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ORIGINAL ARTICLE

Polyunsaturated fatty acids and nutritional quality of five freshwater fish species cultivated in the western region of Santa Catarina, Brazil

Ácidos graxos poli-insaturados e qualidade nutricional de cinco espécies de peixe de água doce cultivadas na região oeste de Santa Catarina, Brasil

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Abstract

There is a paucity of information about the chemical composition of commercially important freshwater fish species (Nile tilapia, bighead carp, grass carp, common carp and silver carp) cultivated in the western region of Santa Catarina, Brazil. This study determined the moisture, ash, protein and lipid contents and the fatty acid composition, as well as the nutritional quality of the lipids in fillets of these five freshwater fish species. Moisture was the most prominent fish component (74.7%-81.7%), followed by protein (15.8%-18.8%) and lipids (0.4%-8.2%). Saturated palmitic acid (90-1740 mg/100 g) and monounsaturated oleic acid (70-2260 mg/100 g) were the major fatty acids found in all the fish species. The grass and common carps and Nile tilapia (caged) had high contents of γ-linolenic acid (GLA), with an average of 536 mg/100 g. Bighead carp was the richest source of ω-3 PUFA, mainly eicosapentaenoic (EPA, 400 mg/100 g) and docosahexaenoic (DHA, 620 mg/100 g) acids, and had the highest ω-3/ω-6 ratio of 6.11. The nutritional evaluation of the fatty acid profile indicated that average values were: atherogenicity index (AI) ~0.59, thrombogenicity index (TI) ~0.82, hypocholesterolemic/hypercholesterolemic ratio (H/H ~1.98), polyunsaturated/saturated ratio (P/S) ~0.43 and ω-3/ω-6 ratio ~2.18, values suggesting that the consumption of these freshwater fish species could be of benefit to human health.

Keywords: Freshwater fish fillets; Proximate composition; Unsaturated fatty acids; Nutritional quality index; Fish nutrition.

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Resumo

Há pouca informação disponível sobre a composição química de espécies de peixe de água doce (tilápia-do-nilo, carpa-prateada, carpa-cabeça-grande, carpa-capim e carpa-comum) com grande importância comercial e amplamente cultivadas na região oeste de Santa Catarina, Brasil. Este estudo teve por objetivo determinar a composição de umidade, cinzas, proteínas, lipídeos e ácidos graxos, bem como a qualidade nutricional dessas cinco espécies de peixe de água doce. A umidade foi o componente majoritário nos filés de peixe (74,7%-81,7%), seguida de proteína (15,8%-18,8%) e lipídeos (0,4%-8,2%). O ácido palmítico foi o ácido graxo saturado predominante (90-1.740 mg/100 g) e o ácido oleico foi o principal ácido monoinsaturado (70-2.260 mg/100 g) encontrados nos filés. A carpa-capim, a carpa-comum e a tilápia-do-nilo (cultivada em tanques-rede) apresentaram elevado teor de ácido γ-linolênico (GLA), com valores médios de 536 mg/100 g. A carpa-cabeça-grande é rica em ácidos graxos poli-insaturados ω-3, principalmente eicosapentaenoico (EPA), com 400 mg/100 g, e docosa-hexaenoico (DHA), com 620 mg/100 g, além de possuir a maior relação ω-3/ω-6 (6,11). Em relação à qualidade nutricional lipídica dos filés de peixe, os valores médios foram: índice de aterogenicidade (IA), ~0,59; índice de trombogenicidade (TI), ~0,82; razão hipocolesterolêmica/hipercolesterolêmica (H/H), ~1,98; poli-insaturados/saturados (P/S), ~0,43; e ω-3/ω-6, ~2,18, sugerindo que o consumo dessas espécies de peixe de água doce pode ser considerado benéfico para a saúde humana.

Palavras-chave: Filés de peixe de água doce; Análise centesimal; Ácidos graxos insaturados; Índice de qualidade nutricional; Nutrição.

1 Introduction

The western region of the state of Santa Catarina, Brazil, is one of the most important traditional agricultural regions in the country, due to its exceptional poultry- and swine-farming production. This region also has a well-established meat industry based on pork and chicken in a successful integration model involving thousands of family farmers (Boll & Garádi, 1995). Due to its extraordinary development in the food industry, several mostly small and medium-sized farmers, are also involved in freshwater fish cultivation using earthen ponds (Silva et al., 2017). The promotion of freshwater fish cultivation in this region was based on two major considerations: (a) the nutritional value of fish, *i.e.*, enhancing the access of inland people to high-quality protein food; and (b) economic income, *i.e.*, the income of the farmers could be enhanced from the fish sales (Matos et al., 2006; Matos & Matos, 2018a).

With the introduction of Chinese carps (*Ctenopharyngodon idella* - grass carp, *Hypophthalmichthys molitrix* - silver carp, *Hypophthalmichthys nobilis* - bighead carp, *Cyprinus carpio* - common carp) and Nile tilapia (*Oreochromis niloticus*) into Santa Catarina State, several initiatives were taken by EPAGRI (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina) to promote the cultivation of freshwater fish: (a) providing technical support to family farmer producers, (b) inserting fish cultivation into the curriculum of agricultural high schools, (c) encouraging the formation of producer associations, (d) offering courses on fish by-products, and (e) promoting fresh fish markets. These markets frequently occur in inland cities during the Easter period, when the consumption of fish is highly traditional in Brazil, and consumers can buy fresh fish directly from the farmers at the markets (Boll & Garádi, 1995; Matos & Matos, 2018b).

The aquaculture sector in Brazil is clearly expanding, especially in the state of Santa Catarina (Brasil, 2012), where the production of fish farming has grown from 19 tons (2005) to 42 tons (2015), with an average growth of 8.3% per year (Silva et al., 2017). However, despite the impressive growth of fish cultivation, the "*per capita*" consumption of fish at the Brazilian national level (~ 9 kilograms per capita) is below the 12 kilograms recommended by Food and Agriculture Organization (2014). This low consumption level may be attributed to low motivation to eat fish, as well as to limited knowledge concerning the nutritional value of freshwater species.

Fish is an important source of protein worldwide. Globally, it provides about 6 percent of dietary protein in our diet in comparison to the animal protein intake (Food and Agriculture Organization, 2014). Besides being a protein source, fish is also a source of long-chain polyunsaturated fatty acids (PUFAs, both ω-3 and ω-6), such as linolenic acid (LA), γ-linolenic acid (GLA), α-linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are associated with a wide range of human health benefits (Rahmawaty et al., 2013; Sahari et al., 2013; Matos, 2017). The *Dietary Guidelines for Americans – 2010* (DGA) recommends that people consume 200 g of fish per week – especially marine-derived "oily" fish such as tuna, sardines, anchovies, salmon and mackerel – to provide an average consumption of 250 mg EPA and DHA per day (Institute of Medicine, 2015). Other fish, including freshwater fish species, can also provide these fatty acids, but the levels are generally lower than those in marine fish species, so that higher consumption is needed in order to meet the recommendations (Diraman & Dibeklioglu, 2009; Bogard et al., 2015).

The benefits of ω3 PUFAs for humans are associated with the synthesis of eicosanoids, such as leukotrienes, prostaglandins and thromboxanes (Souza, 2010; Kuda et al., 2018). Another important aspect is the nutritional value of PUFAs in human metabolism, which can be estimated by way of health 'indicators' that are calculated using empirical equations: the atherogenicity (AI) and thrombogenicity (TI) indexes, and the hypocholesterolemic/hypercholesterolemic (H/H), polyunsaturated/saturated (P/S) fatty acids and omega-3/omega-6 (ω-3/ω-6) ratios (Ulbricht & Southgate, 1991; Šimat et al., 2015; Petenuci et al., 2016). These indices are strongly associated with disease prevention and health promotion (Rhee et al., 2017; Cherifi et al., 2018).

Given the fact that most consumers, especially in the western region of Santa Catarina, may not be aware of the nutritional quality of fish, and do not have easy access to this information, this study determined the chemical composition of five freshwater fish (silver-, grass-, bighead-, common-carps and Nile tilapia) in terms of the moisture, ash, protein and lipid contents and the fatty acid profile. In addition, the nutritional quality indexes and ratios, AI, TI, H/H, P/S and ω-3/ω-6 ratios were determined using empirical formulas.

2 Material and methods

2.1 Sample collection and preparation

The fish fillets, about 1 kg per species studied, were kindly supplied by the Pescado Pinhal cooperative fish industry, located in the municipality of Concórdia (27°14'02"S, 52°01'40"W), Santa Catarina, Brazil. The fish fillets were processed in a food processor until the formation of a homogeneous mass, which was used for the chemical analyses.

2.2 Fish composition analysis

2.2.1 Moisture

The moisture content was determined in triplicate by drying the fish sample at 105 °C for 3 to 4 h (to constant weight) (Association of Official Analytical Chemists, 2005).

2.2.2 Mineral content

The mineral content of the fish fillets was determined as the ash content, by heating samples in triplicate to about 550 °C for 5 h using a carbolite muffle furnace (Instituto Adolfo Lutz, 2005).

2.2.3 Protein content

Triplicate fish fillet samples were subjected to acid digestion, steam distillation and titration with 0.1 N HCl as indicated for the Kjeldahl method (Association of Official Analytical Chemists, 2005). The protein content was calculated using a nitrogen-to-protein conversion factor of N x 6.25.

2.2.4 Lipid content

After acid digestion of the fish fillets (in triplicate) with 4.0 N HCl, the total lipids were extracted with petroleum ether for 6 h by the Soxhlet method, followed by concentration in a rotary evaporator, drying in an oven and weighing of the residue (Association of Official Analytical Chemists, 2005).

2.2.5 Fatty acid composition

The total fatty acid content of the fish fillets was determined by converting the fatty acids to their corresponding methyl esters (FAME) and analysing by gas chromatography using a GC-2014 chromatograph (Shimadzu, Kyoto, Japan) equipped with a split-injection port, flame-ionization detector and a Restek capillary column (Sigma-Aldrich, St. Louis, USA; 105 m × 0.25 mm ID, 0.25 µm DF-25 coating; 10% cyanopropylphenyl and 90% biscyanopropylsiloxane). The injector and detector temperatures were set at 260 °C, and the oven temperature was initially set at 140 °C for 5 min, then programmed to increase at 2.5 °C min^{-1} to 260 °C, and held at this temperature for 30 min. The injection volume was 1µL with a 10:1 split ratio, and nitrogen was used as the carrier gas at 2.2 mL min^{-1} with a constant pressure of 130.3 pKa. The fatty acid methyl esters were identified by comparison with the retention times of authentic standards (Sigma-Aldrich, St. Louis, USA). The proportions of the individual acids were calculated as the ratio of their peak area to the total area of all observed acids and expressed as mass percentage (Instituto Adolfo Lutz, 2005).

2.3 Nutritional quality indexes of the lipids

To estimate the nutritional quality of the lipid fraction three separate indexes were calculated from the percentages of saturated fatty acids (SFA; lauric C12:0, myristic C14:0, palmitic C16:0, and stearic C18:0 acids), monounsaturated fatty acids (MUFA; oleic C18:1 ω-9 acid), and polyunsaturated fatty acids (PUFA; γ-linolenic C18:3 ω-6, α-linolenic C18:3 ω-3, eicosapentaenoic C20:5 ω-3, and docosahexaenoic C22:6 ω-3 acids) according to (Ulbricht & Southgate, 1991; Santos-Silva et al., 2002):

1. Atherogenicity index (AI) = [(C12:0 + (4 x C14:0) + C16:0)] / (ΣMUFA + Σω-6 + Σω-3);
2. Thrombogenicity index (TI) = (C14:0 + C16:0 + C18:0) / [(0.5 x ΣMUFA) + (0.5 x Σω-6 + (3 x Σω-3) + (Σω-3/Σω-6)];
3. Hypocholesterolemic/hypercholesterolemic fatty acids ratio (H/H) = (C18:1ω-9 + C18:3ω-6 + C18:3ω-3 + C20:5ω-3 + C22:6ω-3) / (C14:0 + C16:0).

2.4 Statistical analysis

A one-way analysis of variance (ANOVA) using STATISTICA Software (version 7.0) from StatSoft Inc was carried out. Statistically significant differences ($p < 0.05$) between the fish species were determined using the Tukey test.

3 Results and discussion

3.1 Chemical composition of the fish species

Table 1 shows the compositions of the five freshwater fish species. Moisture, which refers to the water content of the fish muscle, was the major component of all the fillets analysed, with values ranging from 74.7% to 81.7%. It is important to note that the water content of fish fillets can affect the sensory quality, microbiological stability and changes in the nutritional composition during the shelf life (Silva et al., 2008).

Table 1. Moisture, protein, lipid and ash contents of the five freshwater fish species.

Species	Assay (%)			
	Moisture	Protein	Lipid	Ash
Nile tilapia (pond)	79.7 ± 2.5^{a}	18.8 ± 1.3^{a}	1.0 ± 0.1^{a}	0.9 ± 0.2^{a}
Nile tilapia (cage)	77.8 ± 2.4^{a}	18.1 ± 1.0^{a}	3.6 ± 0.8^{ab}	1.2 ± 0.1^{a}
Silver carp	81.7 ± 3.1^{a}	17.3 ± 1.1^{a}	0.4 ± 0.1^{a}	1.3 ± 0.1^{a}
Bighead carp	74.7 ± 1.8^{a}	17.1 ± 0.6^{a}	8.2 ± 0.1^{c}	1.0 ± 0.2^{a}
Grass carp	76.6 ± 2.3^{a}	18.4 ± 0.9^{a}	3.7 ± 0.7^{ab}	1.0 ± 0.2^{a}
Common carp	78.9 ± 2.2^{a}	15.8 ± 2.2^{a}	4.2 ± 0.5^{b}	0.9 ± 0.2^{a}

Data expressed as the % content ± standard deviation (n = 3). Values in the same column with different superscript letters are significantly different ($p < 0.05$) between the fish species.

The protein content did not vary significantly ($p < 0.05$) amongst the five species studied, ranging from 15.8 to 18.8%, in agreement with previously reported protein contents of about 20% protein (Ramos-Filho et al., 2010), the content depending on the species, size, gender and season. The moisture (average 78.8%) and protein (average 18.0%) contents found in the Nile tilapia fillets (pond and cage) were comparable to those reported by Simões et al. (2007) for Nile tilapia (moisture 77.1%, protein 19.3%).

The ash contents ranged from 0.9% to 1.3%, consistent with data found in the literature of 0.9% to 3.3% (Simões et al., 2007; Ramos-Filho et al., 2010). The ash content reflects the amount of minerals, and fish for human consumption is a valuable source of trace minerals such as iron, manganese, zinc, copper and selenium, which are important nutritional ingredients.

A comparison of the data in Table 1 with previously published data on the composition of the five fish species used in this study, showed they were similar to those of other freshwater fish species that commonly cultivated in Brazil, such as dourado (*Salminus maxillosus*), pintado (*Pseudoplatystoma coruscans*), pacu (*Piaractus mesopotamicus*) and cachara (*Pseudoplatystoma fasciatum*) (Caula et al., 2008; Ramos-Filho et al., 2008; Fernandes et al., 2014).

A third important component in fish fillets is the lipid content. In the present study statistically significant differences ($p < 0.05$) were found between the lipid contents, calculated as the wet weight, of the freshwater fish species. The Nile tilapia (pond) and silver carp fillets had relatively low lipid contents (1.0% and 0.4%, respectively), the Nile tilapia (cage), grass carp and common carp had moderate lipid contents (3.6%, 3.7% and 4.2%, respectively), while bighead carp had the highest lipid content (8.2%) (Table 1). It is noteworthy that ω3 PUFA, such as EPA (C20:5 ω3) and DHA (C22:6 ω3), were 10 to 20-fold higher in bighead carp than in the other species (Table 2). Fish is generally classified into three categories according to the fat content: lean fish (< 5% fat), medium fat fish (5% to 10% fat) and fatty fish (> 10% fat) (Hong et al., 2014). Based on this classification, bighead carp is a medium fat fish (8.2%) and the other freshwater species are characterized as lean fish.

Finally, it is important to add that the previous classification of Nile tilapia as a lean fish (~ 1.0% fat) when cultivated in a pond system, is significantly altered by fish farming activities, that resulted in a higher lipid content (~ 4% fat) for Nile tilapia when cultivated in a cage system (Table 1). This was expected, since the tilapia farmed in a semi-intensive cage system are given food enriched with a plant-based lipid source.

3.2 Fatty acid determination

The proportions of the main fatty acids were measured as the total saturated (SFA), monounsaturated (MUFA) and polyunsaturated (PUFA) ω-3 and ω-6 fatty acids. As shown in Table 2, fifteen fatty acids, ranging from C12:0 to ω-3 C22:6 were identified and quantified as the percentage of the total fatty acid content.

Table 2. Fatty acid compositions of the five freshwater fish species expressed as mg/100 g ± standard deviation (n = 3).

Fatty acid	Nile tilapia (pond)	Nile tilapia (cage)	Silver carp	Bighead carp	Grass carp	Common carp
Saturated (SFA)						
C12:0	10 ± 1	-	<10 ± 1	20 ± 2	<10 ± 1	-
C14:0	30 ± 3	10 ± 1	10 ± 2	240 ± 8	70 ± 2	40 ± 1
C15:0	20 ± 2	10 ± 1	10 ± 1	40 ± 1	-	<10 ± 1
C16:0	**180 ± 6**	**870 ± 12**	**90 ± 3**	**1740 ± 15**	**830 ± 17**	**830 ± 12**
C17:0	20 ± 1	10 ± 1	10 ± 1	50 ± 5	20 ± 2	10 ± 1
C18:0	110 ± 7	230 ± 6	50 ± 2	230 ± 8	160 ± 8	210 ± 8
C22:0	10 ± 1	30 ± 2	40 ± 3	90 ± 4	60 ± 4	50 ± 3
Monounsaturated (MUFA)						
C16:1	50 ± 3	150 ± 3	10 ± 1	640 ± 4	230 ± 10	270 ± 8
C18:1 ω-9	**240 ± 7**	**1400 ± 14**	70 ± 4	**2260 ± 22**	**1250 ± 23**	**1920 ± 14**
C22:1 ω-9	10 ± 1	-	-	-	-	<10 ± 1
C24:1	10 ± 1	20 ± 1	10 ± 1	40 ± 1	10 ± 1	10 ± 1
Polyunsaturated (PUFA)						
C18:3 ω-6 (GLA)	10 ± 2	**490 ± 10**	20 ± 1	170 ± 7	**580 ± 10**	**540 ± 5**
C18:3 ω-3 (ALA)	20 ± 1	30 ± 2	10 ± 1	20 ± 1	10 ± 1	50 ± 2
C20:5 ω-3 (EPA)	10 ± 1	20 ± 1	20 ± 2	**400 ± 10**	50 ± 3	20 ± 2
C22:6 ω-3 (DHA)	10 ± 1	10 ± 1	20 ± 2	**620 ± 10**	50 ± 3	30 ± 2
Σ SFA	380 ± 6	1250 ± 10	210 ± 6	2410 ± 18	1140 ± 16	1140 ± 14
Σ MUFA	300 ± 4	1570 ± 8	90 ± 5	2940 ± 15	1490 ± 14	2200 ± 15
Σ PUFA	30 ± 2	550 ± 6	80 ± 5	1210 ± 13	690 ± 8	640 ± 10
Σ ω-3	40 ± 1	60 ± 2	50 ± 2	1040 ± 11	110 ± 3	100 ± 3
Σ ω-6	10 ± 2	490 ± 10	20 ± 1	170 ± 7	580 ± 10	540 ± 5
EPA + DHA	20 ± 1	30 ± 1	40 ± 2	1020 ± 10	100 ± 3	50 ± 2

Bold numbers indicate the major fatty acids in the fish fillets.

The freshwater fish species had a high proportion of oleic acid (C18:1 ω-9) and palmitic acid (C16:0), with the exception of silver carp that had a low lipid content (0.4%) and consequently a low fatty acid content. The data also showed that bighead carp had a moderate concentration of ω-3 PUFA, predominantly eicosapentaenoic (EPA, ω-3 C20:5) and docosahexaenoic (DHA, ω-3 C22:6) acids, while Nile tilapia (cage), and grass and common carps contain moderate concentrations of γ-linolenic acid (GLA, ω-6 C18:3). Furthermore, bighead, common and grass carps and Nile tilapia (cage) showed the same relative MUFA > SFA > PUFA pattern, while the pattern in Nile tilapia (pond) and silver carp was slightly different, with SFA > MUFA > PUFA.

3.2.1 Saturated fatty acids

In all the species, the most abundant saturated fatty acid (SFA) was palmitic acid (C16:0, 90-1740 mg/100 g), followed by stearic acid (C18:0, 50-230 mg/100 g) and myristic acid (C14:0, 10-240 mg/100 g) (Table 2). Bighead carp contained the highest C16:0 content (1.7 g/100 g), while Nile tilapia (cage) (870 mg/100 g), grass carp (830 mg/100 g) and common carp (830 mg/100 g) had intermediate C16:0 contents. Nile tilapia (pond) and silver carp had the lowest C16:0 contents (180 and 90 mg/100 g, respectively), as well as the lowest lipid contents (0.4% to 1.0%) amongst the fish fillets studied.

3.2.2 Monounsaturated fatty acids

Common carp exhibited the highest monounsaturated fatty acid (MUFA) content, representing about half of the total fatty acid content (~ 55.3%). Nile tilapia (cage), grass carp and bighead carp contained intermediate concentrations of MUFAs, on average about 45% of the total fatty acid contents. The MUFAs detected in all the species studied were: C16:1, ω9 C18:1, ω9 C22:1 and C24:1, with a high variation in composition amongst the fish species. In general, oleic acid (ω9 C18:1) was the main MUFA found in all the fish fillets, ranging from 240 to 2260 mg/100 g, except for silver carp (70 mg/100 g) (Table 2).

The consumption of fish fillets that contain oleic acid, which is also found in olive oil, has several health benefits, such as increasing the HDL (high-density lipoprotein) content and reducing the blood pressure (Hlais et al., 2013). The fact that, for example, bighead carp had both the highest content of ω9 C18:1 (2.2 g/100 g) and a favourable concentration of ω3 PUFAs, suggested that the consumption of this fish fillet would be beneficial to human health.

3.2.3 Polyunsaturated fatty acids

There is general agreement that the composition of polyunsaturated ω-3 and ω-6 fatty acids (PUFAs) in fish tissue varies depending on the fish diet and on factors such as the species, gender, age, size, reproductive status, sexual maturity, feed, water temperature, geographic location and season (Almeida et al., 2009; Ramos-Filho et al., 2010; Petenuci et al., 2016). The present results showed that the freshwater fish species contained a substantial amount of PUFAs with carbon chains ranging from C_{18} to C_{22}, but that Nile tilapia (pond) and silver carp had very low PUFA contents.

Table 2 shows that the maximal levels of GLA (ω-6 γ-linoleic acid) in grass carp, common carp and Nile tilapia (cage) were between 490 and 580 mg/100 g. It must be mentioned that GLA is a precursor of the C_{20} eicosanoids which synthesize prostaglandin, which has several beneficial effects. For instance, it has anti-inflammatory properties and can reduce the risk of heart disease and attenuate the pain associated with inflammation in rheumatoid arthritis (Martin et al., 2006). Based on the known health benefits, Food and Agriculture Organization (2014) recommended a daily GLA intake of 500-750 mg, making the grass and common carps, which contain an average of 560 mg GLA/100g fillet, an excellent source of GLA.

The main ω-3 PUFAs found in freshwater fish are α-linoleic acid (ALA, ω-3 C18:3), eicosapentaenoic acid (ω-3 C20:5) and docosahexaenoic acid (ω-3 C22:6). Although marine fish oil generally has a higher EPA + DHA content than freshwater fish oil, bighead carp contained levels of EPA + DHA (1.0 g/100 g) comparative to those of some marine fish (Hong et al., 2014). These data support the finding that bighead carp is a typical filter-feeder fish, consuming plankton, which contains substantial ω-3 PUFA concentrations (Li et al., 2011; Matos et al., 2016).

In some cases the fatty acid profile of fish depends on a number of factors, with the dietary nutrients being the easiest one to manipulate (Cladis et al., 2014; Obirikorang et al., 2015). In order to control costs, diets with readily available fatty acids, such as palm and coconut oils, rich in SFA, canola and rapeseed oils, rich in MUFA, and sunflower, corn and soybean oils, rich in ω-6 PUFA oil, are often used in aquaculture (Teoh & Ng, 2016). Tilapia farming is the most popular type of aquaculture in the world (Food and Agriculture Organization, 2014), and although little information is available on the feed formulations of farmed fish obtained from commercial vendors, the Nile tilapia (cage) fillets had higher concentrations of SFA, MUFA and ω-6 fatty acids than the Nile tilapia (pond) (Table 2).

3.3 Nutritional quality indexes of lipids

The evaluation of the nutritional quality of the lipids using the indexes and ratios calculated, allows for a better understanding of the functional health effects of the different fatty acids. Table 3 lists the nutritional quality indexes for the lipid fraction of the fish fillets from the different freshwater fish species.

Table 3. Nutritional quality indexes for the fatty acid profiles of the fillets of five freshwater fish species.

Species	AI	TI	H/H	P/S	ω-3/ω-6	ω-6/ω-3
Nile tilapia (pond)	0.88	1.41	1.38	0.10	4.00	0.25
Nile tilapia (cage)	0.42	0.97	2.21	0.44	0.12	8.16
Silver carp	0.76	0.62	1.50	0.38	2.50	0.40
Bighead carp	0.65	0.47	1.75	0.50	6.11	0.16
Grass carp	0.51	0.79	2.15	0.60	0.18	5.27
Common carp	0.34	0.69	2.94	0.56	0.18	5.40

AI = Atherogenicity index; TI = Thrombogenicity index; H/H = Σ Hypocholesterolemic/Σ Hypercholesterolemic ratio; P/S = Polyunsaturated/Saturated ratio; ω-3/ω-6 = Σ of Omega 3 series/Σ of Omega 6 series; ω-6/ω-3 = Σ of Omega 6 series/Σ of Omega 3 series.

The polyunsaturated to the saturated fatty acids ratio (P/S) is an index used to express the nutritional quality of the lipids in a certain diet. In general, foods with a P/S ratio below 0.45 have been considered as undesirable for a human diet, due to their potential to induce hypercholesterolemia (Fernandes et al., 2014). In the present study, the P/S ratios for the grass, common and bighead carps were > 0.45 (0.50 to 0.60), while the P/S ratios for Nile tilapia (cage and pond) and silver carp were < 0.45 (0.10 to 0.44). Ramos-Filho et al. (2008) reported P/S ratios < 0.45 for some Brazilian freshwater fish fillets, for example, cachara (0.44) and pacu (0.13).

However, the P/S ratio alone may not be sufficient to determine the nutritional quality of the lipids, since it does not take into account the metabolic effect of the MUFAs (*e.g.*, ω-9 C18:1). The Σhypocholesterolemic/Σhypercholesterolemic fatty acid index (H/H) is therefore an important additional index to determine the effect of individual fatty acids on the cholesterol metabolism (Santos-Silva et al., 2002). In terms of the nutritional value, a greater H/H ratio is directly proportional to a high PUFA content, which is considered more beneficial for human health. Common carp, Nile tilapia (cage) and grass carp have high H/H values (2.15 to 2.94), which are comparable to the H/H values of marine fish such as mackerel or sardine, with H/H values of 2.46 (Fernandes et al., 2014). In contrast, Ramos-Filho et al. (2008) reported H/H values for the Brazilian freshwater fish fillets of pintado and dourado of 1.84 and 1.49, respectively.

The atherogenicity (AI) and thrombogenicity (TI) indexes are two other frequently used indexes showing the potential to stimulate platelet aggregation (Ulbricht & Southgate, 1991; Santos-Silva et al., 2002). Foods with low AI and TI values have a greater potential to protect against coronary disease. In the present study, the AI values ranged from 0.34 to 0.88, with the common carp (0.34) and Nile tilapia (cage) (0.42) showing the lowest AI values (Table 3). The Pintado and pacu fish species are reported to have comparable AI values of 0.49 and 0.86, respectively (Ramos-Filho et al., 2008). The lowest TI value was observed in the bighead carp fillet (0.47), which is comparable to the TI values reported for the freshwater fish cachara (0.59) and the marine fish white needle (0.44) (Fernandes et al. (2014).

Several researchers have proposed the ω-6/ω-3 ratio as a useful indicator for the nutritional value of fish oil, with a lower ratio being more effective in preventing cardiovascular diseases associated with the plasma lipid levels (Li et al., 2011; Rahmawaty et al., 2013; Sahari et al., 2013; Rhee et al., 2017). According to nutritional recommendations (Food and Agriculture Organization, 2014), the ω-6/ω-3 ratios in the human diet should not exceed 5.0. Three of the fish fillets analysed here had ω-6/ω-3 ratios above 5.0, *i.e.* Nile tilapia (cage) (8.16), common carp (5.40) and grass carp (5.27). These ω-6/ω-3 ratios may be due to the high linoleic acid levels in the terrestrial plant-based feed products used in modern aquaculture (Šimat et al., 2015), which will affect the ω-6/ω-3 ratios in the edible part of the fish, especially for farmed Nile tilapia. Improved

formulations of the feed administered to farmed Nile tilapia may increase the nutritional quality of the lipids. For instance, Visentainer et al. (2005) investigated the fatty acid composition in the muscles of Nile tilapia (*O. niloticus*) under an intensive culture system, after administering feed that was gradually enriched with flaxseed oil, resulted in a higher concentration of ω3 PUFA in the muscle tissue.

4 Conclusions

The present study determined the chemical compositions and lipid nutritional quality indexes of five freshwater fish species. On average the fish fillets contained 78.2 g moisture, 17.5 g protein, 3.5 g lipid and 1.0 g ash per 100 g of biomass. The total lipid contents and fatty acid compositions varied for each fish species, with bighead carp containing considerable concentrations of ω-3 PUFA, while the grass and common carps and Nile tilapia (cage) had substantial amounts of ω-6 PUFA.

The present data indicated that the majority of the fish species studied appeared to have high nutritional value for humans. These results are of great interest for populations in the western region of the state of Santa Catarina, Brazil, who consume these fish, and are relevant for local authorities considering adding fish meat to school meals. Continued studies are needed in order to collect more information and increase our understanding of the nutritional value and health benefits of freshwater fish for human consumption.

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