69 ± 0.17[b]	1.05 ± 0.16[b]

internal standard. The results were expressed in percentage of total FA detected, being the quantification made according to the response factor determined for each FA present in the standards, in comparison with the heneicosanoic acid (internal standard). Determinations were performed in quadruplicate for each pooled sample. Experimental error due to the analytical methodology was estimated to be below 4%.

Nutritional quality was assessed by hypocholesterolemic/hypercholesterolemic fatty acid ratios (H/H index) using (Fernandes *et al*., 2014) and equation that used in calculation of results was shown in below:

$$\frac{(C18:1\omega9 + C18:2\omega6 + C20:4\omega6 + C18:3\omega3 + C20:5\omega3 + C22:5\omega3 + C22:6\omega3)}{(C14 + C16)}$$

Statistical Analysis

Data are reported as mean ± SD and analysed by means of a T-Student test and the differences between means were evaluated as significant at $P<0.05$. The data were performed using the software IBM SPSS Statistics 23.

Results and Discussion

Morphometric Analysis

According to Roo *et al*. (2015), maturation of cultured Almaco jack occurs after the fourth winter, when they reach 67 cm and over 6 Kg. Though no significant differences were observed in morphometric data, according to the maturity scale used in the present study and microscopical observations, females of Almaco jack were at two different maturation stages: resting and pre-spawning (Figure 1; Table 1). Macroscopically pre-spawning stage differed in colour, with a bigger size and covered in light blood vessels. Microscopically, resting ovaries were characterized by the presence of a few atretic oocytes and primary oocytes (Figure 1a) and pre-spawning for containing many oocytes in a different maturation phases (Figure 1b). The higher gonad and liver weight in females at pre-spawning stage could indicate the further development of these tissues, which is in agreement to their maturation stage. As a consequence, females at pre-spawning presented significantly higher gonadosomatic index (GSI) with a mean of 2.93 whereas resting females presented lower GSI (0.69). As for HSI, values were also significantly higher in females at pre-spawning, with an index of 1.62% compared to 1.05% resting females.

Total Lipid

Lipids are one of the main sources of energy reserves in fish and the biological condition (species, maturation stage, age and sex) of fish is known to influence the transfer of lipids from their storage tissues to other tissues, in order to fulfill physiological actions (Kandemir & Polat, 2007).

The lipid content in the different tissues of wild Almaco jack ranged between 9.72-36.17% (Table 2), with highest lipid content exhibited in liver samples of fish at pre-spawning stage. Overall, females at pre-spawning stage presented higher lipid content in all sampled tissues, with a marked increase in dorsal muscle. Dorsal muscle lipid content was higher in our samples (24.04%) when compared to the results found in the muscle of *S. fasciata* at the same maturation stage (Nogueira *et al*., 2016) and of *S. dumerilli* (Haouas, Zayene, Guerbej, Hammami, & Achour, 2010; Rodríguez-Barreto *et al*., 2012), but similar to those found by Rodríguez-Barreto *et al*. (2014) in indoor cultivated *S. dumerilli*. Such differences highlight the need of knowing fish nutritional value, especially when fish are not easy to distinguish, as is the case between Almaco jack adults and greater amberjack juveniles. Differences in lipid composition might be explained by species specific variation and due to methodological procedures. Muscle samples in the present study were collected from the dorsal muscle of Almaco jack. Thakur, Morioka, Itoh & Obatake (2003) and Shioya, Takemura, Ishizuka & Yamaguchi (2012) demonstrated that *Seriola quinqueradiata* muscles accumulated lipid in an ordered manner, with the individual muscles also accumulating lipids in a specific order, depending on the season. For comparison purposes, clarification of the proximate composition of different muscles and their seasonal trends would enable more detailed analyses aimed at optimizing the utilization and assessing potential differences among species and seasons. Still, comprising more than 8% of lipid content in their chemical composition, all the analysed tissues of wild Almaco jack female may be classified from a human nutritional standpoint as a high fat content fish (Ackman, 1989), similarly to other carangidae (Sutharshiny, Sivashanthini, & Thulasitha, 2013; Nogueira *et al*., 2016).

Fatty Acid Profiles

In Table 2, muscle, liver and gonad fatty acid compositions of wild Almaco jack from the eastern Atlantic Ocean were shown. Twenty-six main fatty acids (FA) were identified in all samples. The total fatty acids (mg/100g sample) were higher in the liver samples from both maturation stages, followed by dorsal muscle of pre-spawning females. Comparison with S. *fasciata* at the same maturation stage and captured in the same region (Nogueira *et al*., 2016), indicates that Almaco jack muscle samples are richer (9.737, 19.174 and 8.205 g/100g) than S. *fasciata* (6.514, 13.857 and 7.959 g/100g) in all sampled tissues (muscle, liver and gonad, respectively).

The FA profiles revealed that high amounts of saturated fatty acid (SFA) and monounsaturated fatty

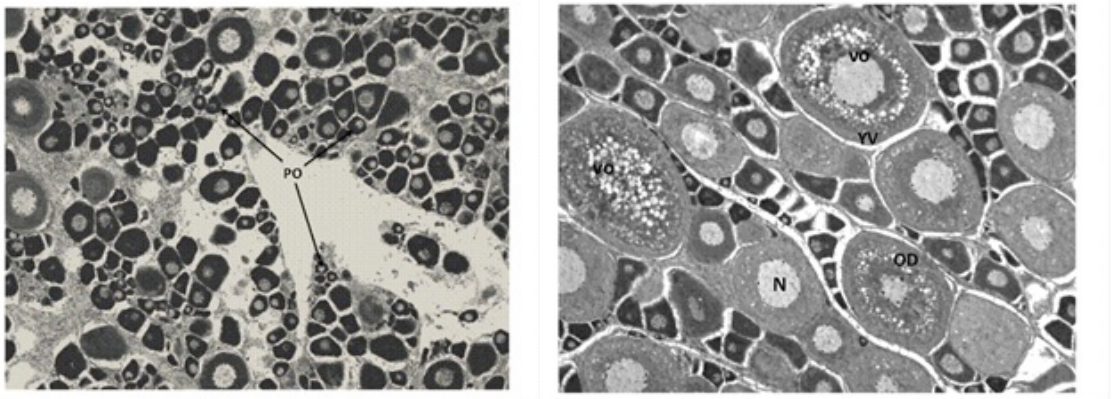

Figure 1. Microscopic aspects of maturity stages of *S.rivoliana.* ***a)*** Ovary at rest with some primary oocytes (100x). ***b)*** Ovary at pre-spawning stage with oocytes at different stages of vitellogenesis (200x). PO-primary oocytes; VO: vitellogenic oocytes; N: nucleus; YV yolk vesicles; OD: oil droplets.

Table 2. Fatty acid profile (% relatively to the total fatty acid detected)**;** total fatty acid and total lipid (g/100g) in muscle, liver and gonads of wild Almaco jack female at two maturation stages

Fatty acid (%)	Muscle		Liver		Gonads	
	Pre-spawning	Resting	Pre-spawning	Resting	Pre-spawning	Resting
C14:0	2.48 ± 0.44^a	2.45 ± 0.15^a	0.67 ± 0.12^a	0.76 ± 0.02^a	1.79 ± 0.03^a	2.90 ± 0.30^a
C16:0	45.06 ± 0.07^a	46.28 ± 1.87^a	35.42 ± 0.08^a	47.80 ± 0.74b^a	35.61 ± 0.59^a	38.35 ± 1.07^a
C18:0	12.43 ± 1.03^a	12.91 ± 0.68^a	22.50 ± 0.05^a	14.78 ± 0.40^b	14.33 ± 0.27^a	11.88 ± 0.18^b
Others[1]	1.50 ± 0.02^a	1.77 ± 0.06^b	0.96 ± 0.12^a	0.79 ± 0.04^a	2.18 ± 0.18^a	2.06 ± 0.06^a
Total - SFA	*61.48 ± 1.38^a*	*63.41 ± 0.99^a*	*59.55 ± 0.13^a*	*64.13 ± 0.28^b*	*53.91 ± 0.17^a*	*55.20 ± 1.25^a*
C16:1ω7	3.98 ± 0.15^a	3.14 ± 0.31^a	2.61 ± 0.05^a	2.39 ± 0.02^a	4.08 ± 0.12^a	2.41 ± 0.12^b
C18:1ω9	32.48 ± 1.31^a	26.99 ± 0.57^b	32.61 ± 0.03^a	30.02 ± 0.26^b	36.55 ± 0.39^a	25.26 ± 0.21^b
C20:1ω9	1.11 ± 0.07^a	1.07 ± 0.07^a	1.74 ± 0.12^a	1.07 ± 0.14^a	1.72 ± 0.17^a	1.03 ± 0.09^a
Others[2]	0.73 ± 0.12^a	1.12 ± 0.12^a	0.55 ± 0.10^a	1.16 ± 0.23^a	0.87 ± 0.10^a	1.14 ± 0.02^a
Total - MUFA	*38.30 ± 1.40^a*	*32.32 ± 0.46^b*	*37.51 ± 0.04^a*	*34.64 ± 0.12^b*	*43.21 ± 0.24^a*	*29.84 ± 0.20^b*
C18:2ω6	0.13 ± 0.02^a	0.10 ± 0.01^a	0.10 ± 0.04	*n.d.*	0.39 ± 0.01^a	0.11 ± 0.00^b
C20:4ω6 (AA)	*n.d.*	0.07 ± 0.01	0.17 ± 0.02^a	0.05 ± 0.01^b	0.18 ± 0.06^a	0.95 ± 0.08^b
C20:5ω3 (EPA)	*n.d.*	0.17 ± 0.01	0.24 ± 0.04^a	0.04 ± 0.01^b	0.29 ± 0.08^a	0.84 ± 0.04^b
C22:5ω6	*n.d.*	*n.d.*	0.08 ± 0.01	*n.d.*	0.03 ± 0.01^a	0.17 ± 0.04^a
C22:5ω3	*n.d.*	0.02 ± 0.00	0.10 ± 0.01	*n.d.*	0.07 ± 0.01^a	0.27 ± 0.06^a
C22:6ω3 (DHA)	0.08 ± 0.01^a	3.92 ± 0.51^b	2.09 ± 0.29^a	1.14 ± 0.14^a	1.84 ± 0.20^a	12.62 ± 0.82^b
Others[3]	*n.d.*	*n.d.*	0.14 ± 0.04	*n.d.*	0.07 ± 0.03	*n.d.*
Total - PUFA	*0.22 ± 0.03^a*	*4.27 ± 0.53^b*	*2.93 ± 0.17^a*	*1.23 ± 0.15^b*	*2.88 ± 0.41^a*	*14.96 ± 1.04^b*
Σω3	0.08 ± 0.01^a	4.11 ± 0.52^b	2.44 ± 0.26^a	1.18 ± 0.15^b	2.21 ± 0.30^a	13. 73± 0.92^b
Σω6	0.13 ± 0.02^a	0.17 ± 0.01^a	0.46 ± 0.08^a	0.05 ± 0.01^b	0.59 ± 0.08^a	1.23 ± 0.12^b
DHA/EPA	*n.d.*	22.70 ± 1.79	8.90 ± 2.68^a	29.57 ± 2.36^b	6.45 ± 1.15^a	15.02 ± 0.25^b
*Total FA**	*9.737 ± 0.839^a*	*4.165 ± 0.444^b*	*19.174 ± 0.155^a*	*9.938 ± 0.423^b*	*8.205 ± 0.687^a*	*5.523 ± 0.522b^a*
*Total lipids**	*24.04 ± 0.31^a*	*9.72 ± 0.86^b*	*36.17 ± 3.88^a*	*20.65 ± 0.32^b*	*21.78 ± 0.96^a*	*13.48 ± 0.87^b*

n.d. –not detected; Limit of detection for all fatty acids:0.01 %; Limit of detection for total fatty acids:0.001 g/100 g; *- Total fatty acids and total lipids were expressed in g per 100g of dry weight (DW); Different letters in the same line and the same tissue mean significant differences (P<0.05). Values are mean of quadruplicates ± SD; n=4 of pooled samples; Other [1] – C15:0; C17:0; C20:0; C22:0; Other [2] – C18:1ω7; C22:1ω9; C22:1ω11; C24:1ω9; Other [3] - C18:4ω3; C20:2ω9; C20:4ω3; SFA: Saturated fatty acids; MUFA- monosaturated fatty acids; PUFA- polyunsaturated fatty acids.

acid (MUFA) were found in all tissues (Figure 2), similarly to many other fish species (IGFA, 2001; Turchini, Gunasekera, & Silva, 2003). In comparison with other reports of Almaco jack (Saito, 2012), our data clearly showed higher content of SFA (59.55 to 64.13 %) and MUFA (32.32 to 38.30 %) in both liver and muscle samples. Higher SFA contents found in our study, may be related to the fact that total SFAs tend to increase in fish living in warm waters, since temperature affects the fatty acids composition (Delgado, Estevez, Hortelano, & Alejandre, 1994). Moreover, Turchini *et al*. (2003) suggested that fish can regulate and maintain certain levels of body lipid saturation by the *de novo* synthesis which could contribute to explain the high levels of SFA and MUFA found in the present study.

The major SFA identified in both maturation stages in all tissues was palmitic acid (C16:0, 35.42% - 47.80%), followed by stearic acid (C18:0, 11.88% - 22.50%) (Table 2), which is similar to that found by Saito (2012) within liver and muscles of Almaco jack and by Ökzüz (2012) in *S. dumerilli*. From a nutritional standpoint, low concentrations of myristic fatty acid in the different tissues of resting and pre-

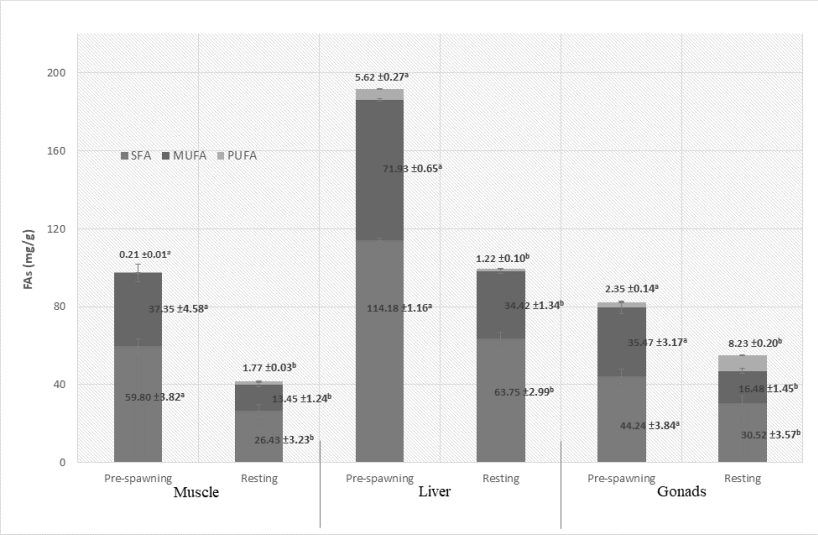

Figure 2. Composition (mg/g) of different families the fatty acids in wild Almaco jack females at resting and pre-spawning stage in different tissues. SFA- saturated fatty acid; MUFA- monounsaturated fatty acid; PUFA-polyunsaturated fatty acids. Different letters in the same tissue indicate significant differences (P<0.05).

spawning females (0.67 to 2.48 %), demonstrates a positive factor in their human consumption, since according to Fernandes *et al*. (2014), hypercholesterolemia is promoted by the lauric (C12:0) and myristic (C14:0) fatty acids.

The MUFA content constituted about one third of the total FA in all analysed tissues of wild Almaco jack females (Table 2). The major MUFAs were palmitoleic (C16:1ω7) and oleic (C18:1ω9) acids. Oleic acid values accounted more than 25% of total lipid fatty acids detected. Only a small number of fish species have been mentioned to present oleic acid values above 20%, including another jack, S. *quinqueridiata* (Vassallo-Agius *et al*., 2001). Our results could be explained by the fact that Almaco jack is a roving predator of small fishes (Honebrink, 2000) and gut contents of wild populations of fish with total length similar to those sampled in the present study include mostly mackereks *Scomber japonicus* and *Trachurus picturatus* (Barreiros *et al*., 2003), which are known to be rich in oleic acid (Celik, 2008; Nogueira, Cordeiro, & Aveiro, 2013) and could contribute to the high level of this fatty acid.

High amounts of oleic acid presented in our samples (25.26 to 36.55 %) enhance the consumption of Almaco jack in human nutrition, since this acid has particular importance for the stimulation of bile secretion, which is necessary for digestion and absorption of fats (Reale *et al*., 2006).

Almaco jack resting females and pre-spawning females showed significant variations between them in the relative proportions of total PUFA in the different tissues (P<0.05). The highest amount of PUFA was noticed in gonads of resting Almaco jack (14.96%). Still, our results are much lower when compared to published results for the for *S. dumerili* (Rodríguez-Barreto *et al.*, 2012; Öksüz, 2012). Differences found between studies were mainly due to the lower DHA and EPA content found in the present study, which may be related to fish age and nutritional status. It is known that marine fish have limited capacity to synthesize DHA and EPA from the essential FA, and consequently the percentages of these ω3 PUFAs in several tissues of fish are dependent on diet and changes in the nutritional habits of the fish (Prato & Biandolino, 2012). Moreover, Saito (2012) suggested that wild fish grow slowly due to oligotrophy in the wild oceans, as well as the biosynthesis and high accumulation of long-chain PUFA in tissue requires a longtime. Jacks used in this study were young and some had not reached first maturation. Older wild samples can slowly, but gradually, accumulate long-chain PUFA, while the breeding time of the younger samples, which is only one or two years, cannot accumulate sufficient levels of long-chain PUFA. However, DHA contents in gonads of resting females were similar to other marine fish species, such as Sand smelt, Red mullet, Grey wrasse and Grass goby (ranging from 5.90 to 17.39%) (Prato & Biandolino 2012; Guil-Guerrero, Venegas-Venegas, Rincón-Cervera, & Suárez, 2011).

As for the ω6 PUFA, linoleic acid (LA, C18:2ω6) is an essential FA with great physiological importance, being accumulated in adipose tissues or converted into LC - PUFA, such as arachidonic acid (AA, C20:4ω6), EPA and DHA (Prato & Biandolino 2012). In the present study, the most abundant ω6 PUFAs were LA and AA (Table 2). In gonads, Almaco jack females at pre-spawning stage showed the highest amounts of LA (0.39%), while highest content of AA (0.95%) was found in resting females. Similar results were found in other marine species from several locations (Prato & Biandolino 2012;

Fernandes *et al*., 2014; Özogul & Özogul, 2007; Guil-Guerrero *et al*., 2011). The low levels of AA found in tissues of wild Almaco jack at two maturation stages may constitute an advantage for consumer's cardiovascular health (Prato & Biandolino, 2012).

Fish nutritional values are favorable to human health when high levels of ω3 PUFAs and small amounts of ω6 PUFAs are present. An increase in the human dietary ω3/ω6 ratio helps to prevent coronary heart diseases by reducing plasma lipids and risk of cancer (Prato & Biandolino, 2012). All studied tissues contained higher amounts of ω3 PUFA than ω6 PUFA (Table 2, Figure 3) corroborating the assumption that marine fish are rich sources of ω3 PUFA.

The H/H index (Figure 4) refers to the hypocholesterolemic/ hypercholesterolemic fatty acid ratio, being associated to cholesterol metabolism (Fernandes *et al*., 2014). In human health, higher H/H index values in lipids are considered more beneficial. H/H index values ranged between 0.64 to 1.05 with the highest values being observed in gonads of both maturation stages and in the liver of pre-spawning females.

Conclusion

Though fish are recommended and consumed without consumer´s awareness of the possibility of the nutritional status of the fish according to their size and age, our study highlighted the existence of significant differences between resting and pre-spawning Almaco

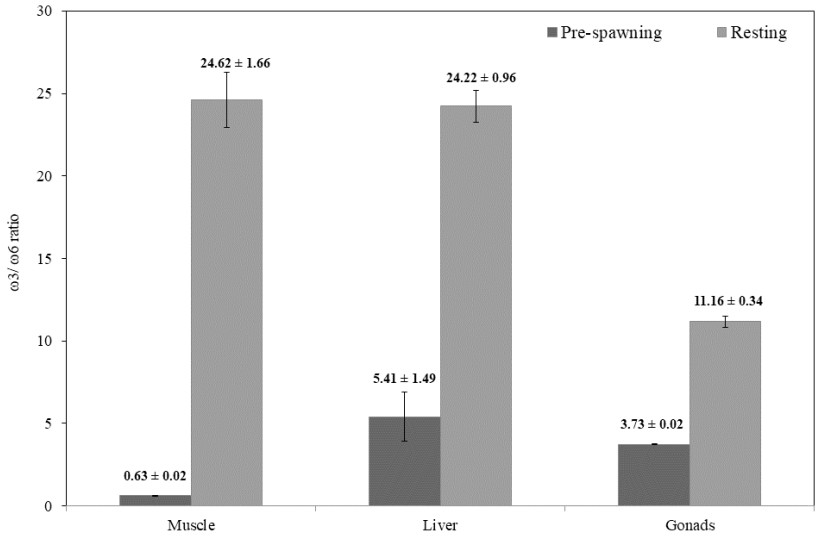

Figure 3. ω3/ω6 ratio in wild Almaco jack females at resting and pre-spawning stage in different tissues.

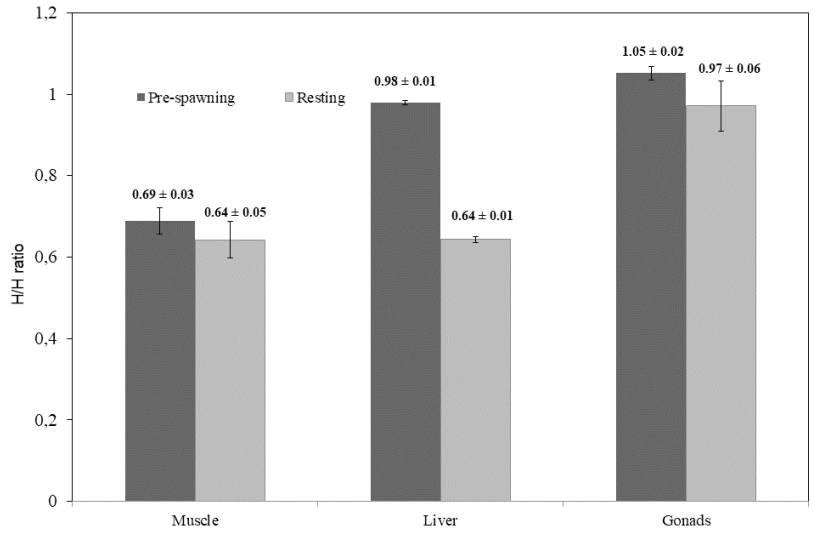

Figure 4. Hypocholesterolemic/Hypercholesterolemic fatty acids (H/H) ratio in wild Almaco jack females at resting and pre-spawning stage in different tissues.

jacks. Significantly higher lipid and fatty acid content were observed in pre-spawning females (total lipid: 21.8- 36.2% DW; total FA: 8.2-19.2% DW), when compared to resting females (total lipid: 9.7-20.7% DW; total FA: 4.2-9.9% DW). Still, resting females were best recommended for human health as they were characterized by higher contents of ω3 PUFA (muscle ω3 PUFA content was 19 times higher than what was observed for pre-spawning females), predominantly DHA and ω3/ω6 ratio. Of the several tissues analysed, livers and gonads revealed to be as well good sources of fatty acids, ranging between 55.2 mg/g in resting female gonads and 191.7 mg/g in livers of pre-spawning females. Moreover, ω3/ω6 and H/H ratios of liver and gonads of pre-spawning females were, respectively, 8.6-5.9 times (ω3/ω6) and 1.4-1.5 times (H/H) higher, than muscle ratios.

These results are useful to evaluate the utilization of by-products of this species for sustainable fisheries and to further increase their biology knowledge.

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