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Inclusion of fish meal in the coating of Nile tilapia nuggets

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Abstract

This study evaluated the effect of fish meal in the coating of Nile tilapia nuggets on their physicochemical and sensory characteristics. Nuggets and flours were developed from mechanically separated meat of tilapia. For breading, the nuggets were assigned four types of coating (0, 20, 40, and 60% of fish meal inclusion in the Panko-type coating flour), then pre-fried, frozen, and subsequently subjected to complete frying. In the pre-fried nuggets, the inclusion of fish flour in the coating caused a linear increase in protein, lipid, ash, and caloric value, while in the fried nuggets, there were a linear decrease in moisture and a linear increase in lipids and caloric value. The inclusion of fish meal resulted in a decrease in brightness (L*) and an increase in the intensities of red (a*) and yellow (b*) in the fried nuggets. Adding fish meal to the nuggets' coating resulted in a linear decrease in hardness, elasticity, cohesiveness, gumminess, chewiness, and shear strength, however, without affecting the overall acceptability of the nuggets. Thus, it is concluded that the inclusion of up to 60% of fish meal in the coating of Nile tilapia nuggets is indicated to improve the nutritional profile of the product.

Keywords: fish products; *Oreochromis niloticus*; sensory analysis; texture profile analysis.

Practical Application: Nutritional profile of nuggets improves with inclusion of fish meal in the coating.

1 INTRODUCTION

In the fish processing industry, residues refer to by-products and leftovers, such as muscle trimmings, skin and fins, bones, heads, viscera, and scales, with relatively low commercial value (Coppola et al., 2021). In the tilapia processing industry, these by-products of the fishing industry can reach almost 69% of the total weight of the raw material because the fillet yield is around 31–36% (Yoshida et al., 2019).

Thus, food waste disposal is a current and pressing issue, requiring new solutions to implement sustainable waste management practices (Alfio et al., 2021). A good alternative for the destination of fish carcasses is the use of mechanically separated meat (MSM).

The MSM consists of the mechanical separation of the meat originally adhered to the heads, bones, and skin of fish, being considered a processing residue that can be consumed by humans and, therefore, can be used for the manufacture of ready-to-eat products (Palmeira et al., 2016). Several meat products have been developed using the MSM as the main raw material (Bedrníček et al., 2020). Among meat products, breaded fish (nuggets) receive attention due to their significant increase in consumption in recent years, leveraged by socioeconomic changes that have influenced changes in habits (Silva et al., 2021). Breaded products have pleasant sensory characteristics, such as a crispy outer layer and a soft, moist, and juicy interior (Tamsen et al., 2018). This crispy outer layer is achieved by breading.

Breading is a popular topping system, and some breading systems may contain seasoning, further enhancing flavor, aroma, and appearance characteristics (Barros et al., 2020). Due to its industrial and economic importance, industries that work with breaded products or that are thinking of implementing this line need to be aware of the process and the types of breading available. One should also be aware of the particularities of the ingredients involved, especially with regard to breading flour. The breading operation involves three fundamental steps: *pre-dust* (pre-flouring), *batter* (suspension of solid in liquid), and *breading* (final coating) (Sreelakshmi & Ninan, 2021).

Commonly, wheat flour and breadcrumbs are used to coat commercially produced nuggets. However, studies have been conducted with the aim of innovating and bringing a healthier profile to breaded products (Silva et al., 2021). In this sense, the partial substitution of flour for covering breaded products with flour from the dog's eye fish (*Priacanthus arenatus*) was proposed by Bonfim et al. (2020). Studies using Nile tilapia as the raw material, the main species produced by Brazilian aquaculture (Peixe BR, 2023), are important to provide alternatives for the management of by-products from processing industries and to leverage fish consumption in Brazil.

Thus, the objective of this study was to evaluate the effect of fish meal in the coating of Nile tilapia MSM nuggets on their physicochemical and sensory characteristics.

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MATERIALS AND METHODS

2.1 Elaboration of coating flours

The MSM of Nile tilapia used for the preparation of flours and nuggets was donated by Mar e Terra (Itaporã, MS, Brazil).

For the preparation of fish meal, Nile tilapia MSM was initially defrosted in a refrigerator (± 5°C) for 24 h and then cooked for 60 min in a pressure cooker. Then, the material was pressed in a manual press and the press cake was crushed in a multiprocessor. The resulting mass was dehydrated in a forced ventilation oven for 20 h at 60°C. At the end of this process, a new milling was performed, followed by sieving (methodology adapted from Souza et al., 2017), resulting in fish meal.

Fish meal was used to prepare the coating flours. To compose the coating flours, the Panko-type coating flour was used as a base, which was replaced by fish flour in the proportions of 0, 20, 40, and 60%.

2.2 Elaboration of the nuggets

An amount of 4 kg of nuggets was prepared using Nile tilapia MSM as the raw material based on a basic formulation (Table 1). After weighing the ingredients, they were manually mixed and molded into circles of 5 cm in diameter and 1 cm in height.

In the breading process, all nuggets were subjected to pre-dust, which consisted of passing the nuggets in rice flour. Then, the nuggets were dipped in batter, composed of wheat flour (17.3%), corn starch (10.4%), powdered milk (1.7%), salt (1.4%), and water (69.2%) (Cortez-Netto et al., 2010). In the final step (*breading*), the nuggets were assigned to four treatments (1 kg per treatment), corresponding to the four types of coating (0, 20, 40, and 60% of inclusion of fish meal in the covering meal) (Figure 1). The values were stipulated according to the results of a previous study conducted by Bonfim et al. (2020).

The nuggets (Figure 2) were pre-fried in vegetable oil at 180°C for 30 s and then frozen. For complete frying, the frozen nuggets were fried at 180°C for 3 min.

Table 1. Formulation of Nile tilapia nuggets.

Ingredients	%
Mechanically deboned meat (CMS) of Nile tilapia	85
Ice	5
Maize starch	3
Isolated soy protein	2
Salt	1.5
Dehydrated onion	1.5
Dehydrated garlic	0.9
Dehydrated chives	0.5
Dried parsley	0.5
White pepper	0.1
Total	100

2.3 Proximate composition and caloric value

Analyses of the centesimal composition were performed in duplicate, in five pre-fried nuggets per treatment and five fried nuggets per treatment, the moisture, ash, and lipid contents being determined according to the AOAC methodology (2005). The crude protein contents were determined by the Kjeldahl semi-micro method, described by Silva and Queiroz (2002). The carbohydrate content was determined by the difference of the other constituents (Instituto Adolfo Lutz, 2008). The caloric value was calculated according to Atwater and Woods (1896) in which the conversion factors were considered 4 kcal/g for protein and carbohydrates, 2 kcal/g for total dietary fiber, and 9 kcal/g for lipids. The results were expressed in kcal/100 g.

2.4 Determination of color, yield, and percentage of shrinkage

The color determination was carried out in 10 nuggets per treatment, after pre-frying and after complete frying process, using a portable colorimeter (Minolta ® model CR-400), calibrated in the CIELAB system, obtaining the values of luminosity L * (L* = 0 black and L* = 100 white), chroma a* (red–green component), and chroma b* (yellow–blue component), over an angle of 90°. Three measurements were collected per nugget.

The yield of the raw material was determined by the difference in the initial weight of the raw sample (g) and the measurement of the weight of the fried sample (g), expressed in percentage, according to Berry (1992) and Seabra et al. (2002), according to the Equation 1:

$$\%Yield = \frac{Fried\ Sample\ Weight}{Raw\ Sample\ Weight} x100 \quad (1)$$

The shrinkage of the nugget diameter (%) was measured before and after grilling (cm) with the aid of a digital caliper (Profield, Brazil), according to Berry (1992) and Seabra et al. (2002), as shown in Equation 2:

$$\%\text{Shrinkage} = \frac{Raw\ Sample\ Diameter\ -\ Fried\ Sample\ Diameter\ x100}{Raw\ Sample\ Diameter} \quad (2)$$

2.5 Shear force determination and texture profile analysis

Shear force determination and TPA were performed in 10 raw and fried samples of nuggets using a texturometer TA.XT plus (Stable Micro Systems Texture Analyzer, United Kingdom), equipped with a 50-kg load cell and a Warner–Bratzler Blade probe (for shear force determination) or a 36-mm cylindrical probe (P/36) (for TPA).

The parameters for the TPA were 1.00 mm/s in the pre-test, 5.00 mm/s of velocity in the test and post-test, a distance of 10,000 mm, a time of 5 s, high trigger type and a force of 0.04903 N, and auto tare mode. Hardness, fracturability, elasticity, cohesiveness, chewiness, and resilience parameters were calculated using the Exponent software package, version 6.1.9.1 (Stable Micro Systems, Surrey, United Kingdom).

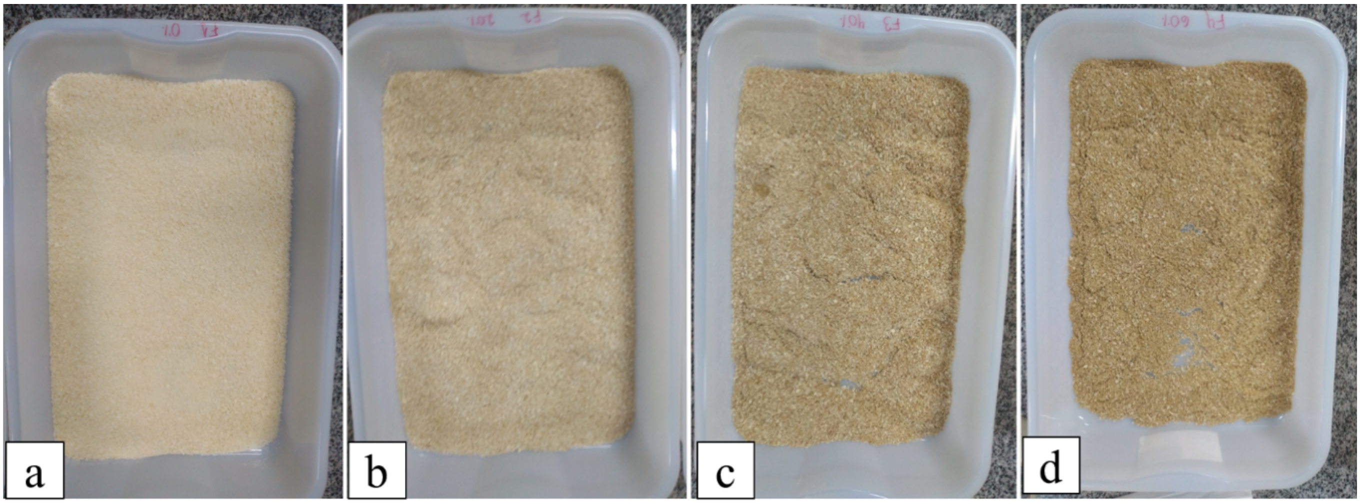


Figure 1. Coating flours for Nile tilapia nuggets: (A) 0%, (B) 20%, (C) 40%, (D) 60% inclusion of fish meal in the coating flour.

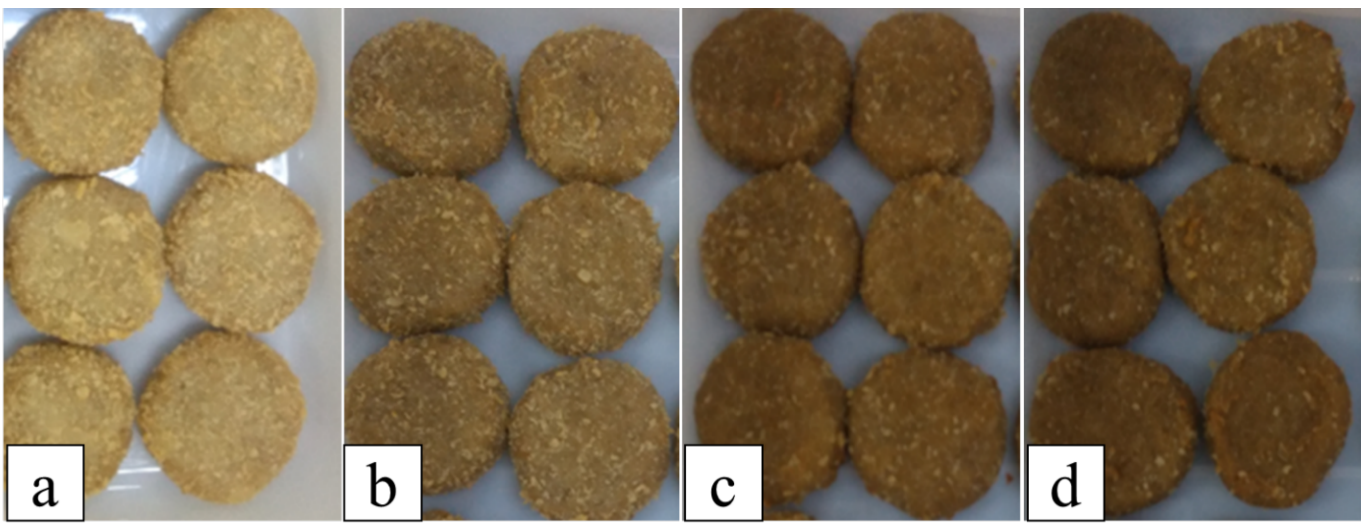


Figure 2. Nile tilapia nuggets after pre-frying: (A) 0% (B) 20% (C) 40%, (D) 60% inclusion of fish meal in the covering meal.

The parameters for the shear force were 1.00 mm/s in the pre-test speed, 2.00 mm/s in the speed test, and 10.00 mm/s in the post-test speed, a distance of 35,000 mm, a time of 5 s, high trigger type and a force of 0.04903 N, and auto tare mode.

2.6 Sensory analysis

Sensory analysis was approved by the Ethics Committee for Research with Human Beings of the Universidade Federal da Grande Dourados (CEP/UFGD) under protocol no. 5.644.903.

The tests were performed using 60 randomly selected and untrained tasters, with six sessions and 10 different consumers for each session. Each consumer evaluated four samples coded with a random three-digit code per session, corresponding to the different treatments. Samples were served in a randomized design to avoid order and transposition effects (Macfie et al., 1989). Consumers were asked to taste and rate each sample on the acceptability of five attributes (odor, color, taste, texture, and general acceptability) using a nine-point scale, ranging from 1 (dislike extremely) to 9 (like extremely). The average scale was not included, as described by Font i Furnols et al. (2008). Consumers were asked to eat crackers and rinse their mouths with water before evaluating each sample, including the first sample.

To evaluate the acceptability index (AI) of the products, Equation 3 was used, according to Dutcosky (2013).

$$AI\% = \frac{average\ product\ score}{9} \times 100 \quad (3)$$

The purchase intention for the products was also evaluated using a five-point hedonic with extremes 1 (definitely would not buy) and 5 (definitely would buy) (Damásio & Silva, 1996).

2.7 Statistical analysis

The experiment was carried out in a completely randomized design, with 4 treatments (0, 20, 40, and 60% inclusion of fish meal in the covering meal) and 10 replications per treatment, with the nugget considered the experimental unit.

The results were submitted to regression analysis using the Multiple Procedure Regression of the Statistica 7.1 software (StatSoft France, 2005), evaluating the effects of the levels of inclusion of fish meal in the coverage at a 5% level of significance. All data were expressed as mean ± standard error of the mean.

For the sensory analysis data, in addition to regression analysis, principal component analysis (PCA) was performed to identify relationships between treatments and sensory attributes and shown in graphic form with the aid of the Statistica 7.1 software.

3 RESULTS

In the centesimal composition and caloric value of the pre-fried nuggets (Table 2), a linear increase ($P < 0.05$) in the protein, lipid, ash, and caloric value of the nuggets can be observed, according to the increase in the levels of inclusion of fish meal in the coating. The moisture and carbohydrate contents were not different ($P > 0.05$) among the pre-fried nuggets.

However, after the frying process, a linear reduction ($P < 0.05$) of the nuggets' moisture can be observed, followed by a linear increase ($P > 0.05$) in the lipid content and caloric value of the nuggets, according to the increase in the inclusion levels of fish meal in the coating (Table 2). Unlike what was observed in the pre-fried nuggets, after the frying process, there was no difference ($P > 0.05$) between the protein and ash contents of the products.

In the analysis of the color of the nuggets (Table 3), it was observed that for both pre-fried and fried nuggets, there were a decrease in brightness (L*) and an increase in the intensity of red (a*) ($P < 0.05$), according to the increase in the inclusion levels of fish meal in the coating. However, the pattern of yellow intensity (b*) was different for the pre-fried and fried nuggets, while for the pre-fried nuggets the yellow intensity decreased ($P < 0.05$) as the levels of fish meal inclusion increased in the coating. After the frying process, there was an increase ($P < 0.05$) in the intensity of yellowness in the nuggets.

Table 2. Nutritional composition (g/100 g) and caloric value of pre-fried and fried Nile tilapia nuggets prepared with different levels of fish flour in the coating.

	Inclusion levels of fish meal in coating				**P-value**
	0%	**20%**	**40%**	**60%**	
Pre-fried					
Moisture	56.29 ± 0.39	56.38 ± 0.30	55.85 ± 3.29	53.41 ± 2.10	0.287
Protein	14.71 ± 0.22	15.03 ± 0.52	15.40 ± 0.22	16.97 ± 0.69	0.003[1]
Lipid	11.59 ± 0.18	11.60 ± 0.45	14.66 ± 0.56	15.02 ± 0.47	0.000[2]
Ash	1.54 ± 0.21	1.98 ± 0.26	1.94 ± 0.10	2.25 ± 0.07	0.016[3]
Carbohydrate	15.88 ± 0.32	15.01 ± 1.17	12.15 ± 2.79	12.35 ± 2.01	0.102
Caloric value (kcal/100 g)	226.62 ± 2.42	224.58 ± 1.05	242.18 ± 14.73	252.44 ± 8.12	0.021[4]
Fried					
Moisture	49.74 ± 1.27	48.23 ± 0.61	47.93 ± 0.49	44.18 ± 2.13	0.009[5]
Protein	17.71 ± 0.64	17.57 ± 0.21	17.46 ± 0.22	18.04 ± 0.17	0.582
Lipid	16.16 ± 0.52	17.63 ± 0.24	17.81 ± 0.73	18.89 ± 0.49	0.002[6]
Ash	2.20 ± 0.17	2.66 ± 0.06	2.14 ± 0.27	2.19 ± 0.12	0.538
Carbohydrate	14.19 ± 1.50	13.91 ± 0.58	14.66 ± 1.15	16.70 ± 1.69	0.159
Caloric value (kcal/100 g)	273.05 ± 6.83	284.58 ± 3.15	288.75 ± 3.51	308.96 ± 9.81	0.001[7]

Linear regressions. [1]$y = 0.0358x + 14.452$ $R^2 = 0.848$; [2]$y = 0.0667x + 11.215$ $R^2 = 0.841$; [3]$y = 0.0104x + 1.6137$ $R^2 = 0.851$; [4]$y = 0.4753x + 222.19$ $R^2 = 0.859$; [5]$y = -0.0849x + 50.066$ $R^2 = 0.861$; [6]$y = 0.0418x + 16.368$ $R^2 = 0.926$; [7]$y = 0.5595x + 272.05$ $R^2 = 0.931$.

Table 3. Coloring, shrinkage, and yield of pre-fried and fried Nile tilapia nuggets prepared with different levels of fish meal in the coating.

	Inclusion levels of fish meal in coating				**P-value**
	0%	**20%**	**40%**	**60%**	
Pre-fried					
L*	50.43 ± 0.48	52.16 ± 0.33	49.16 ± 0.37	47.49 ± 0.21	< 0.001[1]
a*	2.21 ± 0.22	1.91 ± 0.12	3.31 ± 0.13	4.11 ± 0.12	< 0.001[2]
b*	15.45 ± 0.22	15.10 ± 0.58	12.93 ± 0.40	12.91 ± 0.25	< 0.001[3]
Shrinkage (%)	99.94 ± 0.86	99.45 ± 0.47	98.14 ± 0.46	97.34 ± 0.58	0.001[4]
Yield (%)	102.64 ± 0.26	101.00 ± 0.11	101.03 ± 0.43	100.16 ± 0.35	< 0.001[5]
Fried					
L*	50.32 ± 0.94	48.45 ± 0.29	42.26 ± 0.34	43.93 ± 0.46	< 0.001[6]
a*	3.27 ± 0.81	6.07 ± 0.44	6.33 ± 0.32	6.14 ± 0.19	< 0.001[7]
b*	13.54 ± 0.38	15.97 ± 0.28	15.87 ± 0.27	15.90 ± 0.33	< 0.001[8]
Shrinkage (%)	100.05 ± 1.65	99.63 ± 0.59	98.48 ± 0.59	98.86 ± 0.68	0.277
Yield (%)	94.65 ± 1.12	92.73 ± 0.57	94.99 ± 0.54	95.93 ± 0.60	0.092

Linear regressions. [1]$y = -0.0592x + 51.584$ $R^2 = 0.597$; [2]$y = 0.0355x + 1.8204$ $R^2 = 0.818$; [3]$y = -0.0489x + 15.564$ $R^2 = 0.853$; [4]$y = -0.0456x + 100.08$ $R^2 = 0.974$; [5]$y = -0.0371x + 102.32$ $R^2 = 0.851$; [6]$y = -0.1268x + 50.047$ $R^2 = 0.753$; [7]$y = 0.0443x + 4.1235$ $R^2 = 0.615$; [8]$y = 0.0349x + 14.272$ $R^2 = 0.574$.

In the pre-fried nuggets, the increase in the levels of fish meal in the coating caused a linear reduction (P < 0.05) in both the percentage of shrinkage and the yield of the nuggets (Table 3). However, after the complete frying process, these effects were no longer observed (P > 0.05).

In the TPA of the pre-fried nuggets (Table 4), a linear reduction (P < 0.05) was observed in the cohesiveness and resilience parameters, as the levels of inclusion of fish meal in the coating increased. The other parameters were not affected by the treatments. On the contrary, after the complete frying process, a linear decrease (P < 0.05) was observed in the parameters of hardness, elasticity, cohesiveness, gumminess, and chewiness, as the levels of inclusion of fish meal in the coating increased (Figure 3). Following this trend, the shear force of the fried nuggets also showed a similar behavior, with a linear decrease (P < 0.05) in the means. However, for the pre-fried nuggets, no regression effect was observed (P > 0.05).

In the sensory analysis (Table 5), a significant effect (P < 0.05) of the treatments was observed only for the attribute color, with the polynomial regression equation, indicating the maximum average for the nuggets with the inclusion of 40% of fish flour in the coating.

In the PCA (Figure 4), the two axes of the principal components explained 90.18% of the total variance. Regarding the treatments, all evaluated attributes are positioned on the left side of factor 1, located close to the 60% level of inclusion of fish meal in the coating. Treatment 0% is present on the other side (factor 1 on the right), which is inversely related to the analyzed attributes. Color, texture, and general acceptability are present in the same quadrant of the 40 and 60% fish meal treatments, demonstrating an association between them.

4 DISCUSSION

In the centesimal composition of the pre-fried nuggets, it was observed that as the level of inclusion of fish meal in the coating increased, there was an increase in the levels of proteins, lipids, and ash. This trend may be related to differences in the composition of wheat flour (base for manufacturing the Panko-type covering flour used in this study) and fish flour, which gradually increased in concentration, which had significant amounts of protein and lipids. Fish meal is rich in protein, polyunsaturated fatty acids, and other nutrients important for human health, which makes it a valued ingredient in many food products (Souza et al., 2017). The results similar to those of this study were observed by Bonfim et al. (2020), who, when developing *Priacanthus arenatus* fish nuggets with the inclusion of fish meal of the same species in the coating, obtained similar behavior for the centesimal composition. In fact, other works with the inclusion of fish meal in food products found the effect of a linear increase in nutrients as the level of addition increased, as reported for fresh pasta with tilapia flour (Goes et al., 2016) and pizza dough with the addition of tuna flour (Campelo et al., 2017).

On the contrary, after the frying process, the effects previously observed in the pre-fried nuggets were attenuated because there was a difference between the treatments only in the moisture and lipid contents. In fish and fish products, the lipid and moisture contents are inversely proportional (Stolarski et al., 2014), as verified in the present study. Probably, the incorporation of oil due to the frying process, combined with the decrease in moisture content, reduced the effects on the crude protein content verified in the pre-fried nuggets.

The increased caloric values according to the increase in the inclusion levels of fish meal in the pre-fried and fried nuggets

Table 4. Texture profile and shear force of pre-fried and fried Nile tilapia nuggets prepared with different levels of fish meal in the coating.

	Inclusion levels of fish meal in coating				P-value
	0%	20%	40%	60%	
Pre-fried					
Hardness (N)	6.02 ± 0.94	6.39 ± 0.69	6.49 ± 1.24	6.69 ± 0.91	0.635
Fracturability	4.13 ± 1.12	4.02 ± 0.67	6.90 ± 0.83	5.94 ± 0.91	0.105
Elasticity	0.65 ± 0.02	0.64 ± 0.01	1.20 ± 0.45	0.55 ± 0.03	0.156
Cohesiveness	0.40 ± 0.03	0.36 ± 0.02	0.29 ± 0.02	0.30 ± 0.01	< 0.001[1]
Gumminess	2.24 ± 0.34	2.25 ± 0.25	2.00 ± 0.38	2.02 ± 0.31	0.915
Chewiness	1.43 ± 0.22	1.44 ± 0.17	0.80 ± 0.13	1.18 ± 0.25	0.188
Resilience	0.12 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.00	0.046[2]
Shear force (N)	0.78 ± 0.04	0.71 ± 0.02	1.15 ± 0.08	0.80 ± 0.09	0.164
Fried					
Hardness (N)	6.28 ± 0.81	6.26 ± 0.82	4.46 ± 0.83	4.44 ± 0.71	0.043*
Fracturability	4.60 ± 0.62	2.38 ± 0.45	4.45 ± 0.74	3.08 ± 0.50	0.401
Elasticity	0.71 ± 0.02	0.65 ± 0.02	0.61 ± 0.01	0.56 ± 0.02	< 0.001*
Cohesiveness	0.40 ± 0.01	0.38 ± 0.02	0.34 ± 0.02	0.35 ± 0.02	0.037*
Gumminess	2.49 ± 0.34	2.45 ± 0.31	1.60 ± 0.38	1.63 ± 0.35	0.032*
Chewiness	1.74 ± 0.22	1.61 ± 0.20	0.95 ± 0.21	0.91 ± 0.19	0.001*
Resilience	0.12 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.10 ± 0.01	0.123
Shear force (N)	0.44 ± 0.10	0.38 ± 0.04	0.32 ± 0.05	0.22 ± 0.04	0.010[4]

Linear regressions [1]$y = -0.0018x + 0.3893$. $R^2 = 0.881$. [2]$y = -0.0004x + 0.1114$. $R^2 = 0.857$. [3]$y = -0.1312x + 8.058$ $R^2 = 0.862$. [4]$y = -0.0037x + 0.4512$ $R^2 = 0.986$. *Regression equations shown in Figure 3.

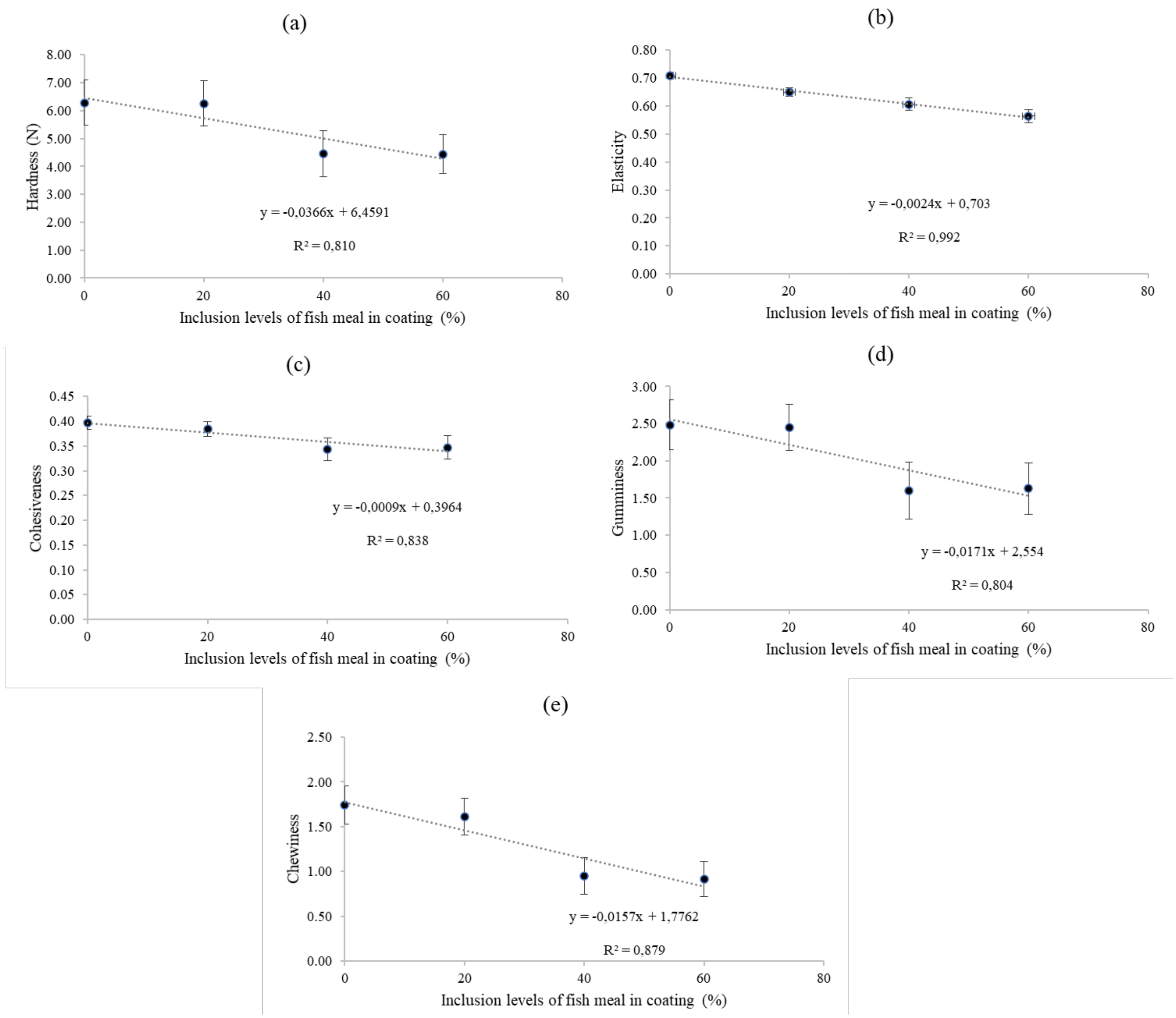
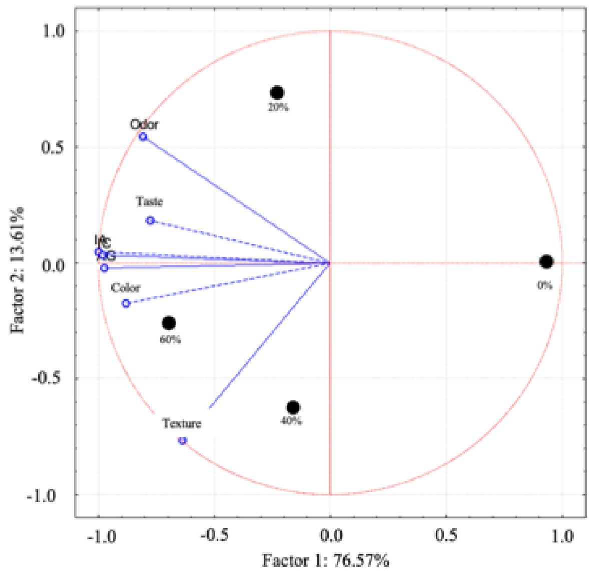


Figure 3. TPA of tilapia nuggets after frying with inclusion of fish meal in the coating. (A) Hardness, (B) elasticity, (C) cohesiveness, (D) gumminess, (E) chewability.

Table 5. Sensory attributes, AI, and purchase intention of Nile tilapia nuggets prepared with different levels of fish meal in the coating.

Attributes	Inclusion levels of fish meal in coating				P-value
	0%	20%	40%	60%	
Odor[1]	6.98 ± 0.22	7.52 ± 0.15	7.24 ± 0.19	7.29 ± 0.19	0.444
Color[1]	5.76 ± 0.25	6.41 ± 0.18	6.62 ± 0.19	6.39 ± 0.24	0.029[3]
Taste[1]	6.62 ± 0.26	6.98 ± 0.23	6.69 ± 0.24	7.23 ± 0.17	0.134
Texture[1]	6.71 ± 0.24	6.71 ± 0.26	6.83 ± 0.22	6.84 ± 0.22	0.626
Overall acceptability[1]	6.60 ± 0.25	6.96 ± 0.20	6.90 ± 0.19	7.13 ± 0.20	0.112
Acceptability index (%)	72.61 ± 2.30	76.87 ± 1.64	76.17 ± 1.75	77.50 ± 1.66	0.091
Purchase intention[2]	3.36 ± 0.15	3.77 ± 0.14	3.74 ± 0.14	3.77 ± 0.14	0.067

[1]Hedonic scale between 1 (dislike extremely) and 9 (like extremely); [2]Hedonic scale between 1 (definitely would not buy) and 5 (definitely would buy); [3]Polynomial regression $y = -0.0005x^2 + 0.0436x + 5.7588$ $R^2 = 0.999$.



AG: Overall acceptability, AI: acceptability index, CI: purchase intention.
Figure 4. Principal component analysis.

are possibly the result of the higher averages of lipids because the calculation of the caloric value considers this nutrient for the most part (Atwater & Woods, 1896).

The color of fried and breaded foods is an important aesthetic attribute that influences initial consumer acceptance (Shan et al., 2018). In this study, it can be seen that the inclusion of fish flour in the coating of the nuggets made them darker with more intense red and yellow colors after the frying process. This fact may be linked to the decrease in the Panko-type coating flour (which is made from wheat flour) as the inclusion levels increase and to the Maillard reaction during frying, which may contribute to changes in the color parameters of the products. During frying, the golden yellow color of the crust originates from the Maillard reaction between the starch and the wheat protein, in addition to the caramelization of the starch (Damodaran, 2007). One should also consider the color of the fish meal used in the present study, which is darker than the Panko-type covering meal, which is lighter in color. Furthermore, color differences between treatments may be related to the degree of moisture loss and oil absorption because moisture content is a key factor affecting the Maillard reaction (Shan et al., 2018), and in this study, the moisture of the fried nuggets decreased linearly as the levels of inclusion of fish meal increased. However, it is important to point out that the nuggets with coatings containing 40% fish flour inclusion had better sensory acceptance in the color attribute, as demonstrated by the sensory analysis, demonstrating that the use of fish flour is desirable in the breading of nuggets.

Texture profile analysis is a useful tool to assess the physical and sensory properties of foods. Hardness, cohesiveness, elasticity, gumminess, and chewiness are important measures that can be used to characterize different aspects of food texture. According to Tamsen et al. (2018), in the TPA, hardness represents the maximum force required to compress the sample and cohesiveness shows the intensity of deformation before tissue destruction. Elasticity is the ability to recover the initial shape after the applied force is eliminated, while gumminess is the force required to overwhelm the samples for swallowing (Tamsen et al., 2018). Chewability indicates the work required to chew the sample (gumminess × elasticity) and is influenced by several factors, including chemical composition, particle size and shape, and physical structure of the food (Tamsen et al., 2018). In this study, the inclusion of fish meal in the coating of the nuggets contributed to decrease not only the shear force, but also the parameters related to the TPA, demonstrating that the higher levels of inclusion of fish meal resulted in softer nuggets. This may be related to the differences both in the granulometry of the flours that were combined in the different treatments (Panko-type topping flour and fish flour), which possibly decreased the crispness of the nuggets, resulting in the decrease in attributes related to texture. In fact, coating with the Panko-type flour, known as the Japanese style of breading, offers a lighter appearance and crispy texture to breading (Perera & Embuscado, 2014).

However, these alterations were not perceived as harmful by the tasters in the sensory analysis because the texture attribute did not show a significant effect between treatments. Even the PCA showed an association between the attributes color, texture, and acceptability and the treatment with the inclusion of 60% fish meal. In addition, the AI was above 70% for all nuggets, indicative of good acceptance by tasters (Dutcosky, 2013). Similar results were also obtained by Bonfim et al. (2020), who obtained good acceptance in nuggets with the inclusion of up to 40% *Priacanthus arenatus* fish flour in the coating. In fact, several other studies prove the feasibility of using fish meal in food products with positive effects on the sensory acceptance of products (Goes et al., 2015; Souza et al., 2021; Vitorino et al., 2020).

5 CONCLUSION

It is concluded that the inclusion of up to 60% fish flour in the coating of Nile tilapia mechanically deboned meat nuggets is indicated to improve the nutritional and sensory profile of breading.

REFERENCES

Alfio, V. G., Manzo, C., & Micillo, R. (2021). From fish waste to value: an overview of the sustainable recovery of omega-3 for food supplements. *Molecules*, *26*(4), 1002. https://doi.org/10.3390/molecules26041002

Associations of Official Analytical Chemists (AOAC) (2005). *Official Methods of Analyses of the Association of Analytical Chemists*. AOAC International.

Atwater, W. O., & Woods, C. D. (1896). *The Chemical Composition of American Food Materials*. Government Printing Office.

Barros, E. L., Barroso, N. G., Camelo-Silva, C., Sanches, M. A. R., Verruck, S., & Vidigal, M. C. T. R. (2020). Tecnologias envolvidas no processamento de empanados. In S. Verruck (Ed.), *Avanços em Ciência e Tecnologia de Alimentos* (pp. 453-466). Cientifica Digital.

Bedrníček, J., Kadlec, J., Laknerová, I., Mráz, J., Samková, E., Petrášková, E., Hasoňová, L., Vácha, F., Kron, V., & Smetana, P. (2020). Onion peel powder as an antioxidant-rich material for sausages prepared from mechanically separated fish meat. *Antioxidants*, *9*(10), 974. https://doi.org/10.3390/antiox9100974

Berry, B. W. (1992). Low fat level effects on sensory, shear, cooking, and chemical properties of ground beef patties. *Journal of Food Science*, *57*(3), 537. https://doi.org/10.1111/j.1365-2621.1992.tb08037.x

Bonfim, B. D. C., Monteiro, M. L. G., Santos, A. F. G. N. D., Vilar, J. D. S., & Conte-Junior, C. A. (2020). Nutritional improvement and consumer perspective of fish nuggets with partial substitution of wheat flour coating by fish (Priacanthus arenatus, Cuvier, 1829) waste flour. *Journal of Aquatic Food Product Technology*, *29*(1), 28-42. https://doi.org/10.1080/10498850.2019.1693462

Campelo, D. A. V., Souza, M. L. R. D., Moura, L. B. D., Xavier, T. O., Yoshida, G. M., Goes, E. S. D. R., & Mikcha, J. M. G. (2017). Addition of different tuna meal levels to pizza dough. *Brazilian Journal of Food Technology*, *20*(1), e2016014. https://doi.org/10.1590/1981-6723.1416

Coppola, D., Lauritano, C., Palma Esposito, F., Riccio, G., Rizzo, C., & Pascale, D. (2021). Fish waste: From problem to valuable resource. *Marine Drugs*, *19*(2), 116. https://doi.org/10.3390/md19020116

Cortez-Netto, J. D. P., Boscolo, W. R., Feiden, A., Maluf, M. L. F., Freitas, J. M. A., & Simões, M. R. (2010). Formulação, análises microbiológicas, composição centesimal e aceitabilidade de empanados de jundiá (*Rhamdia quelen*), pacu (*Piaractus mesopotamicus*) e tilápia (*Oreochromis niloticus*). *Revista do Instituto Adolfo Lutz*, 69(2), 181-187. https://doi.org/10.53393/rial.2010.v69.32654

Damásio, M. H., & Silva, M. A. A. P. (1996). *Curso de treinamento em análise sensorial*. Fundação Tropical de Tecnologia "André Tosello"

Damodaran, S. (2007). Amino Acids, Peptides, and Proteins. In S. Damodaran, K. L. Parkin, & O. R. Fennema (Eds.), *Fennema's Food Chemistry* (pp. 219-323). CRC Press.

Dutcosky, S. D. (2013). *Análise sensorial de alimentos*. Champagnat.

Font i Furnols, M., Gispert, M., Guerrero, L., Velarde, A., Tibau, J., Soler, J., Hortós, M., García-Regueiro, J. A., Peréz, J., Suárez, P., & Oliver, M. A. (2008). Consumers' sensory acceptability of pork from immunocastrated male pigs. *Meat Science*, *80*(4), 1013-1018. https://doi.org/10.1016/j.meatsci.2008.04.018

Goes, E. S. D. R., Souza, M. L. R. D., Campelo, D. A. V., Yoshida, G. M., Xavier, T. O., Moura, L. B. D., & Monteiro, A. R. G. (2015). Extruded snacks with the addition of different fish meals. *Food Science and Technology*, *35*(4), 683-689. https://doi.org/10.1590/1678-457X.6818

Goes, E. S. D. R., Souza, M. L. R. D., Michka, J. M. G., Kimura, K. S., Lara, J. A. F. D., Delbem, A. C. B., & Gasparino, E. (2016). Fresh pasta enrichment with protein concentrate of tilapia: nutritional and sensory characteristics. *Food Science and Technology*, *36*(1), 76-82. https://doi.org/10.1590/1678-457X.0020

Instituto Adolfo Lutz (2008). *Procedimentos e determinações gerais: métodos físico-químicos para análise de alimentos*. Instituto Adolfo Lutz.

MacFie, H. J., Bratchell, N., Greenhoff, K., & Vallis, L. V. (1989). Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests. *Journal of Sensory Studies*, *4*(2), 129-148. https://doi.org/10.1111/j.1745-459X.1989.tb00463.x

Palmeira, K. R., Másico, E. T., Monteiro, M. L. G., Lemos, M., & Conte Junior, C. A. (2016). Ready-to-eat products elaborated with mechanically separated fish meat from waste processing: challenges and chemical quality. *CyTA-Journal of Food*, *14*(2), 227-238. https://doi.org/10.1080/19476337.2015.1087050

Peixe BR (2023). *Anuário 2023 Peixe BR da Piscicultura*. Associação Brasileira da Piscicultura.

Perera, C., & Embuscado, M. E. (2014). Texture design for breaded and battered foods. In Y. L. Dar, & J. M. Light (Eds.), *Food texture design and optimization* (pp. 128-158). John Wiley & Sons.

Seabra, L. M. A. J., Zapata, J. F. F., Nogueira, C. M., Dantas, M. A., & Almeida, R. B. D. (2002). Fécula de mandioca e farinha de aveia como substitutos de gordura na formulação de hambúrguer de carne ovina. *Food Science and Technology*, *22*(3), 245-248. https://doi.org/10.1590/S0101-20612002000300008

Shan, J., Chen, J., Xie, D., Xia, W., Xu, W., & Xiong, Y. L. (2018). Effect of xanthan gum/soybean fiber ratio in the batter on oil absorption and quality attributes of fried breaded fish nuggets. *Journal of Food Science*, *83*(7), 1832-1838. https://doi.org/10.1111/1750-3841.14199

Silva, D. J., & Queiroz, A. C. (2002). *Análises de alimentos: métodos químicos e biológicos*. Editora UFV.

Silva, M. C. A., Leite, J. S. A. F., Barreto, B. G., Neves, M. V. A., Silva, A. S., Viveiros, K. M., Passos, R. S. F. T., Costa, N. P., Silva, R. V., & Cavalheiro, C. P. (2021). The impact of innovative gluten-free coatings on the physicochemical, microbiological, and sensory characteristics of fish nuggets. *LWT-Food Science and Technology*, *137*, 110409. https://doi.org/10.1016/j.lwt.2020.110409

Souza, M. L. R., Silva, D. D. S., Pereira, I. L., Rocha, L. M. P., Oliveira, G. G., Coradini, M. F., Matiucci, M. A., Feihrmann, A. C., & Goes, E. S.R. (2021). Inclusion levels of flour made from smoked Nile tilapia trimmings in extruded corn snacks. *Research, Society and Development*, *10*(8), e33410817243-e33410817243. https://doi.org/10.33448/rsd-v10i8.17243

Souza, M. L. R., Yoshida, G. M., Campelo, D. A. V., Moura, L. B., Xavier, T. O., & Goes, E. S. R. (2017). Formulation of fish waste meal for human nutrition. *Acta Scientiarum. Technology*, *39*, 525-531. https://doi.org/10.4025/actascitechnol.v39i5.29723

Sreelakshmi, K. R., & Ninan, G. (2021). Coated fish products. In C. O. Mohan, K. Elavarasan, S. Sreejith, & K. R. Sreelakshmi (Eds.), *Fish and marine products processing* (pp. 116-127). Central Institute of Fisheries Technology.

StatSoft France (2005). *STATISTICA (logiciel d'analyse des données), version 7.1*. Retrieved from https://www.statsoft.fr

Stolarski, J. T., Margraf, F. J., Carlson, J. G., & Sutton, T. M. (2014). Lipid and moisture content modeling of amphidromous dolly varden using bioelectrical impedance analysis. *North American Journal of Fisheries Management*, *34*(3), 471-481. https://doi.org/10.1080/02755947.2014.880764

Tamsen, M., Shekarchizadeh, H., & Soltanizadeh, N. (2018). Evaluation of wheat flour substitution with amaranth flour on chicken nugget properties. *LWT-Food Science and Technology*, *91*, 580-587. https://doi.org/10.1016/j.lwt.2018.02.001

Vitorino, K. C., Chambo, A. P. S., Coradini, M. F., Matiucci, M. A., Graton Michka, J. M., Goes, E. S. R., Gonçalves, A. A., & Souza, M. L. R. (2020). Cereal bars flavored with fish protein concentrate from different species. *Journal of Aquatic Food Product Technology*, *29*(1), 65-72. https://doi.org/10.1080/10498850.2019.1694615

Yoshida, G. M., Lhorente, J. P., Correa, K., Soto, J., Salas, D., & Yáñez, J. M. (2019). Genome-wide association study and cost-efficient genomic predictions for growth and fillet yield in Nile tilapia (Oreochromis niloticus). *G3: Genes, Genomes, Genetics*, *9*(8), 2597-2607. https://doi.org/10.1534/g3.119.400116