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Proximate composition, energy value, and lipid quality in loin in different weight classes of pirarucu (*Arapaima gigas*) from fish farming

Ana Sabrina Coutinho Marques Rocha[1,2], Sheyla Cristina Vargas Baldi[3], Maria Luiza Rodrigues de Souza[4], Bruna Laurindo Rosa[1], Emerson Carlos Soares e Silva[5], Rute Bianchini Pontuschka[6], Jerônimo Vieira Dantas Filho[7]*, Jucilene Cavali[1,6]

[1] Universidade Federal do Acre, Programa de Pós-Graduação em Sanidade e Produção Animal Sustentável na Amazônia Ocidental – Rio Branco (AC), Brazil.
[2] Centro Universitário São Lucas, Departamento de Medicina Veterinária – Ji-Paraná (RO), Brazil.
[3] Aquaeficiência Consultoria e Gestão em Aquacultura – Pirassununga (SP), Brazil.
[4] Universidade Estadual de Maringá, Programa de Pós-Graduação em Zootecnia – Maringá (PR), Brazil.
[5] Universidade Federal de Alagoas, Centro de Ciências Agrárias – Laboratório de Aquicultura e Ecologia Aquática – Rio Largo (AL), Brazil.
[6] Universidade Federal de Rondônia, Departamento de Zootecnia – Presidente Médici (RO), Brazil.
[7] Universidade Federal de Rondônia, Programa de Pós-Graduação em Ciências Ambientais – Rolim de Moura (RO), Brazil.
*Corresponding author: jeronimovdantas@gmail.com

Abstract

The study aimed to determine the fatty acids profile, omegas, and lipid quality in loin in different weight classes of pirarucu (Arapaima gigas). A total of six pirarucu loin samples were used and sent to the laboratory by weight class, 1 (< 8 kg), 2 (8.1 to 11 kg), 3 (11.1 to 14 kg), 4 (14.1 to 18 kg), 5 (18.1 to 23 kg), 6 (23.1 to 32 kg), and 7 (> 32 kg). The experimental design was completely randomized, with processing conducted out in triplicate. Data were submitted to analysis of variance (ANOVA) to assess differences in pirarucu loin between weight classes. When ANOVA was statistically significant (α = 0.05), the averages were compared using Tukey's test. Weight class 7 showed higher values of mineral matter = 1.43, crude protein = 28.93, and energy = 526.35 KJ·100g^{-1}. However, weight class 2 showed a higher value of total lipids, 2.60, and moisture, 78.19. The pirarucu loin showed essential fatty acids, EPA, DHA, AA, and ALA, while weight classes 4 and 5 had the highest percentages of PUFAs. However, all weight classes expressed high values in omegas 3, 6, 7, and 9. There is no need to market heavier fish, as pirarucu loin in lighter weight classes 3 and 4 already meet the nutritional demand of the market.

Keywords: Commercialize smaller fish; Essential fatty acids; Fish farming, Nutritional quality.

Composição centesimal, valor energético e qualidade lipídica em lombo em diferentes classes de peso de pirarucu (*Arapaima gigas*) proveniente da piscicultura

Resumo

O estudo teve como objetivo determinar o perfil de ácidos graxos, ômegas e qualidade lipídica em lombo em diferentes classes de peso de pirarucu (Arapaima gigas). Foram encaminhadas ao laboratório seis amostras de lombo de pirarucu por classe de peso, 1 (abaixo de 8 kg), 2 (de 8,1 a 11 kg), 3 (de 11,1 a 14 kg), 4 (de 14,1 a 18 kg), 5 (de 18,1 a 23 kg), 6 (de 23,1 a 32 kg) e 7 (acima de 32 kg). O delineamento experimental foi inteiramente casualizado, com processamento realizado em triplicata. Os dados foram submetidos à análise de variância (Anova) para avaliar diferenças no lombo entre as classes de peso. Quando a Anova foi estatisticamente significativa (α = 0,05), as médias foram comparadas pelo teste de Tukey. A classe de peso 7 apresentou valores mais elevados de matéria mineral, 1,43, proteína bruta, 28,93, e energia, 526,35 KJ·100g^{-1}, no entanto a classe de peso 2 apresentou maior valor de lipídios totais, 2,60, e umidade, 78,19. O lombo apresentou ácidos graxos essenciais, EPA, DHA, AA e ALA. As classes de peso 4 e 5 apresentaram os maiores percentuais de PUFAs, porém todas as classes de peso expressaram valores elevados em ômegas 3, 6, 7 e 9. Não há necessidade de comercializar peixes mais pesados, pois o lombo de pirarucu nas classes de peso 3 e 4 já atendem à demanda nutricional do mercado.

Palavras-chave: Ácidos graxos essenciais; Comercializar peixes menores; Piscicultura; Qualidade nutricional.

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INTRODUCTION

In recent years, the demand for fish has intensified, due to the transmission of information related to its nutritional value and because its consumption adds to the health benefits and promotion of the population's quality of life (Cavali et al., 2022a; 2022c). Scientific research around the world has revealed that fish consumption is associated with a low incidence of cardiovascular diseases, due to fact that fish has essential fatty acids, such as eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), α-linolenic acid (ALA), linoleic acid (AA), etc. (He, 2009; Barik, 2017; Rodrigues et al., 2017; Watanabe and Tatsuno, 2019; Cavali et al., 2022b; 2022d). Clinical and epidemiological studies have suggested for some time that populations that regularly consume fish are lower prone to cardiovascular disease (Santos et al., 2019; Costa et al., 2020).

The content and availability of fatty acids vary between fish species, depending on age and inclusion rates in diet (Nunes et al., 2012). EPA, DHA, ALA, and AA present in species native of the Amazon Basin, such as tambaqui (*Colossoma macropomum*) (Cavali et al., 2022d), pacu (*Piaractus mesopotamicus*), pirapitinga (*Piaractus brachypomus*) (Rodrigues et al., 2020), surubim (*Pseudoplatystoma corruscans*) (Rodrigues et al., 2017), and pirarucu (*Arapaima gigas*) (Cavali et al., 2022a), have a strong antiarrhythmic action on the heart and a powerful antithrombotic action, especially since these acids are direct precursors of prostanoids (Barik, 2017), as well as eicosanoids, both playing important roles in the structure of cell membranes and metabolic processes (Duarte et al., 2020). ALA and AA are necessary to maintain cell membranes, brain functions and the transmission of nerve impulses under normal conditions (Nunes et al., 2012). These fatty acids also participate in the transfer of atmospheric oxygen to the blood plasma, in synthesis of hemoglobin and in cell division. These fatty acids are considered essential, because they are not synthesized by the human organism and most animals, although they can found in tropical fish (Watanabe and Tatsuno, 2019; Duarte et al. al., 2020; Cavali et al., 2022a; 2022c).

The pirarucu *Arapaima gigas* (Schinz, 1822) (Osteoglossiformes: Arapaimidae) is a native of the Amazon Basin species of interest for fish farming in Rondônia state, Brazil (Cavali et al., 2023). In a natural environment, it can reach up to 200 kg of total weight, and its sociocultural importance has determined the growing interest in commercial exploitation (Oliveira et al., 2014). Rondônia state is the largest producer of native fish in Brazil, corresponding to a total 57.2 thousand tons of farmed fish in 2022 (Peixe BR, 2023) and has pirarucu as one of the most important fish in scientific research and fish farming (Silva et al., 2022). However, currently environmental authorities, such as the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), consider natural populations sensitive to extinction, and others consider some microbasins as invasive species. Such facts have generated impediments to licensing and embargoed the development of its production chain in Western Amazon (Dória et al., 2021).

Pirarucu is an important source of animal protein for the Amazonian population, and it is essential to know its lipid composition. Given the information expressed, the benefits of regular consumption of fish reinforce the validity of promoting incentives through public policies to increase commercial availability for consumption. With the aim of reducing production costs (feed can reach 80% of production costs) (Cavali et al., 2023), younger fish may meet the nutritional demand of the market, not requiring the entire conventional production cycle. That is, is it worth reducing the cultivation period? Therefore, this study aimed to evaluate whether lighter pirarucu (< 14 kg) have similar nutritional values compared to fish of higher weight class.

Assuming that raised pirarucu in fish farms is not influenced by Amazon seasonality and considering that fish farms maintain continuous water renewal in excavated tanks, being faced with the presuppositions, this study aimed to determine fatty acid profile, omegas, and lipid quality in loin in different weight classes of pirarucu (*A. gigas*), under semi-intensive raised in excavated tanks in Rondônia state, Western Amazon. This study did not compare the lipid composition of pirarucu in different hydrological periods, although determined the lipid profile in pirarucu loin in different weight classes.

MATERIAL AND METHODS

Bioethical considerations

The study was conducted by the Universidade Federal do Acre, and the analyses were carried out at the Laboratório de Análises de Água e Alimentos, at Universidade Estadual de Maringá, Maringá, PR, Brazil. The research was supported by the Fundação Rondônia de Amparo ao Desenvolvimento das Ações Científicas e Tecnológicas e à Pesquisa do Estado de Rondônia and approved by the Committee on Ethics in the Use of Animals, with protocol No. 012/20121 – Project "Biossegurança, sanidade e qualidade nutricional do pescado". Sample collections were conducted from May to December 2021 in a fish processing unit, registered in the Brazilian System of Products of Animal Origin Inspection, located in Vale do Paraíso city, RO, Brazil.

Commercial diet

The fish processing unit adopted a weight class model for pirarucu proposed by Dantas-Filho et al. (2022): 1 (< 8 kg), 2 (8.1 to 11 kg), 3 (11.1 to 14 kg), 4 (14.1 to 18 kg), 5 (18.1 to

23 kg), 6 (23.1 to 32 kg) and 7 (> 32 kg). The fish received commercial extruded feed according to their age group (weight classes) (Table 1). It is important to present information on the guaranteed levels of the fish feeds 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.

Table 1. Guarantee levels of the fish feeds supplied to pirarucu (*Arapaima gigas*) in different weight classes.

Fish feed composition ($g \cdot kg^{-1}$)	Weight classes		
	1 and 2	3–5	6 and 7
Dry matter (g)	910	910	730
Crude protein (min., g)	42	360	32
Fibrous matter (max., g)	95	95	65
Mineral matter (max., g)[1]	15	15	15
Ethereal extract (min, g)	80	80	40
Calcium (max., g)	20	35	20
Calcium (min., g)	20	20	20
Phosphorus (min., g)	15	15	15

[1]Pantothenic acid (min) – 3 mg; Biotin (min) – 50 mg; Choline (min) – 290 mg; Vitamin A (min) – 28,000 IU; Vitamin B_1 (min) – 2 mg; Vitamin B_{12} (min) – 4 mg; Vitamin B_2 (min) – 3 mg; Vitamin B_6 (min) – 2 mg; Vitamin D_3 (min) – 5,000 IU; Vitamin E (min) – 45 IU; Vitamin K_3 (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 Vale do Paraíso city, RO, Brazil.

Fish sampling and processing

The fish sampled came from fish farms that use a semi-intensive system in excavated tanks. In addition, they maintained a continuous renewal of the water in the excavated tanks.

A total of six pirarucu loin samples were sent to the laboratory by weight class, 1 (< 8 kg), 2 (8.1 to 11 kg), 3 (11.1 to 14 kg), 4 (14.1 to 18 kg), 5 (18.1 to 23 kg), 6 (23.1 to 32 kg), and 7 (> 32 kg) (Dantas-Filho et al., 2022). The fish sampled were selected from production systems that did not adopt productive management that differed from that adopted in most fish farms. For example, fish from fish farms with recent reports of parasitic infestations, deaths due to high stocking densities, undernutrition, farmed in canvas or net tanks, among others, were avoided.

One more detail to be highlighted is that the sampled pirarucu came from several fish farms that commercialized with the fish processing unit. Therefore, the sampling was totally random, obeying the commercial demand.

The pirarucu were removed from the excavated tanks through a fishing net and underwent the process of desensitization by cerebral concussion. Then, they were euthanized by exsanguination sectioning the carotid veins, according to procedures adopted by the fish processing unit. These pirarucus were washed, gutted, and processed into commercial cuts according to market demand (Fig. 1a). The initial stage of processing was performed on the evisceration table, with the procedure of removing the skin with scales, removing the head, and viscera. In definition, the loin is located at the deboned cut top (Fig. 1b).

About the samples storage for later determination of the fatty acids profile, three samples of 4 cm^2 and 50 g of pirarucu loin were taken. These samples were homogenized to obtain greater representation (Fig. 1c I), and were properly identified and stored at -18°C. They were then weighed and stored at 5°C for 12 h, cut into 1-cm^2 pieces, placed in previously weighed and identified aluminum containers and frozen at -20°C for 48 h. After that, the containers with the samples were labeled and frozen again in a freezer at -18°C until the time of composition analysis (Fig. 1c II). To evaluate the lipid composition, a LIOTOP L101 lyophilizer was used for 44 h.

Analysis of proximate composition and energy value

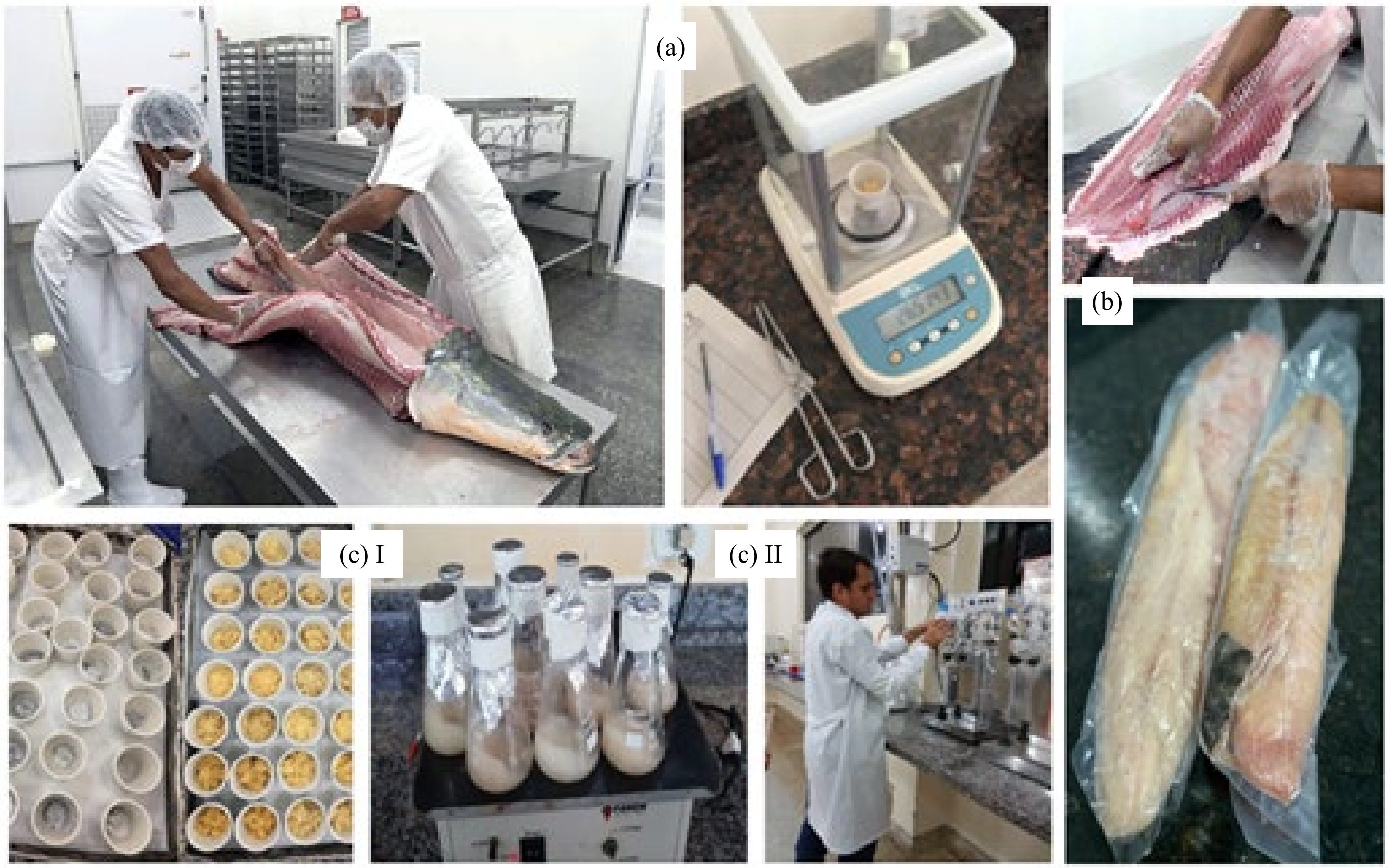
The pirarucu loin samples were first freeze-dried, to subsequently obtain the dry matter, mineral matter, crude protein, and total lipids content (Detmann et al., 2012). For the evaluation of lipids, lyophilized 3.5 g sample were used, and the lipids were extracted with ethanol and chloroform (Brum et al., 2009). For the macrominerals quantification, a complete digestion extract of the sample in sulfuric acid at high temperature (350–375°C) was obtained. Microminerals were analyzed from extracts of acid digestion samples under controlled temperatures, with nitric acid (120°C), and perchloric acid (180–190°C). To carry out the measurements, an atomic absorption spectrometer (model AA 12/1475, United States of America) was used. The minerals K^+, total iron ($Fe^{2+} + Fe^{3+}$), Ca^{2+}, and Mg^{2+} were determined by the AOAC Official 969.23 and 968.08 methods according to the methodology described by Cook (2012). Energy values (in $KJ \cdot 100g^{-1}$) were converted from the sum to calories ($Kcal \cdot 100g^{-1}$). The theoretical calculation performed from Eq. 1:

$$VE = VC\,[4(PB) + 9(LT)]\,[4.184] \quad (1)$$

Where: VE: energy value; VC: caloric value; PB: crude protein content; LT: value in total lipids.

Fatty acid profile determination and lipid quality indices

Total lipids were extracted by the method of Bligh and Dyer (1959), and fatty acid methyl esters were prepared by methylation of triacylglycerols, as described in method 5509 of the International Organization for Standardization (ISO,



Source: Rocha (2022).

Figure 1. Sampling and processing of pirarucu (*Arapaima gigas*) in different weight classes. (a) Filleting and weighing of samples, (b) Preparation and packaged loin, (c) Steps I and II of proximate composition analysis.

1978). The fatty acid methyl esters were analyzed in a 14-A gas chromatograph (Shimadzu Model, 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). Ultrapure gas flows (White Martins) were 1.2 $mL \cdot min^{-1}$ for carrier gas (H_2); 30 $mL \cdot min^{-1}$ for auxiliary gas (makeup) (N_2); and 30 and 300 $mL \cdot min^{-1}$ for flame gases, H_2 and synthetic air, respectively. The sample division ratio (split) was 1/100 (Justi et al., 2005). The column temperature was programmed at the rate of 2°C$\cdot min^{-1}$, 150 to 240°C. The injector and detector temperatures were 220 and 245°C, respectively. Just as Justi et al. (2005), the peak areas were determined using the CG-300 Integrator-Processor (GC scientific instruments), and the peaks identification was performed by comparison with the standards retention times (Sigma Model, United States of America).

Fatty acid profile data were grouped to calculate the values in omegas (3, 6, 7 and n-9) and the lipid quality indices, omega 6/omega 3, UFAs/SFAs, PUFAs/SFAs, thrombogenicity index (TI) (Eq. 2), atherogenicity index (AI) (Eq. 3) (Ulbricht and Southgate, 1991); and ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H) (Eq. 4) (Santos-Silva et al., 2002).

$$AI = [(12{:}0 + 4 \times 14{:}0 + 16{:}0)]/\Sigma MUFAs + \Sigma n\text{-}6 + \Sigma n\text{-}3 \quad (2)$$

$$TI = (14{:}0 + 16{:}0 + 18{:}0)/[(0{,}5 \times \Sigma MUFAs) + (0{,}5 \times \Sigma n\text{-}6) + (3 \times \Sigma n\text{-}3) + (\Sigma\, n\text{-}3/n\text{-}6)] \quad (3)$$

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

Statistical design and analysis

All data obtained were stored and organized in EpiInfo™ software, version 3.5.3, 2011 (OS: MS-Windows, C Sharp programming language). For statistical analyses, the Genes Program was used, provided by the Universidade Federal de

Viçosa, version 13.3 (Cruz, 2013). The experimental design was completely randomized, with pirarucu loin in seven weight classes, with processing performed in triplicate. Data were preliminarily submitted to analysis of variance. After the Shapiro-Wilk test confirmed that the data were normal and homoscedastic, the Tukey's test was applied, with 5% significance.

RESULTS

Weight class 7 showed higher values of mineral matter, 1.43, crude protein, 28.93, and energy, 526.35 $KJ·100g^{-1}$ ($p < 0.05$), compared to other weight classes. However, weight class 2 showed a higher value of total lipids, 2.60, and moisture, 78.19 ($p < 0.05$), compared to other weight classes ($p < 0.05$) (Table 2).

Fatty acids found in pirarucu loin (Table 3) expressed statistically different averages ($p < 0.05$) in relation to different weight classes, except for stearic acid (C18:0), which showed similar averages between the weight classes.

Regarding saturation, weight class 3 expressed the highest value in SFAs, 45.20%, while weight classes 3 and 6 expressed the highest values in MUFAs, 38.40 and 38.50%, respectively. The weight classes 4 and 7 expressed values in UFAs, 61.40 and 61.60%, respectively. Finally, weight classes 4, 5 and 7 expressed the highest values in PUFAs, 25.20, 26.10 and 25.60%, respectively (Table 3).

Weight class 1 showed 40.90% in SFAs, 36.70% in MUFAs and 22.40% in PUFAs, while weight class 2 expressed 43.10% in SFAs, 34.80% in MUFAs and 22.10% in PUFAs, and weight class 3 showed 45.20% in SFAs, 39.40% in MUFAs and 15.40% in PUFAs. Furthermore, weight class 4 expressed 38.60% in SFAs, 36.20% in MUFAs and 25.20% in PUFAs, while weight class 5 showed 43.60% in SFAs, 30.30% in MUFAs and 26.10% in PUFAs. In addition, weight class 6 expressed 41.70% in SFAs, 38.50% in MUFAs, and 19.80% in PUFAs. Finally, weight class 7 showed 38.40% in SFAs, 36% in MUFAs and 25.60% in PUFAs (Table 3).

It is important to highlight some of the fatty acids found, EPA, DHA, ALA, and AA. Weight class 5 showed higher values of EPA 4.91% and DHA 5.77%, while weight classes 5 and 6 showed the highest ALA values, 1.29 and 1.13%, respectively, and weight class 7 showed a higher AA value of 15.02% (Table 3).

Concerning the values in omegas found, weight class 5 showed the highest value in omega 3 (12.72%), and weight classes 4 and 7 showed the highest values in omega 6 (16.79 and 17.09%, respectively). Weight class 6 showed the highest value in omega 7 (8.10%). Finally, weight class 5 showed the highest value in omega 9 (48.38%) (Table 3).

Regarding to lipid quality indices, weight class 3 expressed the highest value in omega 6/omega 3 (6.03), while weight classes 4 and 7 expressed the highest values in UFAs/SFAs (1.59 and 1.60, respectively), and weight classes 4, 5 and 7 expressed the highest values in PUFAs/SFAs (0.63, 0.60, and 0.67, respectively). Except for weight classes 1 and 2, the other ones did not show statistical difference ($p > 0.05$) for AI, with weight classes 4 and 5 mathematically showing the highest values of 0.66. However, weight class 5 expressed the highest value of TI 47.77, while weight classes 1 and 2 expressed the highest values for h/H, 2.31 and 2.25, respectively (Table 3).

DISCUSSION

The pirarucu loin showed excellent levels of lipid quality in different weight classes. However, the current study sought to verify whether it is possible to reduce the cultivation time without prejudice to the industry, and that was affirmative. Weight classes 4 (14.1 to 18 kg) and 5 (18.1 to 23 kg) had the highest energy values and percentages of PUFAs. In addition, weight class 3 (11.1 to 14 kg) had energy values and lipid quality indices similar to heavier weight classes. That's why there is no need to sell heavier fish, as pirarucu loin in weight classes

Table 2. Proximate composition and energy value in 100 g of pirarucu (*Arapaima gigas*) loin in different weight classes*.

Weight classes	Mineral matter[1]	Crude protein	Total lipids	Moisture	Energy[2]
1 (< 8 kg)	1.05 ± 0.22[b]	18.40 ± 4.19[b]	1.95 ± 1.17[ab]	78.59 ± 4.95[a]	381.37[a]
2 (8.1 to 11 kg)	1.09 ± 0.23[b]	19.73 ± 4.49[b]	2.60 ± 1.56[a]	76.56 ± 4.82[ab]	428.11[b]
3 (11.1 to 14 kg)	1.01 ± 0.21[b]	18.49 ± 4.21[b]	2.29 ± 1.38[ab]	78.19 ± 4.93[a]	395.68[b]
4 (14.1 to 18 kg)	1.06 ± 0.22[b]	19.71 ± 4.49[b]	2.09 ± 1.26[ab]	77.13 ± 4.86[ab]	408.57[b]
5 (18.1 to 23 kg)	1.08 ± 0.23[b]	19.30 ± 4.39[b]	1.71 ± 1.06[b]	77.89 ± 4.91[ab]	387.40[b]
6 (23.1 to 32 kg)	1.33 ± 0.28[ab]	24.19 ± 5.51[ab]	1.47 ± 0.89[b]	72.98 ± 4.60[b]	460.20[ab]
7 (> 32 kg)	1.43 ± 0.30[a]	28.93 ± 6.59[a]	1.12 ± 0.67[b]	68.50 ± 4.32[b]	526.35[a]

[1]Mineral matter: total iron, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}); [2]energy value in $KJ·100g^{-1}$; *averages followed by different letters in the columns ([a,b]) are different from each other by Tukey's test ($p < 0.05$).

Table 3. Fatty acid profile, omegas, and lipid quality indices in pirarucu (*Arapaima gigas*) loin in different weight classes**.

Usual nomenclature / Symbology	1 (< 8 kg)	2 (8.1 to 11 kg)	3 (11.1 to 14 kg)	4 (14.1 to 18 kg)	5 (18.1 to 23 kg)	6 (23.1 to 32 kg)	7 (> 32 kg)
Lauric acid[1]/ C12:0	1.21^{c}	2.01^{b}	2.96^{a}	1.50^{c}	1.90^{a}	1.81^{b}	1.64^{b}
Myristic acid[1]/ C14:0	0.89^{c}	1.14^{c}	1.53^{c}	3.53^{a}	2.26^{b}	1.24^{c}	2.44^{b}
Pentadecylic acid[1]/ C15:0	0.03^{b}	0.07^{b}	0.13^{b}	0.05^{b}	0.28^{a}	0.21^{a}	0.09^{b}
Palmitic acid[1]/ C16:0	12.44^{c}	16.12^{b}	25.18^{a}	18.94^{b}	23.35^{a}	24.63^{a}	19.16^{b}
Margaric acid[1]/ C17:0	0.22^{b}	0.27^{b}	0.32^{b}	0.44^{b}	1.54^{a}	0.39^{b}	0.51^{b}
Stearic acid[1]/ C18:0	10.33^{b}	11.67^{a}	12.82^{a}	12.04^{a}	11.27^{ab}	10.20^{a}	12.34^{a}
Arachidic acid[1]/ C20:0	0.19^{c}	0.20^{c}	0.23^{c}	0.38^{b}	0.55^{a}	0.55^{a}	0.52^{a}
Behenic acid[1]/ C22:0	0.75^{a}	0.67^{a}	0.91^{a}	0.30^{b}	0.40^{b}	0.33^{b}	0.29^{b}
Lignoceric acid[1]/ C24:0	0.33^{c}	0.36^{c}	0.37^{c}	0.47^{c}	2.16^{a}	1.23^{b}	0.51^{c}
Palmitoleic acid[2]/ C16:1 n-7	2.60^{b}	3.01^{ab}	3.63^{ab}	2.26^{b}	0.71^{c}	4.92^{a}	0.33^{c}
Cis-10-heptadecenoic acid[2]/ C17:1	0.43^{b}	0.52^{c}	0.78^{b}	0.59^{b}	0.54^{b}	1.07^{a}	0.46^{b}
Oleic acid[2]/ C18:1 n-9	20.87^{b}	28.10^{a}	31.19^{a}	27.74^{a}	18.94^{b}	26.05^{a}	27.76^{a}
Vaccenic acid[2]/ C18:1 n-7	1.80^{c}	2.00^{c}	2.46^{b}	2.32^{b}	3.01^{a}	2.60^{b}	2.14^{c}
Gondoic acid[2]/ C20:1 n-9	0.13^{b}	0.16^{b}	0.17^{b}	0.11^{b}	0.20^{b}	0.95^{a}	0.12^{b}
Erucic acid[2]/ C22:1 n-9	0.20^{c}	0.30^{c}	0.27^{c}	1.80^{a}	0.84^{b}	1.01^{b}	1.64^{a}
α-Linolenic acid (ALA)[2]/ C18:3 n-3	0.50^{b}	0.52^{b}	0.57^{b}	0.57^{b}	1.29^{a}	1.13^{a}	0.63^{b}
Dihomo-α-linolenic acid[2]/ C20:3 n-3	0.45^{b}	0.40^{b}	0.63^{a}	0.78^{a}	0.75^{a}	0.53^{b}	0.69^{a}
Eicosapentaenoic acid (EPA)[2]/ C20:5 n-3	0.60^{c}	0.69^{c}	0.62^{c}	1.52^{b}	4.91^{a}	3.10^{b}	1.37^{b}
Linoleic acid[2]/ C18:2 n-6	8.22^{b}	8.68^{b}	0.57^{c}	14.96^{a}	7.98^{b}	8.14^{b}	15.02^{a}
Gamma linolenic acid (GLA)[2]/ C18:3 n-6	0.28^{b}	0.30^{b}	1.04^{a}	0.44^{b}	0.40^{b}	0.40^{b}	0.54^{b}
Conjugated linoleic acid (CLA)[2]/ C18:2 n-6	8.22^{b}	8.68^{b}	1.66^{c}	10.96^{b}	7.98^{b}	8.14^{b}	15.02^{a}
Eicosadienoic acid[2]/ C20:2 n-6	0.43^{c}	0.53^{c}	1.66^{a}	0.62^{c}	1.99^{a}	1.32^{b}	0.69^{c}
Dihomo-Gamma-linolenic acid (DGLA)[2]/ C20:3 n-6	0.18^{b}	0.20^{c}	0.71^{c}	0.19^{c}	0.93^{a}	0.73^{b}	0.20^{c}
Arachidonic acid (AA)[2]/ C20:4 n-6	0.84^{a}	0.99^{a}	0.11^{c}	0.47^{b}	0.89^{a}	0.25^{c}	0.43^{b}
Docosahexaenoic acid (DHA)[2]/ C22:6 n-3	2.87^{b}	3.05^{b}	4.11^{a}	3.24^{b}	5.77^{a}	3.46^{b}	3.70^{b}
Others*							
Saturated fatty acids (SFAs)	40.90^{ab}	43.10^{a}	45.20^{a}	38.60^{b}	43.60^{a}	41.70 ab	38.40 b
[x]Unsaturated fatty acids (UFAs)	59.10^{ab}	56.90^{b}	54.80^{b}	61.40^{a}	56.40^{b}	58.30 ab	61.60 a
[y]Monounsaturated fatty acids (MUFAs)	36.70^{ab}	34.80^{b}	39.40^{a}	36.20^{ab}	30.30^{c}	38.50 a	36.00 ab
[z]Polyunsaturated fatty acids (PUFAs)	22.40^{ab}	22.10^{b}	15.40^{c}	25.20^{a}	26.10^{a}	19.80 b	25.60 a
Omegas							
Omega 3 (n-3)	4.43^{bc}	4.66^{bc}	2.22^{c}	6.11^{b}	12.72^{a}	8.42^{ab}	6.39^{b}
Omega 6 (n-6)	10.91^{b}	11.75^{b}	13.39^{b}	16.79^{a}	12.29^{b}	11.49^{b}	17.09^{a}
Omega 7 (n-7)	4.40^{bc}	5.01^{bc}	6.09^{b}	4.58^{bc}	3.72^{bc}	8.10^{a}	2.48^{c}
Omega 9 (n-9)	21.90^{c}	29.31^{bc}	32.54^{bc}	31.06^{bc}	48.38^{a}	41.90^{b}	33.09^{bc}
Lipid quality indeces							
Omega 6/Omega 3	2.46^{b}	2.52^{b}	6.03^{a}	2.75^{b}	0.97^{c}	1.36^{c}	2.67^{b}
UFAs/SFAs	1.44 a^{a}	1.32^{a}	1.22^{a}	1.59^{a}	1.29^{a}	1.40^{a}	1.60^{a}
PUFAs/SFAs	0.55^{a}	0.51^{a}	0.35^{b}	0.63^{a}	0.60^{a}	0.47^{a}	0.67^{a}
AI	0.33 b^{b}	0.43^{b}	0.62^{a}	0.66^{a}	0.66^{a}	0.60^{a}	0.59^{a}
TI	20.40^{c}	21.91^{c}	15.52^{c}	28.99^{b}	47.77^{a}	33.61^{b}	29.97^{b}
h/H	2.31^{a}	2.25^{a}	1.26^{c}	1.83^{ab}	1.29^{c}	1.47^{c}	2.09^{ab}

*Other fatty acids with very small amounts; AI: atherogenicity index; TI: thrombogenicity index; h/H: ratio between hypocholesterolemic and hypercholesterolemic fatty acids; [1]saturation: saturated fat; [2]unsaturated fat[2]; [x]saturated fatty acids (SFAs); [y]monounsaturated fatty acids (MUFAs); [z]polyunsaturated fatty acids (PUFAs); **averages followed by different letters in the columns ([a,b,c]) are different from each other by Tukey's test ($p < 0.05$).

3, 4 and 5 already meets the nutritional demand of the market. Therefore, this is an alternative to reduce production costs, a factor that has discouraged fish farmers from raised pirarucu (Batalha et al., 2019; Cavali et al., 2023; Gotardi, 2023).

Analyzing the results obtained with the proximate composition and energy, it was observed that the average values of lipids found allow classifying the pirarucu loin as low in fat (lean) in relation to other commercial cuts of pirarucu, such as filet mignon, tail fillet, and deboned cuts (Cavali et al. 2022a; 2022b). Loin falls into the low-fat category, under 3%. For Arbelaéz-Rojas et al. (2002) and Rodrigues et al. (2020), consumer acceptance is closely related to lipid content, as they improve palatability and provide a higher pleasant flavor to the meat, being rich in PUFAs. Lipids can also negatively influence meat quality, due to *post-mortem* degradative changes, which are fast in fish with higher concentrations of lipids. This fact can lead to a reduction in the service life (Cantonilho and Jesus, 2011).

The lipid content found (< 3%) showed a considerable difference in relation to results found by Cortegano et al. (2017) for wild pirarucu. The authors found a value of 6.38% of total lipids in the dorsal muscle, a region that covers the loin. However, Dantas Filho et al. (2021), researching the chemical composition in commercial cuts of tambaqui (*C. macropomum*) and pirarucu (*A. gigas*), raised and found lipid values in pirarucu loin very close to those obtained in this study, all below 3% for all the weight classes. Regarding other nutritional values, Dantas Filho et al. (2021) and Cavali et al. (2021) obtained similar averages in relation to this study, for the different weight classes, between 1 to 1.43% of mineral matter, 18.40 to 28.93% crude protein, 1.95 to 2, 60% of total lipids, 68.50 to 78.59% of moisture and 381 to 461 $KJ{\cdot}100g^{-1}$. Dantas Filho et al. (2022) determined mineral profiles in commercial cuts of pirarucu from fish farming in Rondônia state. They found values very close to those obtained in this study.

The characteristic of lower fat deposition, as in pirarucu loin, and higher fat, as in filet mignon and tail fillet of pirarucu (Cavali et al., 2022a), has a positive nutritional appeal, because it favors the phospholipid ratio of membrane *vs*. neutral lipids, due to lower deposition of triglycerides in adipocytes (M'barek et al., 2017), favors the acid profile due to greater deposition of PUFAs essential fatty acids, mainly long-chain fatty acids. These fatty acids participate in several metabolic processes beneficial to human health, especially n-3 isomers (Benjamin and Spener, 2009).

Very long-chain PUFAs are derived from AA with priority over EPA and DHA by stretching and desaturation and are able to modulate inflammatory processes by competing with polyunsaturated fatty acids n-6 derivatives of AA, such as DTA, by the deposition of membrane phospholipids in cells of the immune system (Antonelo et al., 2020). According to Harris et al. (2009), it is recommended to consume between 250 and 500 mg of EPA + DHA per day, and, according to Helenius et al. (2020), the conversion of linolenic acid into EPA and DHA fatty acids is limited, and the efficiency in transferring AA to EPA and from EPA to n-3 DHA in adult humans is about 0.2 and 0.05%, respectively. Generally, eicosanoids produced from n-3, mainly EPA and DHA, are reported as essential fatty acids due to inhibition of stearic acid metabolism to inflammatory eicosanoids, because they increase anti-inflammatory mediators, vasodilation and also inhibit platelet aggregation when compared to produce in n-6 series of eicosanoids (Antonelo et al., 2020). That is, the enzymatic action of these polyunsaturated fatty acids in modulating the lipid profile from unsaturated to saturated during metabolism changes the diet efficiency consumed and the profile ingested, making the meat healthier (Vieira et al., 2015).

Comparing the percentage of fatty acids SFAs, MUFAs and PUFAs (Martino et al., 2002; Ng et al., 2003; Orban et al., 2008; Tanamati et al., 2009; Chaijan et al., 2010), when evaluating the fatty acid profile in a whole frozen cut of *P. corruscans*, *Clarias gariepinus*, *Pangasius hypophthalmus*, *P. mesopotamicus*, and *Pangasius bocourti*, respectively, found lower percentages of PUFAs (18.10, 20.50, 12.45, 18, and 14.80, respectively) to values obtained in pirarucu loin in different weight classes.

The omega 6/omega 3 ratio has been also used as a criterion to assess the lipids quality by the World Health Organization (WHO). The excess of AA prevents the transformation of ALA into its derivatives EPA and DHA. The same occurs otherwise, with lower consumption of AA; there will reduction in arachidonic acid activation, because the Δ-6-desaturase enzyme has the purpose of both fatty acids (Martins et al., 2017). However, the enzyme is more specific for n-3 and will require lower percentages of these acids than n-6 fatty acids to produce the same percentage of PUFAs (Gomes et al., 2016). That is, there must be a greater proportion of AA than of ALA, although a balance in value of 4 between dietary supply of the two fatty acids is required, and the ratio of omega 6/omega 3 found in this study was between 0.97 and 6.03. Then, only weight class 3 (11.1 to 14 kg) showed quality for this index.

Regarding lipid quality indices, a method prescribed by the WHO to assess lipid quality is based on the ratio of fatty acids UFAs/SFAs, values below 0.45 being considered unhealthy. Pirarucu loin weight classes expressed values between 1.22 and 1.60, therefore indicating lipid quality and a higher proportion of PUFAs in relation to SFAs. SFAs are considered hypercholesterolemic, and the most worrying for cardiovascular health, in this sense, are myristic, lauric and palmitic acids (Nunes et al., 2012). PUFAs increase blood cholesterol levels by reducing LDL-cholesterol receptor activity and reducing LDL free space in the bloodstream (Grundy and Denke, 1990). Palmitic acid is the most harmful to cardiac functions and the most found in beef and pork fats (Hautrive et al., 2012). Nonetheless, lyristic, lauric and palmitic SFAs were found in insignificant percentages among the lipid contents of pirarucu loin (Table 3).

LDL-cholesterol is known as a low-density lipoprotein. It can accumulate in the arteries and coronary arteries and lead to formation of atherosclerotic plaques that can interrupt blood flow to organs such as the heart and brain, increasing the risk of a heart attack (Jankowska et al., 2010). However, there is another fraction of PUFAs, omegas 3, 6 and 9, present, for example, in pirarucu loin, the HDL-cholesterol, whose function is to remove the LDL-cholesterol from the bloodstream and cause it to be metabolized in the liver (Leite et al., 2015). Tropical fish are excellent suppliers of n-3 and n-6, which are polyunsaturated lipids. That is why bromatological studies indicate the consumption of cooked fish to reduce LDL-cholesterol, maintaining the presence of HDL-cholesterol in the bloodstream (Martins and Oetterer, 2011; Hautrive et al., 2012; Franco et al., 2018; Siqueira et al., 2018).

It is worth mentioning n-7 found. It is a nutrient responsible for increasing sensitivity to insulin, 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 is an n-7 series fatty acid, which has been gaining prominence in scientific publications because it is considered a potent anti-inflammatory. Thus, some studies propose its consumption to reduce the risk of inflammatory and metabolic diseases (Frigolet and Gutiérrez-Anguilar, 2017). Thus, consumption of n-7 is suggested to reduce this trigger related to diabetes and other metabolic diseases (Kratz et al., 2014).

Despite this, the Western diet, rich in industrialized products, cheese, and fried foods and low in fish, fruits, vegetables, and legumes, contributes to omega 6/omega 3 ratio being approximately 20:1, when the WHO recommends about 5:1 (Kratz et al., 2014; Souza et al., 2017). Evidence points to the importance of increasing the consumption of n-3, for the most physiological possible, and for this some changes in diet must be made, such as the consumption of tropical fish (Passos et al., 2016). According to lipid quality data tabulated by some studies (Passos et al., 2016; Rodrigues et al., 2017; Souza et al., 2017; Xiyang et al., 2020), the results of AI, TI and h/H showed in Table 3 express high lipid quality. More specifically, the values found for AI were between 0.33 and 0.66, for TI between 20.4 and 47.77, and finally for h/H between 1.26 and 2.31.

TI and AI indices are related to the potential to stimulate platelet aggregation. Therefore, this study presents data on high lipid quality of *A. gigas* loin compared to the fatty acid profile of other fish. This is due to the significant concentration of antiatherogenic acids, with the potential to prevent the emergence of coronary diseases, as mentioned by Mahan and Escott-Stump (2018). In contrast, a higher h/H ratio obtained from pirarucu loin indicates greater nutritional suitability (oil or fat) for human consumption, because this index is related to cholesterol metabolism (Xiyang et al., 2020).

Faced with variations in lipid composition, what is the most appropriate destination for processing fish? According to the variation in proximate composition, they demand specific forms of processing and preparation, allowing the exploration of new market niches (Valladão et al., 2018). The fish processing of fatter cuts requires greater cleaning of the carcass with removal of excess residual fat, such as deboned, filet mignon, and loin cuts (Cavali et al., 2022b). These cuts will be better in the preparation of baked cookies portions (Lanzarin et al., 2017), although lean commercial cuts, such as pirarucu loin, generate lower waste in industry and are recommended for higher moist dishes, such as moqueca and Amazonian stews or even grilled in the lighter (lower caloric) food option.

In addition, the pirarucu, as well as other animals, tends to deposit higher collagen and fat than protein with age, altering the amino acid and lipid profile, depositing higher support tissue than nutrition. Moreover, fat tends to saturate with advancing age. Furthermore, there is a reduction in protein metabolism in contrast to an increase in energy metabolism (Moyes, 2010).

Currently, there is a market tendency to prefer younger fish, that is, the consumer market has preferred lighter fish. Dantas Filho et al. (2022), and Cavali et al. (2022a; 2022c; 2022d) found, in an attempt to verify the nutritional values of fish that are lighter than what is commonly commercialized, in order to reduce production costs by shortening/reducing the fattening period, that it is not necessary to complete the entire conventional production cycle. For example, pirarucu of 11.1 kg already meets the demand for nutritional values of the consumer market.

CONCLUSION

The lipid composition in different weight classes of pirarucu (*A. gigas*) loin expressed essential fatty acids, including EPA, DHA, AA, and ALA, related to a lower propensity for cardiovascular diseases. Weight classes 4 (14.1 to 18 kg) and 5 (18.1 to 23 kg) showed the highest percentages of PUFAs. However, all weight classes expressed high values of omegas 3, 6, 7, and 9. The omega 6/omega 3, UFAs/SFAs, PUFAs/SFAs, AI, TI, and h/H indices indicated that weight classes of the pirarucu loin have lipid quality, except for omega 6/omega 3. Only weight class 3 (11.1 to 14 kg) showed quality for this index.

There is no market need to heavier fish, as pirarucu loin in lighter weight classes 3 and 4 already meet the nutritional demand of the market. Therefore, nutritional information is important for conservation and the processes, development of products on the market, in addition to guiding the way of preparation, thus providing commercial security for different market niches.

ETHICAL APPROVAL

Ceua protocol number 012/20121 – Universidade Federal de Rondônia; Project "Biossegurança, sanidade e qualidade nutricional do pescado".

CONFLICT OF INTERESTS

Nothing to declare.

DATA AVAILABILITY STATEMENT

Data will be available upon request.

AUTHORS' CONTRIBUTIONS

Conceptualization: Rocha ASCM; Rosa BL; Pontuschka RB; Dantas Filho JV; Cavali J; **Formal Analysis:** Rocha ASCM; Baldi SCV; Souza MLR; **Software:** Rosa BL; Pontuschka RB; Dantas Filho JV; **Data curation:** Rocha ASCM; Rosa BL; Pontuschka RB; Dantas Filho JV; **Supervision:** Silva ECS; Cavali J; **Writing – original draft:** Rocha ASCM; Dantas Filho JV; Cavali J; **Writing – review & edition:** Rocha ASCM; Baldi SCV; Souza MLR; Dantas Filho JV; Cavali J; **Final approval:** Dantas Filho JV.

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