Aquatic Food Studies 4(1), AFS229
https://doi.org/10.4194/AFS229

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RESEARCH PAPER

Nutrient Content of the Invasive *Arapaima gigas* (Osteoglossiformes) in Bolivia

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How to Cite

Carvajal-Vallejos, F.M., Carolsfeld, J., Van Damme, P.A., Montellano, S.V. (2024). Nutrient Content of the Invasive *Arapaima gigas* (Osteoglossiformes) in Bolivia. *Aquatic Food Studies*, 4*(1), AFS229*. https://doi.org/10.4194/AFS229

Article History
Received 21 March 2024
Accepted 18 June 2024
First Online 05 July 2024

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Keywords
Paiche
Arapaimatidae
Alien species
Fish consumption
Bolivian Amazon

Abstract

The Paiche or Paichi (tentatively identified as *Arapaima gigas*) is an introduced species and one of the most important fisheries resources in Bolivia. Its meat has characteristics that have facilitated its commercialization in the main cities of the country. The objective of this work was to describe the nutritional quality of its meat sold in the city of Riberalta (Beni), the main supplier of Paiche meat to inland markets. Tissue samples were collected from the dorsal, abdominal and caudal areas (n=3; 800 g) from three medium-sized specimens (81.6 cm average total length, aproximately 8 kg). Results showed that Paiche meat is rich in proteins (20%), but low in total fats and carbohydrates (0.81 and 0.67%, respectively). The fat-soluble and water-soluble vitamins were low, with values less than 0.027 mg 100 g^{-1}; except vitamin E (average 1.198 mg 100 g^{-1}). Seven fatty acids were found in the abdominal portion, five in the dorsal portion, and none in the caudal portion. Linoleic Acid (Omega 6) was found only in the abdomen. Its regular consumption in the diet is recommended. Studies are needed to see how nutritional value is affected by food preparation for consumption and to assess mercury content.

Introduction

Fish is considered one of the healthiest meats for human consumption, because it is a good source of protein, essential fatty acids such as Omega 3 and 6, vitamins and minerals (Traverso & Avdalov, 2014; Khalili & Sampels, 2018; Molina-Vega et al., 2020). Consumption two times a week of 100 grams by serving, covers more than 50% of the daily protein intake recommended, and could be proactive against coronary hearth diseases and ischemic stroke (Fennema, 1985; FAO & WHO, 2011; Khalili & Sampels, 2018; Molina-Vega et al., 2020). These proteins are of high nutritional value with digestibility greater than 80% (Lowell, 1978; Fjeldheim et al., 2019).

Native and introduced fish species contribute significantly to the wellbeing and livelihoods of local and regional populations in Bolivia (Macnaughton et al., 2017; Montellano et al., 2017; Doria et al., 2018). However, per-capita fish consumption (1.6 kg person^{-1} year^{-1} – FAO, 2005; 2.7 Kg person^{-1} year^{-1} – FAO, 2023; 2.5-5 Kg person^{-1} year^{-1} – Van Damme et al., 2023) remains low in the country, compared with the World Health Organization (WHO) recommendation of 8.5-13 kg person^{-1} year^{-1}, and is one of the lowest in South America (Wiefels, 2006). Nevertheless, is considerable regional variation, with fish being the main source of protein for some indigenous people and peasants living near water bodies (Carolsfeld et al., 2014). The Paiche (Peru) or Paichi (Bolivia), tentatively identified as *Arapaima gigas* (Schinz 1822), is a native species from the lower Amazon and Madeira rivers (Hrbek et al., 2006; Pereira et al. 2022), where it is known as *Pirarucu* or *Arapaima*. The fish was introduced to the Bolivian

Amazon (Upper Madeira River), which is separated of the Lower Madeira River by 300 km of rapids, through an accidental release from incipient aquaculture in the Peruvian portion of Madre de Dios River, more than fifty years ago (Carvajal-Vallejos et al., 2011, 2017).

Paiche meat is characterized by being rich in protein and low in fat, but with significant amounts of fatty acids (Wang Yin et al., 2010; Carolsfeld et al., 2014; Filho et al., 2022). In addition to its nutritional properties, this species does not have intramuscular bones that hinder its consumption, the meat texture is firm, the taste is almost neutral, and the color is generally white (Alcántara et al., 2006). Due to these characteristics, the species has been a fisheries mainstay in Brazil for over a century, was fished to the point of gaining CITES listing and is currently under a very restrictive management policy in that country. While new to Bolivia, it has been well accepted by consumers in the main markets (Navia et al. 2017), sold as either "Paiche" or "Surubí – an Amazonian catfish", and has become one of the most economically important species in the region (Carvajal-Vallejos et al., 2011; Coca et al., 2012; Navia et al., 2017). As such, it is an interesting example of potential control of an invasive species through human consumption (Varble & Secchi, 2013; Huth et al., 2018; Kourantidou et al., 2022), although with potential severe management problems (Nuñez et al., 2012), that can contribute to food security of the country. However, the nutritional content of the species is not well known, and Amazonian wild-caught fish are carrying variable amounts of native mercury, posing a potential risk to consumption (Barbieri et al., 2009; Benefice et al., 2010; Rodriguez-Levy et al., 2022). Knowledge of the nutritional quality of the fish from Bolivian waters and any mercury risk will be beneficial for its responsible marketing, management of its expansion, and development of the fishery. Thus, the aim of the present study was to determine the nutritional content of the invasive Paiche in the Bolivian Amazon, and conclude if this is a good-quality food for people living in rural and urban areas inland of the country.

Material and Methods

Fish were collected at landing sites in the city of Riberalta, considered the main fishing port in the North of Bolivia (Coca et al., 2012), after five hours of being captured and transport on ice on May/2016, receding water season. Samples were extracted from three juvenile Paiche specimens (P1, P2 and P3), with an average total length of 81.6 cm (approximately 8 kg).

Samples of approximately 800 g each were extracted from the dorsal (loin), abdominal (belly) and caudal (tail) portions of the body; portion delimitation and cuts followed Fogaça et al. (2011). A total of nine samples were obtained and frozen in plastic sample jars. Each sample was frozen (-10 ºC) and transported on ice by plane to the Centro de Investigaciones Químicas C.I.Q S.R.L (www.ciq-srl.com) in the city of Quillacollo, Cochabamba Department, Bolivia.

Protein content was analyzed by micro-Kjeldahl method for protein determination (Kjeldahl, 1883); total fat content with a Soxhlet extraction (Gopalasatheeskumar, 2018; Hewivitharana et al., 2020), vitamins were evaluated with linked liquid chromatography-mass spectrometry (LC-MS), and 37 fatty acid species were evaluated with gas chromatography-mass spectrometry (GC-MS). Carbohydrates were determined by indirect calculation through GC-MS. Results from each body portion were averaged for comparisons.

Results

On average the Paiche meat had a significant amount of protein (19.4%), and low concentrations of total fats and carbohydrates (0.81 and 0.67%, respectively) (Table 1). It contained two water-soluble vitamins, Riboflavin and Nicotinic Acid, and six fat-soluble vitamins, K2, D2, A, E (Acetate) and D3, all in low concentrations (<0.03 mg $100g^{-1}$), except vitamin E, which was present in higher concentration (>1 mg $100g^{-1}$).

Saturated fatty acids (Myristic, Palmitic, Stearic) and unsaturated fatty acids (Oleic, Linoleic, Eicosapentaenoic Acid (EPA), Docosahexaenoic Acid (DHA) were observed. Fatty acids with the highest average concentration were Palmitic (18.87% in abdominal portion), Oleic (17.7% in dorsal portion), and Stearic (8.47% in dorsal portion) (Table 1). The other fatty acids showed average relative concentrations of less than 1.8% (Table 1).

The abdomen portion had the highest average protein content (20.4%), in relation to the dorsal and caudal portions. In turn, the dorsal portion showed the highest average carbohydrate content (1.0%) in relation to the other two portions of the body. However, the carbohydrate content was generally low. Fatty acids were higher in the dorsal and abdominal portions and were not detectable in the caudal portion (Table 1)

Riboflavin was detected in low concentrations only in the dorsal and caudal portions. Nicotinic Acid was present in all samples at low concentration (0.1 mg 100 g^{-1}). The average concentrations of fat-soluble and water-soluble vitamins were low, with values less than 0.027 mg 100 g^{-1}. The exception was vitamin E, which had an average concentration of 1.198 mg 100 g^{-1} (Table 1).

Seven fatty acids were found in the abdominal portion, five in the dorsal portion, and none in the caudal portion (Table 1). Palmitic Acid was the highest in the abdominal portion. However, Oleic, Stearic, EPA and DHA acids were more abundant in the dorsal portion. Linoleic Acid (Omega 6) was found only in the abdomen. Several parameters were undetected probably due to their absence in the samples, or quantities were below the detection level.

Table 1. Content of nutrients, micronutrients, and fats in Paiche meat collected in the Riberalta market (Beni Department, Bolivia). The values come from three different body portions of three specimens with an average total length of 81.6 cm

Parameter	Paiche 1			Paiche 2			Paiche 3			Mean ± SD			TM ± SD
	D	A	C	D	A	C	D	A	C	D	A	C	
Protein [%]	16.7	18.7	18.9	18.5	21.3	19.6	22.1	21.1	18.2	19.1±2.75	20.4±1.45	18.9±0.7	19.4±1.75
Total fat [%]	0.40	0.50	1.1	0.20	1.4	0.90	0.50	0.3	2.00	0.37±0.15	0.73±0.59	1.33±0.59	0.81±0.60
Carbohydrates [%]	2.60	1.50	0.8	0.40	0.00	0.00	0.00	0.1	0.60	1.00±1.4	0.53±0.84	0.47±0.42	0.67±0.88
Water-soluble vitamins [mg 100 g^{-1}]													
Thiamine – Vit B1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Riboflavin – Vit B2	ND	ND	ND	<0.1	ND	ND	ND	ND	<0.1	-	ND	-	-
Piridoxina – Vit B6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ascorbic Acid – Vit C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nicotinic Acid – Vit B3	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nicotinamide – amid Vit B3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Folic Acid – Vit B9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pantotenic Acid – Vit B5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Biotin – Vit B7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cobalamin - Vit B12	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fat-soluble vitamins [mg 100 g^{-1}]													
Menaquinone - Vit K2	<0.001	0.001	<0.001	<0.001	0.002	<0.001	<0.001	0.003	<0.001	<0.001±-	0.002±0.001	<0.001±-	-
Menadione - Vit K3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Beta-carotene - ß-Carotene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Succinate - Vit E	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ergocalciferol - Vit D2	0.04	0.08	0.07	ND	0.02	0.02	ND	ND	ND	-	-	-	-
Phylloquinone - Vit K1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Palmitate - Vit A	ND	0.001	0.003	ND	0.002	0.001	0.001	0.003	<0.001	-	-	0.002±0.001	-
Acetate – Vit E	0.009	0.008	0.008	0.006	0.010	0.005	0.007	0.004	0.006	0.007±0.002	0.007±0.003	0.006±0.002	0.007±0.002
Cholecalciferol - Vit D3	0.010	<0.01	0.04	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	-	-	-	-
Tocopherol - Vit E	1.99	0.53	1.56	0.46	0.71	0.50	0.71	3.61	0.72	1.05±0.82	1.62±1.73	0.93±0.56	1.20±1.05
Fatty acids (relative %)													
Myristic – 14:0	ND	2.00	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-
Palmitic – 16:0	19.70	19.60	ND	10.20	18.60	ND	13.30	18.4	ND	14.40±4.85	18.87±0.64	ND	-
Oleic – 18:1(n-9)	16.20	14.80	ND	18.30	15.30	ND	18.80	19.7	ND	17.77±1.38	16.60±2.70	ND	-
Linoleic (ω6) – 18:2(n-6)	ND	3.500	ND	ND	ND	ND	ND	ND	ND	ND	-	ND	-
Stearic – 18:0	8.40	8.60	ND	9.60	6.60	ND	7.40	4.7	ND	8.47±1.102	6.63±1.95	ND	-
EPA (ω3) – 20:5(n-3)	2.10	ND	ND	1.80	1.30	ND	1.20	1.4	ND	1.70±0.46	-	ND	-
DHA (ω3) – 22:6(n-3)	1.10	ND	ND	2.30	0.90	ND	1.90	0.6	ND	1.77±0.61	-	ND	-

* ND: Parameter non detected. -: Not possible to calculate. D: Dorsal portion, A: Abdominal portion, C: Caudal portion. TM: Total mean, SD: Standard deviation.

Discussion

Fish meat is considered one of the main sources of protein in the Amazon Basin, contributing to a balanced diet of the inhabitants (Flores-Nava & Brown, 2010). Fish provide amongst the best relative protein content of meat consumed by humans (Boer et al., 2020), as well as being of beneficial amino acid balance. For example, the high lysine potentiates the utilization of rice protein that is lysine deficient (Ufaz & Galili, 2008). Paiche can contribute to this enriched diet, as it becomes more available in the market.

Results by Carolsfeld et al. (2014) found similar values of protein content (20% of total weight) in wild Paiche from Bolivia as in the current work, but Wang et al. (2010) showed lower values (16.5%) in aquarium grown specimens (Table 2). This difference could be a result of the diet provided to Paiche in aquarium conditions, but other factors as length, size, age, or fishing season could be affecting the difference. The relative content of protein, lipid and carbohydrates in aquaculture diets influences the resulting protein and lipid composition of the fish (Medeiros et al., 2019). Compared to other fish species, Paiche meat contains an intermediate level of protein, with Catfish, Salmon and Tilapia containing slightly higher protein levels than Paiche, and others lower (Perea et al., 2008) (Table 3). Other studies carried out in Brazil showed protein content around 20% in cultured Paiche fillets (Fogaça et al., 2011; Martins et al., 2017).

Considering fats, Salmon is the species with the highest lipid content, followed by Trout and Tambaquí in the analysis of Perea et al. (2008). The Paiche has the lowest average content (0.8) of these (Table 3), representing a low-fat protein alternative for the human diet. Fatty acids are a variable component of the lipid content of meat, differing in total and specific content in fish according to species, state of sexual maturation, diet, seasonality, and other factors (Souza et al., 2020), including the capacity to elongate dietary fatty acids (Bourre, 2005). Cold-water marine fish are well known for the relatively high content of Essential Fatty Acids (polyunsaturated Omega 3 and 6 fatty acids), generally derived from the diet (Taşbozan & Gökçe, 2017). Freshwater tropical fish generally are low in Omega 3 fatty acids (Taşbozan & Gökçe, 2017; Rodrigues et al., 2017).

Table 2. Comparison of the nutritional content of the Paiche meat (relative %) from natural environments in Bolivia (present study), and from aquarium (Wang et al., 2010).

Parameters	Bolivia	Aquarium
Protein	16.7-22.1	16.5
Total fat	0.2-2.0	6.8
Fatty acids		
Myristic	2.0	3.2
Palmitic	19.7-10.2	20.1
Stearic	9.6-4.7	6.6
Oleic	19.7-14.8	28.4
Linoleic	3.5	11.3
EPA	2.1-1.2	1.2
DHA	2.3-0.9	7.4
Total Omega 3	4.4-2.1	8.6
Total Omega 6	3.5	11.3

Table 3. Comparison of protein content and fatty acids in six species of fish (relative %). The results corresponding to Paiche belong to the present study (see Table 1), and the rest of the values to those published by Perea et al. (2008).

Common name	Species	Protein	Fat	EPA	DHA	Linoleic acid
Paiche	*Arapaima gigas*	16.7-22.1	0.2-2.0	1.2-2.1	0.9-2.3	3.5
Salmón	*Oncorhynchus kisutch*	19.4-20.9	7.4-17.0	0.4-1	0.72-1.25	0.7-2.2
Trucha	*Salmo gairdneri*	17.8-20.4	4.1-8.1	0.01-0.02	0.24-0.48	0.6-1.3
Tilapia	*Oreochromis* sp.	18.4-20.8	2.2-4.5	0.0-0.001	0.05-0.12	0.4-0.7
Bagre	*Pseudoplatystoma fasciatum*	20.3-22.1	0.4-1.9	0.0-0.001	0.001-0.004	0.0-0.01
Bocachico	*Prochilodus magdalenae*	16.4-20.4	1.3-5.2	0.0-0.001	0.002-0.006	0.0-0.01
Cachama	*Piaractus brachypomus*	16.7-19.3	1.6-6.3	0.0-0.001	0.001-0.05	0.2-0.8

* EPA, DHA: Omega 3; Linoleic acid: Omega 6

The Paiche analyzed by Wang et al. (2010) showed remarkably higher relative concentrations of total fatty acids than in the present study (Table 2). These fish were fed with a mix of food sources in the aquarium that likely influences the relative amounts of total fatty acids and polyunsaturated fatty acids, including the Omega 3 and 6 fatty acids such as DHA and EPA.

Compared with other fish species, the content of Omega 3 fatty acids is surprisingly high, comparable with that of the cold-water marine salmon (Table 3). The levels in Catfish, Tilapia and Bocachico are more typical of tropical freshwater fish. This is likely due to a dietary deficit of these fatty acids in the tropical ecosystem (Taşbozan & Gökçe, 2017; Parzanini et al., 2020), but points to a previously unreported unusual ability and need in Paiche to elongate the dietary precursors to the Omega 3 fatty acid, or an unknown dietary component in the wild that is high in these fatty acids. The fish is an ancient osteoglossomorph (bony-tongued) species, with relatively unknown physiology.

Omega 6 fatty acids are low in general, with the highest content observed in Salmon, Trout and Paiche (Table 3). Nevertheless, it is the dominant fatty acid in the tropical fish other than Paiche, representing a low ratio of Omega 3: Omega 6. This ratio is important in terms of balancing the inflammatory and beneficial effects of these fatty acids, with a 1:1 ratio the best (Simopoulos, 2010; Gomez et al., 2011).

These results indicate that Paiche is an attractive source of healthy food for both low fat protein and the content of essential fatty acids, comparable with the colder water fish for Omega 3 fatty acids.

Different portions of the fish also have different nutritional values. Fish can store energy with a high caloric content as lipid in considerable quantities (Petenuci, 2016). Most species concentrate the greatest amount of these acids in the abdomen (Testi et al., 2006). Highest values of fatty acids were detected in the abdominal portion in the current research, similar to results obtained by Carolsfeld et al. (2014). However, it was also noted that there is a significant content in the dorsal portion of the Paiche's body.

Paiche meat also contains significant Vitamin E with approximately 1.2 mg 100 g^{-1} (Table 1). This could potentially contribute to 16% of the recommended daily intake of 15 mg day^{-1} (Hernández, 2004) of this vitamin. Paiche meat also contains vitamins D2 and D3 for a total of 0.040 mg 100 g^{-1}, significant relative to the recommended daily intake of 0.005 mg day^{-1} (Hernández, 2004).

Based on the results of this study, Paiche meat is a good source of animal protein, fatty acids, and vitamins important to help address the nutritional demands of people living in urban and rural area in Bolivia. Studies on the effect of different cooking strategies on the nutritional value will be of interest (Liu et al., 2023), as well studies on the mercury content (Rodriguez-Levy et al., 2022). Amazonian fish are known to concentrate mercury from natural and anthropogenic sources in the area (Siqueira et al., 2018), which may represent a dietary risk to balance with the nutritional value, as with tuna (Abelsohn et al., 2011; Afonso et al., 2015). The FAO/WHO Protein Expert Committee recommended in 1985 that an adult should consume 0.75 g of protein per kilogram (kg) of body weight per day, revised by Hernández (2004) and Ruxton and Fiore (2005) to about 1 g kg^{-1} day^{-1}, considering differential recommendations for children and youth. A 70 kg adult should thus eat 56 g of protein per day, which could be addressed by consuming 280 g of Paiche meat. It was showed that mercury is the only trace element that represents an important health risk to humans in the lower Beni River drainage (Bolivian Amazon), and chronic intoxication could occur when consumption of fish in Riberalta or Rurrenabaque (upper Beni River drainage) exceed 83 g day^{-1} in females and 110 g day^{-1} in males (Rodriguez-Levy et al., 2022).

Conclusion

The meat of the invasive fish *Arapaima gigas* sold in the Riberalta market (Beni Department, Northern Bolivian Amazon) is a good-quality food for people living in rural and urban areas inland of the country. Quantity and form of its consumption should be studied in different towns of the Bolivian Amazon and inland cities to recommend optimal amounts ingested, since is known traces of mercury could be present in the flesh.

Ethical Statement

Not applicaple.

Funding Information

This work was carried out with the help of a grant from the Instituto Nacional de Innovación Agraria y Forestal (INIAF), through the financial support of the World Bank, within the subproject "Bases técnicas para el aprovechamiento integral del paiche (*Arapaima gigas*) en el norte del departamento del Beni". The work was co-funded by the International Development Research Center (IDRC), Ottawa, Canada, and with financial support from the Government of Canada, provided through the Department of Foreign Affairs, Trade and Development (Department of Foreign Affairs, Trade and Development – DFATD).

Author Contribution

First author: Conceptualization, methodology, data curation, formal analysis, writing, review and editing, original draft; Second author: Conceptualization, fund acquisition, administrator, writing, review and editing, original draft; Third author: Conceptualization, fund acquisition, administrator, writing, review and editing; Fourth author: methodology, data curation, supervision, review and editing.

Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

Acknowledgements

In memoriam to our colleague Sergio Villafán who passed away during the COVID pandemic.

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