




Fatty acid profile, omegas, and lipid quality in commercial cuts of tambaqui (*Colossoma macropomum* Cuvier, 1818) cultivated in ponds

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Received: November 3, 2021

Approved: August 31, 2022

ABSTRACT

This study aimed to determine the fatty acid profile, omegas, and lipid quality indices in commercial cuts of tambaqui (*Colossoma macropomum*). Samples were collected from two fish processing industries located in Rondônia state, Brazil. The experimental design was completely randomized, with processing performed in triplicate. Data were submitted for analysis of variance (ANOVA) to assess differences between commercial cuts. If ANOVA was statistically significant ($\alpha = 0.05$), the averages were compared using Tukey's test. In the composition of fatty acids, there was a difference ($p < 0.05$) between commercial cuts. The commercial cuts with the highest percentages of saturated fatty acids (SFAs) steak at 47.050%, monounsaturated fatty acids (MUFAs) fillet at 45.120%, and polyunsaturated fatty acids (PUFAs) band at 19.050%. In addition, the band expresses the highest values of omegas 3, 6, 7, and n-9. The indices prescribed Σ PUFAs/ Σ SFAs, Σ PUFAs (n-6/ Σ n-3), atherogenicity index, thrombogenicity index, and ratio between hypocholesterolemic and hypercholesterolemic fatty acids, indicating that commercial cuts have lipid quality. Nutritional information is important for conservation and processing processes, the development of new products on the market, and guidance on the form of preparation, thus providing commercial security for different market niches.

Keywords: Characiformes, essential fatty acids, fish farming, lipid quality indices, Serrasalminidae.

Perfil de ácidos graxos, ômega e qualidade lipídica em cortes comerciais de tambaqui (*Colossoma macropomum* Cuvier, 1818) cultivado em tanques escavados

RESUMO

O objetivo do estudo foi determinar o perfil de ácidos graxos, ômega e índices de qualidade lipídica em cortes comerciais de tambaqui (*Colossoma macropomum*). As coletas de amostras foram realizadas em duas indústrias de processamento de pescado localizadas no estado de Rondônia, Brasil. O delineamento experimental foi inteiramente casualizado, com processamento realizado em triplicata. Os dados foram submetidos à análise de variância (ANOVA) para avaliar diferenças entre cortes comerciais. Quando a ANOVA foi estatisticamente significativa ($\alpha = 0,05$), as médias foram comparadas pelo teste de Tukey. Na composição dos ácidos graxos, houve diferença ($p < 0,05$) entre os cortes comerciais. O corte comercial com maiores percentagens de ácido graxo saturado (AGSs) foi a posta 47,050%, de ácido graxo monossaturado (AGMs) foi o filé 45,120% e de ácido graxo poli-insaturado (AGPs) foi a banda 19,050%. Esta também expressou os maiores valores de ômega 3, 6, 7 e n-9. Os índices prescritos Σ AGPs/ Σ AGSs, Σ AGPs (n-6/ Σ n-3); índice de aterogenicidade; índice de trombogenicidade; razão entre ácidos graxos hipocolesterolêmicos e hipercolesterolêmicos mostram que os cortes comerciais possuem qualidade lipídica. As informações nutricionais são importantes para os processos de conservação e processamento e para o desenvolvimento de novos produtos no mercado, bem como orientam a forma de preparo, proporcionando assim segurança comercial para diferentes nichos de mercado.

Palavras-chave: Ácidos graxos essenciais, characiformes, índices de qualidade lipídica, piscicultura, serrasalminidae.

INTRODUCTION

Rondônia state is the largest producer of native fish in Brazil, and its production corresponds to a total of 65.5 thousand tons of fish produced in the year 2020 (Peixe BR, 2022). Tambaqui (*Colossoma macropomum* Cuvier, 1818) is one of the most cultivated fish and, together with the pirarucu (*Arapaima gigas* Schinz, 1822), they

account for 85% of the fish cultivated in Rondônia state (Meante and Dória, 2017). Studies around the world have revealed that fish consumption is associated with a low incidence of coronary heart disease due to the fact that fish meat is composed of essential fatty acids (Njinkoue et al., 2016). Clinical and epidemiological studies have eventually suggested that people who regularly consume meat or fish oil are less prone to heart disease (Job et al., 2015). Eicosapentaenoic (EPA) and docosahexaenoic (DHA) fatty acids have strong antiarrhythmic action on the heart and strong antithrombotic action. Above all, they are direct precursors of prostanoids and play important roles in the structure of cell membranes and metabolic processes (Dantas Filho et al., 2022). Linoleic (AA) and α -linolenic (ALA) acids are needed to maintain cell membranes, brain functions, and transmission of nerve impulses under normal conditions (Nunes et al., 2011).

The aforementioned fatty acids also participate in the transfer of atmospheric oxygen to blood plasma, hemoglobin synthesis, and cell division, being called essential because they are not synthesized by the human body but can be found in the meat and fat of tropical fish (Valenti et al., 2021). However, the content and availability of fatty acids vary among fish species, depending on age and inclusion rates in the diet (Parthasarathy and Joseph, 2011; Petenuci et al., 2019). Tambaqui (*C. macropomum*) is an important source of animal protein and essential fatty acids for the Amazonian population, with the essential fatty acids such as EPA, DHA, AA, and ALA (Petenuci et al., 2019; Zhang et al., 2020; Cavali et al., 2022b). In addition, it is one of the highlighted species for cultivation in the North Region; as it originates from the Amazon River, it adapts to the conditions of the region and easily adapts to the growing environments (Porto et al., 2021).

Tambaqui meat is easily digestible due to its high biological value proteins, as it efficiently provides energy and essential fatty acids (Batalha et al., 2017; Lima et al., 2018). Several vegetable oils are rich sources of n-6 series monounsaturated (MUFAs) and polyunsaturated (PUFAs) fatty acids, such as those from olive, soybean, and corn, while fish oils represent the sources of n-3 PUFAs (Rodrigues et al., 2017; Cavali et al., 2022a). Lipids have energetic, structural, hormonal, and biochemical functions, among others (Petenuci et al., 2019). The benefits arising from the regular consumption of fish reinforce the validity of promoting incentives through public policies to increase commercial availability for consumption. In this context, fish farming emerges as a viable alternative to continue increasing food supply in the coming years (Brabo et al., 2016; Valenti et al., 2021).

Considering the above, nutritional information on fish is important for conservation and processing processes, the development of new products on the market, such as leaner commercial cuts, and guidance on how to process certain tender cuts with a higher lipid content, thus providing food and commercial security to different populations and market niches. Therefore, it is essential for the fish industry to assess the lipid composition of native Amazonian fish, such as tambaqui, in order to confirm that this fish stores quality nutrients, according

to indices recommended by the international literature, including the World Health Organization (WHO).

Assuming that raised tambaqui in fish farms is not influenced by Amazon seasonality and considering that fish farms maintain continuous water renewal in ponds, being faced with the presuppositions, this study aimed to determine fatty acid profile, omegas, and lipid quality of commercial cuts of tambaqui (*C. macropomum* Cuvier, 1818) under semi-intensive cultivation in ponds in the Rondônia state, Western Amazon. This study did not compare the lipid composition of tambaqui in different hydrological periods but determined the lipid profile in commercial cuts of tambaqui in the weight class considered ideal for commercialization.

Materials and Methods

Bioethical considerations

The study was conducted by the Universidade Federal de Rondônia (UNIR) and the analyses were carried out at the Laboratórios de Águas e Alimentos, Universidade Estadual de Maringá (UEM). The research was supported by the Rondônia Research Support Foundation (FAPERO) and approved by the Ethics Committee on the Use of Animals (CEUA/UNIR), under protocol number 02/2019/UNIR for sample collection and 12/2021 for carrying out the analyses of experimental trials. Therefore, sample collections were carried out from May 2019 to December 2020 in two fish processing units registered in the Brazilian System of Inspection of Animal Products (SISBI-POA), located in the municipalities of Ariquemes and Vale do Paraíso, in Rondônia state, Brazil.

Commercial diet

In fish farms, the extruded commercial feed was supplied, containing 36% crude protein at a feeding rate of 1.0% in relation to body weight. The feed was supplied twice a day, from 10 a.m. to 5 p.m., for 130 days (Table 1). It is important to point out that it is important to present information on the guaranteed levels of the rations provided by fish farms in order to demonstrate that the commercial fish farms adopt a standardized diet. Therefore, there is no possibility of a difference in feeding to cause significant variations in the results of the fatty acid profile.

Fish sampling and processing

The sampled fish come from the same nursery and from fish farms that use a semi-intensive system in ponds. In addition, they maintained a continuous renewal of water from the ponds.

According to Dantas Filho et al. (2021) and Dantas Filho et al. (2022), 80 specimens of the tambaqui were used, with a body weight in the weight class of 1.80–2.41 kg, considered ideal for commercialization. A total of 20

fish per commercial cuts were obtained for the analysis of lipid composition. The sampled fish were selected from previously characterized fish farms, excluding batches from production systems that adopted a production management different from that adopted in fish farms, such as reports of parasitic infestations, deaths due to high stocking densities, undernutrition, cultivation in nettanks, fish tank network, and others (Dantas Filho et al., 2022).

The stunning and slaughter methods were carried out by the fish processing units (Brasil, 2017). In the processing units, fish were washed, gutted, and processed into commercial cuts according to market demand. The initial processing step was performed on the evisceration table, with the procedure of removing the skin with scales, after removing the head and viscera. After evisceration, there is a “cleaning step” (carcass cleaning) in which the inner part of the fish is cleaned by removing blood and visceral fat. To prepare the fillet and rib cuts (Figures 1A and 1B), the fish were divided into bands after removing the spine from the evisceration table (Dantas Filho et al., 2022).

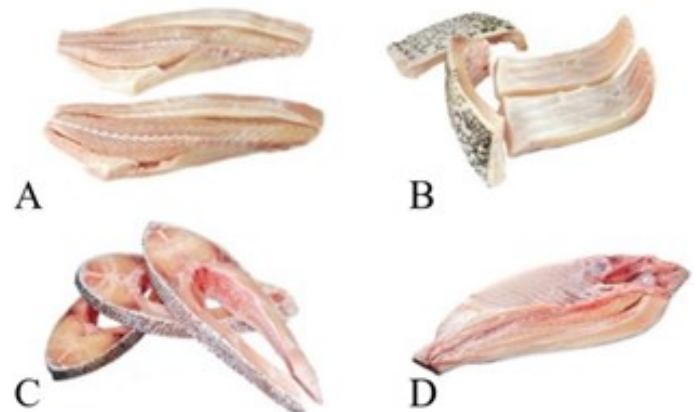
However, in the clean area, the intramuscular spines were removed and the fillet and rib cuts were separated. For the preparation of the steak’s cut, the fish that went through the “cleaning step” were frozen and later sawed using a piece of equipment called a band-saw (Figure 1C). For the band cut (Figure 1D), the head was kept, removing only spines and fins (Dantas Filho et al., 2021).

Next, three samples of 4 cm² and 50 g were taken from each commercial cut (fillet, ribs, steak, and band) and were homogenized in order to obtain greater representation. These samples were properly identified and stored at -18°C. Then, they were weighed and stored at 5°C for 12 h, cut into 1 cm² pieces, placed in aluminum containers previously weighed and identified, and frozen at -20°C for 48 h. After this, the containers with the samples were labeled and frozen again in a freezer at -18°C until the moment of composition analysis. To evaluate the lipid composition, a LIOTOP L101 lyophilizer was used for 44 h.

Fatty acid profile assessment

Total lipids were extracted following the method of Bligh and Dyer (1959), and fatty acid methyl esters were prepared by methylation of triacylglycerols, as described in ISO method 5509 (ISO, 1978). The fatty acid methyl esters were analyzed using a 14-A gas chromatograph (Shimadzu, Japan) equipped with a flame ionization detector and a fused silica capillary column (50 m long, 0.25 mm internal diameter, and 0.20 µm Carbowax 20M film thickness). The flow rate of ultrapure gases (White Martins) was 1.2 mL min⁻¹ for the carrier gas (H₂), 30 mL min⁻¹ for auxiliary gas (makeup) (N₂), and 30 mL min⁻¹ for H₂ flame gases, and 300 mL min⁻¹ for synthetic air.

The injection volume was expressed in µL, and the sample division ratio was 1:100 (Santos et al., 2017). The column temperature was programmed at a rate of 2°C min⁻¹, from 150 to 240°C. Injector and detector temperatures were 220 and 245°C,



Source: Dantas Filho et al. (2021).

Figure 1. Representation of commercial cuts of the tambaqui (*Colossoma macropomum*) cultivated in ponds in Rondônia state, Western Amazon. (A) Fillet; (B) ribs; (C) steak; (D) band.

Table 1. Guarantee levels of the feed supplied to tambaqui (*Colossoma macropomum*) cultivated in ponds in Rondônia state, Western Amazon.

Feed composition	Content (g kg ⁻¹)	Feed composition	Content (g kg ⁻¹)
Dry matter (g)	910	Ethereal extract (min, g)	80
Crude protein (min, g)	360	Calcium (max, g)	35
Fibrous matter (max, g)	95	Calcium (min, g)	20
Mineral matter (max, g) ¹	15	Phosphorus (min, g)	15

¹Amount of nutrients per kg for crude protein ration (36%). Pantothenic acid (min): 3 mg; biotin (min): 50 mg; choline (min): 290 mg; vitamin A (min): 28,000 IU; vitamin B₁ (min): 2 mg; vitamin B₁₂ (min): 4 mg; vitamin B₂ (min): 3 mg; vitamin B₆ (min): 2 mg; vitamin D₃ (min): 5,000 IU; vitamin E (min): 45 IU; vitamin K₃ (min): 2 mg; vitamin C (min): 500 mg; copper (min): 10 mg; total iron (min): 90 mg; iodine (min): 0.40 mg; niacin (min): 50 mg; manganese (min): 10 mg; zinc (min): 180 mg; selenium (min): 0.60 mg.

Source: Fish processing units in the Vale do Paraíso and Ariquemes, RO, Brazil.

respectively. According to Santos et al. (2017), the peak areas were determined using the Integrator-Processor CG-300 (CG Scientific Instruments), and the identification of the peaks was performed by comparison with the retention times of the pattern (Sigma, USA).

Lipid quality indices

Fatty acid profile data were pooled to calculate the ratio of $\sum\text{PUFAs}/\sum\text{SFAs}$ and the ratio of $\sum\text{PUFAs}$ (n-6/n-3), following the WHO prescriptions. The other data found by lipid quality indices were compared with indices recommended in the studies, such as those by Ulbricht and Southgate (1991), Hernández-Martínez et al. (2016), Passos et al. (2016), Rodrigues et al. (2017), and Souza et al. (2017).

The nutritional quality of the lipid fraction was also obtained from the fatty acid profile through the atherogenicity index (AI), thrombogenicity index (TI) (Ulbricht and Southgate, 1991), and the ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H) (Santos-Silva et al., 2002).

The mathematical formulas of these lipid quality indices are as follows (Equations 1, 2 and 3):

$$\text{AI} = [(12:0+4\times 14:0+16:0)]/\sum\text{PUFAs}+\sum\text{n-6}+\sum\text{n-3} \quad (1)$$

$$\text{TI} = (14:0+16:0+18:0)/[(0.5\times\sum\text{MUFAs})+(0.5\times\sum\text{n-6})+(3\times\sum\text{n-3})+(\sum\text{n-3}/\text{n-6})] \quad (2)$$

$$\text{h/H} = (18:1\text{n-9} \text{n-6}+18:2 \text{n-6}+20:4 \text{n-6}+18:3 \text{n-3}+20:5 \text{n-3}+22:5 \text{n-3}+22:6 \text{n-3})/(14:0+16:0) \quad (3)$$

Statistical design and analysis

The experimental design was completely randomized with four commercial cuts for the industrial processing of tambaqui (*C. macropomum*), being the processing carried out in triplicate. Data were subjected to analysis of variance (ANOVA) to assess the differences between commercial cuts. If the ANOVA seemed statistically significant ($\alpha = 0.05$), the means were compared using the Tukey's test. The software used to perform the statistical analyses was the Genes Program made available by the Universidade Federal de Viçosa (UFV), version 13.3 (Cruz, 2013).

RESULTS

First, concerning the fatty acid composition, fillet expressed percentage of SFAs 39.4%, MUFAs 45.12%, and PUFAs 15.43%. Ribs expressed percentage of SFAs 42%, MUFAs 42.71%, and PUFAs 15.29%. Steak expressed percentage of SFAs 47.05%, MUFAs 39.88%, and PUFAs 13.08%. Finally, band expressed percentage of SFAs 37.43%, MUFAs 43.52%, and PUFAs 19.05%. Therefore, the cut band showed the highest

balance between SFAs and MUFAs and the highest PUFAs content (Table 2).

Fatty acid composition showed a statistical difference ($p < 0.05$) between the commercial cuts, with the exception of octadecenoic acid (C18:1 n-7) and DHA, which expressed no difference ($p > 0.05$) (Table 2).

The highest value of ALA was found in steak $2.686 \pm 0.004\%$, followed by fillet $2.154 \pm 0.050\%$, ribs $1.350 \pm 0.002\%$, and band $1.277 \pm 0.001\%$. As for AA, the highest value was found in the fillet $3.313 \pm 0.027\%$, followed by ribs $1.115 \pm 0.005\%$, band $0.634 \pm 0.004\%$, and steak $0.181 \pm 0.001\%$. However, EPA was found to have the highest value in band $0.927 \pm 0.056\%$, followed by steak $0.687 \pm 0.002\%$, ribs $0.315 \pm 0.005\%$, and fillet $0.167 \pm 0.013\%$. The highest value of DHA was found in fillet $0.570 \pm 0.028\%$, followed by band $0.526 \pm 0.006\%$, ribs $0.451 \pm 0.001\%$, and steak $0.417 \pm 0.001\%$. Therefore, ALA, AA, and EPA show statistical differences ($p < 0.05$) between commercial cuts (Table 2).

The highest total value of $\sum\text{(n-3)}$ was found in band 4.565%, followed by steak 4.229%, fillet 3.163%, and ribs 2.429%. The highest total value of $\sum\text{(n-6)}$ was found in band 14.485%, followed by ribs 12.865%, fillet 12.269%, and steak 8.855%. The highest total value of $\sum\text{(n-7)}$ was found in ribs 6.926%, followed by band 6.717%, steak 5.435%, and fillet 2.569%. However, the highest total value of $\sum\text{(n-9)}$ was found in fillet 42.133%, followed by band 36.541%, ribs 35.312%, and steak 33.780%. For all total values of omegas, there was a statistical difference ($p < 0.05$) between the commercial cuts (Table 3).

The lipid quality index $\sum\text{PUFAs}/\sum\text{SFAs}$ expressed the highest value in the band 0.509, followed by fillet 0.391, ribs 0.364, and steak 0.278. However, the $\sum\text{PUFAs}$ (n-6/n-3) index had the highest value in the ribs 5.296, followed by fillet 3.879, band 3.173, and steak 2.094. Both in the $\sum\text{PUFAs}/\sum\text{SFAs}$ lipid quality index and in the $\sum\text{PUFAs}$ (n-6/n-3) index, there was a statistical difference ($p < 0.05$) between the commercial cuts (Table 3).

The AI expressed the highest value in the steak 0.726, followed by the ribs 0.472, fillet 0.407, and band 0.398. The TI the highest value was found in the steak 1.102, followed by ribs 1.087, fillet 0.958, and band 0.797. Despite the results of h/H, the highest value was found in the band 2.255, followed by the fillet 2.160, ribs 1.858, and steak 1.377. In the AI, TI, and h/H, there was a statistical difference ($p < 0.05$) between the commercial cuts (Table 3).

DISCUSSION

The commercial cuts of tambaqui (*C. macropomum*) expressed considerable percentages of MUFAs, and the tambaqui fillet 45.120 had the highest value, followed by band 43.518, ribs 42.712, and steak 39.875. These values are above 23.89 found in *Pangasius hypophthalmus* fillet by Sokamte et al. (2020). It is noteworthy that MUFAs have been associated with a decrease in total cholesterol and

low-density lipoprotein (LDL) cholesterol, as well as an increase in plasma levels of high-density lipoprotein (HDL) cholesterol (Kratz et al., 2014; Mahan and Escott-Stump, 2018). LDL cholesterol is known as bad cholesterol; it can accumulate in the arteries and coronary arteries and can lead

to the formation of plaques that can interrupt the blood flow to organs, such as the heart and brain, increasing the risk of heart attack (Jankowska et al., 2010). However, good HDL cholesterol has the function of removing bad LDL cholesterol from the bloodstream (Leite et al., 2015).

Table 2. Fatty acid profile (%) in commercial cuts of the tambaqui (*Colossoma macropomum*) cultivated in ponds in Rondônia state, Western Amazon.

Fatty acid (%) Usual nomenclature/symbol	Commercial cuts			
	Fillet	Ribs	Steak	Band
Lauric acid ¹ /C12:0	0.666 ± 0.078 ^c	1.588 ± 0.004 ^b	3.072 ± 0.002 ^a	1.254 ± 0.006 ^b
Myristic acid ¹ /C14:0	0.160 ± 0.008 ^c	0.318 ± 0.001 ^b	1.390 ± 0.010 ^a	0.405 ± 0.015 ^b
Pentadecylic acid ¹ /C15:0	0.077 ± 0.008 ^b	0.103 ± 0.001 ^a	0.109 ± 0.001 ^a	0.053 ± 0.020 ^b
Palmitic acid ¹ /C16:0	23.359 ± 0.022 ^b	24.545 ± 0.002 ^b	29.804 ± 0.001 ^a	22.038 ± 0.001 ^b
Margaric acid ¹ /C17:0	0.182 ± 0.008 ^b	0.205 ± 0.005 ^b	0.335 ± 0.002 ^a	0.152 ± 0.001 ^b
Stearic acid ¹ /C18:0	13.307 ± 0.336 ^a	13.479 ± 0.003 ^a	10.177 ± 0.003 ^b	11.821 ± 0.002 ^b
Arachidic acid ¹ /C20:0	0.388 ± 0.013 ^a	0.213 ± 0.002 ^b	0.249 ± 0.002 ^b	0.275 ± 0.004 ^b
Behenic acid ¹ /C22:0	0.312 ± 0.030 ^b	0.659 ± 0.001 ^{ab}	0.821 ± 0.002 ^a	0.064 ± 0.001 ^c
Lignoceric acid ¹ /C24:0	0.660 ± 0.028 ^a	0.573 ± 0.001 ^{ab}	0.326 ± 0.003 ^b	0.046 ± 0.001 ^c
Palmitoleic acid ² /C16:1 n-7	0.411 ± 0.060 ^c	4.575 ± 0.002 ^a	3.037 ± 0.002 ^b	4.135 ± 0.004 ^{ab}
Sapienic acid ² /C16:1 n-9	4.469 ± 0.192 ^a	0.415 ± 0.001 ^b	0.327 ± 0.001 ^b	0.306 ± 0.020 ^b
Cis-10-heptadecenoic acid ² /C17:1	0.418 ± 0.011 ^b	0.474 ± 0.001 ^b	0.660 ± 0.002 ^a	0.260 ± 0.030 ^c
Oleic acid ² /C18:1 n-9	36.464 ± 0.042 ^a	34.182 ± 0.001 ^{ab}	32.558 ± 0.002 ^b	35.833 ± 0.003 ^a
Vaccenic acid ² /C18:1 n-7	2.158 ± 0.033 ^b	2.351 ± 0.002 ^b	2.898 ± 0.002 ^a	2.582 ± 0.001 ^b
Gondoic acid ² /C20:1 n-9	0.204 ± 0.065 ^a	0.117 ± 0.002 ^b	0.120 ± 0.002 ^b	0.117 ± 0.001 ^b
Erucic acid ² /C22:1 n-9	0.431 ± 0.006 ^a	0.111 ± 0.001 ^b	0.275 ± 0.002 ^b	0.195 ± 0.004 ^b
α-Linolenic acid (ALA) ² /C18:3 n-3	2.154 ± 0.050 ^b	1.350 ± 0.002 ^c	2.686 ± 0.004 ^a	1.277 ± 0.001 ^c
Dihomo-α-linolenic acid ² /C20:3 n-3	0.272 ± 0.017 ^c	0.313 ± 0.001 ^c	0.439 ± 0.005 ^b	1.835 ± 0.001 ^a
Eicosapentaenoic acid (EPA) ² /C20:5 n-3	0.167 ± 0.013 ^c	0.315 ± 0.005 ^c	0.687 ± 0.002 ^b	0.929 ± 0.056 ^a
Linoleic acid ² /C18:2 n-6	8.123 ± 0.006 ^b	8.781 ± 0.001 ^b	6.418 ± 0.001 ^c	11.421 ± 0.005 ^a
Gamma linolenic acid (GLA) ² /C18:3 n-6	0.078 ± 0.019 ^c	0.198 ± 0.004 ^b	0.262 ± 0.012 ^b	0.482 ± 0.001 ^a
Conjugated linoleic acid (CLA) ² /C18:2 n-6	8.123 ± 0.006 ^b	8.781 ± 0.001 ^b	6.418 ± 0.001 ^c	11.421 ± 0.005 ^a
Eicosadienoic acid ² /C20:2 n-6	0.166 ± 0.007 ^b	1.208 ± 0.002 ^a	1.215 ± 0.001 ^a	0.253 ± 0.001 ^b
Dihomo-Gamma-linolenic acid (DGLA) ² /C20:3 n-6	0.130 ± 0.035 ^b	1.170 ± 0.002 ^a	0.205 ± 0.005 ^b	0.953 ± 0.005 ^a
Arachidonic acid (AA) ² /C20:4 n-6	3.313 ± 0.027 ^a	1.115 ± 0.005 ^b	0.190 ± 0.001 ^c	0.634 ± 0.004 ^c
Docosahexaenoic acid (DHA) ² /C22:6 n-3	0.570 ± 0.028 ^a	0.457 ± 0.001 ^a	0.417 ± 0.001 ^a	0.526 ± 0.006 ^a
Others				
¹ Saturated fatty acids (SFAs)	39.450	42.000	47.050	37.430
² Unsaturated fatty acids (UFAs)	60.550	58.006	52.959	62.568
Monounsaturated fatty acids (MUFAs)	45.120	42.712	39.875	43.518
Polyunsaturated fatty acids (PUFAs)	15.430	15.294	13.084	19.050

If there are averages followed by different letters in the columns (a, b, c), they are different from each other by Tukey's test ($p < 0.05$).

Table 3. Omegas and lipid quality indices in commercial cuts of the tambaqui (*Colossoma macropomum*) cultivated in ponds in Rondônia state, Western Amazon.

	Commercial cuts			
	Fillet	Ribs	Steak	Band
Omegas	3.163 ^b	2.429 ^c	4.229 ^a	4.565 ^a
∑PUFAs (n-3)	12.269 ^b	12.865 ^b	8.855 ^c	14.485 ^a
∑PUFAs (n-6)	2.569 ^c	6.926 ^a	5.435 ^b	6.717 ^a
∑PUFAs (n-7)	42.133 ^a	35.312 ^b	33.780 ^c	36.541 ^b
∑PUFAs (n-9)	3.163 ^b	2.429 ^c	4.229 ^a	4.565 ^a
Lipid quality indices				
∑PUFAs/∑SFAs	0.391 ^b	0.364 ^b	0.278 ^b	0.509 ^a
∑PUFAs (n-6/n-3)	3.879 ^b	5.296 ^a	2.094 ^c	3.173 ^b
AI	0.407 ^b	0.472 ^b	0.726 ^a	0.398 ^b
TI	0.958 ^a	1.087 ^a	1.102 ^a	0.797 ^b
h/H	2.160 ^a	1.858 ^a	1.377 ^b	2.255 ^a

SFAs: saturated fatty acids; MUFAs: monounsaturated fatty acids; PUFAs: polyunsaturated fatty acids. AI: atherogenicity index; TI: thrombogenicity index; h/H: ratios between hypocholesterolemic and hypercholesterolemic fatty acids. If there are averages followed by different letters in columns (a, b, c), they are different from each other by Tukey's test ($p < 0.05$).

Tropical fish are great suppliers of ∑PUFAs (n-3, n-6), which are polyunsaturated lipids, so bromatological studies indicate that the consumption of cooked fish lowers LDL cholesterol by maintaining the presence of HDL cholesterol in the bloodstream (Martins and Oetterer, 2011; Franco et al., 2018; Siqueira et al., 2020). Ng et al. (2003), when evaluating the fatty acid profile of African catfish (*Clarias gariepinus*) fillets fed with different diet rations formulated with 10% of lipids from cod liver oil (CLO), found a value of 20.5% for ∑PUFAs, which is higher than the values found in tambaqui cuts found here. Martino et al. (2002), when evaluating the fatty acid profile of *Pseudoplatystoma corruscans* fillets fed with different diet rations formulated with 18.5% of lipids from lard, corn oil, soybean oil, and linseed oil, found the following values, respectively, for ∑PUFAs: 18.1, 40.8, 47.7, and 48.1%.

Thus, fish fed with a lard-enclosed pork ration expressed lower ∑PUFAs than the tambaqui band of 19.0%. Orban et al. (2008), when evaluating the fatty acid profile of *P. hypophthalmus* fillets, found a value of 12.45% for PUFAs, which is lower than the values found for all tambaqui cuts found here. However, Tanamati et al. (2009), when evaluating the fatty acid profile of *Piaractus mesopotamicus* fillets, found a value of 18.00% for PUFAs, which was lower than the values found for tambaqui band 19.05%. Chaijan et al. (2010), when evaluating the fatty acid profile of *Pangasius bocourti* fillets, found lower percentages of PUFAs with 14.80%, than in fillet 15.43%, ribs 15.29%, and band 19.05% of tambaqui found here.

Fallah et al. (2011) determined the fatty acid profile of trout (*Oncorhynchus mykiss*) in Northern Iran and found higher PUFAs of 25% than the tambaqui cuts found here, but with a lower percentage of 28% for MUFAs. However, Njinkoue et al. (2016) compared the fatty acid profiles of the meat of *Pseudotolithus typus* and *Pseudotolithus elongatus*, two species widely consumed on the West coast of Africa, and found percentages of PUFAs below 15%.

According to fatty acid composition determinations obtained by Petenuci et al. (2019), it can be seen that tambaqui (*C. macropomum*) has a lower percentage of PUFAs than salmon (*Salmo salar*) 47.3%, sardines (*Triportheus angulatus*) 19.8%, sea bass (*Centropomus undecimalis*) 18.7%, and *Caranx hippos* 20.08%, with the exception of the tambaqui band, which shows a value of 19.05% for PUFAs, being in a higher percentage than for sea bass. As in this study, Martins et al. (2017) found considerable amounts of ∑PUFAs (1,443.4 mg/100 g) in the cuts of pirarucu (*A. gigas*), most of which were composed of n-3 acids (1,376.1 mg/100 g of fresh muscle), in addition to the essential fatty acids such as EPA, DHA, AA, and ALA.

Group n-3 are anti-inflammatory. Unlike n-6, they promote vasodilation and inhibition of platelet aggregation and are related to the prevention of hypertension, atherosclerosis, hypercholesterolemia, arthritis, and other autoimmune and inflammatory diseases, as well as the most diverse cancers (Souza et al., 2017). It is worth emphasizing that, generally, eicosanoids produced from n-3 fatty acids, mainly EPA and DHA, are reported as essential fatty acids due to the inhibition of stearic metabolism to inflammatory eicosanoids, as they increase the anti-inflammatory mediators and vasodilation and inhibit platelet aggregation, compared to those produced by the n-6 series of eicosanoids (Antonelo et al., 2020). That is, the enzymatic action of these PUFAs in the modulation of the lipid profile from unsaturated to saturated during metabolism changes the efficiency of the consumed diet and the ingested profile, making meat healthier (Vieira et al., 2015).

The most beneficial n-3 fatty acids are EPA and DHA (Pal et al., 2018). According to Harris et al. (2009), it is recommended to consume between 250 and 500 mg of EPA+DHA per day. A key function of ALA is as a substrate for the synthesis of long-chain n-3 fatty acids, found in fish, EPA and DHA, which are present in the retina of the eye and the cerebral cortex (Damodaran et al., 2010). Very long-chain PUFAs are derived from ALA with priority to EPA and DHA by elongations and denaturations, and have the ability to modulate inflammatory processes competing with ∑PUFAs (n-6) derived from AA, such as docosahexaenoic acid (C22:4) by deposition of phospholipids from the membrane of immune system cells (Petenuci et al., 2019; Antonelo et al., 2020). According to Burdge and Calder (2005), the conversion of ALA to EPA and DHA fatty acids is limited, and the efficiency in transferring ALA to EPA and to DHA in adult humans is about 0.2 and 0.05%, respectively.

With regard to EPA percentage, Orban et al. (2008), when evaluating the fatty acid profile of *P. hypophthalmus* fillets,

identified EPA 0.19 as a lower value than in ribs 0.315 ± 0.005 , steak 0.687 ± 0.002 , and band 0.927 ± 0.056 of tambaqui found here. With regard to DHA content, Li et al. (2009) and Tanamati et al. (2009), when evaluating the fatty acid profile of American catfish (*Ictalurus punctatus*) and *P. mesopotamicus* fillets, found values of 0.75 and 1.90, respectively, values higher than those found in tambaqui fillet of 0.570 ± 0.028 found here. However, Orban et al. (2008), when evaluating the fatty acid profile of *P. hypophthalmus* fillets, found a value of 0.083 which was lower than that found in tambaqui fillet 0.570 ± 0.028 found in this study. Additionally, Martino et al. (2002) and Wink-Kong et al. (2003), when evaluating the fillets of African catfish (*C. gariepinus*) (DHA 2.00) and *P. corruscans* (DHA 2.20), found values greater than those found in tambaqui fillet 0.570 ± 0.028 here found.

Above all, the percentages of AA, eicosatrienoic acid (C20:3 n-6), and octadecadienoic acid (C18:2 n-6) can also be highlighted. They are fatty acids that help speed up the healing process and renew red cells and defense cells (Cavali et al., 2022b). These three PUFAs were found in the analyzed sections. Despite this, not all PUFAs in the n-6 group are beneficial. According to Souza et al. (2017), the Σ PUFAs (n-6) are pro-inflammatory. They increase the production of cytokines with vasoconstrictor action and promote platelet aggregation. They are related to the occurrence of cardiovascular, autoimmune, and inflammatory diseases such as arthritis, asthma, psoriasis, lupus, and ulcerative colitis.

Hexadecenoic acid (C16:1 n-7) and octadecenoic acid (18:1 n-7) were found in all sections in this study. Octadecenoic acid was also at high levels in the MUFAs fraction in the muscle of *Salmo trutta macrostigma* (Akpınar et al., 2009). It is noteworthy that the n-7 fatty acid was found in tambaqui cuts; this nutrient is responsible for increasing insulin sensitivity, preventing type 2 diabetes. It reduces inflammatory processes and LDL cholesterol levels, in addition to improving the elasticity of the arteries. In short, it helps in the treatment of metabolic syndromes (Passos et al., 2016).

Palmitoleic acid (C16:1 n-7) was proposed as a lipokine, a molecule produced by adipocytes that acts as a signaling agent in several organs, which regulates systemic metabolic homeostasis, stimulating insulin action in muscle and suppressing hepatic steatosis (Blanco and Soengas, 2021); 9-hexadecenoic acid (palmitoleic acid, C16:1 n-7) is a fatty acid of the n-7 group, which has been gaining prominence in scientific publications as it is considered a potent anti-inflammatory. Furthermore, it is suggested that these MUFAs increase the gene expression of PPAR- α , an inhibitor of nuclear factor kappa B (NF κ B), recognized for increasing cellular inflammation (Souza et al., 2017). In addition, palmitoleic acid acts as an important signal for metabolic reactions in adipocytes (Passos et al., 2016; Blanco and Soengas, 2021). Thus, some studies propose its consumption to reduce the risk of inflammatory and metabolic diseases (Frigolet and Gutiérrez-Anguilar, 2017).

Likewise, research carried out in obese rats demonstrated that the administration of palmitoleic acid for 12 weeks promoted

an improvement in insulin sensitivity, since this fatty acid regulates the phosphorylation cascade mediated by the hormone in question (Souza et al., 2017). It is noteworthy that this benefit was also verified clinically. A study approved by the Human Subjects Review Committee, at the University of Washington, USA, was conducted with 17 subjects and found a positive correlation between plasma concentrations of palmitoleic acid and improved insulin sensitivity. Thus, n-7 consumption is suggested to reduce this trigger related to diabetes and other metabolic diseases (Kratz et al., 2014). Another study was carried out with 20 patients diagnosed with ulcerative colitis and indicated that supplementation with palmitoleic acid for 8 weeks was responsible for a significant reduction in interleukin-6 (a cytokine related to the inflammatory condition of the disease). In addition, some researchers have observed an increase in the gene expression of HNF4- γ (hepatocyte nuclear factor 4 gamma) and HNF-a (hepatocyte nuclear factor alpha), proteins that are also involved in the immune response to this condition (Bueno-Hernandez et al., 2017). In addition, group n-7 can be found in some oilseeds, such as macadamia and some tropical fish (Passos et al., 2016). In a balanced way, these fatty acids can be part of the diet, promoting their benefits to organic balance (Jankowska et al., 2010; Bueno-Hernandez et al., 2017).

In a study carried out by Moraes et al. (2018) with the supplementation of n-9 by enteral injection in mice with induced sepsis, there was a significant reduction in the detected inflammation. Albuquerque et al. (2016) analyzed the effect of n-9 (C18:1 n-9) oleic acid supplementation on sepsis and suggested that oleic acid has a beneficial role in sepsis by decreasing metabolic dysfunction, supporting the benefits of diets rich in MUFAs. The main component of olive oil is n-9 oleic acid, at MUFAs. Gultekin et al. (2014) found similar results in humans when providing a total parenteral nutrition solution enriched with n-3 containing n-9 as there was a decrease in the levels of inflammatory mediators and an improvement in biochemical parameters in septic patients.

In this study, oleic acid was identified in high values in fillet 36.464 ± 0.042 , band 35.833 ± 0.003 , ribs 34.182 ± 0.001 , and steak 32.558 ± 0.002 . Oleic acid has also been identified as the main MUFAs in the muscle of *S. trutta macrostigma* (Akpınar et al., 2009) and in the muscle of *O. mykiss* (Gladyshev et al., 2022). Oleic acid is a characteristic of MUFAs in fish tissue. The 9-hexadecenoic acid (C16:1 n-9) was also found in all sections of the tambaqui as well as in the *O. mykiss* muscle (Gladyshev et al., 2022).

A method prescribed by WHO to assess lipid quality is based on the Σ PUFAs/ Σ SFAs ratio, with values below 0.45 being considered unhealthy (Wood and Enser, 1997; WHO, 2005). The commercial cutoff band had the best Σ PUFAs/ Σ SFAs index of 0.509. The SFAs are considered hypercholesterolemic and the most concerning for cardiovascular health, in this sense, are myristic (C14:00), lauric (C12:00), and palmitic (C16:00) acids (Nunes et al., 2012). SFAs increase the blood cholesterol level by reducing the activity of the LDL cholesterol receptor

and reducing the LDL-free space in the bloodstream (Chiu et al., 2017). Palmitic acid (C16:00) is the most harmful to cardiac functions and is the most found in bovine and swine fats (Hautrive et al., 2012).

According to Martino et al. (2002), Lu et al. (2003), Orban et al. (2008), and Tanamati et al. (2009), the nutritional composition in the *P. corruscans*, *P. hypophthalmus*, Nile Tilapia (*Oreochromis niloticus*), and *P. mesopotamicus* fillets was found to have Σ PUFAs/ Σ SFAs of 0.44, 0.26, 0.53, and 0.35, respectively. Furthermore, *P. corruscans*, *P. hypophthalmus*, and *P. mesopotamicus* do not have lipid quality according to WHO (2005) and Zhang et al. (2020). However, Petenuci et al. (2019) found a PUFAs/SFAs value of 0.97 for *Brycon cephalus*.

The proportion of n-6/n-3 has also been used as a criterion to assess lipid quality, which must be greater than 4 as established by WHO. The commercial cuts for ribs had the best proportion of Σ PUFAs (n-6/n-3) at 5.296; it was the most efficient category for production and commercialization. This value is above the 3.19 found by Petenuci et al. (2019) for *B. cephalus*. However, an excess of AA prevents the transformation of ALA into its derivatives EPA and DHA. The same happens in the opposite case, with lower consumption of AA; there will be a reduction in the activation of arachidonic acid (n-6), because the enzyme Δ -6-desaturase has an affinity for both the fatty acids (Jankowska et al., 2010; Siqueira et al., 2020). However, the enzyme is more specific for n-3 and will need lower percentages of these acids than the n-6 group to produce the same amount of PUFAs (Jankowska et al., 2010). That is, there must be a greater proportion of AA than ALA. Therefore, a balance in the supply of the two fatty acids through the diet is necessary. The Western diet, rich in industrialized products, cheeses, and fried foods and low in fish, fruits, vegetables, and legumes, contributes to the Σ PUFAs (n-6/n-3) being approximately 20:1, when the recommended value is around 5:1 (Kratz et al., 2014). Evidence points to the importance of increasing the consumption of Σ PUFAs (n-6/n-3) as physiologically as possible, and for this, some changes in diet should be made, such as the consumption of tropical fish (Passos et al., 2016).

The AI and TI are related to pro-atherogenic and anti-atherogenic fatty acids, with atheromas being fibrous fatty plaques located inside the arteries, and pro-antithrombotic and antithrombotic, with thrombosis being caused by a blood clot in veins (Ulbricht and Southgate, 1991). Lower AI and TI values are desirable to prevent cardiovascular disorders, as high AI and TI values can stimulate platelet aggregation and subsequent thrombus and atheroma formation in the cardiovascular system (Rodrigues et al., 2017). Furthermore, higher h/H values are considered more beneficial to human health, as this index is related to the specific effects of fatty acids on cholesterol metabolism (Hernández-Martínez et al., 2016).

Among the fish species analyzed by Zhang et al. (2020), the AI values ranged from the lowest (0.56) value in the *Sillago sihama* to the highest (1.25) value in the *Siganus fuscissens*. In the tambaqui sections analyzed here, the AI varied from 0.398 in the tambaqui band to 0.726 in steak; these values are lower

than those prescribed in the fish species analyzed by Zhang et al. (2020). The AI value found for the band is similar to that found by Petenuci et al. (2019) for *B. cephalus* (0.39). Regarding the TI values, there was a variation from 0.34 in the *Trypauchen vagina* (0.73), in *Trichiurus lepturus* while in tambaqui cuts analyzed here TI varied 0.797 in the band and 1.102 in the put, being slightly above those prescribed in the analyzed fish species by Zhang et al. (2020). These values are also above those found by Petenuci et al. (2019) for *B. cephalus* (0.64).

However, the h/H ratios ranged between 0.65 in *Selaroides leptolepis* and 1.41 in *T. vagina*, which are slightly lower than in the tambaqui sections analyzed here, since the h/H index was steak 1.377 and band 2.255. Therefore, better values were found in this study. Thus, comparing so much with the study by Zhang et al. (2020) and the studies by Passos et al. (2016), Rodrigues et al. (2020), and Souza et al. (2017), it is possible to see that tambaqui cuts have high lipid quality.

CONCLUSION

Commercial cuts of tambaqui (*C. macropomum*) in the weight class of 1.80–2.41 kg have essential fatty acids for human health, EPA, DHA, AA, and ALA, related to a lower propensity to cardiovascular diseases. The tambaqui band is the commercial cut with the highest content of PUFAs, and also expressed the highest values in omegas 3, 6, 7, and n-9. Regarding the lipid quality indices, Σ PUFAs/ Σ SFAs, Σ PUFAs (n-6/ Σ n-3), AI, TI, and h/H, all indicated that tambaqui cuts have lipid quality, especially fillet and band.

ACKNOWLEDGMENTS

The authors acknowledge the Fundação Rondônia de Amparo ao Desenvolvimento das Ações Científicas e Tecnológicas e à Pesquisa do Estado de Rondônia (FAPERÓ) for their financial support to the research project and the Programa Nacional de Cooperação Acadêmica na Amazônia (PROCAD-AM) (UNIR/UFAC/USP) for granting a postdoctoral scholarship to Jerônimo Vieira Dantas Filho.

CONFLICT OF INTERESTS

Nothing to declare.

FINANCIAL SUPPORT

This study was funded in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES)–Brazil through the Programa Nacional de Cooperação Acadêmica na Amazônia (PROCAD-AM).

AUTHORS' CONTRIBUTIONS

Cavali, J.: Conceptualization, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing — original draft; Writing — review & editing. Marmentini, R.P.: Data curation, Investigation, Methodology, Software, Validation, Formal Analysis, Investigation, Writing — original draft, Writing — review & editing. Dantas Filho, J.V.: Conceptualization, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing — original draft, Writing — review & editing. Pontuschka, R.B.: Data curation, Investigation, Methodology, Software, Validation, Formal Analysis, Investigation, Writing — original draft, Writing — review & editing. Schons, S.V.: Conceptualization, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing — original draft, Writing — review & editing.

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