Research Article

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Yield and chemical composition in *Arapaima gigas* fillets, reuse of by-products for flour make and quality of vegetable tannin-tanned leathers

Abstract

Objective: The aimed of this study was to evaluate the yield and chemical composition of paiche (*Arapaima gigas*) fillets and use of head and spine for elaboration of flour and quality of the skins tanned with vegetable tannin.

Main Body: Therefore, different flours were developed and evaluated in terms of chemical composition, minerals, fatty acid and amino acid profile, pH, Aw, colorimetry, granulometry and microbiology. Paiche evaluated had 12.61 kg and 120.5 cm in total length, with a skinless fillet yield 44.56%, totaling 55.44% of filleting by-products. Among these, there was possibility of using the spine 16.17%, head 16.49% and skin 16.81%. The fillets had 71.41% moisture, 20.34% protein, 5.58% lipids and 1.05% minerals. Natural flour was obtained from spines and heads, with an average yield 15.48%, and the spine flour had better nutritional value, containing 54.42% of protein and 7.24% of lipids, in addition to lower Aw 0.27, despite head flours having higher levels of calcium and phosphorus. Spine flour showed a more reddish color and smaller granulometry, where the Mean Geometric Diameter (MGD) was 0.24%, making its inclusion in food products easier. Leathers have higher tensile strength 13.85 N mm^{-2} and elasticity 86% in transverse direction. The skins within the by-products generated can tanned with vegetable tannin, shown high quality resistance and being able to used for making clothes, bags and shoes, adding a substantially high economic value to products.

Keywords: amino acid profile, aquaculture by-products, colorimetry and granulometry of flours, leather resistance, minerals

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Introduction

The consumption of fish meat has been increasing in recent decades, due to population growth and concern with the search for healthy and nutritional quality foods. According to Dias et al.,[1] *per capita* consumption of fish in year 2017 was 20.5 kg. Paiche *Arapaima gigas* (Schinz, 1822) is the largest freshwater fish, reaching 2.5 meters and 150 kg, and due to its size, flavor, and meat value, it has aroused increasing interest in fish farming.[2] Thus, several studies are being carried out with the objective of improving the zootechnical index of the species, seeking better technologies for production in higher density[3] and increased productivity.

In year 2014, paiche production in Brazil was approximately 11.7 tons, it is a very appreciated fish species in the Amazon region, being considered cod from Amazon basin,[4] however, its production is still not expressive. In fish farming, paiche can reach 10 to 12 kg in a year.[2] Due to the type of breathing of the paiche being pulmonated (compulsory aerial), and the animal's constant need to go to the surface to breathe, makes it a fish that supports changes in water quality, better tolerating stress due to low need for dissolved oxygen in water, a physiological characteristic that provides ease of production in environments with lower oxygen availability[5,6]. In addition to the high rusticity in terms of water parameters and handling, it can even be produced in high storage densities,[1,3] for production with a high survival rate.[7]

According to Dias et al.[1], these by-products, also considered tailings, are not valued or are even poorly exploited. These have been used to manufacture fish flour intended for preparation of rations, or else, part of it, discarded in the vicinity of the place, contributing to increase the problem of environmental contamination. It also ends up being a main problem of sanity of the facilities, being necessary alternatives for the use of industrial waste is of economic order. The reuse of these by-products could reduce input costs, minimizing environmental pollution problems and the unit cost of raw materials.[8]

According to Dantas-Filho et al.[9] there are many ways of using by-products, most of them through mechanically separated meat (MSM) such as fish burgers, nuggets, sausage, sausage, and *pâté*. However, little is said about using products (vertebral column with ribs and meat by-products remaining from filleting and spines). This can used to make fish flour for use in human food.[10] Since the number of by-products generated is very high, in addition to these presents around the same nutritional characteristics of the main product, which is meat. Although, fish often becomes a rejected product, mainly due to odor, taste, and presence of bones, however, it has fatty acids, minerals in high amounts, essential amino acids, mainly lysine,[11] vitamins and proteins o which makes it a product of high nutritional value.[12] Corrêa et al.,[13] another residue that can used is fish skin to produce leather, where this residue can vary 4.5 to 14% of the animal's body weight, and can vary according to the species, and the way it is used withdrawn.

Given the overview presented, an alternative for using the carcass and head is the production of fish flour for inclusion in human food,[12] both as a raw material for the development of new products and for inclusion in other foods processed foods adding value to them, such as lasagna,[14] spinach cake[15] and pizza,[16] with high acceptance by the general population, being an alternative to stimulate fish consumption.[15] And as an alternative for the use of fish skin is the production of leather called ecological using vegetable tannin.[17,18]

Given the assumptions, the aimed of this study was to evaluate the yield and chemical composition of paiche fillets and reuse of the head and spine to produce flour for human and quality of leathers tanned with vegetable tannin.

Material and methods

This animal study was conducted with the approval from Department of Medicina Veterinária, Universidade Estadual de Maringá – UEM, Brazil. Permission to conduct the research was granted with reference No. 088/2022, ensuring that all necessary safety and ethical considerations were met following the guidelines of National Biosafety Rules 2005 and Punjab Animal Health Act 2019.

This study was conducted out at the Fish Technology Laboratory, at the Experimental Farm of Iguatemi (EFI), belonging to the UEM, Brazil. The raw materials came from a fish farm located in Macapá city, AP, Brazil, for elaboration of the tests. Measurements and weights were collected at the processing unit in Macapá city. The fillets, heads, and carcasses (spine or vertebral column with the remaining filleting meat) and skins of paiche were packed and frozen (±18° C) to transported to Maringá city, PR, Brazil, where the tests were carried out. Transport was carried out in isothermal boxes from Macapá city to Maringá city, by air. Afterwards, they were placed in a freezer at the UEM laboratory, until the tests were carried out.

A total of 10 specimens of paiche used to evaluate the morphometric measurements, weights, and processing yields (fillet and by-products). Analyzes were performed to characterize the fillets, such as chemical composition, fatty acid, and amino acid profile. The analyzes performed were only descriptive.

Flours preparation, yield analysis and dehydration flours curve

Paiche flours were prepared from the head and spine (spines and remaining meat from filleting), at the Fish Technology Laboratory at EFI. Both the spine and head flours followed the same methodology used by Souza et al.[19] Raw materials were prepared (fins removed from carcasses and head gills) and washed. After that, they were placed in a pressure cooker and added to solution prepared in 40 liters of water, 2.0 g of butyl-hydroxy-toluene antioxidant and 4 ml of 15% Peracetic acid (peroxitane 1512® - it is a balanced mixture of peracetic acid, peroxide of hydrogen, Acetic acid and stabilizing vehicle) homogenized. This volume was divided into eight pressure cookers, making eight repetitions to produce carcass flour (spine) and then a new preparation for the eight repetitions for head flour.

The cooking of raw materials was carried out for 60 min at beginning of the pans pressure. After pressure was released from the pans, they were opened, and material drained and taken to pressing (hydraulic press with a capacity of 10 tons) to extract excess water and oil. The cake obtained from pressing was ground in an industrial meat grinder (model CAF-10), with an 8 mm disk, then distributed in aluminum trays, weighed, and placed in a forced circulation oven at 90°C for 24 hours. This drying period was followed by 24 hours to analyze the dehydration process. After 24 hours, the material was ground again in a knife mill (willye-model TE-650), to obtain a fine-grained flour. This same methodology was applied to preparation of paiche head flour.

The flours obtained were properly packaged and stored in a freezer at -18° C until moment of analysis and use for product development. Only a small portion of each treatment was kept in a refrigerator for the microbiological analysis, which took place around 24 h after the completion of its preparation.

The calculation of flour yield was performed as a function of the final product in relation to initial weight of the raw material. The dehydration curve was also determined, for this purpose, the trays were weighed every 2 hours during 24 h of dehydration of the flours inside forced air circulation oven (dehydration process) at 90° C.[20]

Proximate composition analysis, caloric value, fatty acid profile and aminogram

Proximate composition analysis was carried out at the Laboratory of Animal Food and Nutrition, belonging to the UEM. A total of 8 aliquots of each flour used for determinations of proximate composition (moisture and minerals) according to Association of Official Analytical Chemists methodology AOAC.[21] Crude protein contents were evaluated by semi-micro Kjeldahl method.[22] For extraction of total lipids, the methodology described by Bligh and Dyer[23] was followed.

Carbohydrate contents were estimated using a mathematical formula that considers values summed of moisture, protein, lipids, and minerals, substituted by 100%. The total caloric value was obtained by multiplication of the average values summed of protein, lipids and carbohydrates multiplied by factors 4, 9 and 4, respectively.[12]

Characterization of amino acid profile, it was performed according to methodology described by Hagen et al.,[24] at the CBO Analysis Laboratory, at the Universidade Estadual de Campinas (UNICAMP), Campinas city, SP, Brazil. From content of the lipid extraction, the determination of fatty acid profile was performed. Fatty acid esters were isolated and analyzed by gas Chromatography (Agilent, model 7890A), coupled to a mass detector (Agilent 5975C), using a ZB-Wax

Polyethylene Glycol column. The carrier gas was Helium, and the injection flow was 1 mL min^{-1} Split 1:10. Fatty acid identifications were performed using the following criteria: comparison of retention times of methyl esters of sigma standards (USA) with those of samples and comparison of ECL (Equivalent Chain Length) values of methyl esters of samples with values from literature.[25]

Physicochemical and microbiological analyzes

The quantification of minerals (calcium and phosphorus) was performed according to methodology described by AOAC.[25] To obtain samples pH, they were homogenized with distilled water and read using a pH meter (DM 22, digimed). The determination of water activity was performed using the Labswift-Novasina device.

The flours granulometry was evaluated using the methodology described by Abimilho.[26] A fraction of 100 grams was deposited in a system of superimposed sieves (30, 35 and 50 mesh, respectively 600, 500 and 300 µm, according to ABNT standards) and subjected to agitation for a time not exceeding 3 min to obtain of material retained on each sieve. To determine Mean Geometric Diameter (MGD), the method for determining the granulometry of ingredients for use in swine and poultry rations was used.[27]

For colorimetry, luminosity (L) values were evaluated using a colorimeter (MINOLTA CR-10, Minolta Camera CO, Osaka, Japan), where L* defines luminosity (L*=0 black and L*=100 white), a* (red-green component) and b* (yellow-blue component) by CIELAB color system.[28]

Microbiological analyzes were performed for the most probable number (MPN) of coliforms at 35°C and 40°C, counts of *Staphylococcus coagulase positive* in CFU g^{-1} and of *Salmonella* spp., according to APHA.[29] The microbiological protocol followed the standards established by Resolution RDC No. 331/2019,[30] of the National Health Surveillance Agency, of Normative Instruction (IN) 60/2019.

Tanning and resistance testing of the leathers

The leathers were tanned ah the Skin Tanning and Processing Laboratory, at the UEM. The tanning process was based on the study by Souza et al.[19] with adaptations. A total of 10 paiche skins were used for the experiment. The skins were thawed at room temperature with (0.5%) surfactant, where they were stripped to remove the hypodermic layer.

The entire tanning process was carried out in a drum (cylindrical equipment with rotation control, 4 to 16 rpm, during the tanning process). This is used to facilitate the pumping of chemicals into the skin. In the lime step, 3% lime and 2% soda ash were used to open and clean the fibrous structures. Pickling was performed at 8°Baumé, with 3% Formic acid (3%) diluted, for 60 min, followed by addition of the tanning agent (10% vegetable tannin) for 120 minutes. After 48 hours of rest to better occur the crosslinking process between the tanning agent and collagen fibers. The neutralization of leathers was carried out using sodium bicarbonate (2%). In retanning and dyeing slurry, 4% vegetable tannin and 1% dye were used for 60 minutes. The fatliquoring was done with an emulsion of 10% oil at a temperature of 50 °C for 60 minutes, being fixed with 2% of Formic acid diluted in water. After fixing, the skins were placed to dry and then they were manually softened, for later removal of the specimens.

For strength test, samples were taken longitudinally, transversally, and diagonally, with 10 specimens for each direction, the samples were taken with the aid of a balancer - ABNT-NBR ISO 2418,[31] where the tensile strength to elongation - ABNT-NBR ISO 3376[32] and progressive tearing - ABNT-NBR 11055.[33] The tests were performed on the EMIC dynamometer with a load removal speed of 100 ± 20 mm min^{-1}.

Scanning electron microscopy (SEM)

Samples of 0.5 cm were taken from the tanned leathers, they were simply fixed with adhesive tapes on the stabs, with the surface of the flesh side of the leather facing up, to evaluate the intertwining of collagen fibers. These samples of paiche tanned leathers were photographed using the SHIMADZU-SS550 SEM provided by the Complexo Central de Apoio à Pesquisa (COMCAP/UEM). The samples were not metallized, as a low vacuum was used.

Experimental design and statistical analysis

The experiment was carried out considering a completely randomized design, with two treatments (cut used to prepare flours, being spine and head) and eight replications per treatment. The experimental unit was the batch of 1.25 kg of raw material used in the preparation of different flours (head and spine).

To analyze resistance quality of the leathers tanned with vegetable tannin, a completely randomized design was used, with three treatments, with direction of the leather being these treatments (Trat1=longitudinal, Trat2=transverse and Trat3=diagonal). For statistical analysis of the data resulting from the sensory analysis, the proc GENMOD (SAS, 2010 version) was used, considering the distribution of the variables as being gamma with an inverse link function.

The results of the analyzed parameters (chemical composition, pH, water activity (Aw), colorimetry, granulometry and yield) were compared by Student's t test ($\alpha = 0.05$). While the physicomechanical tests were first submitted to ANOVA and then submitted to Tukey's test ($\alpha = 0.05$). The microbiological, mineral, fatty acid and amino acid analyzes performed in this study, were only descriptive. The Statistical Analysis System Software (SAS Inst. Inc. Cary, NC, USA), version 9 was used.

Results and discussion

The evaluation of fish carcass has great economic and production importance. With this information, it is possible to estimate productivity within fish farming and consequently for the fish processing industry. With yield quantification, producer will be able to plan and determine number of fish that will be necessary to slaughtered and distributed to commerce. The morphology of fish, that is, the morphology of the fish, can translated into proportion of fillet to be produced in a particular species of fish, as it is a phenotype related to fillet yield, the fish shape is also part of the choice criteria of fish by the consumer.

Paiche evaluated in the current study expressed an average slaughter weight of 12.61 kg, with an average total length of 120.5 cm and a standard (headless) of 110.7 cm. The animals had an average circumference length of 48.8 cm. An animal of this size had fillets of 5.62 kg (two units), spine (vertebral column with ribs and remaining meat from filleting) of 2.04 kg, head of 2.08 kg, skins of 2.12 kg (two units) and only 0.85 kg of viscera remains. Thus, the skinless fillet yield was 44.56%, totaling 55.44% of filleting by-products, of which there is the possibility of using the spine, head, and skin in the elaboration of products.

Concerning paiche from fish farming in the filleting process, in this study it showed a high fillet yield, much higher than many other farmed fish, with high commercial value and importance for the fishing industry. As an example, Nile tilapia (*Oreochromis niloticus*) had an average fillet yield of 33%[33] and tambaqui (*Colossoma macropomum*) of 32.6%.[34]

Paiche deboned and fillet also reach a higher value than other commercial fish from fisheries such as catfish, *Brachyplatystoma filamentosum* of 33.44%, *Brachyplatystoma rousseauxii* of 32.73% and *Pseudoplatystoma tigrinum* of 27.22%.[15] However, paiche is a species that needs a year of cultivation to reach slaughter weight, that is, for commercialization, with good management and feeding.[17] Although, Nile tilapia reaches the ideal weight for slaughter in 3 to 4 months with a weight of 600 to 800g.[20]

However, the high yield of the paiche fillet did not exceed the yield found for the same species, from extractive fishing or capture from natural environment, which obtained 57% of meat yield.[7] Since, in the current study, the length of paiche from fishing reached 2.0 ± 0.3 m and an average weight of 64 ± 28.2 kg, with an animal weight much higher than those from fish farming, as recorded in this study, where paiches reached 120.5 cm and 12.61 kg. According to Coutinho et al.,[35] the yield of paiche fillet varies 56.6 to 57.9% depending on the analyzed weight classes (30-40 kg), while paiche weighing over 60 kg can reach yields fillet with skin up to 65%.

However, for fish farmed, the slaughter weight is usually much lower, being between 10 and 20 kg, which can consequently reduce the percentage of meat (yield). Cavali et al.,[36] analyzing yield and composition of paiche fillet in different weight classes (7 to 16 kg), reported that the average yield was 48.62% and there was no direct relation between the total weight of the fish, fish and fillet yield in this weight range evaluated.

According to Souza et al.[19] the sex, size or age of the fish, filleting method and the filleting skill are factors that influence fillet yield values at the time of fish processing. According to Souza et al.,[19] there is an influence of weight on fillet yield with and without skin of Nile tilapia, where increasing fish weight increases yield 38.54 to 40.47%. However, comparing these yields of Nile tilapia fillet with paiche fillet, without a doubt, paiche was much higher, despite being expected, because the body size of paiche is much higher than that of Nile tilapia and its anatomical shape is cylindrical, resulting in greater meat yield.

The data linked to composition of paiche meat are also very important for determining the conservation process and preparation of products for commercialization. However, data on processing yield identify edible amount of the fish and nutrients that make up the fillet.

At the end of ground mass preparation in a meat grinder, this mass of meat was placed in a dehydrator and monitored for 24 hours, with the flours being weighed every 2 hours to analyze the moisture losses in the dehydration process. Behavior of the dehydration process was of a quadratic effect curve, whose equation that explains is a $y = -0.6901x^2 + 22.577x + 28.279$ ($R^2 = 0.9022$). Deriving this equation, the optimal time for dehydration of paiche spine flour was 16h and 21 minutes, consequently reducing time spent on energy for the dehydration process of this flour by 8 h and 19 minutes.

The dehydration time used for elaborate paiche flour was 24 hours, to obtain the lowest possible moisture content and reduction in Aw, to guarantee the better results regarding shelf life of the fish flour. Period used has been 24 hours at 60°C for the dehydration process reported by several authors in the literature.[14,15,36,37] Although, this study evaluated the dehydration process for paiche flour and the optimal time of the dehydration curve, which was 16h and 21 min, consequently reducing time spent on energy for the flour dehydration process by 8h and 19 min, allowing a reduction in its production cost. However, the dehydration process was carried out at a higher temperature, being 90°C, while the authors used 60°C.

Knowing chemical composition of paiche fillet and its by-products is important to direct them to food, knowing their nutritional potential. Filleting by-products tend to have same characteristics as fillet meat. Therefore, the remaining meat in the carcass, resulting from filleting process, must also have high nutritional quality. Based on this, the fillets were evaluated for their chemical composition and then the flours made with the by-products (head and spine) of filleting.

Analyzing chemical composition in paiche fillet (Table 1), it is observed that the fillet showed 71.41% moisture, 20.34% crude protein, low 5.58% lipid content (and around 1.05% mineral matter. These values are within the levels found in the literature. Martins et al.[38] evaluated paiche fillets weighing 18.6 kg and 1.3 m in length and reported that they had 52.2 to 78.2% moisture, 17.8 to 25.8% crude protein, 1.0 to 17.1% total lipids and 0.9 to 1.2% of mineral matter, values close to those found in this study. Cavali et al.[36] and Martins et al.[8] observed 75.0 and 75.5% moisture, 20.1 and 21.4% crude protein, 0.6 and 2.6% total lipids and 2.5 and 0.9% mineral matter in the dorsal region of paiche. Oliveira et al.[7] observed 79.5 and 77.9% moisture, 17.6 and 16.1% crude protein, 0.6 and 2.5% total lipids and 0.9 and 0.8% mineral matter, respectively in the dorsal and ventral regions of paiche muscle.

Table 1 Proximate composition, minerals, pH, Aw and yield of paiche (*Arapaima gigas*) flours made spine and head

Proximate composition (%)	Paiche flours		p value
	Spine	Head	
Moisture	4.12 ± 0.08a	3.96 ± 0.07a	0.3749
Crude protein	54.42 ± 0.57a	52.58 ± 0.59b	0.0288
Total lipids	7.24 ± 0.78 aa	4.55 ± 0.90b	0.0004
Mineral matter	35.23 ± 0.34a	36.21 ± 0.38a	0.981
Carbohydrates	2.14 ± 1.43b	6.64 ± 0.17a	0.0211
Calorific value	295.28 ± 0.54a	277.93 ± 2.19b	< 0.01
Calcium	5.63 ± 0.47b	7.25 ± 0.52a	0.0004
Phosphorus	7.08 ± 0.19b	7.74 ± 0.23a	0.0006
pH	7.07 ± 0.02a	7.02 ± 0.08a	0.2098
Aw²	0.27 ± 0.03a	0.19 ± 0.11b	0.0215
Yield (%)	15.44 ± 0.11a	15.52 ± 0.15a	0.7704

Means in same column followed by different lowercase letters differ from each other by Student's t test (p <0.05). Data expressed as mean ± standard deviation

The observed variations can be attributed to aspects such as sex, age of the animal, species, diet, seasonality, and source of capture, as well as the analyzed muscle portion. Generally, fish muscle contains about 60 to 85% moisture, varying with species, time of year, age, sex and nutritional status. In addition, mineral matter contents are between 0.80 to 1.4% for bony fish in general.[39]

There is a classification of fish in terms of fat content, in which fish with levels below 2.5% of fat are considered lean and between 5 and 10% are considered semi-fatty. Fernandes et al.[25] classified fish according to fat content, where fatty fish is considered to have a fat content above 10%, moderately fatty (5-10%) and lean (<5%). Thus, paiche meat is classified as lean. This classification in relation to paiche is also due to its behavior in its natural habitat, as it is a species that occupies the final part of the food chain and does not have a continuous migration in spawning.[25,36,39]

The classification of fish by fat content is important, as it can directly influence production performance and acceptance by consumer market, in addition to altering palatability of fish meat.[40] In summary, it can say that there are several factors related to chemical composition of meat, such as the animal species (or fish), analyzed muscle part, age, sex, physiological phase, weight, time of year or seasonality, diet or nutritional status, among others.

To better use filleting by-products for human consumption, it is important to evaluate the products generated, such as flour and its inclusion in products of low nutritional value. Goes et al.[15] and Justen et al.[41] developed the flour from Nile tilapia carcasses for inclusion in food products (noodles and extruded snacks) with excellent results in terms of acceptance and nutritional value.

The flour made from paiche spine (15.44%) had a similar yield to head (15.52%) (Table 2). Yield values obtained in this study were higher than the values found by Odhiambo et al.[42] for Nile tilapia head and carcass (spine) flour, where its yield was 13%. The same author also evaluated MSM meat flour which obtained an even lower yield of 9%, however, it is known that the yield of MSM is lower due to removal of bone material during processing. Therefore, this high yield value in the flour preparation process is attributed to a high percentage of spine of and skull of the fish, providing a high amount of mineral matter.

Table 2 Colorimetry and granulometry of paiche (*Arapaima gigas*) flours made from different parts of the fish

Paiche flours	Colorimetry			MGD³
	L^1	a*	b*	(%)
Spine	73.83 ± 0.20ª	0.43 ± 0.07ª	10.25 ± 0.12ª	0.23 ± 0.01ª
Head	74.10 ± 0.17ª	0.21 ± 0.58b	9.93 ± 0.10ª	0.25 ± 0.03ª
p value	0.5931	0.0202	0.1809	0.0705

Means in same column followed by different letters differ from each other by Student's t test (p <0.05). L^1, luminosity; a*, red-green component; b*, yellow-blue component. MGD^3 = Mean geometric diameter.

Prepared paiche flours (spines and head) showed around 3.96 to 4.12% moisture, 54.42 to 52.58% crude protein, 4.55 to 7.24% total lipids and 35.23 to 36.21% mineral matter. Analyzing these values regardless of part of the raw material used, considering only the fish species, the values of crude protein and lipids were higher and the mineral matter lower than those observed by Justen et al.[41] These authors reported that flavored Nile tilapia flour with 5.04% moisture contained 45.50% crude protein, 14.60% lipids and 26.31% mineral matter. This variation is due to species depending on how the raw material used to produce flour was found, in addition to method applied in the elaboration of this flour. These researchers cited smoked the carcasses and then pressed them, in which the spines and heads were cooked and then pressed, in this procedure there is an increase in the surface area of the fish residue (it is divided into many pieces), facilitating extraction of excess water and natural fat from the fish, reflecting the moisture and final fat content in the product.

In flour it is composed of carbohydrates, even in small amounts. This fact is due to fact that meat by-products remain on the carcass. Carbohydrates absorbed by body are converted by hepatocytes into glycogen polysaccharides[43] that is, polysaccharides that contain more than twenty units of monosaccharides, abundantly found in the liver and in skeletal muscle.[44]

Moisture flours made with paiche filleting by-products was low (Table 1), there was no significant difference, being within the recommended for whole dry fish, where it should not contain more than 12% of moisture, according to Regulation of the Industrial and Sanitary Inspection of products of animal origin in Brazil.[45]

The ash content of a food corresponds to its mineral fraction, that is, the inorganic fraction of the food, called mineral matter.[46] When analyzing mineral part of these flours, there was no significant difference between them, although the contents were very high (35.23 and 36.21%) (Table 1). This is due to high amount of bone present in the flours, referring to spine and skull of the fish. However, when calcium and phosphorus were analyzed, head flour provided higher levels compared to spine flours. Perhaps this is also associated with the amount of meat present together in the spine used to make the flour, where it is noted that the protein content was higher for this flour (Table 1).

According to Michelato et al.[33] the flour prepared from headless Nile tilapia carcasses was composed of calcium values equal to 4.10 g kg^{-1}, while phosphorus 2.69 g kg^{-1} in composition of the flours, values much lower than those found in this study (Table 1). Justen et al.[41] found 6.57 g kg^{-1} of calcium and 3.52 g kg^{-1} of phosphorus for Nile tilapia carcass flour. However, these values were lower than those obtained with paiche flour. This difference is due to part of the raw material used to make the flour, species, and method of making the flour. In this experiment it was by cooking method, while the mentioned authors used the smoking method.

Observing crude protein content values of fillet and flour (Table 2), it is noted that the fillet was 87.02%, because the analysis was performed on the ground and dehydrated fillet, to compared in the same flour's composition. However, the spine flours expressed 55.63% of crude protein content and head 41.46% in relation to crude protein content of the fillets. These values are lower as a function of the amount of bone material present in the flours.

Meantime, Aw was significantly higher for spine flours (0.27), perhaps due to the more intensive process for washing the carcasses. However, this spine flours had a higher content of crude protein (54.42%) and lipids (7.24%) (Table 1). Justen et al.[41] reported values of 0.34 and 0.46, respectively, of Aw for spine flour prepared with headless Nile tilapia carcass. In this study, the pH values did not vary between treatments, remaining at 7.02, considered neutral. The pH close to neutrality with high Aw can be conducive to introduction of microorganisms in fish, although because it is a flour that is a dry material with Aw below 0.60, it indicates that microbial growth is more difficult to occur.[7]

Yield values observed in this study were 15.44% for spine flours and 15.52% for head flour, values different from those found by Godoy et al.[47] The authors researched Nile tilapia and the yield was higher due to methodology used in this study, where the carcass first went through the process of brine with herbs, then it was smoked. In this process, there is a small loss of liquids, by leaching, to be then ground, dehydrated, and thus obtained flour, thus justifying the difference in this study.

There was no significant difference for the luminosity and chroma b*, of the two elaborated flours, whose average values were 73.97 and 10.09, respectively. Flour made from paiche spine had a higher chroma a* value (0.43), tending to have a more reddish color compared to head flour (0.21). Odhiambo et al.,[42] evaluating flour obtained from carcass, head and MSM of Nile tilapia, reported that there was variation in luminosity (77.19 to 55.32), with the darkest being MSM flour (55.32) and lightest was the carcass (77.19). These authors reported that the high fat content of MSM flour reduced the effect of light, leaving it darker (opaque) when compared to the others. However, it is noted that in addition to type of raw material used, the species also influences result of the flour luminosity, because the results obtained in this study, the luminosity of the spine flour (carcass) of paiche was lower compared to that of Nile tilapia. Although in this study there was no difference between the brightness of the spine and head flours.

The authors reported that the chroma a* of the flours had an average value of 4.73, although MSM flour (4.44) had a significantly lower value than the head and carcass flours, which were more prone to red color. As for chroma b*, the variation was 4.13 to 9.51, shown a tendency to yellow, although with greater intensity for MSM flour.

Colorimetry results of these elaborated flours differ from those obtained by Costa et al.[20] who, when studying production of high nutritional value flour, using MSM Nile tilapia, reported lower values for L* (50.57 to 59.16), chroma a* (0.80 to 3.39) and higher for chroma b* (12.03 to 14.24). These differences mentioned between these parameters of the colorimetry of this study with paiche flours, and the literature are due to different factors, such as the origin of the raw material, type of cut or type of residue used, the methodology applied for elaboration of the flours and species used. It is important to highlight that the analyzed flours are from different species of fish, which can directly affect the color, where the authors used Nile tilapia as a basis for flour production.

Granulometry of the flours was very similar where the Mean Geometric Diameter (MGD) was 0.23 and 0.25%, respectively for spine and head flour, which did not differ (p >0.05) statistically (Table 2). Due to low flours moisture, it was possible to make a better grinding, reducing particle size of these flours, thus facilitating their inclusion in products with the purpose of nutritional enrichment.

Granulometry of fish flours is directly related to equipment used for crushing, the drying quality and reduction of fat in the raw material. However, it is known that the smaller the particle size, the greater and faster the absorption by body,[27] in addition to ease of inclusion in food products without its perception. In this paiche fillets, a total pf 19 amino acids were identified, of which 10 are essential, as well in spine and head flour. The essential amino acids identified were arginine, histidine, phenylalanine, isoleucine, leucine, lysine, methionine, threonine, tryptophan, and valine. Corroborating with Mansano et al.[11] who states that fish have these 10 essential amino acids. However, from nutritional point of view, the percentage of amino acids in the fillet was much higher than those found in spine and head flour. The main amino acids (above 5%) in the fillets were Aspartic acid, Glutamic acid, alanine, arginine, glycine, leucine, lysine. However, evaluating two flours, the spine flour had a higher percentage of Glutamic acid and glycine, while the head flour had cystine, glycine and proline in greater proportion (Table 3). Torati et al.[48] analyzed cephalic fluid released by paiche, mainly in period of parental care, where 422 proteins were identified, therefore, this cephalic secretion released by paiche may be reason for alteration of the amino acids present in the head flour, however more information is lacking about the biochemical nature of this cephalic fluid.

It is noted in Table 3 that the amino acids phenylalanine, tyrosine and tryptophan are found in smaller proportions in head flour, compared to spine flour, which may be associated with the decarboxylation of these aromatic amino acids, in the production of biogenic amines (neurotransmitters), as according to Mansano et al.[11] serotonin or 5-hydroxytryptamine (5-HT) belongs to the group that also includes catecholamines (adrenaline, noradrenaline and dopamine), being responsible for synthesis, for the most part, from decarboxylation of aromatic amino acids such as phenylalanine, tyrosine and tryptophan.

Table 3 Amino acid profile in dehydrated fillet and in paiche (*Arapaima gigas*) spine and head flour

Amino acids (%)	Dehydrated fillet	Flours	
		Spine	Head
Aspartic acid	7.76 ± 0.38	2.49 ± 0.12	1.53 ± 0.08
Glutamic acid	13.14 ± 0.65	5.52 ± 0.27	3.66 ± 0.18
Alanine	5.29 ± 0.26	3.35 ± 0.17	3.18 ± 0.16
Arginine*	5.12 ± 0.25	3.26 ± 0.16	2.98 ± 0.15
Cystine	1.06 ± 0.07	0.65 ± 0.04	0.98 ± 0 .07
Phenylalanine*	3.49 ± 0.22	1.84 ± 0.12	1.27 ± 0.08
Glycine	5.67 ± 0.38	5.61 ± 0.37	6.90 ± 0.46
Histidine*	1.77 ± 0.12	0.89 ± 0.06	0.59 ± 0.04
Isoleucine*	3.91 ± 0.26	1.90 ± 0.13	1.13 ± 0.08
Leucine*	6.44 ± 0.45	3.02 ± 0.21	1.82 ± 0.13
Lysine*	7.63 ± 0.53	3.40 ± 0.24	2.14 ± 0.15
Methionine*	2.60 ± 0.18	1.32 ± 0.09	0.83 ± 0.06
Proline	3.95 ± 0.33	3.53 ± 0.29	4.13 ± 0.34
Serine	3.32 ± 0.27	1.74 ± 0.14	1.28 ± 0.10
Taurine	1.97 ± 0.16	0.11 ± 0.01	0.06 ± 0.00
Tyrosine	2.78 ± 0.23	1.45 ± 0.12	0.78 ± 0.06
Threonine*	3.86 ± 0.32	2.00 ± 0.16	1.37 ± 0.11
Tryptophan*	0.74 ± 0.12	0.31 ± 0.05	0.16 ± 0.03
Valine*	3.84 ± 0.65	2.03 ± 0.34	1.29 ± 0.22
Total (%)	84.34	44.42	36.08
Crude protein (%)	87.02	48.41	41

*Essential amino acids.

Mansano et al.[11] stated that lysine is the most abundant essential amino acid in fish. However, Aspartic and Glutamic acids were the ones that were in greater proportions in paiche fillets. However, in spine flours, the amino acids found in greater proportions were Glutamic and glycine and in head flours were glycine and proline. Souza et al.,[19] evaluating flours made from processing by-products of different fish species, reported that in Nile tilapia and salmon flour the amino acids found in greater proportions, above 75 mg g^{-1} of protein were lysine, Glutamic acid, aspartic, glycine, leucine and phenylalanine + tyrosine, amino acids also found in paiche spine flour, although with lower percentages.

Paiche fillets showed an excellent amino acid profile, with five of the amino acids (isoleucine, lysine, methionine, threonine, and valine) with percentages above the nutritional requirement recommended for children and adults, two amino acids (histidine and leucine) had very similar levels and two much lower (phenylalanine and tryptophan) than the required percentages, of which tryptophan is the limiting amino acid (0.74%). According to Elango et al.[49] the amino acids that meet the nutritional requirements recommended for children up to ten years old and adults (over 18 years old) are phenylalanine + tyrosine with 6.3 g $100g^{-1}$, histidine 1.9 g $100g^{-1}$, isoleucine 2.8 g $100g^{-1}$, leucine 6.6 g $100g^{-1}$, lysine 5.8 g $100g^{-1}$, methionine + cystine 2.5 g $100g^{-1}$, threonine 3.4 g $100g^{-1}$, tryptophan 1.1 g $100g^{-1}$ and valine 3.5g $100g^{-1}$.

When evaluated the flours (spine and head) regarding amino acid profile, they only meet requirements for adults according to WHO.[49] Spine flour has higher amino acid contents compared to head flour. Spines flour has five amino acids (isoleucine 1.90%, leucine 3.02%, lysine 3.4%, threonine 2.0% and valine 2.03%) within the values necessary to meet the requirements of an adult, more have three more amino acids with levels close to those required (histidine 0.89%, methionine 1.32% and tryptophan 0.31%), while head flour has only three amino acids within the requirement (lysine 2.14%, threonine 1.37% and valine 1.29%), three more close (isoleucine 1.13%, leucine 1.82% and methionine 0.83%) and two much lower than the requirement (histidine 0.89%, tryptophan 0, 16%). The requirement to supply an adult in essential amino acids is 1.6g 100g^{-1} of histidine, 1.3g 100g^{-1} of isoleucine, 1.9g 100g^{-1} of leucine, 1.6g 100g^{-1} of lysine, 1.7g 100g^{-1} of methionine + cystine, 0.9g 100g^{-1} of threonine, 0.5g 100g^{-1} of tryptophan and 1.3g 100g^{-1} of valine. Therefore, between the two flours, the one with the better nutritional quality is that of spine.

In paiche fillets, where 29 fatty acids were identified, being four of them the mainly, Palmitic (27.62%), Stearic (13.71%), Oleic (27.01%) and Linoleic (12.19%) acids.[36] For the flours, it was not different in terms of the mainly fatty acids, remaining the same four fatty acids, although percentages were higher in spine flours in relation to the head flours (Table 4). Nonetheless, when comparing fatty acids of spine flour to those found in fillet, the flour has lower Palmitic (19.27%) and Stearic (10.39%) acids and higher Oleic (32.36%) and Linoleic acids contents (19.88%)[36]. These differences must be related to region of the fish's body that was used for flours elaboration and methodology applied in production of these flours.

Table 4 Fatty acid profile of dehydrated fillet and paiche (*Arapaima gigas*) spine and head flours

Fatty acids (%)	Paiche flours	
Usual nomenclature / symbology	**Spine**	**Head**
Lauric acid¹/ C12:0	0.11 ± 0.02	0.11 ± 0.02
Myristic acid¹/ C14:0	1.28 ± 0.24	2.78 ± 0.52
Pentadecylic acid¹/ C15:0	0.28 ± 0.05	1.18 ± 0.21
Palmitic acid¹/ C16:0	19.27 ± 3.60	26.25 ± 4.90
Margaric acid¹/ C17:0	0.50 ± 0.09	2.30 ± 0.43
Stearic acid¹/ C18:0	10.39 ± 1.94	6.68 ± 1.25
Arachidic acid¹/ C20:0	0.34 ± 0.06	0.66 ± 0.12
Behenic acid¹/ C22:0	0.13 ± 0.02	0.38 ± 0.07
Lignoceric acid¹/ C24:0	0.11 ± 0.02	0.27 ± 0.05
Palmitoleic acid²/ C16:1 ω7	3.42 ± 0.63	4.74 ± 0.88
Sapienic acid²/ C16: 1ω10	-	0.16 ± 0.03
Cis-10-heptadecenoic acid²/ C17:1	0.27 ± 0.05	0.89 ± 0.17
Oleic acid²/ C18:1 ω9	32.36 ± 6.04	22.42 ± 4.19
Vaccenic acid²/ C18:1 ω7	2.15 ± 0.40	4.76 ± 0.89
Gondoic acid²/ C20:1 ω9	0.49 ± 0.09	0.61 ± 0.11
Alpha linolenic acid²/ C18:3 ω3	1.22 ± 0.23	1.26 ± 0.24
Stearidonic acid²/ C18:4 ω3	0.08 ± 0.01	0.11 ± 0.02
Di-homo-alpha-linolenic acid²/ C20:3 ω3	0.22 ± 0.04	-
Eicosapentaenoic acid EPA²/ C20:5 ω3	0.17 ± 0.03	0.43 ± 0.08
Linoleic acid²/ C18:2 ω6	19.88 ± 3.71	6.53 ± 1.22
Gamma linolenic acid GLA²/ C18:3 ω6	0.97 ± 0.18	-
Conjugated linoleic acid CLA²/ C18:2 ω6	0.16 ± 0.30	-
Eicosadienoic acid²/ C20:2 ω6	0.37 ± 0.07	0.36 ± 0.07
Di-homo-gamma-linolenic acid DGLA²/ C20:3 ω6	0.81 ± 0.15	0.35 ± 0.07
Arachidonic Acid²/ C20:4 ω6	1.51 ± 0.27	1.45 ± 0.27
Others*	3.51	8.1
¹Saturated fatty acids (SFAs)	32.41	40.61
²Unsaturated fatty acids (UFAs)	64.08	44.07
Monounsaturated fatty acids (MUFAs)	38.69	33.58
Polyunsaturated fatty acids (PUFAs)	25.39	10.49
Omega 3 (ω3)	1.69	1.8
Omega 6 (ω6)	23.7	8.69
Omega 9 (ω9)	32.85	23.03
Omega 6/omega 3 (ω6/ω3)	14.02	4.82
UFAs/SFAs	1.98	1.08

*Other fatty acids that appeared in minimal amounts when evaluated individually.

According to Van Rooijen et al.,[50] Palmitic acid is responsible for increasing low-density lipoprotein (LDL-cholesterol), thus it is considered hypercholesterolemic in the diet, that is, responsible for increasing the risk of diseases such as obesity and insulin resistance. Although, despite the high value observed, it is a product that will normally be consumed very little daily by individuals, therefore, it is not worrying, mainly because the flour has other important fatty acids in addition to other essential nutrients for the body. Concerning Stearic acid, it can be considered neutral in its effects on lipoproteins.[51]

Total percentage of saturated fatty acids found in this study was 32.41 and 40.61%, respectively, for spine and head flour. Thus, flour with the lowest content of saturated fatty acids can considered of better nutritional quality for human consumption, therefore, the paiche spine. Oleic acid was found in the highest content, among MUFAs of elaborated flours. It is known that MUFAs can help lower the level of total blood cholesterol LDL, and even increase HDL. Nutritious monounsaturated fats can keep your heart rhythm normal and reduce your risk of certain cancers. The consumption of monounsaturated fats helps in the regulation of insulin and blood sugar levels, which is beneficial for the individual, especially for people with diabetes. These fatty acids (Oleic acid), belonging to group of MUFAs that are also rich in vitamin E. Oleic acid according to Hoshino et al.[51] is considered a neutral fatty acid for the risk of hypercholesterolemia (elevation of blood cholesterol levels above 200mg dL^{-1}). However, some authors report that this fatty acid may have a hypocholesterolemic effect, lowering the serum concentration of total cholesterol.

Now discussing about omega 9, it is a MUFAs, being related to healthier triglyceride levels, as well as helping to decrease total blood cholesterol levels LDL and increase HDL. Dietary Reference Intakes recommends an acceptable intake of 1.6 g day^{-1} α-Linolenic acid for men and 1.1 g day^{-1} for women. Consuming paiche flours, to obtain these adequate recommendations, a daily consumption of approximately 130g g^{-1} per day of spine or head flour for men and 89.4g g^{-1} per day for women would be necessary.

Total percentage of omega 3 fatty acids in flours was similar, however for omega 6 fatty acids, the spine flours showed much higher values than the head ones (Table 3). Thus, the omega6/omega3 ratio in fillets and head flour were 4.77 and 4.82, respectively, being considered high. Nonetheless, the ratio for spine flour was much higher than these mentioned values. And value recommended by the Japan Society of Lipid Nutrition for this ratio should be a maximum of 4 to 5/1 for healthy adults, and the ideal should be 1/1 or 2/1. The 2/1 ratio is recommended in prevention of chronic diseases in the elderly.[52] These high values are due to type of fatty acids contained in feed that the fish receives, especially from freshwater, where there is a greater amount of omega 6.[53] In contrast to what was discussed above, Cavali et al.[17,36] report that the western population has a very high omega[6]/omega[3] ratio, reaching 20-30/1. According to these authors, this high ratio is related to multiplicity of vegetable oils available and currently consumed by this population, as they are rich in omega 6.

Souza et al.[19] reported that the flours made with fish by-products had six types of mainly fatty acids, being Oleic (18:1 ω9), Palmitic (16:00), CLA-conjugated Linoleic (18:2 ω6), Docosahexaenoic (22:6 ω3) and Palmitoleic (16:1 ω7) acids in Nile tilapia, salmon, tuna, and sardine flours. Palmitic fatty acid being high in all four flours (21.05g kg^{-1}; 28.83g kg^{-1}; 18.86g kg^{-1} and 16.97g kg^{-1}, respectively), while Oleic (5.16 g kg^{-1}) was much lower than for sardines. Docosahexaenoic acid was higher in marine fish flour (29.81 to 36.49g kg^{-1}). These results are very different from those found in paiche flours.

Through microbiological analysis results, it was possible to verify the quality of the by-products (spine and head) used in the preparation of fish flour, whose values for most probable number (MPN) of coliforms at 35 and 45°C were less than 3 MPN, Colony Forming Unit (CFU) count for *Staphylococcus coagulase positive* was less than $1x10^2$ (CFU g^{-1}) and absent in 25g of sample for *Salmonella* spp. According to Silva et al.[54] Amazonian fish with *Staphylococcus coagulase positive* counts between 105 and 106 CFU g^{-1} are considered highly contaminated and considered unfit for human consumption. Based on these results, none of the samples evaluated represents a potential risk for consumers. Therefore, the importance of good practices in the handling and conservation of flours as a food ingredient should be observed, as they can included in formulations of various products or consumed directly.

According to Mansano et al.[11] environmental factors, such as relative moisture, microbiological water quality and temperature, as well as all factors related to elaborated product (pH, Aw and acidity), also play a fundamental role in the microbiological quality of the final product and can thus compromise the shelf life of the industrialized food product. Therefore, with good microbiological quality, low moisture, and Aw of the flours, as well as pH are very important factors for conservation and storage of the product, guaranteeing the obtaining of a quality final product for consumption and inclusion in food products.

After transforming the paiche skins into leather, with the use of vegetable tannin, they were subjected to tensile strength tests and stretching and progressive tearing, the results of which are shown in Table 5. When analyzing paiche leather between the directions of removal of specimen (longitudinal, transverse and diagonal) the leather showed no significant difference (p <0.05) for thickness, maximum force, progressive tearing (N mm^{-1}) and applied strength to determine tear (Table 5). For deformation, elongation and traction there was a significant difference (p >0.05). The leather in the transverse direction expressed higher tensile strength (13.85 mm^{-2}), higher elasticity (86.2%) and the deformation reached 5.2 cm. This strength observed is due to arrangement and intertwining of collagen fibers. They are superimposed layers of collagen fibers intertwined with each other that provide the highest resistance of the leather when subjected to vegetable tannin tanning.[17] According to Souza et al.[19] and Vilhena et al.[18] the way in which the fibers are arranged in the histological architecture of the skin is possible to determine greater resistance of the leathers.

Table 5 Resistance of paiche (*Arapaima gigas*) leathers tanned with vegetable tannin

Parameters	Direction			p value
	Longitudinal	Transverse	Diagonal	
Thickness (mm)	2.31 ± 0.42^a	2.49 ± 0.45^a	2.46 ± 0.44^a	0.4795
Maximum Strength (N)	302.93 ± 92.82^a	271.53 ± 83.20^a	231.21 ± 70.87^a	0.0763
Deformation (mm)	32.27 ± 8.78b	52.00 ± 14.15a	39.00 ± 10.61b	0.0001
Stretching (%)	57.67 ± 16.15b	86.20 ± 24.14^a	62.57 ± 17.52b	0.0001
Traction (N mm^{-1})^2	12.94 ±3.55ab	13.85 ± 3.80^a	10.09 ± 2.77b	0.013
Tear (N mm^{-1})	46.12 ± 11.97^a	46.54 ± 12.08^a	45.47 ± 11.80^a	0.9714
Tear strength (N)	109.73 ± 23.70^a	110.33 ± 23.83^a	98.64 ± 21.31^a	0.3191

Means in same line followed by standard deviation with lowercase letters differ from each other by Tukey's test (p <0.05).

The thickness varies according to species, habits, and part of animal body. Leathers thickness of paiche analyzed did not showed a significant difference, although when compared with thickness of fish leathers species reported by other authors, this value was much higher.[55,56] Neu et al.[57] analyzed the thickness of different regions of Nile tilapia leather and reported that the mean thickness was 0.68 mm. Also, Matiucci et al.[58] reported thickness of Nile tilapia leather of 0.68 mm, pacu (*Piaractus mesopotamicus*) 0.82 mm and tambaqui (*Colossoma macropomum*) 0.89 mm. It is observed that there is a variation in the thickness of the leathers depending on the species of fish, although it may also be related to region of the skin, tanning agent, among other factors.

Matiucci et al.[58] and Franco et al.[59] analyzed tanning in three different species of fish, Nile tilapia, pacu and tambaqui, where the values found for maximum force to perform the traction and stretching test were 81.06N for Nile tilapia, 153.06 N for pacu and 224 .25 N for tambaqui. These values are lower than the average resistance value showed by paiche leather, which was 268.56 N. Thus, it showes that paiche leather was 19.76% stronger than tambaqui leather, because to break the specimen it needed more strength compared to tambaqui leather, whereas for Nile tilapia leather it was 231.30%. Although, considering leatherd direction, it was the diagonal region that showed a result closer to tambaqui (Table 3).

Concerning leather elasticity, despite paiche leather shown greater elasticity in the transverse direction (86.20%), the average leather elasticity was 68.81%, a value higher than those reported by Matiucci et al.,[58] for Nile tilapia (52.63%), pacu (72.50%) and tambaqui (66.69%) leathers, which was the closest to average elasticity value of paiche leather. However, leathers with greater elasticity were observed by Oliveira et al.[27] These authors reported that Nile tilapia (108.43%) and salmon (111.00%) leathers showed a high elongation value resulting from action of fatliquoring, providing greater resistance and elongation (elasticity) in the leather, improving characteristics physicomechanical properties of this leather. In research by Franco et al.[59] and Oliveira et al.[27] the ratio of oil used by leather thickness was 9.33, while in this study with paiche, despite a higher percentage of oil used in the fatliquoring stage, when observed the ratio with leather thickness was much lower (4/13). Therefore, the greater amount of oil fixed on leather as a function of its thickness, the better elasticity results.

For leather traction, despite the diagonal direction shown less resistance, the average value of leather traction was 12.29 N mm^{-2}. These resistance values are much lower than those of other leathers reported by Oliveira et al.[27] Despite the greater thickness of paiche leather, Nile tilapia (22.17 N mm^{-2}), cachara *Pseudoplatystoma fasciatum* (21.04 N mm^{-2}) and salmon (18.21 N mm^{-2}) leathers were more strength, and these leathers were 80.39, 71.20 and 48.17%, respectively, more strength than paiche leather.

When comparing the mean values obtained for determination of progressive tearing (N mm^{-1}) of paiche leathers (46.04 N mm^{-1}) in this study, it is observed that they were much lower than those reported by Oliveira et al.[27] The authors reported for Nile tilapia 79.17 N mm-

[1], cachara *P. fasciatum* 82.36 N mm^{-1} and salmon 105.69 N mm^{-1}. This must also be related to action of the grease applied by authors. Matiucci et at.[58] showed values of 63.72 N mm^{-1} for pacu, 80.01 N mm^{-1} for tambaqui, these values were also higher than those of paiche, although for Nile tilapia the value was lower (40.18 N mm^{-1}).

Through this analysis leathers resistance, it can be inferred that the paiche leathers can used to make clothing, as concluded by Cavali et al.,[36] because according to quality requirements for bovine leather for clothing (established by the Specification Commission of the Leather Institutes of Ceará state) the tensile or tensile strength must be 12 N mm^{-2} (IUP6/DIN 53328) and tear 15 N mm^{-1} (IUP8/DIN 53329). However, there are no records specifying for fish leathers. It is only possible to compare with the results found for bovine leather. Also, there is already a reference that mentions that bovine leather tanned with chromium salts must have at least 9.80 N mm^{-2} of tensile strength to be used for making clothing.[60] Given this information, paiche leathers tanned with vegetable tannin can used to make clothing, be used for shoes, despite requiring greater resistance in the leather, although it can be supplied with the use of coating that helps in the leather resistance for this purpose end, as well as Cavali et al.[17] and Vilhena et al.[18] concluded. It is also an excellent alternative for use in bags, wallets, and accessories in general.

Most importantly, the resistance regardless quality of the paiche leathers, its beauty, resulting from its protective lamellae and insertion of the scales, is an inimitable characteristic that most values this type of leather, determining the better economic value, as well as the size of that leather.[59] The size and depth of the lamellae protecting and inserting the scales become more noticeable and interesting, forming a unique and specific mosaic for use in making bags and shoes.[17,18,61]

Conclusion

In addition to nutritional quality and high fillet yield, paiche (*Arapaima gigas*) generates by-products with great potential for use, due to their microbiological and nutritional quality. Part of the by-products can be used in the preparation of flours for inclusion in food products of low nutritional value, providing enrichment, due to the high biological quality of the protein, minerals, lipids, with an excellent profile of unsaturated fatty acids, especially Oleic acid, in addition to of polyunsaturated. Leather, tanned with vegetable tannin, has a high quality of resistance. These paiche processing by-products add more value to the production chain of this species, in addition to gaining a more noble and ecologically suitable destination, avoiding the environmental impact resulting from the improper disposal of these by-products.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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