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Amazon Caviar – Profile of fatty acids, omegas and lipid quality indeces in roes of *Arapaima gigas*

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Abstract: The study evaluated the fatty acid profile, omegas, and lipid quality indices in roes of paiche (*Arapaima gigas*) to determine its viability as the "Amazonian Caviar." A total of four samples were analyzed in triplicate, obtained from 20 fish with an average weight of 4.5 kg, sourced from a fish processing agroindustry in Rondônia registered with SISBI-POA. The roe was lyophilized for the analysis of dry matter, minerals, crude protein, and total lipids. Lipid extraction used 3.5 g of sample and ethanol/chloroform solvents. Minerals with daily value percentages (DV%) above 15% were considered sources, such as iron (women), calcium, and magnesium; below 15%, they were classified as rich, including iron (men), potassium, and sodium. The roe showed 2.3% omega-6, 1.75% omega-3, 1.71% omega-9, and 8.68% omega-7, along with atherogenicity (0.85%), thrombogenicity (1.90%), and h/H (0.73%) indices.

O Caviar da Amazônia – Perfil de ácidos graxos, ômegas e índices de qualidade lipídica em ovas de *Arapaima gigas*

Resumo: O estudo avaliou o perfil de ácidos graxos, ômegas e índices de qualidade lipídica das ovas de pirarucu (*Arapaima gigas*) para determinar sua viabilidade como o "Caviar da Amazônia". Foram analisadas quatro amostras em triplicata, obtidas de 20 peixes com peso médio de 4,5 kg, provenientes de uma agroindústria em Rondônia cadastrada no SISBI-POA. As ovas foram liofilizadas para análise de matéria seca, minerais, proteína bruta e lipídios. A extração lipídica utilizou 3,5 g de amostra e solventes etanol/clorofórmio. Minerais com valores diários (VD%) acima de 15% foram considerados fontes, como ferro (mulheres), cálcio e magnésio; abaixo de 15%, foram classificados como ricos, incluindo ferro (homens), potássio e sódio. As ovas apresentaram 2,3% de ômega-6, 1,75% de ômega-3, 1,71% de ômega-9 e 8,68% de ômega-7, além de índices de aterogenicidade (0,85%), trombogenicidade (1,90%) e h/H (0,73%).

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Introduction

Caviar is a coproduct derived from unfertilized roe obtained from the slaughter of female fish. The first records of caviar date back to the 4th century (350 B.C.), as the Greeks consumed sturgeon roe at banquets. However, the term "caviar" originated in 850 A.D. from the Turkish word "khavyar," meaning "fish roe" (VASCONI *et al.*, 2024).

The primary fish producing caviar is the sturgeon (*Acipenser* spp.), one of the oldest fish species in the world, inhabiting the Caspian Sea (situated between Asia and Europe). It is the second-largest saltwater fish globally, after the whale shark (*Rhincodon typus*), reaching up to 6 meters in length (LIMA; BATISTA, 2012). The most renowned species is the Beluga (*Huso huso*, Linnaeus, 1758), which produces the most expensive and rare roe from larger fish (600–800 kg). These roe are dark gray, well-separated, large, and delicate (BIGGIO, 2016; ALVES, 2021). The larger the roe, the higher their market value (MARMENTINI *et al.*, 2024).

Factors contributing to the high-status symbolism of caviar include the late sexual maturity of female sturgeons, which spawn for the first time between 16 and 22 years old, with intervals of 5 to 7 years between spawns (VECSEI; SUCUI; PETERSON, 2002), and the difficulty of fishing in the depths of the Pontus-Caspian basin. However, more economically accessible caviar alternatives exist, such as salmon (*Salmo salar*) roe (MARMENTINI *et al.*, 2024).

The pirarucu (*Arapaima gigas*, Schinz, 1822) is a freshwater fish native to the Amazon basin and one of the largest scaled freshwater fish in the world, measuring up to 2.5 meters (ESCUDERO; LA VEGA, 2024) in the wild and weighing up to 200 kg (OLIVEIRA *et al.*, 2014). This species has socio-economic importance for aquaculture in Rondônia state, a northern state of Brazil, which in 2024 became the country's largest producer of native fish and ranked third in overall aquaculture production (ROCHA *et al.*, 2023; MARMENTINI *et al.*, 2024). In the same year, the state produced 57,200 tons, according to the 2024 annual report from the Brazilian Aquaculture Association (PEIXE BR, 2024).

Pirarucu (*A. gigas*) are seasonal breeders, with females reaching sexual maturity at 5 years of age (ESCUDERO; LA VEGA, 2024). Their ovaries can carry an average of 180,500 oocytes, although only 25% (45,125) are available per spawning (Serrat *et al.*, 2019). Popularly known as the "Amazonian Cod," the pirarucu is the first tropical fish not belonging to the Gadiformes order or from deep, cold waters, like the Atlantic Cod, Pacific Cod, Saithe, Ling, and Zarbo, to earn this title (COUTINHO *et al.*, 2010).

Fish are a source of all essential amino acids required for human health, such as leucine, lysine, isoleucine, glutamic acid, and aspartic acid, key components of myosin. Health professionals recommend fish consumption for its richness in omega-3 and omega-6 fatty acids (*n*-3 and *n*-6), which can reduce cardiovascular morbidity and mortality (OLIVEIRA *et al.*, 2014; CAVALI *et al.*, 2023). Nutritionally, roe values are comparable to those of fish meat, as roe contain all the amino acids necessary to form a new organism (MARMENTINI *et al.*, 2024).

Given the assumptions, this study aimed to identify the fatty acid profile, omegas, and lipid quality indices of pirarucu (*Arapaima gigas*) roe from aquaculture operations in the interior of Rondônia, to evaluate their viability for commercialization as "Amazonian Caviar."

Methodology

The research was conducted by the Centro Universitário São Lucas Ji-Paraná Afya. The roes samples of pirarucus (*A. gigas*) were sent to the Water and Food Analysis Laboratory at the Universidade Estadual de Maringá (UEM).

This research was approved by the Animal Ethics Committee of the Universidade Federal de Rondônia (UNIR), Rolim de Moura Campus, Rondônia state, Brazil. The authorization was granted under protocol No. 0012/2021, linked to the research project titled "Biosafety, sanitary and nutritional quality of fish".

A total of four samples of roes (triplicate) taken from 20 specimens of pirarucu (*Arapaima gigas*) were used, totaling 60 samples. The fish weighed approximately 4.20 to 4.80 kg and came from a fish processing agroindustry registered in the Brazilian Inspection System for Products of Animal

Origin (SISBI-POA), located in the municipality of Vale do Paraíso in the state of Rondônia.

Initially, the samples were freeze-dried to determine the dry matter, mineral matter, crude protein and lipid contents. To evaluate the lipids, 3.5 g of the freeze-dried sample were used and the lipids were extracted with ethanol and chloroform (BLIGH; DIER, 1959). To quantify the macrominerals, an extract was produced from the complete digestion of the sample in sulfuric acid at high temperature (350-375° C) (Santos-Silva *et al.*, 2002). The microminerals were analyzed from extracts of acid digestion samples at controlled temperatures, with nitric acid (120° C) and perchloric acid (180-190° C) (SANTOS-SILVA *et al.*, 2002).

A model AA 12/1475 atomic absorption spectrometer was used to perform the evaluations. The minerals Na^+, K^+, total iron (Fe^{2+} + Fe^{3+}), Ca^{2+} and Mg^{2+} were determined by AOAC Official Method 969.23 and 968.08.24. The gross energy content of the roe was obtained by adding the amounts of calories from proteins and lipids from a theoretical calculation, considering that each 1g of protein provides X kcal and each 1g of lipid provides Y kcal. The final nutritional value expressed in kcal $100g^{-1}$ of the sample was then converted to kJ $100g^{-1}$.

The measurements were taken using an atomic absorption spectrometer model AA 12/1475. The minerals Na^+ and K^+ were determined by the Official AOAC method 969.23 and the minerals Total Iron, Ca^{2+} and Mg^{2+} were determined by the Official AOAC method 968.08. Once the mineral composition results were obtained, the data were compared with the minimum recommended daily mineral intake values (for men and women – in relation to total iron), and the comparative analysis was performed by calculating the percentage of daily supply (Vdsm) in relation to the recommendations for average daily mineral intake (mg/day). The calculation was performed using the Equation (1).

Eq. (1) Vsdm = Vmf/Vmr x 100.

Where "Vdsm" indicates the daily mineral intake value; "Vmf", the mineral value found in 100g; "Vmr", the minimum mineral intake value recommended by the WHO.

The total lipids were extracted by the Bligh and Dyer method, and the fatty acid methyl esters were prepared by methylation of triacylglycerols, as described in the International Organization for Standardization method (ISO 5509). The fatty acid methyl esters were analyzed in a 14-A gas chromatograph (Shimadzu, Japan), equipped with a flame ionization detector and a fused silica capillary column (50 cm long, 0.25 internal diameter and 0.20 µm Carbowax 20M).

The ultrapure gas flows (White Martins) were 1.2 mL min^{-1} for carrier gas (H_2), 30 mL min^{-1} for auxiliary gas (make-up) N_2); 30 and 300 mL min^{-1} for flame gases, H_2 and synthetic air, respectively.

The profiles of saturated fatty acids (SFAs), unsaturated fatty acids (UFAs) and polyunsaturated fatty acids (PUFAs) were evaluated according to higher and lower concentration, and the omegas and lipid quality indices. To determine the values of omegas and fatty acids, the following fatty acids and omegas were identified: omega 3 (*n*-3) and omega 9 (*n*-9), classified as UFAs, omega 6 (*n*-6), omega 3 (*n*-3), omega 9 (*n*-9); omega 7 (*n*-7) and saturated MUFAs, whose values were determined from the mean and calculated the ratio between UFAs/SFAs and *n*-6/*n*-3. To determine lipid quality, the atherogenicity (AI) (Equation 2) and thromogenicity (TI) (Equation 3) indices were calculated, according to equations 1 and 2, and the ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H) (Equation 4), according to Santo and Silva *et al.* (2002).

(Eq.2) AI = [12:0 + 4 x 14:00 + 16:0]/∑MUFAs + ∑*n*-6 +∑*n*-3.

(Eq. 3) TI = (14:0 + 16:0 + 18:0)/[(0,5 x ∑MUFAs)+(0,5 x ∑ *n*-6) +(3 x *n*-3)+(∑ *n*-3/ *n*-6)].

(Eq. 4) h/H = (18:1 *n*-9 + 18:2 *n*-6 + 20:4 *n*-6 + 18:3 *n*-3 + 20:5 *n*-3 + 22:5 *n*-3 + 22:6 *n*-6)/(14:0 + 16:0).

Results and discussion

Pirarucu roe is composed, per 100g, of 6.13mg of total iron; 373.14mg of potassium; 327.35mg of sodium; 26.22mg of calcium; 20.07mg of magnesium. According to the MSD Manual, the daily requirement of these nutrients for humans is equivalent to 8mg and 18mg of total iron for men and women, respectively; 3.4g and 2.6g of potassium for men and women; 1.5g of sodium and 1g of calcium for both, and 420mg and 320mg of magnesium, recommended for men and women, respectively (Table 1). The recommended amount of these minerals is 76.63% and 34.05mg of total iron, 10.97mg and 14.35mg of potassium, 21.82mg of sodium, 2.62mg of calcium, 4.77mg and 6.27mg of magnesium (Table 2).

Table 1 - Recommended Daily Mineral Requirements for Adult Humans.

Minerals	Values
Total Iron	8 – 18mg*
Potassium (K^+)	3.4 – 2.6g*
Sodium (Na^+)	1.5g
Calcium (Ca^{2+})	1.0g
Magnesium (Mg^{2+})	420 – 320mg*

*Recommended values for men and women.
Source: MSD Manual, 2024.

Table 2 - Daily supply (%) in roes of pirarucu (*Arapaima gigas*), according to the recommendations for average daily consumption (mg/day) of the minerals iron, potassium, sodium, calcium and magnesium for adults (men and women).

Minerals	Recommended intake (mg/day)	VD%
Total Iron	76.63 – 34.05mg*	8 - 18%
Potassium (K^+)	10.97 – 14.35mg*	34 - 26%
Sodium (Na^+)	21.82mg	15%
Calcium (Ca^{2+})	2.62mg	10%
Magnesium (Mg^{2+})	4.77 – 6.27mg.	4 - 3%

*(Values indicated for men – women). VD%: daily value in percentage.
Source: Personal archive.

The fatty acid profile found in pirarucu roe presented 38.23% saturated fatty acids (SFAs), 27.47% unsaturated fatty acids (UFAs), while polyunsaturated fatty acids (PUFAs) 53.51%. Of the saturated fatty acids, the highest percentage was palmitic acid (C16:0) which corresponded to 23.75%, and the lowest was lauric acid (C12:0), with 2.46%. As for the unsaturated fatty acids, the decreasing percentage was: oleic acid (C18:1 *n*-7) with 22.04%; linolenic acid (C18:2 *n*-6), 11.27%; thymnodonic acid (C20:5 *n*-3), 4.07%; and arachidonic acid (C20:4 *n*-6), 0.87% (Table 3).

Table 3 - Fatty acid profile (%) in roes of pirarucu (*Arapaima gigas*).

Usual Nomenclature/Symbolism	Values (%)
Saturated	
Lauric Acid / C12:0	2.46
N-Tridecyl Acid / C13:0	0.52
Myristic Acid / C14:0	0.31
Pentadecyl Acid / C15:0	0.33
Palmitic Acid / C16:0	22.75
Margaric Acid / C17:0	1.66
Stearic Acid / C18:0	14.35
Arachidic Acid / C20:0	0.32
N-Henecosoic Acid / C21:0	0.40
Behenic Acid / C22:0	0.48
Ignoceric Acid / 24:0	1.23
Insaturated	
Heptadenoic Acid / C17:1	0.53
Palmitoleic Acid / C16:1 N-7	0.68
Eicosadienoic Acid / C16:1n-9	4.69
Vaccenic Acid / C18:1 n-7	3.32
α-Linolenic Acid (ALA) / 18:3 n-3	1.13
Linoleic Acid / C18:2 n-6	11.27
Oleic Acid / C18:1 n-7	22.04
Di-Homo Y-Linolenic Acid / C20:3 N-6	0.64
Gondoic Acid / C20:1 n-9	0.11
Eicosapentaenoic (Thymnodonic) Acid (Epa) / C20:2 N-6	0.65
Docosadienic Acid / 22:2n-6	0.18
Y-Linolenic Acid (GLA) / C18:3 N-6	0.19
Di-Homo -(α-Linolenic) Acid / C20:3 n-3	0.27
Erucic Acid / C22:1n-9	0.69
Arachidonic Acid / C20:4 N-6 (AA)	0.87
Nervonic Acid/24:1n-9	1.36
Cervonic Acid / 22:6n-3 (DHA)	1.54
Timnodonic Acid (Eicosapentaenoic) / C20:5 N-3	4.07
Somatória (∑)	
SFAs	46.34
UFAs	53.70
MUFAs	26.04
PUFAs	27.66

Percentages of saturated (SFAs), unsaturated (UFAs), monounsaturated (MUFAs) and polyunsaturated (PUFAs) fatty acids.

In roes of pirarucu, 1.75% of *n*-3, 2.3% of *n*-6, 8.68% of *n*-7 and 1.71% of *n*-9 were found. Regarding the lipid quality indexes, 1.51% difference in concentration between unsaturated and saturated fatty acids (UFAs/SFAs) and 1.31% in the ratio between *n*-6/ *n*-3 were found (Table 4).

Table 4 - Omegas and lipid quality indices in roes of pirarucu (*Arapaima gigas*).

	Variables	Content (%)
	n-3	1.75
	n-6	2.3
	n-7	8.68
Omegas	*n*-9	1.71
	UFAs/SFAs	1.58
	n-6/n-3	1.31
Indices	AI	0.85
	TI	1.90
	h/H	0.73

Results expressed as percentage (%) of total fatty acids. Saturation: saturated fatty acids (SFAs), unsaturated fatty acids (UFAs); Percentage of total fatty acids; Atherogenicity Index (AI); Thrombogenicity Index (TI); Ratio between hypocholesterolemic and hypercholesterolemic fatty acids (h/H).

According to the results, roes of pirarucu is a good source of sodium and potassium—electrolytes involved in the Na/K pump, which is responsible for electrolyte balance, cellular homeostasis, and muscle contractions. Additionally, it is rich in iron, essential for blood cell formation and oxygen transport, which is particularly important for women. Calcium, vital for bone and teeth formation and strength, and magnesium, which assists sodium and potassium in muscle contractility, are also present.

Pirarucu roe contains 53.7% unsaturated fatty acids (UFAs), including 26.04% monounsaturated fatty acids (omega-7: 8.68%) and 27.66% polyunsaturated fatty acids (PUFAs), comprising omega-6 (2.3%), omega-3 (1.75%), and omega-9 (1.71%). These fatty acids possess anti-thrombogenic and anti-atherogenic potential, particularly omega-3 (SANTOS *et al.*, 2018; COUTINHO *et al.*, 2019; MARMENTINI *et al.*, 2024). It is worth noting that pirarucus are carnivorous fish, obtaining omega-6 and omega-3 fatty acids by consuming other fish (herbivores/omnivores) that feed on primary sources of these omegas, such as phytoplankton. As a result, species like tambaqui (*Colossoma macropomum*) tend to exhibit higher levels of omega-6 and omega-3 compared to pirarucu.

In a study conducted by Oliveira *et al.* (2023) and Marmentini *et al.* (2024), tambaqui, another common Amazonian species widely farmed in the state of Rondônia, exhibited higher values: omega-3 (1.97%), omega-6 (10.71%), omega-9 (36.11%), and omega-7 (4.1%) compared to pirarucu. These differences can be attributed to the omnivorous dietary habits of tambaqui.

Regarding lipid indices, such as the atherogenic index (AI) and thrombogenic index (TI), which evaluate the thrombogenic and atherogenic potential of a food, as well as the hypocholesterolemic/ hypercholesterolemic index (h/H), which measures the balance between fatty acids that lower and raise cholesterol levels, the pirarucu roe showed an AI of 0.85%, a TI of 1.90%, and an h/H index of 0.74%. Ideally, AI and TI values should be as close to zero as possible, indicating a higher proportion of anti-thrombogenic and anti-atherogenic fatty acids, such as omega-6 and omega-3, thereby reducing the risk of cardiovascular disease (TURAN *et al.*, 2007; ANTUNES *et al.*, 2018). For the h/H index, desired values are close to 2, representing a ratio of two hypocholesterolemic to one hypercholesterolemic fatty acid.

Rahman *et al.* (1995), Çelik *et al.* (2005), and Martins, Martins and Pena (2017) emphasize that omega-3 concentrations are generally higher in marine fish compared to freshwater species. This discrepancy is attributed to factors such as the adipose tissue layer provided by PUFAs for adaptation to water temperature, the greater diversity of phytoplankton in oceans compared to rivers, and the hypertonicity of marine water. However, in the study by Oliveira *et al.* (2014), freshwater species like pirarucu (*Arapaima gigas*) with 0.18 g/100g, filhote (*Brachyplatystoma filamentosum*) with 1.84 g/100g, and trout (*Salmo trutta fario*) with 1.60 g/100g showed higher PUFA levels compared to coastal fish from Brazil, such as pescadinha (*Merluccius merluccius*) with 1.26 g/100g, and deep-sea fish like cherne (*Hyporthodus niveatus*) with 0.44 g/100g. Among these species, Chilean salmon (*Salmo salar*) stood out with an impressive 3.11 g/100g of this fatty acid.

Although there are more accessible caviar sources, such as salmon, pirarucu roe could introduce a new delicacy to the market—a novel income source for fish farmers under the branding of "Amazonian Caviar," as no tropical-origin caviar currently exists. Pirarucu roe is a nutrient-rich source of essential minerals such as sodium, potassium, calcium, magnesium, and iron, supporting cellular homeostasis, muscle function, and oxygen transport. It also contains 53.7% unsaturated fatty acids (UFAs), including omega-6, omega-3, and omega-9, with notable anti-thrombogenic and anti-atherogenic properties. While omega-3 levels in pirarucu roe are lower than in other Amazonian species like tambaqui, the roe's lipid profile remains valuable for cardiovascular health.

Lipid indices, including the atherogenic index (AI), thrombogenic index (TI), and hypocholesterolemic/hypercholesterolemic index (h/H), suggest that pirarucu roe offers favorable health benefits. Compared to marine fish, pirarucu roe's omega-3 levels reflect its carnivorous diet and reliance on secondary sources of PUFAs. Freshwater fish like tambaqui exhibit higher PUFA content due to omnivorous feeding habits.

Pirarucu roe's unique nutritional profile positions it as a promising tropical caviar alternative, potentially creating new market opportunities for Amazonian aquaculture. The commercialization of pirarucu roe as caviar represents a strategic opportunity for the development of aquaculture in northern Brazil. Traditional sturgeon caviar, widely recognized for its high market value and gourmet status, faces challenges related to the sustainability of sturgeon fishing, its lengthy reproductive cycle, and high production costs. In contrast, the pirarucu (*Arapaima gigas*) is a native Amazonian species with a shorter reproductive cycle and potential for sustainable production, making its roe a viable and accessible alternative for the consumer market.

Pirarucu roe has a nutritional profile that enhances its competitiveness in the alternative caviar market. It is rich in sodium and potassium, essential for cellular homeostasis and muscle contraction, as well as iron, calcium, and magnesium, which play a key role in blood formation, oxygen transport, and bone health. Its lipid content also highlights pirarucu roe as a functional food, containing 53.7% unsaturated fatty acids (UFAs), including omega-3, omega-6, and omega-9, known for their antithrombotic and anti-atherogenic properties.

The introduction of pirarucu roe into the caviar market requires strategic positioning and product valorization. Branding it as "Amazonian Caviar" can add value by associating it with the region's biodiversity and sustainability. Furthermore, initiatives that certify the sustainable origin of production can increase its acceptance in both national and international markets, especially among consumers seeking ecological alternatives to sturgeon caviar.

From an economic viability perspective, pirarucu is already widely farmed in northern Brazil, facilitating the integration of roe production as a high-value-added byproduct. Utilizing the roe can increase profitability for local producers and diversify income sources in Amazonian aquaculture, reducing reliance solely on fish meat.

Therefore, the commercialization of pirarucu roe as an alternative to traditional caviar holds significant potential for the regional economy. With proper investment in research, certification, and marketing strategies, "Amazonian Caviar" can establish itself as a gourmet product, adding value to the pirarucu production chain and promoting the sustainability of fish farming in the Amazon.

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Conclusion

The roes of pirarucu (*Arapaima gigas*) are composed of significant amounts of MUFAs and PUFAs; essential fatty acids (EPA, DHA, AA, ALA and GLA), which meet the daily mineral demands of adults. It has surprising amounts of omega 3, 6 and 7, high lipid quality, good AI, TI and h/H indices. It can be concluded that pirarucu roe has high nutritional value and can be considered nutritionally viable for human consumption.

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