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Artisanal Production and Stability of Flour and Ash from *Plagioscion* spp. Residues

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Abstract

The production of flour and ash from Amazonian fish residues is a valuable strategy for valorizing by-products from the regional fish processing industry. These by-products can be repurposed in the manufacture of animal feed or agricultural fertilizers, thereby contributing to reduced environmental impacts. In this context, this study investigated the production and stability of these by-products from filleting residues of South American silver croaker, collected in local fish processing facilities. Hot bath and hot plate cooking methods were applied using various combinations of processing parameters (water-to-fish ratios, cooking time, temperature, and drying duration). The resulting products were packaged appropriately and then evaluated for yield and moisture content, as well as for sensory characteristics throughout storage, to evaluate the overall efficiency of each method. The results demonstrated efficient production of both flour and ash, with optimal flour production achieved using the hot plate method combined with extended drying time, which exhibited low moisture content and remained microbiologically stable at room temperature. The artisanal production of flour and ash from Amazonian fish residues using these methods represents a promising alternative that contributes to environmental sustainability and promotes the valorization of Amazonian fishery resources.

Keywords: co-products, fish, processing, sustainability, utilization

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Producción artesanal y estabilidad de harina y ceniza de residuos de *Plagioscion* spp.

Resumen

La producción de harina y ceniza a partir de residuos de pescado amazónico constituye una estrategia valiosa para la valorización de subproductos de la industria regional de procesamiento de pescado. Estos subproductos pueden reutilizarse en la elaboración de alimentos para animales o fertilizantes agrícolas y contribuyen a la reducción de impactos ambientales. En este contexto, este estudio investigó la estabilidad de producir dichos subproductos a partir de residuos de fileteo de la pescada sudamericana, recolectados en plantas locales de procesamiento. Se aplicaron los métodos de cocción en baño caliente y en plancha caliente, utilizando diversas combinaciones de parámetros de procesamiento (proporciones agua-pescado, tiempo de cocción, temperatura y duración del secado). Los productos obtenidos fueron envasados adecuadamente y evaluados en cuanto a rendimiento y contenido de humedad, así como en cuanto a sus características sensoriales durante el almacenamiento, para valorar la eficiencia general de cada método. Los resultados demostraron una producción eficiente tanto de harina como de ceniza, con resultados óptimos para la harina obtenida mediante el método de plancha caliente y con tiempos de secado prolongados, que presentaron bajo contenido de humedad y se mantuvieron microbiológicamente estables a temperatura ambiente. La producción artesanal de harina y ceniza a partir de residuos de pescado amazónico, y aplicando este método, representa una alternativa prometedora que contribuye a la sostenibilidad ambiental y promueve la valorización de los recursos pesqueros amazónicos.

Palabras clave: coproductos, pescado, procesamiento, sostenibilidad, aprovechamiento

Produção artesanal e estabilidade da farinha e cinza de resíduos de *Plagioscion* spp.

Resumo

A produção de farinha e cinza a partir de resíduos de peixes amazônicos é uma estratégia valiosa para a valorização dos subprodutos da indústria frigorífica pesqueira regional. Estes subprodutos podem ser usados na fabricação de rações ou fertilizantes agrícolas, além de contribuir para a redução de danos ambientais. Neste contexto, o presente trabalho investigou a produção e estabilidade desses subprodutos a partir de resíduos do fileteamento do peixe pescada, coletados em frigoríficos locais. Para a produção, foram utilizadas as formas de cocção banho quente e chapa quente em diversas combinações de fatores (proporção entre água e resíduos, tempo de cocção, temperatura e tempo de secagem). Os produtos foram apropriadamente embalados e neles foram analisados rendimento e umidade, assim como características sensoriais dos produtos durante a estocagem, com o intuito de avaliar a eficiência de cada cocção. Os resultados demonstraram que a produção de farinha e cinza foi eficiente, com ótima produção pelo método de cocção chapa quente e empregando maior duração do tempo de secagem, e estas exibiram baixa umidade e se mantiveram microbiologicamente estáveis em temperatura ambiente. A produção artesanal de farinha e cinza a partir de resíduos de peixes amazônicos, utilizando o método chapa quente, representa uma alternativa promissora, que contribui para a sustentabilidade ambiental e promove a valorização dos recursos pesqueiros da Amazônia.

Palavras-chave: coprodutos, peixe, processamento, sustentabilidade, aproveitamento

1. Introduction

Overall, fish consumption in Brazil remains low (Ouriveis et al., 2020), approximately 5.7 kg per capita in 2017-2018 (Wagner et al., 2023), with 53.4% of 88,571 Brazilian adults reporting no weekly fish consumption (Santin et al., 2022). However, regional analyses indicate that Brazil's North region exhibits the highest consumption levels, with 70.7% of 1,093 Northerners adults preferring fish to other meats, whereas red meat predominates in the remaining four geographic regions (Lopes et al., 2016).

Santarém, a city located in the Western portion of Pará State (part of the North region of Brazil), is among the leading centers for the purchase of fresh fish, supplying regional processing facilities (Pereira et al., 2019). In Santarém's market, the South American silver croaker (*Plagioscion squamosissimus* Heckel, 1840) is among the most consumed fish species, extensively used by the local processing industry for fillet production (Coelho, 2023).

Increased fish consumption leads to a higher volume of processing residues, which vary depending on the degree of processing applied (Rodrigues et al., 2024). Some species are eviscerated immediately after capture as a strategy to preserve quality, and their residues are discarded directly into the water bodies from which the fish were harvested. When fish is filleted and, in some cases, skinned, additional residues such as skin and bones with attached flesh are generated. These can account for up to 50% of the original fish mass and are often not separated for disposal in landfills or recycling systems (Rodrigues et al., 2024; Silva et al., 2020).

Although organic residues can be naturally degraded over time, ecological imbalances occur when their accumulation exceeds the environment's assimilation capacity. Therefore, adopting efficient alternatives for utilizing fishery residue, like those described below, offers a competitive advantage through product diversification and income generation, while also contributing to environmental sustainability and socio-environmental responsibility (Murakami et al., 2024; Nascimento & Pinto Filho, 2021; Naves, 2019).

For human consumption, Figueiredo et al. (2023) reported the viability of minced fish from mapará (*Hypophthalmus* spp.) filleting residues for fish burger production, obtaining high consumer acceptance, potential low cost of production, and high index of monetary aggregation. Correa et al. (2022) developed flavoured flour from pirarucu (*Arapaima gigas*) residues and incorporated it into extruded snacks, reporting higher acceptance than products made with standard flour.

For agricultural applications, Ahuja et al. (2020) indicated that fish processing residuals can be processed in several ways: emulsions, enzymatic hydrolysates, microbial fermentation products, or acidic silage. These processes enable the production of both liquid and solid fertilizers and allow combination with other ingredients to produce fish-based composts, digestates, or fish waste-seaweed fertilizers. Such products represent a promising source of raw materials that may replace, for example, the dried poultry manure currently applied.

Ciptono and Khoir (2022) produced fish flour from fisheries waste from the Cirata Reservoir, mixed it with vegetable residues, and used it to produce a bokashi organic fertilizer. When applied to *Ipomoea reptans* plants, the fertilizer containing 30% fish flour resulted in higher growth rates, greater plant height, and increased plant weight compared with other treatments. Industrially, the production of flour and/or ash requires simple and accessible techniques, whereas artisanal production often requires adaptation or even elimination of certain processing steps. However, these adjustments remain largely underexplored in Brazilian research, particularly concerning the use of Amazonian fish residue.

This study aimed to partially characterize and identify the most effective method for the artisanal production of flour and ashes from Amazonian fish residues, focusing on potential agricultural applications. Specifically, it evaluates the percentage yield and moisture content of both products, determines shelf life through sensory analysis under ambient storage conditions, and, for flour, identifies the most efficient production method based on cooking and drying steps.

2. Materials and Methods

2.1 Sample Collection and Handling for Unwashed Minced Fish Residue (UMFR) Production

Residues of South American silver croaker (*Plagioscion* spp.) (head, bones, viscera, scales, skin, and fins) (Figure 1A) were collected from local fish-processing facilities in Santarém, Pará, Brazil. This species, locally known as "pescada", was selected because it is widely marketed year-round in the Brazilian North region, despite seasonal variations. It also has low lipid content, is highly commercialized, and is extensively used in local facilities for fillet production (Pereira et al., 2019).

The residues were collected over five days during the filleting of different batches of this fish species. Each day, an unquantified portion of the processing residues was separated until a sufficient volume to fill two sacks per day. At the end of the collection period, the total mass obtained was 77.5 kg.

These residues were transported in insulated containers to the Laboratório de Microbiologia e Processamento do Pescado (Laboratory of Microbiology and Fish Processing) of Universidade Federal do Oeste do Pará (Federal University of Western Pará) and kept refrigerated until grinding (Figure 1B). The total mass collected was fractionated into twelve lots. Each lot was individually ground in an industrial mill, resulting in the unwashed minced fish residue (UMFR). Each lot of UMFR was subdivided into three replicates of approximately 1.5 kg each. UMFR replicates were placed in rectangular plastic bags (60 × 40 cm), filled to about 40 × 40 × 5 cm (length × width × height), and stored at −18 °C until use in flour and ash production.



Figure 1. South American silver croaker residues: A) chilled on the day of collection, B) ground, C) under hot plate cooking, D) under hot bath cooking, and E) converted into ash

2.2 Flour Production from UMFR

Flour was produced from thawed UMFR using twelve treatments, each conducted in triplicate. Treatments varied according to cooking method [hot bath (HB) or hot plate (HP)], water-to-fish ratio (two levels, applied only to HB), drying temperature, and drying time (two levels for each factor, applied to both cooking methods). Details of each treatment are provided below and summarized in Table 1.

Table 1. Experimental treatments to produce flour and ash from South American silver croaker (*Plagioscion* spp.) residues using hot bath (HB) and hot plate (HP) methods

Cooking method	Water-to-UMFR ratio*	Cooking time (min)**	Drying temperature (°C)***	Drying time (min)**	Experimental identification (treatments)
Flour from fish residues					
Hot bath	3:1	20	180	120	HB.R3.D180.120M
	4:1				HB.R4.D180.120M
	3:1			240	HB.R3.D180.240M
	4:1				HB.R4.D180.240M
	3:1		200	120	HB.R3.D200.120M
	4:1				HB.R4.D200.120M
	3:1			240	HB.R3.D200.240M
	4:1				HB.R4.D200.240M
Hot plate	n.a.****	20	180	120	HP.T20.D180.120M
		45		240	HP.T45.D180.240M
		20	200	120	HP.T20.D200.120M
		45		240	HP.T45.D200.240M
Ashes from fish residue					
Hot plate	n.a.****	120	n.a.****	n.a.****	AS.HP.120M

* Water-to-fish (unwashed minced fish residue, UMFR) ratio, in volume (liter) and weight (kilo); ** minutes; *** Celsius degree; **** n.a. = not applied in this cooking method.

According to Gonçalves and Nunes (2021), HB cooking is recommended for raw materials with lipid content greater than 3%, whereas HP, for those with lower lipid. Additionally, the water-to-fish ratio is also considered an important processing parameter. In the present study, regardless of the lipid content of the South American silver croaker residues, both cooking methods and water-to-fish ratios were used to investigate the potential effects of temperature on the nutritional characteristics of the resulting flours.

Furthermore, for the drying step, temperatures of 180 °C (Stevanato et al., 2007) and 200 °C (Ferreira, 2021) were used in the laboratory tests, as they can be reproduced in conventional ovens, even by small-scale farmers with limited financial resources.

2.2.1 Hot Bath (HB) Cooking of UMFR

The UMFR was mixed with clean water in two water-to-fish ratios (3:1 or 4:1, coded as R3 and R4, respectively, Table 1), each tested separately. At this stage, some fish agglomerates tended to form at the beginning of cooking but were dispersed through vigorous stirring in the heated water.

To maintain uniform temperature throughout the bath, gentle manual stirring (using a large spoon) was applied every five minutes until boiling was reached. Cooking was conducted at approximately 100 °C for 20 minutes, measured from the onset of boiling, which was indicated by the upward movement of solid particles to the surface.

2.2.2 Hot Plate (HP) Cooking of UMFR

The HP cooking technique was developed in this study as an innovative method. This method was adapted to laboratory conditions using a plow disk, simulating the metal pans traditionally employed for cassava flour production, a practice widely disseminated in northern Brazil. This adaptation aimed to make the technique more

accessible and reproducible for broader application. In this HP method, no additional water was used, and temperature was not monitored; instead, cooking time was controlled (Figure 1C).

The UMFR was spread over the surface of the heating plate (plow disk) and stirred until all visible water from the sample had evaporated. The first triplicate was heated for 20 minutes (coded as T20) and the second for 45 minutes (coded as T45). The resulting material was then distributed in metal trays for drying under the same conditions applied to the HB flour, as detailed below.

2.3 Drying of Flour from HB and HP Cooking Methods

Triplicates of the partially dried flours were spread in uniform layers on metal trays and placed in a static-air drying oven, which operates similarly to a conventional oven, to evaluate suitable drying temperature and times. In separate treatments, samples were dried at 180 °C and 200 °C (coded as D180 and D200, respectively), with exposure times of 120 and 240 minutes (coded as 120M and 240M, respectively).

During drying, all samples were stirred every 30 minutes to ensure uniform heat exposure. Additionally, to minimize the influence of potential non-uniformity in the oven's internal temperature, the trays were rotated so that each occupied the lowest position closest to the heat source at least once.

2.4 Ash Production

Ash (AS) was obtained by burning approximately 300 g of South American silver croaker UMFR per replicate on a metallic surface (plow disk) on a low-pressure stove flame. The temperature of this operation was not monitored, as the objective was to obtain a dry, reduced product that was black, no longer emitting smoke, and easily ground into powder (Figure 1E).

Under these conditions, eight replicates were processed, each reaching the described characteristics after two hours. For identification, the ash produced in this study was coded as AS.HP.120M (Table 1).

2.5 Packaging and Storage of HB, HP, and AS Products

All products were allowed to cool completely in the same containers used during their preparation. No preservative supplements were added. After cooling, samples of flours and ash designated for moisture analyses were separated into plastic containers with lids or common plastic bags.

Other samples, intended for sensory stability analysis, were placed in common plastic bags and manually spread to form a uniform rectangular prism to facilitate stacking. These samples were then sealed using a conventional heat-sealing device, with sufficient care to ensure that the atmospheric air inside the package was substantially reduced before sealing, while maintaining the rectangular prism shape.

Some samples could not be stored in a dry and fresh environment as initially intended; however, the reasons for this decision are explained in the Results and Discussion section.

2.6 Yields of HB, HP, and AS Products

The average yield (expressed as a percentage) was calculated as the ratio of each product weight to raw material weight used in each treatment, adapted from the descriptions provided by Serrão and Atayde (2020), Atayde et al. (2021), and Figueiredo et al. (2023).

2.7 Moisture Content of HB, HP, and AS Products

This parameter was determined using the gravimetric oven-drying method, through weight loss by desiccation, until constant weight was reached in a static-air oven (Atayde et al., 2021), beginning after 7 days of storage. Analyses were performed in triplicate for each treatment.

Moisture percentage was calculated using the specific formula provided in Adolfo Lutz (Zenebon et al., 2008).

2.8 Sensory Stability of HB, HP, and AS Products

The products obtained in this study were subjected to weekly sensory analysis to evaluate their attributes for sensory stability assessment, beginning on the first day of storage. Due to the unavailability of appropriate equipment, only sensory aspects were assessed, using sight, smell, and touch as evaluation criteria. No reference samples of flour or ash were available for comparison.

Therefore, qualitative characteristics considered desirable for each product after 20 days of storage at room temperature were defined based on commonly accepted quality descriptions reported in Food and Drugs Administration – FAO (Food and Agriculture Organization of the United Nations, 1986), Gonçalves and Nunes (2021), and Koning (2005), as described below.

For flour:

a) free-flowing powdery appearance, with grain sizes ranging from small to minute;

b) little or no visible moisture sheen or apparent fat;

c) characteristic odor of dried fish, strong but not unpleasant;

d) no color changes;

e) no apparent microbial (fungal or bacterial) growth.

For ash:

a) loose appearance, with very fine granulation;

b) little or no sheen or apparent fat;

c) characteristic odor of burnt meat;

d) no color changes over time;

e) no apparent microbial (fungal or bacterial) growth during storage.

2.9 Statistical Analysis

Raw yield and moisture data were submitted to descriptive and inferential statistical analysis using PAST software, version 3.14 (Hammer et al., 2001), at a 5% significance level.

3. Results and Discussion

The average yield, moisture content, and sensory characterization of flour and ash after 20 days of storage, together with their shelf-life viability, are summarized in Table 2 according to the applied treatments.

Table 2. Yield, moisture indexes, sensory characterization, and sensory stability of flours and ash from South American silver croaker (*Plagioscion* spp.) residues

Treatments	Yield* (%)	Moisture* (%)	Sensory characterization**	SS***
Flour from fish residue				
HB.R3.D180.120M	39.61 ± 7.36	(-) ****	A	Unstable
HB.R4.D180.120M	41.33 ± 3.87	(-) ****	A	Unstable
HB.R3.D180.240M	37.44 ± 2.11	40.98 ± 2.90	A	Unstable
HB.R4.D180.240M	29.23 ± 4.12	(-) ****	A	Unstable
HB.R3.D200.120M	31.74 ± 5.74	(-) ****	A	Unstable
HB.R4.D200.120M	36.53 ± 2.45	43.17 ± 0.45	A	Unstable
HB.R3.D200.240M	19.95 ± 0.62	3.55 ± 0.45	B	Stable
HB.R4.D200.240M	19.12 ± 2.32	5.03 ± 0.11	B	Stable
HP.T20.D180.120M	36.07 ± 2.07	(-) ****	A	Unstable
HP.T45.D180.240M	26.16 ± 0.68	2.08 ± 0.19	B	Stable
HP.T20.D200.120M	(-) ***	(-) ****	A	Unstable
HP.T45.D200.240M	26.61 ± 0.82	2.79 ± 0.10	B	Stable
Ash from fish residue				
AS.HP.120M	14.50 ± 2.30	1.96 ± 0.25	C	Stable

*Mean ± standard deviation; **In this column, capital letters means: A = predominantly flocculated appearance, clumped, no uniform powder, strong sheen, initially cooked fish odor progressing to putrid, color changed from brown to darker shades, fungal growth observed over time; B = uniform dry powder, without strong sheen, odor of dried fish, stable reddish-brown color, no fungal growth observed; C = powdery aspect, characteristic sheen, slight odor of burnt fish, black or grayish color, no fungal growth observed.; *** Sensory stability; (-)**** = not calculated due to rapid spoilage.

3.1 Yields Analysis of HB, HP, and AS Products

In the present study, yield values for HB and HP flours ranged from 19.12% to 41.33%, which were consistent with or exceeded the ranges reported by Gonçalves and Nunes (2021). The lowest yield obtained here suggests that the processing operations adopted did not compromise the product quality. In contrast, the highest yields, when analyzed together with the corresponding moisture levels (in the flour where this parameter could be measured), confirmed the inadequacy suggested by those authors, since flour yields above 25% were later deemed unstable due to fungal growth.

As the data followed a normal distribution, a parametric inferential statistic (Student's t-test) was applied, with results summarized in Table 3. The factors of cooking method and water-to-fish ratio (for HB flours), as well as the drying temperature (for HP flours), were not significant for average yield. In other words, the tested variations did not cause substantial changes in flour yield. However, when each cooking method was considered separately, drying temperature (for HB) and cooking time (for HP) had a statistically significant effect. In both cases, higher values of these factors (temperature and time) led to reduced flour yield.

When considered individually, drying time significantly affected the yield for both cooking methods. In both cases, longer heat exposure resulted in greater yield reduction, likely due to more efficient moisture removal. For ash, although the artisanal burning conditions used in the present study have not been previously described in the literature, they likely contributed to the observed yield, which falls within the range reported in previous studies (11.59% - 19.40%) (Ferreira, 2021; Stevanato et al., 2007).

Table 3. Results of Student's t-test for mean yields of South American silver croaker (*Plagioscion* spp.) residue flours and their associated factors

Factors	Mean yield* of factors	t-value	Df	p-value**
Influence of cooking method (HB *vs* HP)	31.87 ± 8.87 *vs* 29.61 ± 4.99	0.92	25	0.368
Influence of water-to-fish ratio in HB (R3 *vs* R4)	32.18 ± 8.95 *vs* 31.55 ± 9.18	0.17	21	0.866
Influence of drying temperature in HB (180 *vs* 200 °C)	36.90 ± 6.32 *vs* 26.84 ± 8.34	3.33	20	0.003
Influence of drying time in HB (120 *vs* 240 min)	37.30 ± 5.84 *vs* 26.43 ± 8.13	3.76	19	0.001
Influence of cooking time in HP (20 *vs* 45 min)	36.07 ± 2.07 *vs* 26.39 ± 0.72	7.88	2	0.016
Influence of drying temperature in HP (180 *vs* 200 °C)	31.12 ± 5.60 *vs* 26.60 ± 0.82	1.94	5	0.111
Influence of drying time in HP (120 *vs* 240 min)	36.07 ± 2.07 *vs* 26.39 ± 0.72	7.88	2	0.016

* Mean ± standard deviation; ** In lines, p-value < 0.05 indicates a statistically significant difference in flour yield for the method/factor analyzed.

Rao and Kamasastri (1971), studying sun-dried fish flours, reported even higher ash content, ranging from 22.62% to 34.79%. However, these values were obtained as part of the proximate composition of the products, and the burning procedure used to determine them was conducted at temperatures above 550 °C in a muffle furnace. These temperatures and equipment represent analytical conditions considerably more controlled than those applied experimentally in the present study, which may have influenced this difference.

Although yield is affected, maximizing fish flour yield regardless of other factors is not a reliable strategy for obtaining a high-quality product.

3.2 Moisture Content Analysis of HB, HP, and AS Products

For moisture content (Table 2), some values obtained for the HP flours (when measurable) were below the recommended range of 5 to 10% established by Koning (2005).

For HB flour, moisture could not be determined in most treatments due to product spoilage, which occurred within one week of observation. In the single HB treatment in which moisture was measurable, the value was extremely high, greatly exceeding the ideal range reported by Koning (2005), and the product deteriorated after 12 days of storage. This, in association with other nutritional factors (not investigated or quantified in the present study), may have contributed to sensory alterations discussed later in the Sensory Stability Assessment section.

For HP flour, treatments with shorter drying times did not allow moisture determination either. Conversely, in those subjected to longer drying times, all samples exhibited moisture values markedly below the recommended range, similar to values typically observed for ash.

The initial sensory characteristics observed in HB and some HP flours (Table 2) –still lumpy after grinding, shiny and heavy, with a moist appearance– indicated this outcome. The time-heat combination employed was insufficient to reduce the moisture properly and stabilize the products.

Only the HP treatments with higher drying temperatures (200 °C) and longer drying durations (240 minutes) showed moisture values below the recommended range, and their sensory characteristics aligned with the pre-established ideal standards; therefore, their adoption is recommended in artisanal production.

Koning (2005) noted that very dry fish flours, such as those produced in this study, are hygroscopic and susceptible to spontaneous combustion. This suggests two possible requirements: (a) adjustment of the production process, or (b) the adoption of moisture-resistant packaging, preferably impermeable and vacuum-sealed, for safer storage.

The determination of moisture in food products enables the identification of quality standards and helps assess potential microbiological risks associated with product water content (Ferrato, 2022). High moisture levels in foods, such as those observed in most of the flours analyzed in this study, promote accelerated spoilage, as observed in the present study, leading to alterations in texture, nutritional value, and chemical and enzymatic reactions (Paula, 2009). In the present study, HB flours were considered lower in quality and more susceptible to these alterations than HP flours, likely due to their higher moisture content.

For the moisture content of the flours in this study, inferential statistical analyses indicated significant differences between cooking methods (HB vs. HP, $p = 6.723 \times 10^{-6}$) and among treatments within each method ($p = 5.501 \times 10^{-28}$ for HB; $p = 3.654 \times 10^{-8}$ for HP).

3.3 Sensory Characterization and Stability Assessment of HB, HP, and AS Products

For product stability assessment, according to the initial sensory characterization, the flours were stored under different conditions.

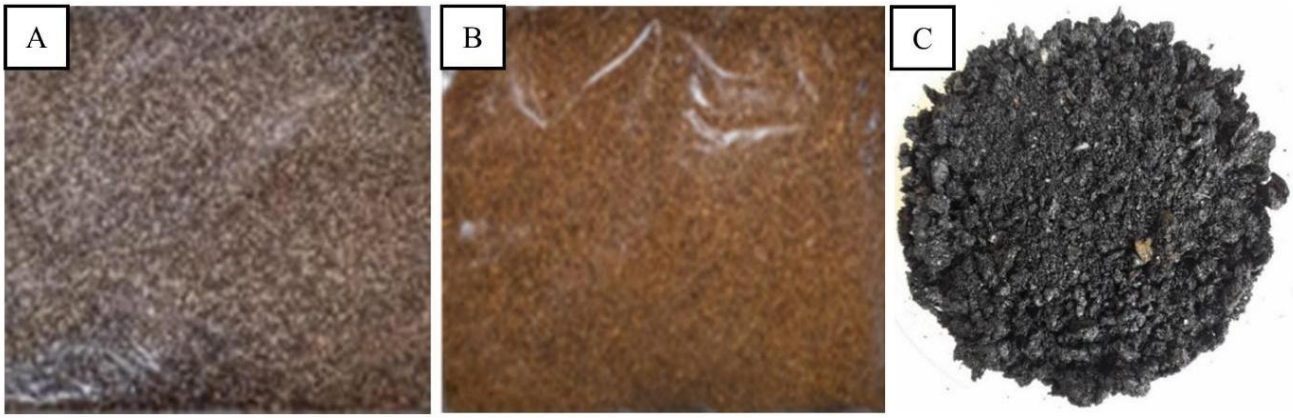

Figure 2. Flours from A) hot bath, B) hot plate, and C) Ash

Only HB and HP flours produced under higher cooking and, mainly, higher drying temperatures (Figure 2A and 2B) exhibited initial characteristics consistent with the desirable standards (Table 2) and were therefore stored at room temperature (25-30 °C), which is desirable for commercial application. These products, as well as the ashes (Figure 2C), exhibited low initial moisture content and maintained the pre-established desirable sensory characteristics (Table 2) throughout storage.

In contrast, all flours dried during 120 minutes (Table 2) exhibited sensory characteristics markedly different from the pre-established desirable standards and these were therefore stored under refrigeration (5-7 °C). This preservation method is undesirable or not suitable for products intended for use as fertilizers or feed ingredients because of its high operational cost.

Even under refrigeration, products whose initial or final characteristics deviated from the desirable criteria deteriorated over time and were therefore considered unstable, mainly due to evident fungal growth (Figure 3).

Fungal germination and spore development are inhibited under low-moisture conditions, which limits the availability of resources required for hyphal attachment and nutrient absorption, thereby reducing fungal persistence (van Laarhoven et al., 2015). In the present study, fungal colonies were observed only in flours with high moisture content, and this moisture level was not significantly reduced due to insufficient temperature or heat exposure time. This condition, together with the nutritional composition of the flours (not investigated here), likely favored microbial growth.

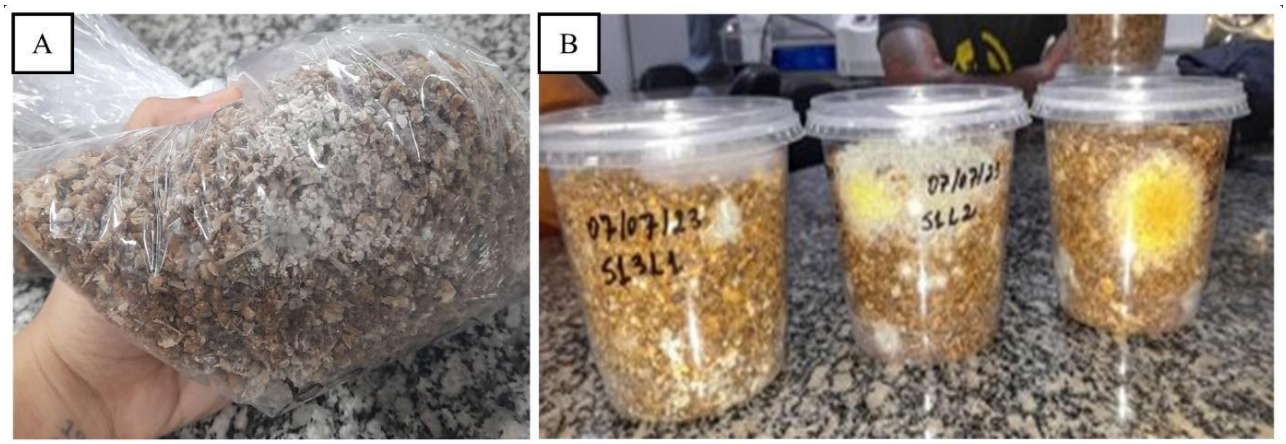

Figure 3. Microbial contamination in flours obtained by A) hot bath and B) hot plate

Technical literature recommends the use of sun exposure for drying fish flours (Oosthuizen et al., 2020; Rao & Kamasastri, 1971). However, as demonstrated by Parussolo et al. (2019) in food production environments, the airborne fungal genera with high proteolytic capacity pose significant contamination risks in products like the flour obtained in this study. Thus, sun drying was not considered in this study.

The beneficial effects of the symbiosis between fungi and the roots of cultivated plants have been well documented by several researchers, including Vieira et al. (2021). However, if fungal growth occurs before this association, as observed in the unstable flours of this study, the efficiency of the symbiosis will be compromised.

No sensory alterations were observed in the flours subjected to the longest drying time, indicating that these production conditions were the most suitable. For AS, a stable product was obtained despite the single treatment applied. It should be noted that all products considered stable in this study maintained their original sensory characteristics for at least 6 months after the initial sensory stability assessment reported here. This finding strengthens the applicability of the artisanal techniques described in this study.

Therefore, the proper production of fish residue flour with extended shelf-life, as obtained in this study, may enable multiple uses beyond its traditional use in animal feed, including its application in composting to obtain organic fertilizers, as reported by Ciptono and Khoir (2022). However, further analyses –such as proximate composition analysis, macro- and microelement quantification, and microbiological enumeration— are required before such uses to ensure safety for agricultural uses and human handling.

4. Conclusions

This study demonstrated that the production of flour and ash from residues of South American silver croaker (*Plagioscion* spp.) is efficient with the hot plate method, cooking for 45 minutes, plus 240 minutes drying at 180-200 °C. Ash production through combustion proved to be a simple and efficient approach. These production conditions can be reproduced in artisanal settings and result in products with satisfactory yield, appropriate sensory characteristics, low moisture content, and sensory stability for at least 6 months. Hot bath for 20 minutes, plus 240 minutes drying at 200 °C also reached sensory stability, although at a lower yield. An additional positive aspect of these techniques is their contribution to environmental sustainability, by reducing waste and environmental damage and promoting resource recycling for local agricultural production.

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Transparency of Data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author Contribution Statement

	JP Ribeiro	VV Feitosa	JMA Guimarães	DDC Fonseca	LIF Pereira	HM Atayde
Conceptualization	■					■
Data curation	■		■	■	■	■
Formal analysis	■					■
Funding acquisition						■
Investigation	■	■	■	■	■	■
Methodology	■	■	■	■	■	■
Project administration	■					■
Resources						■
Supervision	■					■
Validation	■	■				■
Visualization	■	■	■	■	■	■
Writing – original draft	■	■				■
Writing – review and editing	■					■

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