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Effect of the inclusion of fish residue oils in diets on the fatty acid profile of muscles of males and females lambari (*Astyanax altiparanae*)[1]

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ABSTRACT - This study evaluated the effects of two lipids sources of fish residue (tilapia and salmon) compared with a vegetable oil source (soybean oil) on the fatty acid profiles of male and female lambari. This experiment was developed in a completely randomized experimental design in a 3 × 2 factorial arrangement, totaling 6 treatments resulting from the combination of the three experimental diets for both sexes, with four replications for each treatment. This study involved 120 male (2.58±0.13 g) and 72 female lambari (4.00±0.09 g), fed the experimental diets twice a day until apparent satiation for a period of 60 days. Oleic, linoleic, palmitic and stearic fatty acids were found at higher concentrations in all experimental oils and diets, as well in the muscle of male and female lambari. The low amounts of arachidonic, eicosapentaenoic and docosahexaenoic acids in the experimental diets and subsequent greater concentrations in muscle tissue, suggested that lambari are able to desaturate and elongate the chain of fatty acids with 18 carbons. The fish of both sexes that received the diet with soybean oil showed high levels of n-6 fatty acids, especially of C18: 2n-6 and low levels of eicosapentaenoic and docosahexaenoic acids. The diet with salmon residue oil promoted higher levels of fatty acids of the n-3 series and resulted in the best n-3/n-6 ratio in the muscle of male and female lambari. The oils from fish residues can be a substitute for traditional fish oil and its use in the lambari diets does not impair its growth.

Key Words: docosahexaenoic acid, eicosapentaenoic acid, salmon residue oil, soybean oil, tilapia residue oil

Introduction

Although fishmeal and fish oil provide sufficient quantities of amino acids and essential fatty acids, the use of these ingredients in the fish nutrition does not guarantee the sustainability of aquaculture (Tacon & Metian, 2008), since the production in the fishery sector is stagnant (FAO, 2010).

Foods rich in fatty acids from the n-3 series, like eicosapentaenoic (EPA, C20: 5n-3) and docosahexaenoic acids (DHA, C22: 6n-3), and with a balanced n-3/n-6 ratio are related to several human nutritional benefits (Bazan, 2006; Mozaffarian et al., 2005). Therefore, a major disadvantage in replacing fish oil by vegetable oils in the preparation of fish feed is the inevitable change in the fatty acid profile composition of fish muscle. Preparations containing a large amount of vegetable-based ingredients will promote increased levels of n-6 and decreased levels of n-3, resulting in the loss of that particular nutritional health benefit (Turchini et al., 2009).

A strategy to improve the fatty acid profile composition in the fish muscle, while also promoting environmental sustainability, is the use of oil obtained from fish-processing residues (Turchini et al., 2009). Studies have shown the efficiency of trout offal oil (Turchini et al., 2003), catfish residue oil (O'Neal & Hohler, 2008) and tilapia residue oil (Boscolo et al., 2008).

The lambari-do-rabo-amarelo species belongs to the family Characidade and subfamily Tetragonopterinae, previously classified as *Astyanax bimaculatus*, receiving the new nomenclature *Astyanax altiparanae* (Garutti & Britski, 2000). This species has become an attractive option for commercial production, because of the easy capture of fingerlings, their rapid growth, their simplicity and ease in handling, as well as their great potential for the commercial market (Porto-Foresti et al., 2005). Due to these characteristics, the lambari has been investigated concerning factors related to its production, such as stocking density (Vilela & Hayashi, 2001), feeding level and frequency (Hayashi et al., 2004; Meurer et al., 2005) and nutrition (Abimorad & Castellani, 2011; Cotan et al., 2006; Signor et al., 2008).

With the growth of aquaculture, it has become necessary to carry out research studies on the use of generated residues in a species with a potential for farming. The objective of this study was to investigate the effects of two sources of

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oil obtained from tilapia and salmon residues, compared with soybean oil, upon the fatty acid profile compositions found in lambari.

Material and Methods

The experiment was conducted in Pirassununga (21°59' S, 47°26' W), São Paulo state, Brazil, within a closed system with constant water circulation and oxygenation; a photoperiod of 12 hours of light and 12 hours of darkness. Water quality parameters, pH, dissolved oxygen and temperature were all monitored on a daily basis and the concentrations of ammonia and nitrite were monitored weekly.

Mean temperature, dissolved oxygen, pH, ammonia and nitrite levels observed during the experimental period were 25.92±0.4 °C; 4.60±0.2 mg/L; 7.37±0.15; 0 ppm and 0 mg/L, respectively. These values were within the acceptable levels for the farming of *Astyanax altiparanae* (Porto-Foresti et al., 2005).

Three experimental diets were formulated (Table 1) with the same lipid content (50 g/kg); their only variation was the source of oil: soybean and tilapia and salmon residue. The control diet was formulated with soybean oil purchased in Pirassununga, São Paulo, Brazil. The tilapia residue oil was extracted by means of centrifugation of the carcass without any milled viscera and head for 30 minutes (Centrifuge Thermo IEC Centra GP8R, 4200 rpm). The lipid supernatant fraction from the Nile tilapia residue was collected with a pipette and filtered using a vacuum pump, containing filter paper (Whatman #4) and sodium sulfate for retaining the solid waste and remaining moisture. The salmon residue oil was provided by Damm Food Products Ltd (São Paulo, SP), extracted under heat during the preparation of fish meal. The combination of fish meal, soybean meal and corn gluten was used as protein source (Table 2). Corn and wheat bran were used as sources of carbohydrates. In order to minimize lipid oxidation, an antioxidant (BHT) was added to the fish feed formulation, which was extruded into grains of 2 mm of diameter.

This experiment was developed in a completely randomized design, in a 3 × 2 factorial arrangement, totaling 6 treatments resulting from the combination of the three experimental diets for both sexes, with four replications (tank) for each treatment. This study involved 192 lambari during the growth period; their sex was already identifiable (spines on the anal fin of the male). This total comprised 120 males (average weight 2.58±0.13 g) and 72 females (average weight 4.00±0.09 g). Each experimental group was stocked in fiberglass tanks (60 cm × 55 cm × 50 cm) having a useful capacity of 120 L. The fish were fed the extruded experimental diets twice a day (8:00 am and 5:00 pm) until apparent satiety, for a period of 60 days. The cleaning of each tank was done on alternate days.

At the end of the experiment, three fish per replicate were sacrificed with an overdose of anesthetic (benzocaine, g/L); these fish were then frozen (-80 °C) for evaluation of the fatty acid profile.

Samples of the experimental diets and the fish carcasses were obtained for determination of the proximate composition (moisture, crude protein, ash and lipids), using methodology from the AOAC (2005), and only the muscle tissue was used for the determination of the fatty acid profiles from each treatment.

The method used for the total lipid extraction was the one described by Bligh & Dyer (1959). The lipids were saponified according to the procedures described by Hartman & Lago (1973). The methyl esters from the fatty acids were separated using gas chromatography and the identification of fatty acids was performed by comparing the retention times of fatty acid standards (Sigma no. Cat 189-19). To determine the fatty acids profile, a gas

Table 1 - Formulation and proximate composition of experimental diets

Ingredients (g/kg)[1]	Experimental diets		
	Soybean oil	Tilapia residue oil	Salmon residue oil
Soybean meal	290.8	290.8	290.8
Corn (grain)	260.0	260.0	260.0
Wheat bran	107.0	107.0	107.0
Corn gluten	85.0	85.0	85.0
Corn starch	30.0	30.0	30.0
Fishmeal	120.0	120.0	120.0
Kaolin	50.0	50.0	50.0
Soybean oil	50.0	-	-
Tilapia residue oil	-	50.0	-
Salmon residue oil	-	-	50.0
Vitamin and mineral supplement[2]	5.0	5.0	5.0
Salt	2.0	2.0	2.0
Butylated hydroxytoluene	0.2	0.2	0.2
Analysis			
Dry matter (g/kg)	923.7	931.3	936.1
Crude protein (g/kg)	325.5	315.3	320.2
Crude lipid (g/kg)	65.3	79.6	72.7
Crude fiber (g/kg)	33.5	33.5	33.5
Ash (g/kg)	115.2	109.9	111.9
NFE (g/kg)[3]	460.5	461.7	461.7
Gross energy (kcal/kg)	4347.27	4347.27	4347.27

[1] Crude protein and crude lipid, in g/kg: fishmeal: 611 and 81; corn: 86 and 54; wheat bran: 160 and 33; corn gluten: 673 and 27; corn starch: 0.55 and 0.18; soybean meal: 461 and 8.

[2] Composition of the vitamin and mineral supplement Supre Mais® (guaranteed levels per kg feed) - Minerals: choline chloride - 108 g; niacin - 24,000 mg; selenium - 100 mg; iodine - 100 mg; cobalt - 10 mg; copper - 3,000 mg; iron - 50,000 mg; manganese - 20,000 mg; zinc - 30,000 mg; vitamins: A - 1,200,000 UI; B1 - 4,800 mg; B12 - 4,800 mg; B6 - 4,800 mg; C - 48 g; D3 - 200,000 UI; E - 12,000 mg; K3 - 2,400 mg; folic acid - 1,200 mg; biotin - 48 mg; calcium pantothenate - 12,000 mg.

[3] EqNPN - 1000 – (crude protein + crude lipid + crude fiber + ash).

Table 2 - Fatty acid composition (mg/g) of the oils and experimental diets

Fatty acids	Oils			Diets		
	Soybean	Tilapia	Salmon	Soybean	Tilapia	Salmon
C14:0	0.00	22.90	29.15	0.40	1.55	2.15
C15:0	0.00	1.45	2.90	0.10	0.15	0.20
C16:0	93.65	192.65	125.25	14.30	18.30	14.90
C16:1	0.00	44.90	38.20	0.75	3.00	2.80
C17:0	1.00	1.90	2.90	0.25	0.20	0.30
C17:1	0.00	1.90	3.80	0.00	0.05	0.20
C18:0	30.60	50.20	39.70	4.20	4.60	3.90
C18:1n-9	234.20	386.70	215.55	26.20	32.90	24.25
C18:2n-6	529.85	139.60	110.40	36.00	25.45	23.75
C18:3n-3	51.65	7.60	20.05	2.05	1.20	2.00
C20:0	3.80	1.90	1.90	0.55	0.45	0.40
C20:1n-11	3.35	18.65	31.50	0.40	1.10	1.90
C22:0	5.70	1.00	1.00	0.80	0.25	0.25
C20:2n-6	0.00	9.60	19.10	0.40	0.50	1.00
C20:4n-6	0.00	7.60	5.70	0.10	0.45	0.40
C20:3n-6	0.00	7.60	1.90	0.00	0.35	0.10
C20:5n-3	0.00	1.45	69.30	0.10	0.15	3.55
C22:5n-3	0.00	0.00	42.10	0.00	0.10	2.05
C22:6n-3	0.00	4.80	117.60	0.20	0.50	5.65
∑sat[1]	136.75	277.70	202.70	21.25	25.70	22.20
∑mono[2]	237.55	454.10	297.80	27.70	36.70	29.40
∑poly[3]	579.80	180.70	401.50	38.20	28.40	39.10
∑n-3	51.65	16.50	250.95	2.30	1.95	13.45
∑n-6	528.20	164.40	149.60	35.90	26.45	25.70
n-3/n-6	0.10	0.10	1.68	0.06	0.07	0.52

[1] Sum of saturated fatty acid.
[2] Sum of monounsaturated fatty acid.
[3] Sum of polyunsaturated fatty acid.

chromatograph type GC-14B, Shimadzu was used, along with a fused silica capillary column, type OMEGAWAX250 (30 m × 0.25 mm × 0.25 a) n0 cat. 24136-SUPELCO, with the following analytical conditions and programming: 100 °C for 2 minutes; heating 4 °C/min up to 220 °C maintaining this temperature for 25 minutes; injector temperature of 250 °C; temperature of the detector 280 ºC; gas carrier velocity (H2) of 1 ml/min; SPLIT 1/100; injection volume of 1µL; FID (Flame Ionization Detector).

Data were subjected to a variance analysis (ANOVA) at 5% probability, using the GLM procedure of software SAS (Statistical Analysis System, version 9.2). When interaction between factors (sex and diet) occurred, breaking down was performed and the Tukey test ($P<0.05$) was applied to evaluate comparisons of means; statistical differences were presented as interaction means. When the interaction between factors did not result in statistical significance, the differences were presented in the marginal means of each factor (sex and diet).

Results and Discussion

The different lipid sources used in this study (soybean oil, Nile tilapia residue oil and salmon residue oil) did not present any interaction in growth between the sexes (data not shown), which corroborates previous studies using different lipid sources at equivalent levels in the diet of fish (Caballero et al., 2002; Izquierdo et al., 2003; López et al., 2009; Martino et al., 2002; Turchini et al., 2003; Rosenlund et al., 2001).

The moisture and ash values taken from the carcasses of both male and females resulted in no difference, and interaction was observed between the mean values of crude protein and crude lipids (Table 3). Females had higher protein content in the muscle tissue compared with males, regardless of the diet consumed. The male lambari fed the diet containing soybean oil had higher levels of crude protein, followed by those on a diet with salmon oil and then finally tilapia oil. Both female and males fed soybean oil had a higher content of ether extract in their muscles than those fed the diet with fish oil (Table 3). No damage (necrosis or cell degeneration) was observed in the intestinal epithelium of *Spaurus aurata* that had been fed by replacing 60 to 80% of the fish oil content with vegetable oil (linseed, soybean, canola), but higher lipid deposition was verified in the enterocytes for fish fed vegetable oils (Caballero et al., 2003). On the other hand, the replacement of 60% of fish oil by soybean oil resulted in higher lipid deposition in the hepatocytes of rainbow trout (Caballero et al., 2002).

Table 3 - Proximate composition (g/kg) of body proximate composition of male and female lambari

Analysis	Sex	Lipid source of the diet			Mean	P value			CV (%)
		Soybean oil	Tilapia residue oil	Salmon residue oil		Diet	Sex	Diet*Sex	
Moisture	Female	697.3±2.70	708.4±2.70	707.4±2.70	704.37±1.56A	0.323	0.057	0.461	5.24
	Male	725.0±2.70	749.2±2.70	733.7±2.70	735.97±1.56A				
Mean		711.15±1.91a	728.80±1.91a	720.55±1.91a					
Crude protein	Female	187.3±0.13Aa	188.5±0.13Aa	185.8±0.13Aa	187.19±0.08	<0.001	<0.001	<0.001	1.31
	Male	172.9±0.13Ba	155.0±0.13Ac	166.6±0.13Ab	164.82±0.08				
Mean		180.10±0.09	171.75±0.09	176.2±0.09					
Ash	Female	42.1±0.10	45.2±0.10	38.6±0.10	42.53±0.06A	0.172	0.309	0.060	4.22
	Male	46.1±1.10	40.5±0.10	42.9±0.10	43.17±0.06A				
Mean		44.10±0.07a	42.85±0.07a	40.75±0.07a					
Ether extract	Female	75.2±0.22Aa	50.3±0.22Ab	49.8±0.22Ab	58.42±0.13	<0.001	0.033	0.035	6.80
	Male	63.6±0.22Ba	51.8±0.22Ab	46.8±0.22Ab	54.08±0.13				
Mean		69.40±0.16	51.05±0.16	48.30±0.16					

Means followed by different lowercase and capital letters in rows and columns, respectively, differ by the Tukey test (P=5%).
CV - coefficient of variation.

In a study that described the fatty acid composition of commercially important fish from Brazil, the palmitic acid was the predominant fatty acid, followed by C16:1, C18:1 and C14:0 in the flesh of lambari (Gutierrez & Silva, 1993). In the present study, the fatty acids found in greatest amounts, both in the diets (Table 3) as well as in the lambari muscle tissue (Table 4), were: oleic (C18:1n-9); linoleic (C18:2n-6); palmitic (C16:0) and stearic (C18:0), which is probably related to the inclusion of vegetable ingredients in the experimental diets. The palmitic acid was the most abundant, followed by stearic, oleic acid, EPA and DHA in the liver and muscle tissue fatty acid profile from male and female *Salmo trutta macrostigma* (Akpinar et al., 2009). Despite being a freshwater fish, the trout presented high levels of EPA and DHA, which may be related to the lower temperature necessary for the survival of this species as well as the fact that they were captured directly from the river, i.e., from their natural food environment or still having the ability of elongation and desaturation of precursory fatty acids.

Studies conducted by Izquierdo et al. (2003), Martínez-Llorens et al. (2007), Martino et al. (2002) and Vargas et al. (2008) verified that the fatty acid profile of the diet reflects on the composition of fatty acids in fish tissue. Linoleic acid (C18: 2n-6) was found at higher levels among the polyunsaturated fatty acids in the oils and the experimental diets, except for salmon oil, which showed to have a higher concentration of DHA. Soybean oil is an ingredient rich in linoleic acid (529.85 mg/g), which was reflected in the diet (36.00 mg/g) as well as in the muscle tissue of male (10.95 mg/g) and female fish (14.70 mg/g) (Table 3). They had been fed soybean oil, which had a greater amount of this fatty acid compared with the two other experimental groups (tilapia: 25.45, 6.50 and 8.85 mg/g; salmon: 23.75, 8.70 and 9.90 mg/g, respectively).

The muscle tissue from animals fed the salmon-oil diet showed higher values of saturated fatty acids (males: 15.30 and females: 20.10 mg/g) and monounsaturated fatty acids (males: 21.45 and females: 23.10 mg/g), and the mean values of polyunsaturated fatty acids were higher in muscle tissue from fish on soybean oil (males: 14.75 and females: 18.60 mg/g), followed by salmon oil (males: 13.30 and females: 14.65 mg/g) and TI (males: 9.25 and females: 12.45 mg/g) regardless of the sex (Table 5).

Female muscle tissue had higher levels than males in most of the fatty acids which were different for the sex factor ($P<0.001$ or $P<0.01$). The greater accumulation of these fatty acids in females is probably related to their greater need to retain energy. This is because during the period of ovarian maturation, females require a large availability of macro and micronutrients for transfer to the oocytes (Cejas et al., 2004). As lipid mobilization depends on the species of fish, this may be obtained from the fat reserves of one or more tissues, particularly muscle and liver tissues (Adams, 1999).

The levels of essential linoleic fatty acid (C18:3n-3) were found to be higher in the muscle tissue from fish fed soybean and salmon oils, for both male and female groups. The arachidonic fatty acid (ARA - C20: 4n-6) is the major eicosanoid precursor in fish cells as the prostaglandins, thromboxans and leukotrienes (Bell et al., 1994) and it controls many physiological functions, including reproduction (Sargent et al., 1999). The prostaglandins stimulate ovarian and testicular steroidogenesis and the ovulation control (Kellner & Van Der Kraak, 1993). The arachidonic fatty acid was present at higher concentrations

Table 4 - Fatty acid composition (mg/g) of the muscle tissue from male and female lambari

Fatty acids	Sex	Lipid source of the diet			Mean	P value			CV (%)
		Soybean oil	Tilapia residue oil	Salmon residue oil		Diet	Sex	Diet*Sex	
C14:0	Female	0.40±0.02Ac	0.70±0.02Ab	1.05±0.02Aa	0.72±0.01	<0.001	<0.001	0.003	7.00
	Male	0.30±0.02Bb	0.45±0.02Bab	0.60±0.02Ba	0.45±0.01				
Mean		0.35±0.01	0.57±0.01	0.82±0.01					
C15:0	Female	0.10±0.00Ab	0.10±0.00Ab	0.20±0.00Aa	0.13±0.00	<0.001	<0.001	<0.001	0.00
	Male	0.10±0.00Ab	0.10±0.00Ab	0.10±0.00Bb	0.10±0.00				
Mean		0.10±0.00	0.10±0.00	0.15±0.00					
C16:0	Female	12.15±0.01	12.65±0.01	14.20±0.01	13.00±0.00A	<0.001	<0.001	0.676	2.12
	Male	8.60±0.01	8.90±0.01	10.35±0.01	9.28±0.00B				
Mean		10.38±0.0b	10.78±0.0b	12.28±0.0a					
C16:1	Female	1.10±0.02Ac	1.55±0.02Ab	2.10±0.02Aa	1.58±0.01	<0.001	<0.001	0.005	2.99
	Male	0.80±0.02Bc	1.15±0.02Bb	1.50±0.02Ba	1.15±0.01				
Mean		0.95±0.01	1.35±0.01	1.80±0.01					
C18:0	Female	3.95±0.07	3.95±0.07	4.35±0.07	4.08±0.04A	<0.001	<0.001	0.068	2.21
	Male	3.80±0.07	3.45±0.07	3.95±0.07	3.73±0.04B				
Mean		3.87±0.05ab	3.70±0.05b	4.15±0.05a					
C18:1n-9	Female	17.00±0.13Ab	17.50±0.13Ab	20.20±0.13Aa	18.23±0.08	<0.001	0.007	0.008	1.87
	Male	17.55±0.13Ab	15.90±0.13Bc	18.95±0.13Aa	17.47±0.08				
Mean		17.27±0.09	16.70±0.09	19.57±0.09					
C18:2n-6	Female	14.70±0.10Aa	8.85±0.10Ab	9.90±0.10Ab	11.15±0.06	<0.001	<0.001	0.001	2.29
	Male	10.95±0.10Ba	6.50±0.10Bc	8.70±0.10Bb	8.72±0.06				
Mean		12.82±0.07	7.67±0.07	9.30±0.07					
C18:3n-6	Female	0.30±0.00Aa	0.30±0.00Aa	0.20±0.00Ab	0.27±0.00	<0.001	<0.001	<0.001	0.00
	Male	0.20±0.00Ba	0.20±0.00Ba	0.20±0.00Aa	0.20±0.00				
Mean		0.25±0.00	0.25±0.00	0.20±0.00					
C18:3n-3	Female	0.60±0.01Aa	0.30±0.01Ab	0.60±0.01Aa	0.50±0.00	<0.001	0.002	0.027	6.30
	Male	0.50±0.01Ba	0.30±0.01Ab	0.45±0.01Ba	0.42±0.00				
Mean		0.55±0.01	0.30±0.01	0.52±0.01					
C20:1n-9	Female	0.45±0.02Bb	0.60±0.02Aab	0.70±0.02Ba	0.58±0.01	0.002	0.001	0.033	7.41
	Male	0.75±0.02Aab	0.65±0.02Ab	0.90±0.02Aa	0.77±0.01				
Mean		0.60±0.01	0.62±0.01	0.80±0.01					
C20:4n-6	Female	0.60±0.01Aa	0.55±0.01Aa	0.30±0.01Ab	0.48±0.00	<0.001	0.356	0.007	6.08
	Male	0.50±0.01Aa	0.50±0.01Aa	0.40±0.01Ab	0.47±0.00				
Mean		0.55±0.01	0.52±0.01	0.35±0.01					
C20:3n-3	Female	1.00±0.02Aa	0.85±0.02Aa	0.40±0.02Bb	0.75±0.01	<0.001	0.005	0.002	5.83
	Male	0.85±0.02Ba	0.60±0.02Bb	0.50±0.02Ab	0.65±0.01				
Mean		0.92±0.01	0.72±0.01	0.45±0.01					
C20:5n-3	Female	0.10±0.00Ab	0.10±0.00Ab	0.80±0.00Aa	0.33±0.00	<0.001	<0.001	<0.001	0.00
	Male	0.10±0.00Ab	0.10±0.00Ab	0.50±0.00Ba	0.23±0.00				
Mean		0.10±0.00	0.10±0.00	0.10±0.00					
C22:6n-3	Female	1.00±0.02Bb	1.15±0.02Ab	2.15±0.02Aa	1.43±0.01	<0.001	0.356	<0.001	3.98
	Male	1.35±0.02Ab	0.80±0.02Bc	2.25±0.02Aa	1.47±0.01				
Mean		1.17±0.01	0.97±0.01	2.20±0.01					

Means followed by different lowercase and capital letters in rows and columns, respectively, differ by the Tukey test (P=5%).
CV - coefficient of variation.

in the muscle tissue of both males and females fed soybean oil and tilapia residue oil, and this can be related to higher levels of C18:2n-6 in oils and diets of these treatments, because linoleic acid is a precursor of the arachidonic acid synthesis.

However, higher amounts of EPA and DHA were observed in the muscle tissue of females (EPA: 0.80 and DHA: 2.15 mg/g) and males (EPA: 0.50 and DHA: 2.25 mg/g) that had been fed salmon oil.

Lambaris of both sexes which received the soybean oil diet had higher levels of n-6 fatty acids, especially C18:2n-6, which is to be found in large amounts in vegetable oils. On the other hand, lambari of both sex fed the diet with salmon oil demonstrated higher levels of n-3 fatty acids, especially EPA and DHA. Both of them are typically found in seawater fish oil. Seawater fish require a supply of EPA and DHA (NRC, 1993) because they have limited capacity (Sargent et al., 2002) or inability (Tocher, 2010) to carry

out the biosynthesis of EPA and DHA from their short-chain precursors, due to the lack of a Δ5 desaturase gene. Thus, the oil extracted from salmon residues is a source of long-chain omega 3 fatty acid (Wu & Bechtel, 2008).

Unlike seawater fish, almost all freshwater fish have the ability to convert linoleic acid (C18: 2n-6) into arachidonic acid (C20: 4n-6) and the linolenic acid (C18: 3n-3) into EPA (20 : 5n-3) and finally into DHA (C22: 6n-3), through a process involving a series of desaturation and elongation enzymes (Sargent et al., 2002; Turchini et al., 2006). It is suggested that lambari have the capacity of elongation and desaturation due to a greater presence of DHA and a decrease in linolenic acid levels found in the muscle tissue than in diets with soybean oil and tilapia residue oil, for both sexes. This fact was also evident in other Brazilian species of freshwater fish, such as pintado, *Pseudoplatystoma coruscans* (Martino et al., 2002; Tanamati et al., 2009); jundiá, *Rhamdia quelen* (Vargas et al., 2008); pacu, *Piaractus mesopotamicus* (Tanamati et al., 2009); and matrinxã, *Brycon cephalus* (Almeida & Franco, 2007).

However, the fish groups of both sexes demonstrated low values of these long-chain fatty acids, with maximum 0.8 mg/g for EPA and 2.25 mg/g for DHA, which can be related to the diet composition. Studies have reported (Tocher et al., 2002; Francis et al., 2009) that the supply of feed with higher amounts of EPA and DHA decreases the desaturases activities, resulting in no or low generation of synthesis of EPA and DHA. Thus, the levels of EPA and DHA in the muscle of the fish fed salmon oil are related, largely, to the deposition from the diet. And in fish fed diets prepared with soybean oil and tilapia residue oil, it would not have enough precursor for EPA and DHA production. Another hypothesis can be that the highly unsaturated fatty acids are transferred to other tissue(s) of the fish, and probably, this it is not related to the muscle.

Females and males fed diets containing fish residue oil (tilapia residue oil and salmon oil) had a n3/n-6 ratio higher than the minimum values (>0.25) recommended by the World Health Organization for the prevention of coronary heart disease. However, fish of both sexes fed soybean oil demonstrated lower values. Due to the nutritional importance of polyunsaturated fatty acids for humans, it is recommended to feed the fish with fish-oil-based diets, at least during the finishing period (Fountoulaki et al., 2009) in order to ensure appropriate levels of n-3 fatty acids in their organisms. In addition, the use of fish residue as an alternative ingredient to the nutrition of aquatic organisms adds value to the products generated by aquaculture and contributes to the sustainability of this activity.

Table 5 - Total fatty acid composition, sum of fatty acid class (mg/g) and n-3/n-6 ratio of muscle tissue from male and female lambari

Fatty acid	Sex	Treatments			Mean	P value			CV (%)
		Soybean oil	Tilapia residue oil	Salmon residue oil		Diet	Sex	Diet*Sex	
Total	Female	56.30±0.41	52.30±0.41	59.80±0.41	56.13±0.24A	<0.001	<0.001	0.142	1.93
	Male	48.65±0.41	41.70±0.41	52.00±0.41	47.45±0.24B				
Mean		52.47±0.29ab	47.00±0.29b	55.90±0.29a					
∑Sat[1]	Female	16.90±0.13	17.70±0.13	20.10±0.13	18.23±0.08A	<0.001	<0.001	0.172	2.07
	Male	13.10±0.13	13.20±0.13	15.30±0.13	13.87±0.08B				
Mean		15.00±0.09b	15.45±0.09b	17.70±0.09a					
∑Mono[2]	Female	18.65±0.15Ab	19.75±0.15Ab	23.10±0.15Aa	20.50±0.09	<0.001	0.003	0.006	1.87
	Male	19.20±0.15Ab	17.80±0.15Bb	21.45±0.15Ba	19.48±0.09				
Mean		18.92±0.11	18.77±0.11	22.27±0.11					
∑Poly[3]	Female	18.60±0.14Aa	12.45±0.14Ac	14.65±0.14Ab	15.23±0.08	<0.001	<0.001	0.006	2.54
	Male	14.75±0.14Ba	9.25±0.14Bc	13.30±0.14Bb	12.43±0.08				
Mean		16.67±0.10	10.85±0.10	13.97±0.10					
∑n-3	Female	2.70±0.04Ab	2.40±0.04Ab	3.95±0.04Aa	3.17±0.02	<0.001	0.006	0.009	3.60
	Male	2.80±0.04Ab	1.80±0.04Bc	3.70±0.04Ba	2.77±0.02				
Mean		2.75±0.03	2.10±0.03	3.82±0.03					
∑n-6	Female	15.60±0.10Aa	9.70±0.10Ab	10.40±0.10Ab	11.90±0.06	<0.001	<0.001	<0.001	2.25
	Male	11.65±0.10Ba	7.20±0.10Bc	9.30±0.10Bb	9.38±0.06				
Mean		13.62±0.07	8.45±0.07	9.85±0.07					
n-3/n-6	Female	0.17±0.01Bc	0.25±0.01Ab	0.38±0.01Aa	0.27±0.00	<0.001	<0.001	<0.001	2.07
	Male	0.24±0.01Ab	0.25±0.01Ab	0.40±0.01Aa	0.30±0.00				
Mean		0.20±0.01	0.25±0.01	0.39±0.01					

Means followed by different lowercase and capital letters in rows and columns, respectively, differ by the Tukey test (P=5%).
CV - coefficient of variation.
[1] Sum of saturated fatty acid.
[2] Sum of monounsaturated fatty acid.
[3] Sum of polyunsaturated fatty acid.

Conclusions

The fatty acid profile of the muscle from male and female lambari showed similar composition across the experimental diets, with a highlight to the salmon oil, which promoted significant deposition of n-3 highly unsaturated fatty acid. The oil extracted from salmon and tilapia residue can be a substitute for traditional fish oil, once it does not hinder the growth performance and provides levels of n-3 fatty acids above the minimum required for good nutritional health in humans.

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