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Development and characterization of fish nuggets obtained from mechanically separated meat of spotted sorubim

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Abstract. The fish industry has recently sought to diversify its product offerings to meet high consumer demand beyond just fresh fish. The use of mechanically separated fish meat (MSM) enables the production of various products, including breaded items. This study aimed to develop fish nuggets using MSM from spotted sorubim (*Pseudoplatystoma corruscans*) as the primary raw material, utilizing various formulations, and to evaluate the pH, shear force, microbiological safety, and sensory attributes of the developed products. The varying ingredients (4%) were bamboo fibre (F_1), collagen fibre (F_2), and textured soy protein (F_3). The average pH of 6.5 showed no statistical difference between formulations ($p > 0.05$), indicating that the varying ingredients did not affect this parameter. However, shear force varied significantly ($p < 0.05$), with the highest value of 8.82 N observed for F_3. Sensory analysis revealed no significant differences ($p > 0.05$) between formulations for most attributes, except for taste, where F_1 scored higher than F_2 and F_3. The acceptance index was above 80% for all formulations. F_1 showed the highest "certainly would purchase" response at 26.7%. Both F_1 and F_3 had a combined acceptance rate of 60% for "certainly and probably would purchase", while F_2 had a 50% acceptance rate. The results suggest that taste plays a crucial role in the sensory acceptance of the nuggets, with bamboo fibre positively enhancing flavour.

Keywords and phrases: fish waste, texture, sensory analysis

1. Introduction

The view of fish as an excellent source of protein for maintaining good health has garnered significant recognition (*Chen et al.*, 2022). Unfortunately for Brazil, people's average consumption of fish is still very low: at under 10 kg consumed each year.

Brazil's per capita fish consumption ranks well below the worldwide average (20.5 kg per year). It also falls below the European average (21.1 kg per year) and the Asian average (24.6 kg per year) (*FAO*, 2022). The low fish consumption in Brazil is attributed to a lack of public awareness about the health benefits of fish consumption, economic factors, and social/cultural practices that favour other protein sources (*Mitterer-Daltoé et al.*, 2013; *Lopes & de Freitas*, 2023). The past performance of China is representative of the potential for future growth in fish consumption, as the annual per capita consumption saw great improvement, increasing from 4.2 kg in 1961 to 40.1 kg in 2019 (*FAO*, 2022). One of the most effective ways to stimulate increased fish consumption in Brazil would be to increase the availability of convenient/prepared fish items to the public for purchase.

In Brazil, some of the fresh-water fish most consumed are tilapia, tambaqui, and pacu, while imported salmon is the marine fish species most widely consumed, reflecting both local aquaculture production and market availability (*Lopes and de Freitas*, 2023). *Pseudoplatystoma corruscans*, commonly known as the spotted sorubim, is another highly valued indigenous species that occupies a large portion of the La Plata and São Francisco River basins. The fish is widely known for its mild flavour, firm flesh, and lack of intrinsic bones (*Faustino et al.*, 2010; *Pachla et al.*, 2020).

In commercial applications, a significant portion of the total weight of fish is discarded during processing. Depending on the species, the technique of removal from the bone, and the quality of the fillet, up to 70% of the total weight may be discarded as unwanted by-product. However, there is an opportunity to recover this underutilized portion of meat from the fish processing and transform it into an acceptable product, e.g. by obtaining mechanically separated meat (MSM) (*Azambuja et al., 2025*). Given their versatility and cost-effectiveness, MSM is becoming a popular way to maximize resource utilization and create new and innovative convenience products. It serves as a viable intermediate ingredient in various types of products, including fish burgers, fish sausages, and fish-breaded products (*Adrah & Tahergorabi*, 2022). The term "breaded product" generally refers to an industrial food derived from a variety of sources, either moulded or simply coated with a suitable breading to improve the product's appearance and/or texture. Fish nuggets are an example of moulded/processed fish products that are breaded and then fried or baked (*Oppong et al.*, 2021), providing a convenient, shelf-stable product that is accepted by a wide range of consumers (*Panza et al.*, 2020).

Functional ingredients are often added to restructured fish products to enhance their texture, moisture retention, and structural integrity (*Cavenaghi-Altemio & Fonseca*, 2024a–b). In this study, three different ingredients were compared for their respective technological uses: bamboo fibre (which can both facilitate moisture retention and reduce oil absorption) (*Kučerová et al.*, 2013), collagen fibre, which aids in improving binding capabilities and the firmness of restructured fish products

(*Cavenaghi-Altemio et al.*, 2024), and textured soy protein, which adds proteins as well as aids in creating a structural framework (*Angor & Al-Abdullah*, 2010). Testing these functional ingredients enabled a comparison of how they all function in improving the quality of restructured products obtained from MSM of sorubim fish.

Therefore, this study aimed to develop breaded products (nuggets) using MSM from spotted sorubim as the main raw material, to test different functional formulations, and to evaluate their pH, shear force, microbiological safety, and sensory attributes.

2. Materials and methods

2.1. Mechanically separated meat (MSM) of spotted sorubim

Carcasses of spotted sorubim (*Pseudoplatystoma corruscans*) were obtained from a regional fish-processing facility (Itaporã, MS, Brazil). After transport under refrigerated conditions, the carcasses were immediately processed to obtain MSM. The deboning process was carried out using a mechanical separator (HT 250, High Tech, Brazil) equipped with a 3 mm outlet. The machine operated with temperatures of 6 °C at the input and 10 °C at the output, as described elsewhere (*Cavenaghi-Altemio et al.*, 2020) (*Figure 1*). The resulting MSM was utilized in the preparation of nugget formulations.

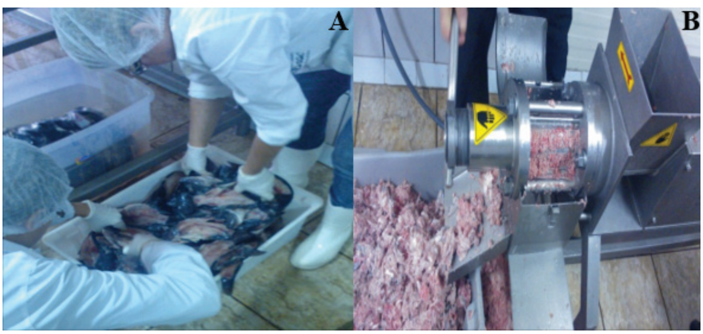

Figure 1. Spotted sorubim (*Pseudoplatystoma corruscans*) carcasses (A) utilized to produce the mechanically separated meat (MSM) (B)

2.2. Fish nuggets developed using MSM of spotted sorubim

Fish nuggets were produced by thoroughly mixing the MSM with the additional ingredients corresponding to each formulation (*Table 1*). After homogenization, the mixture was kept under refrigeration for 24 hrs. Portions of approx. 35 g were shaped into nuggets and coated using a three-step breading process consisting of pre-dusting, applying liquid batter, and final breading. The breaded products were then pre-fried by immersion in soybean oil at 180 °C for 30 seconds and subsequently stored at -20 °C for 12 hours prior to analysis.

Table 1. Composition of three formulations of fish nuggets

Stage	**Ingredients**	**Formulations (%)**		
		$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{F_3}$
Mass	MSM of spotted sorubim	91.9	91.9	91.9
	Refined salt	1.3	1.3	1.3
	Curing salt	0.5	0.5	0.5
	Fat emulsifier	0.5	0.5	0.5
	Garlic	0.5	0.5	0.5
	Coriander	0.2	0.2	0.2
	Cumin	0.2	0.2	0.2
	Black pepper	0.1	0.1	0.1
	Guar gum	0.3	0.3	0.3
	Carrageenan gum	0.5	0.5	0.5
	Bamboo fibre	4.0	-	-
	Collagen fibre		4.0	-
	Textured soy protein	-	-	4.0
Predust	Wheat starch	70	70	70
	Cassava starch	27	27	27
	Refined salt	3	3	3
Batter	Wheat flour	19	19	19
	Cassava starch	7	7	7
	Refined salt	1.2	1.2	1.2
	Baking powder	0.3	0.3	0.3
	Egg	0.01	0.01	0.01
	Sugar	2.49	2.49	2.49
	Milk	70	70	70

The pre-dusting and breading materials, as well as the commercial batter, were supplied by Baptistella Alimentos Ltda (Itatiba, SP, Brazil). Bamboo fibre (Creasplend S20) was provided by Nutrassim Food Ingredients (Extrema, MG, Brazil), and condiments and additives were obtained from Conatril Industrial de

Alimentos Ltda (Rio Claro, SP, Brazil). All remaining ingredients were purchased from local retailers (Dourados, MS, Brazil).

2.3. Determination of pH and shear force

The pH was measured in triplicate with a digital pH meter (HI99163) using a blended sample (*Spitzer & Werner*, 2002). Shear force, as an indicator of tenderness, was determined using a TA.XT2i texture analyser with a Warner-Bratzler blade on standardized cubes, following a specified protocol (*Kang & Chen*, 2015).

2.4. Microbiological analysis

Microbiological analysis was conducted on duplicate samples for the enumeration or detection of thermotolerant coliforms, coagulase-positive *Staphylococcus*, and *Salmonella* spp. This involved homogenization, serial dilution, and plating onto selective media as per established guidelines (*USDA/FSIS*, 2019).

2.5. Sensory analysis

A sensory assessment was performed by a panel of 30 trained judges using a nine-point hedonic scale (1 = dislike extremely, 9 = like extremely) to assess colour, flavour, tenderness, crispness, and overall acceptability. Purchase intention was measured on a five-point scale ranging from "certainly would buy" to "certainly would not buy", and results were expressed as percentages (*Cavenaghi-Altemio & Fonseca*, 2024a). The Acceptance Index (AI) was calculated, with samples scoring above 70% considered acceptable (*Stone & Sidel*, 2004).

2.6. Statistical analysis

All data were subjected to statistical analysis using ANOVA and the Tukey test at a 5% significance level with Statistica 8.0 software. The acceptance index and the purchase intention were presented in percentages.

3. Results and discussions

3.1. pH and shear force

Table 2 presents the results for pH and shear force. The average pH was 6.5, with no statistical difference between formulations ($p > 0.05$), indicating that the varying ingredients did not affect this parameter. This is in accordance with the reported pH ranges from 6.45 to 6.56 for fried kibbeh obtained from MSM of spotted sorubims (*Cavenaghi-Altemio & Fonseca*, 2024b), from 6.46 to 6.58 for sausages obtained from MSM of hybrid sorubims (*Cavenaghi-Altemio et al.*, 2018), and from 5.73 to 6.65 for inlaid ham-type products obtained from MSM of hybrid sorubims (*Cavenaghi-Altemio et al.*, 2021). These values are sufficiently above the isoelectric point of fish muscle proteins to ensure optimal water-holding capacity and structural integrity in the final product.

The highest shear force of 8.82 N was observed for F3, which differed ($p < 0.05$) from the values obtained for F1 and F2, which did not show a difference between each other (*Table 2*). The nuggets' texture is mainly influenced by the capacity of the batter formulation to maintain the cohesion and stability of water, fat, carbohydrate, protein, and other components during preparation and to reduce the moisture loss and oil adsorption during frying (*Albert et al.*, 2009; *Varela & Fiszman*, 2011; *Ma'ruf et al.*, 2019). In the case of the formulation containing texturized soy protein (F_3), the increased shear force of the nuggets is attributed to the soy protein's better ability to form strong structures (*Hong et al.*, 2022). Its high protein content provides structural integrity, forming a fibrous meshwork structure that contributes to a denser and more cohesive texture. Moreover, the ability to retain water and act as a binder enhances the overall matrix of the nugget (*Kumar et al.*, 2022; *Zhao et al.*, 2022). These properties likely contributed to the significantly higher ($p < 0.05$) shear force of F_3 compared to the bamboo fibre (F_1) and the collagen fibre (F_2) formulations.

Table 2. pH and shear strength of three formulations of fish nuggets

Parameter	**Formulation**		
	F_1	**F_2**	**F_3**
pH	$6.50^a \pm 0.02$	$6.49^a \pm 0.02$	$6.49^a \pm 0.01$
Shear force (N)	$7.84^a \pm 0.38$	$8.14^a \pm 0.26$	$8.82^b \pm 0.27$

Note: Values (means ± standard deviations) with the same superscript letter in the same row do not differ statistically at $p > 0.05$. F_1, F_2, and F_3 are in accordance with *Table 1*.

3.2. Microbiological safety assessment

Microbiological analysis was performed to guarantee food safety prior to the sensory evaluation (*Table 3*). The results were within the limits established by the Brazilian legislation for breaded products, including for thermotolerant coliforms at 45 °C (maximum of 10^2 CFU g^{-1}), Coagulase-positive *S. aureus* (maximum of 5×10^2 CFU g^{-1}), and *Salmonella* sp. (absence in 25 g) (*Brazil*, 2019), and were in compliance with international standards (*ICMSF*, 2011).

Table 3. Microbiological evaluation of three formulations of fish nuggets

Parameter	**Formulation**		
	$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{F_3}$
TTC at 45 °C	< 1.0×10^{2} CFU g^{-1}	< 1.0×10^{2} CFU g	< 1.0×10^{2} CFU g^{-1}
CPSA	< 1.0×10^{1} CFU/g^{-1}	< 1.0×10^{1} CFU g^{-1}	< 1.0×10^{1} CFU g^{-1}
Salmonella sp.	Absence in 25 g	Absence in 25 g	Absence in 25 g

Notes: CFU: colony-forming units; TTC: thermotolerant coliforms; CPSA: coagulase-positive *Staphylococcus aureus*; F_1, F_2, and F_3 are in accordance with *Table 1*.

3.3. Sensory acceptance and purchase intention

Table 4 presents the average scores and acceptance indices for the evaluated sensory attributes. Mean scores across all attributes ranged from “like slightly” (6) to “like very much” (8). The acceptance index for all formulations and attributes consistently exceeded the 80% threshold, confirming that the nuggets were considered acceptable overall (*Stone & Sidel*, 2004).

Table 4. Sensory analysis of three formulations of fish nuggets

Attributes	**Formulations**		
	$\mathbf{F_1}$	$\mathbf{F_2}$	$\mathbf{F_3}$
Colour	$7.10^{a} \pm 1.12$ (86.4)	$6.53^{a} \pm 1.48$ (81.5)	$6.80^{a} \pm 1.21$ (84.9)
Taste	$7.33^{a} \pm 0.99$ (88.1)	$6.57^{b} \pm 1.30$ (83.5)	$7.13^{ab} \pm 1.20$ (85.6)
Softness	$7.69^{a} \pm 0.99$ (88.6)	$7.60^{a} \pm 1.13$ (87.1)	$7.57^{a} \pm 1.17$ (86.6)
Crunchiness	$7.40^{a} \pm 1.00$ (88.1)	$6.70^{a} \pm 0.84$ (88.9)	$7.33^{a} \pm 1.18$ (86.1)
OA	$7.20^{a} \pm 1.10$ (86.7)	$6.87^{a} \pm 1.36$ (83.5)	$7.00^{a} \pm 1.14$ (86.0)

Notes: OA: overall acceptance. Values (means ± standard deviations) with the same superscript letter in the same line do not differ statistically at $p > 0.05$. Values in parentheses refer to the acceptance indices (%). F_1, F_2, and F_3 are in accordance with *Table 1*.

No statistical differences ($p > 0.05$) were observed among formulations for colour, softness, crunchiness, or overall acceptance. However, taste scores differed significantly ($p < 0.05$), with F_1 (bamboo fibre) receiving the highest score (*Table 4*). Although bamboo fibre itself is generally tasteless (*Kučerová et al.*, 2013), other ingredients may have negatively influenced the taste of F2 and F_3. For example, collagen (F_2) has been linked to the development of off-flavours (*Szopa et al.*, 2022), and textured soy protein (F3) has been reported to reduce flavour scores in certain meat products (*Angor & Al-Abdullah*, 2010). Nonetheless, the flavour impact of soy varies widely depending on the raw material and processing conditions (*Grasso et *al.*, 2019). The superior taste score of F_1 suggests that the bamboo fibre formulation produced the most favourable flavour profile among the variants (*Figure 2*).

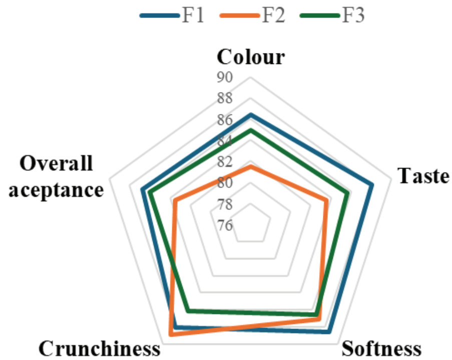

Figure 2. Acceptance indices (%) of the fish nuggets. Formulations (F_1, F_2, and F_3) according to *Table 1*

This sensory preference is reflected in the purchase intention data (*Figure 3*). The highest frequency for "certainly would purchase" was 26.7% for F_1, aligning with its superior Taste score. When combining "certainly would purchase" and "probably would purchase," F_1 and F_3 each reached 60% acceptance, while F_2 reached 50%. Notably, rejection rates ("certainly would not purchase" and "probably would not purchase") were 0% for both F_1 and F_3 and only 3% for F_2 (*Figure 3*).

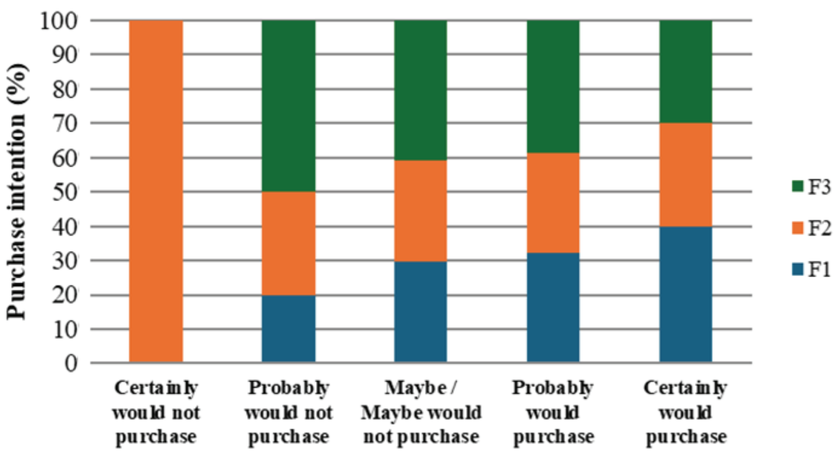

Figure 3. Purchase intention of the fish nuggets. Formulations (F_1, F_2, and F_3) according to *Table 1*

The strong correspondence between the significantly higher taste score of F1 and its leading purchase intention underscores Taste as the key discriminating factor and the most influential driver of sensory acceptance, particularly since other sensory attributes – colour, softness, crunchiness, and overall acceptance – did not differ significantly among formulations ($p > 0.05$) (*Table 4*).

Comparisons with previous studies on similar fish products reinforce these findings. For example, literature reports scores ranging from 6.12 to 7.50 for taste, odour, texture, and overall acceptance of fish fingers obtained with 94.9% MSM of hybrid sorubim, with purchase intentions ranging from 62 to 82%, depending on the breading type (*Cavenaghi-Altemio & Fonseca*, 2024a). Similarly, nuggets with 86% MSM of Nile tilapia (*Oreochromis niloticus*) received scores above 7.0, averaging 7.4, for colour, flavour, texture, aroma, overall acceptance, and purchase intention (*Bacelar et al.*, 2021). The average score of the overall acceptance of six formulations of nugget developed with residue from the tail and head of spotted sorubim ranged from 6.02 to 6.68. In a ranking test, the spotted sorubim nugget was preferred over the commercial product made from Argentine hake (*Merluccius hubbsi*) residue (*Silva et al.*, 2015).

4. Conclusions

The study successfully demonstrated that incorporating texturized soy protein (F3), bamboo fibre (F1), and collagen fibre (F2) into fish nugget formulations yields products that are all microbiologically safe and exhibit high sensory acceptability (acceptance index > 80%). The results showed that the choice of ingredients had a significant impact on specific quality characteristics. While the F_3 (soy protein) formulation resulted in a significantly higher shear force, providing superior structural integrity and a firmer texture, the F_1 (bamboo fibre) formulation achieved a statistically higher score for taste, demonstrating the most favourable flavour profile. This sensory advantage of F_1 subsequently translated into the highest purchase intention among the three variants. Therefore, while all formulations were deemed acceptable, the bamboo fibre formulation (F_1) is the most promising for commercial application, as it successfully combines a desirable texture (similar to F2 in terms of shear force) with superior taste and consumer preference.

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