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Nutritional, sensorial, and microbiological quality of canned pirarucu fillets from wild fishing and pisciculture

Qualidade nutricional, sensorial e microbiológica de conserva de filé de pirarucu proveniente da pesca e da piscicultura

Calidad nutricional, sensorial y microbiológica del filete de pirarucú conservado procedente de la pesca y la piscicultura

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Abstract
Pirarucu (*Arapaima gigas*) is one of the largest freshwater fish in the world. Dried salted fillet of pirarucu is the main product commercialized in northern Brazil, whereas frozen and smoked fillets are less frequently available. The present study aimed to produce canned pirarucu from wild fishing and pisciculture to add value, encourage fish consumption, and diversify canned fish products, as well as to subsequently evaluate the microbiological quality and physicochemical and sensorial characteristics these products. The fillets were sanitized in chlorine solution, immersed in brine (3% refined salt), drained, cut, and packed in cans. Thereafter, 2% hot brine was added, and the cans were subjected to exhaustion, seaming, thermal treatment, and cooling. The containers that revealed no bulging, pinholes, or leaks, and pH<0.2, measured both before and after incubations, indicated that the samples were commercially sterile. The canned fillets presented limited ash content variability, and no significant difference was observed in the moisture, lipid, or protein content. Moreover, sensory tests revealed that the canned fillet prepared with pirarucu from pisciculture was preferred over those prepared with wild-caught fish in terms of texture, flavour, and overall impression attributes, thereby directly reflecting a positive purchase intention for the product. Furthermore, canned pirarucu, whether originating from wild fishing or pisciculture, is a product with high nutritional value and sanitary quality, valuable sensory acceptance, and extended shelf life.
Keywords: *Arapaima gigas*; Conservation; Heat treatment; Value-added.

Resumo
O pirarucu é um dos maiores peixes de água doce do mundo. Na região Norte do Brasil, a manta salgada seca é o principal produto processado, sendo encontrados com menor frequência os filés congelados e os defumados. Com o intuito de agregar valor e incentivar o consumo da espécie, e diversificar os produtos de peixes enlatados, o objetivo deste trabalho foi desenvolver conservas de pirarucu da pesca e da piscicultura e avaliar os produtos quanto às suas características físico-químicas e sensoriais e qualidade microbiológica. Os filés foram higienizados em solução clorada, imersos em salmoura (3% sal refinado), drenados, cortados e acondicionados em latas. Em seguida, adicionou-se o líquido de cobertura (salmoura a 2%) e as foram latas submetidas aos processos de exaustão, recravação, tratamento térmico e resfriamento. As embalagens não apresentaram estufamento, microfuros ou

vazamentos e os resultados obtidos na medição do pH inicial e após as incubações (inferior a 0,2), indicaram que as amostras estavam comercialmente estéreis. As conservas apresentaram pequena variabilidade no teor de cinzas e nenhuma diferença significativa nos teores de umidade, lipídeos e proteínas. Os testes sensoriais indicaram que a conserva elaborada com o pirarucu da piscicultura foi preferida à conserva elaborada com o pirarucu da pesca nos atributos textura, sabor e impressão global, refletindo diretamente numa intenção positiva de compra do produto. A conserva de pirarucu, proveniente da pesca ou da piscicultura, é um produto de qualidade nutricional e sanitária, boa aceitação sensorial e maior vida útil.
Palavras-chave: *Arapaima gigas*; Conservação; Tratamento térmico; Valor agregado.

Resumen
El pirarucú es uno de los peces de agua dulce más grandes del mundo. En el norte de Brasil, la manta seca salada es el principal producto procesado, siendo menos frecuentes los filetes congelados y ahumados. Con el objetivo de agregar valor e incentivar el consumo de la especie, y diversificar los productos pesqueros enlatados, el objetivo de este trabajo fue desarrollar conservas de pirarucú provenientes de la pesca y piscicultura y evaluar los productos en cuanto a sus características físico-químicas y sensoriales y calidad microbiológica. Los filetes fueron desinfectados en una solución clorada, sumergidos en salmuera (3% de sal refinada), escurridos, cortados y envasados en latas. Luego se añadió el líquido de cobertura (2% de salmuera) y las latas fueron sometidas a procesos de agotamiento, prensado, tratamiento térmico y enfriamiento. Los paquetes no presentaron hinchazón, microagujeros ni fugas y los resultados obtenidos al medir el pH inicial y después de las incubaciones (menos de 0,2), indicaron que las muestras eran comercialmente estériles. Las conservas mostraron poca variabilidad en el contenido de cenizas y ninguna diferencia significativa en el contenido de humedad, lípidos y proteínas. Las pruebas sensoriales indicaron que la conserva elaborada con pirarucú procedente de piscicultura fue preferida a la conserva elaborada con pirarucú procedente de pesca en términos de textura, sabor e impresión general, reflejando directamente una intención positiva de compra del producto. El pirarucú en conserva, procedente de la pesca o piscicultura, es un producto de calidad nutricional y sanitaria, buena aceptación sensorial y mayor vida útil.
Palabras clave: *Arapaima gigas*; Conservación; Tratamiento térmico; Valor agregado.

1. Introduction

The demand for healthy and convenient products - easy to prepare, semi-ready, or ready to eat - has increased in recent years, with considerable growth in various options available in the market. The increased diversity of products in this segment has contributed to the loss of interest among certain consumers for foods that need greater handling and preparation time. Among these, the demand for fish has reduced, although many consumers still prefer fresh fish produce (Ono & Campos, 2016). Fish is an important food source, and is rich in proteins with high biological value, omega-3 polyunsaturated fatty acids, vitamins, and minerals, and presents low cholesterol content (Andrade et al., 2009; Soares & Gonçalves, 2012); however, it requires extensive processing as it is highly susceptible to spoilage.

The fishing industry has developed considerably, driven by consumer demand for convenient foods with nutritional, sensorial, and high sanitary quality, as well as by the need to offer a greater variety of processed products and implement technological innovations. Industrial processing adds value to canned products by increasing their shelf life and product diversity and is more acceptable by the consumer, besides offering better quality control and complete use of by-products and waste (Mesquita, 2017).

Canned fish is prepared by packing intact fish in an airtight container, which is then subjected to sterilization. The use of airtight packaging eliminates microbiological contamination after heat treatment and sterilization, which destroys any vegetative forms of pathogenic or deteriorating microorganisms (which can change the sensory characteristics of the product) and spores, thereby safeguarding commercial sterility (Brasil, 2001; Franco & Landgraf, 2002; Brasil, 2011).

Commercial sterility is achieved by applying sufficient heat to the product, alone or in combination with other appropriate treatments, or equivalent technology, to render uncontaminated food free of microorganisms capable of multiplying in ambient conditions during storage and distribution (Normative Instruction no. 60, December 13, 2019; Brasil, 2019).

The Brazilian canned fish industry developed canned sardines in vegetable oil that accounted for 95% of the total canned fish production in the 1970s (Cozer, 2015). Presently, sardines account for 76% of the national market; followed by tuna at 22%; and mussels, salmon, mackerel, herring, and other species at 2%. The range of species that can be canned and practical products developed make this segment relevant to the domestic market and human nutrition. Another important factor is the lack of cooling requirements for storage, distribution, and commercialization of these products (Gonçalves, 2019).

The Brazilian Agricultural Research Corporation (Embrapa) has been prospecting and studying several freshwater fish species as alternative raw materials for the industrial canning process. These studied species include cachapinta (a hybrid of barred sorubim (*Pseudoplatystoma fasciatum*) and spotted sorubim (*Pseudoplatystoma corruscan*; Torrezan et al., 2013), matrinxã (*Brycon amazonicus*; Chicrala et al., 2015), freshwater sardine (*Hemiodus unimaculatus*; Sousa et al., 2019), and tilapia (*Oreochromis niloticus*; Furtado et al., 2010). Moreover, other freshwater and marine species, such as tilapia (Pizato et al., 2012; Costa et al., 2022; Feiden et al., 2022; Costa et al., 2023), Argentine anchoita (*Engraulis anchoita*; Colembergue et al., 2011), Acoupa weakfish (*Cynoscion acoupa*), South American silver croaker (*Plagioscion squamosissimus*; Telles et al., 1975), pacu (*Piaractus mesopotamicus*; Szenttamázy et al., 1993), tucunaré (*Cichla ocellaris*; Von Dentz et al., 2022), piavuçu (*Leporinus macrocephalus*; Von Dentz et al., 2022), and lambari (*Astyanax altiparanae*; Von Dentz et al., 2022) have been studied by other research institutions.

The pirarucu (*Arapaima gigas*) is one of the largest freshwater fish in the world and inhabits the Amazon river basin exclusively, mainly in Bolivia, Brazil, Colombia, Guyana, and Peru. It can reach 1.7 m in length with a body mass of 80 kg by 6-7 years of age, with a maximum size of 3 m, weighing about 200 kg (Ono & Campos, 2016; Cortegano et al., 2017). Pirarucu is of high economic value and has been exploited by native populations since the eighteenth century. This intense exploitation has led to a remarkable decline in population, to a point that it is presently considered an almost extinct species in certain regions and overexploited in others. In response to the overfishing of natural stocks, government authorities have created several restrictions on its exploitation (Brasil, 2004; Ono & Kehdi, 2013).

Pirarucu fish farming is performed within tropical pisciculture and has been extensively carried out in Brazil; moreover, it has gained immense attention by international entrepreneurs who consider this production a great potential business (Ono & Campos, 2016). This interest stems from the rapid growth rate of the species, suitable adaptation to fish farming conditions, high muscle yield, and high-quality meat - light colour, firm texture, mild flavour, absence of intramuscular bones, and low-fat content (Ono & Campos, 2016; Cortegano et al., 2017; Vieira et al., 2018; Coutinho et al., 2019). The pirarucu from fish farming also allows differentiated cuts such as medallions. This caveat is important, since both wild fish weighing more than 50 kg and farmed fish weighing approximately 10-12 kg can have thick loins (Ferreira, 2016). Such characteristics place the pirarucu competitively in a niche market of high-quality and value-added products (Mesquita, 2017).

Although the commercialized volume is relatively small, the availability of farmed pirarucu significantly increased from 2009 to 2016. Moreover, the customers generally avoid consuming fish originating from pisciculture due to hygienic-sanitary issues and irregular supply (Ono & Campos, 2016). Despite increasing production, farmed pirarucu is generally disapproved for its taste, particularly, by the native population of the Amazon region who grew up consuming fresh fish from wild fishing (Ferreira, 2016).

Despite being well-known among the general population, most consumers are unaware of the nutritional and sensory quality of pirarucu meat (Ono & Campos, 2016). Previous studies have reported moisture, ash, lipid, and protein contents ranging between 52.20% and 77.96%, 0.59% and 2.46%, 0.56% and 8.26%, and 13.09% and 25.80%, respectively respectively (Fogaça et al., 2011; Oliveira et al., 2014; Martins et al., 2017; Cortegano et al., 2017; Coutinho et al., 2019; Pino-Hernández et al., 2020). This variability stems from the physiology, diet, and muscle activity of the fish, as well as the seasonality, environment, and muscle region analysed (Thammapat et al., 2010). The high nutrient content, pH near neutrality (6.75), and high-water activity (0.99) make pirarucu, and other fishes, highly susceptible to spoilage (Martins et al., 2015).

In northern Brazil, the dried salted reverse butterfly fillet, a cut corresponding to the right and left fillets joined by the ventral region, is the main processed product and is commonly sold in supermarkets and farmer markets. Other products, such as frozen and smoked fillets, are found less frequently. Presently, different processing methods related to product processing, preservation, and development have been reported in the literature, with the commercialization of products such as pickles, pancetta, carpaccio, sausage, and pirarucu canned in Brazil nut milk sauce, Brazil nut milk with plantain, coconut milk, and coconut milk with plantain (Carvalho & Lessi, 1975; Oliveira, 2007; Gonzaga Júnior, 2010; Reis, 2015; Bemvindo, 2017; Chicrala et al., 2017; Silva, 2018; Vieira et al., 2018; Coutinho et al., 2019; Martins et al., 2019; Pino-Hernández et al., 2020).

Thus, the present study aimed to develop canned pirarucu, and to evaluate the physicochemical, sensorial, and microbiological quality of the subsequent product in order to diversify the canned fish products, thereby adding value and encouraging its consumption to enhance further production of this species.

2. Methodology

Materials

The pirarucu fillet originating from wild fishing (WF) was purchased from the local market in Belém, Pará, Brazil, whereas that from pisciculture (PF) was purchased from the riparian fishing community of São Miguel do Aritapera, Santarém, Pará, Brazil. The fillets were sanitized in chlorine solution with sodium hypochlorite (2.10-6 kg/kg concentration; 10%-12% active chlorine) for 180 s, washed with drinking water, packed in plastic bags, sealed, and frozen at -20 °C.

The cans with aluminium filled epoxy phenolic interior coating (0.08335 m inside diameter, 0.039 m height, and 0.002 m depth) and the lids (0.0833 m inside diameter, 0.00445 m height, and 0.0018 m depth) used in processing of the canned fish were donated by GDC Alimentos S.A., Calvo Group, Itajaí, Santa Catarina, Brazil.

Canning

The canned fish was prepared according to the method by Torrezan et al. (2013). The fillets were thawed in a domestic refrigerator for about 43,200 s, and then immersed for 2,400 s in brine containing 3% refined salt. Thereafter, scraps and thinner ends were removed, and the fillets were cut into approximately 0.03 m wide strips, transverse to their length. Subsequently, a 2% hot brine solution was added over the canned fish, which was further subjected to an exhaustion tunnel with steam injection and a speed-controlled belt conveyor. The hermetic closure was performed in a semiautomatic sealing machine, and the thermal treatment was performed in a fixed horizontal autoclave (0.75 m3 capacity STERIFLOW®; STSR15-040, Roanne, France). The autoclave and cold spot temperatures in the cans were monitored by thermocouples in the machine. The Zenon software application (JS Automation, Voiron, France) was used for temperature control and data analysis.

After heat treatment, the cans were cooled to an internal temperature of 35 °C-40 °C to avoid loss of product quality, particularly texture, and to evaporate the remaining water on the outside of the packaging, to avoid corrosion. The cans were then stored in a clean, ventilated, and moisture-free place until physicochemical analysis and sensory tests could be performed.

Microbiological analyses

Microbiological analyses of the fresh pirarucu fillets and the commercial sterility test of the canned products were performed at Brazilian Agricultural Research Corporation, Food Agroindustry (Rio de Janeiro, Brazil). Coagulase-positive *Staphylococcus* and *Staphylococcus aureus* were detected and enumerated (Lancette & Bennett, 2001). *Salmonella* spp. was detected in food (absent in 0.025 kg) according to ISO 6579-1 (International Organization For Standardization, 2017). A standard count of aerobic mesophilic bacteria was performed following the method of Morton (2001), and filamentous fungi and yeasts were enumerated following the protocol of Beuchat and Cousin (2001).

Commercial sterility test

The commercial sterility test was performed according to RDC no. 12 of the Brazilian Health Regulatory Agency (Brasil, 2001). Three replicas of each product were provided; one had its initial pH measured, second was incubated at 35 °C-37 °C for 10 days, and the third was incubated at 55 °C for 5 days. After the incubation period, the closed cans were evaluated for possible external deformities and then opened for pH analysis (Dryer & Deibel, 1992).

Physicochemical analyses

Duplicates were used to determine the moisture, ash, and protein content (Association of Official Analytical Chemists, 2011). The lipid content was determined according to the method by Bligh and Dyer (1959).

Sensory analysis

The canned pirarucu fillets from WF and PF were evaluated for sensory attributes, such as appearance, texture, flavour, and overall impression, via a nine-point hedonic scale acceptance test. For statistical evaluation of the results, the hedonic scale categories attributed by the consumers were subsequently converted to numerical values, where 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely (Stone & Sidel, 2004). The purchase intention test was also applied to verify the consumer's willingness to purchase the product using a structured five-point scale converted to numerical values, where 1 = definitely would not buy, and 5 = definitely would buy (Meilgaard et al., 1999).

The session was conducted with 67 untrained consumers of both sexes, aged between 18 and 70 years, who reported prior consumption of canned fish. The sensory analysis was previously approved by the Research Ethics Committee of Integrated College Brazil Amazon (FIBRA), on February 6, 2019 (protocol no. 05703818.8.0000.8187), according to the current standards for studies involving humans (Brasil, 2012). The canned fillets were cut into cubes weighing approximately 0.02 kg, placed in disposable aluminium capsules, heated, and kept at 60 °C throughout the sensory analysis. For assessing appearance, the sensory evaluation was performed with the fish inside the cans, without fragmentation or heating. The samples were presented to the consumers coded with random three-digit numbers, in a monadic test and balanced order of presentation. The acceptance index (AI) was calculated using the Equation 1. The physicochemical and sensory analyses were performed at Brazilian Agricultural Research Corporation, Eastern Amazon (Belém, Pará, Brazil).

$$AI (\%) = (M \times 100)/9 \tag{1}$$

where M is the mean of the scores obtained from the sample, and nine is the maximum score of the hedonic scale used (Teixeira et al., 1987).

Statistical analysis

The Shapiro-Wilk test was used to verify the normality of data distribution and F-test verified the homogeneity of variance. Data with normal distribution and homoscedasticity were subjected to t-test. Data do not follow a normal distribution and/or homogeneity of variance were subjected Wilcoxon rank sum test. Statistical analyzes were performed using R software version 4.1.1 (R Core Team, 2021).

3. Results and Discussion

Table 1 summarizes the results of the microbiological analyses carried out on the unprocessed pirarucu fillets.

Table 1 - Microbiological analysis of unprocessed pirarucu fillets.

Microbiological analysis	WF	PF
Standard count of aerobic mesophilic bacteria (CFU/g)	8.2×10^5	6.0×10^4
Count of filamentous fungi and yeasts (CFU/g)	3.3×10^1	2.3×10^3
Detection and enumeration of coagulase-positive *Staphylococcus/Staphylococcus aureus* (CFU/g)	$<1.0\times10^4$	$<1.0\times10^1$
Detection of *Salmonella* spp. in food (absent in 25 g)	Absence	Absence

Source: Authors (2024).

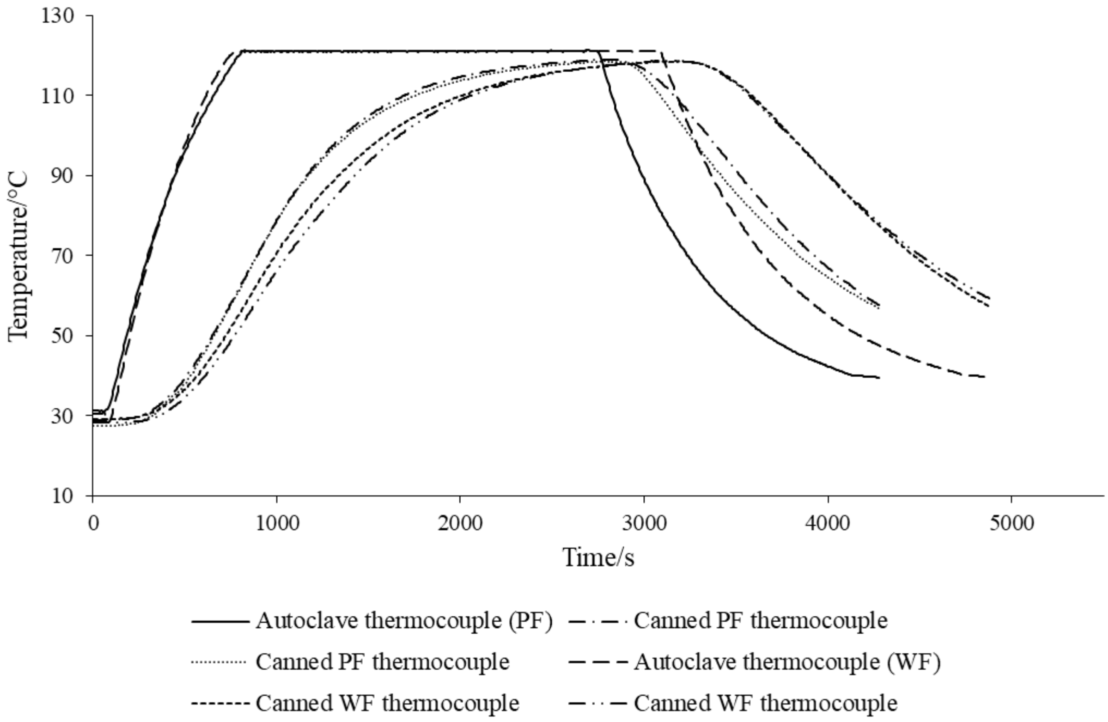
The results of the microbiological analyzes shown in Table 1 indicated that the unprocessed pirarucu fillets were within the microbiological standards established by the current legislation (Resolution RDC no. 12, January 2, 2001 from the Brazilian Health Regulatory Agency; Brasil, 2001). The standard count of aerobic mesophilic bacteria is important for determining whether the product is fit for consumption, as most pathogenic bacteria belong to the mesophilic group (Morton, 2001). The limit on the standard mesophilic aerobic bacterial count is 106 CFU/g for unfermented products, and 108 CFU/g for fermented products (Franco & Landgraf, 2002). The analyzed product exhibited a count of $<10^6$ CFU/g, and was therefore fit for consumption. Moreover, $<10^4$ CFU/g filamentous fungi were found in the unprocessed pirarucu fillets, which is within the accepted range (Normative Instruction no. 60, December 23, 2019; Brasil, 2019).

The heat penetration curves of the PF and WF canning processes are illustrated in Figure 1.

The sterilization time for the canned PF and WF was 1,920 and 2,280 s, respectively. The temperature and Z value used in both processes were 121 °C and 10 °C, respectively, and the F0 values obtained were 330 s (farmed pirarucu) and 343.2 s (wild pirarucu).

Figure 1 shows that the heat penetration curves of both PF and WF processes exhibited no statistical difference ($p>0.05$), although the speed of heat penetration in canned PF was slightly higher than that in canned WF, thereby indicating that WF had a firmer texture than that of PF. Fillet texture is influenced by several factors, including age, size, and nutritional content of the fish; storage temperature; and postmortem factors, such as glycolysis, pH, and rigor mortis (Hyldig & Nielsen, 2007).

Figure 1 - Heat penetration curves of canned pirarucu fillet processing in brine with 2% salt, performed in a fixed horizontal autoclave. WF: Pirarucu fillet from wild fishing and PF: Pirarucu fillet from pisciculture.



Source: Authors (2024).

Table 2 summarizes the results of the commercial sterility test, and Table 3 displays the results of the chemical composition analysis of PF and WF samples.

Table 2 - pH of canned pirarucu fillets from wild fishing (WF) and pisciculture (PF) before and after the incubation periods.

Canned	Initial pH	Final pH (55 °C)	Final pH (35 °C-37 °C)
WF	6.56	6.58	6.62
PF	6.53	6.48	6.49

Source: Authors (2024).

After incubation at 35 °C-37 °C for 10 days and at 55 °C for 5 days, no bulging was observed in the packages and the variation in the initial and final pH values shown in Table 2 were less than 0.2, indicating that the samples were commercially sterile (RDC no. 12 of the Brazilian Health Regulatory Agency; Brasil, 2001).

Table 3 - Chemical composition of canned pirarucu fillets from wild fishing (WF) and pisciculture (PF).

Parameter	WF	PF
Humidity (%)	77.32±0.53a	77.02±0.56a
Ash (%)	1.09±0.03b	1.31±0.06a
Lipids (%)	1.53±0.03a	1.56±0.04a
Proteins (%)	19.05±0.46a	19.42±0.22a

Means followed by the same letter in the column are not significantly different by the Tukey's test at 5% probability. Source: Authors (2024).

The chemical composition results shown in Table 3 revealed variation in the ash content between WF and PF ($p<0.05$), and no significant difference ($p>0.05$) in the moisture, lipids, and protein contents. The variation in the ash content between WF and PF, which can be attributed to the genetic, physiological, and environmental factors (Thammapat et al., 2010).

Table 4 shows a significant difference between the mean acceptance of the canned WF and PF pirarucu fillets in all sensory attributes analysed ($p<0.05$). In terms of appearance, WF displayed the highest sensory classification; however, PF was preferred to wild fish in the other attributes assessed. Besides the global impression, the attributes of texture and flavour presented average acceptance equivalent to the term "like very much" (8.0), which resulted in an AI of 89%, 9 points above the index achieved for the WF. These results indicate a remarkable acceptance of PF by consumers, with higher performance compared to WF.

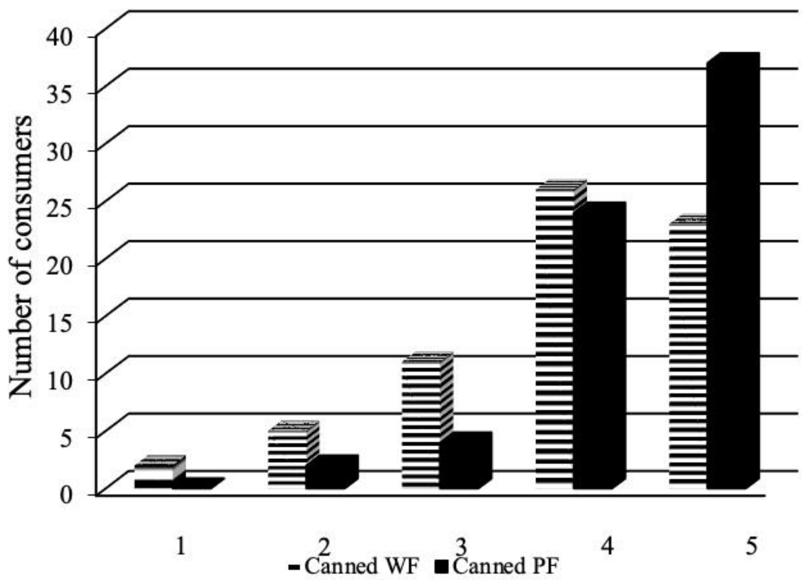
Table 4 - Mean acceptance values by attribute and acceptance index (AI) for canned pirarucu fillets from wild fishing (WF) and pisciculture (PF).

Sample	Appearance	Texture	Flavour	Overall impression		Purchase intention
	Mean	Mean	Mean	Mean	AI (%)	Mean
WF	7.85a	7.40b	7.12b	7.24b	80.43	3.94b
PF	7.34b	8.01a	8.01a	8.01a	89.05	4.43a

Means followed by the same letter in the column did not differ significantly by the Tukey's test at 5% probability.
Source: Authors (2024).

The histogram in Figure 2 shows that the purchase intention test corroborated the consumers' preference for the canned PF, with more than 55% responding they definitely would buy the PF product. The test also revealed a low percentage of rejection ("definitely would not buy" and "probably would not buy").

Figure 2 - Purchase intention histogram (number of consumers) for canned pirarucu fillet originating from wild fishing and pisciculture. 1. Definitely would not buy, 2. Probably would not buy, 3. May or may not buy, 4. Probably would buy, and 5. Definitely would buy.



Source: Authors (2024).

4. Conclusion

The pirarucu can be considered as an alternative raw material for the canning process in the fishing industry. The canned fish from both WF and PF is a nutritional product with high sanitary quality, acceptable sensory characteristics, and prolonged shelf life. Sensory tests indicated that the canned PF pirarucu fillet was preferred over the WF fillet in terms of texture, flavour, and overall impression, thereby directly reflecting a positive purchase intention of the product.

As a suggestion for future work, it is proposed to develop canned pirarucu fillets with other covering liquids, such as palm oil containing or not fines herbes.

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