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RESEARCH PAPER

Corn and cassava flours can replace wheat flour in gluten-free fish fingers

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Abstract

The aim of this work was to develop and to characterize fish fingers prepared with mechanically separated meat of hybrid surubim, with and without gluten. Four treatments were evaluated by varying the three steps of pre-dusting, battering, and breading. They have included wheat flour (T1), fishmeal (T2), corn flour (T3) or a blend of corn flour and cassava flour (T4). Characterization was carried out in terms of chemical, physical, microbiological, and sensory analyzes. Moisture content of the samples varied from 59.73% (T3) to 61.14% (T1), protein from 10.60% (T3) to 14.25% (T2), crude fiber from 11.00 to 11.42%, lipid from 4.42 (T1) to 10.91% (T2), and ash from 1.96% (T3) to 2.60% (T2). The highest breading yield (27.15%) coincided with the lowest shear strength (5.75 N) for T1. A darker color was observed for T2, which was prepared with fish meal. The average scores of the sensory attributes ranged from 6.12 to 7.50. All treatments presented acceptance indexes above 70%, except for the color attribute of T2. The purchase intentions for "certainly would purchase" and "possibly would purchase" were 82, 64, 72, and 72% for T1, T2, T3, and T4, respectively, with a rejection index ranging from 6 to 14%. It was concluded that treatments with corn flour (T3) and the mixture 1:1 of corn flour and cassava flour (T4) are good alternatives to replace wheat flour (T1), favoring celiac consumers.

Keywords

Food alternative, Celiac disease, Breading, Fish valorization, Fishmeal

Introduction

Fish meat is a valuable alternative or substitute for red meat. However, some species present low consumer preference due to the presence of intramuscular bones. Thus, to improve consumer acceptability, it becomes essential to develop convenient products derived from fish meat (Conte et al. 2014). Surubim is a freshwater fish with high commercial value due to the tasty meat with low fat content and absence of intramuscular spines (Hisano et al. 2013). These distinct characteristics turn their meat into a valuable product (Cavenaghi-Altemio et al. 2023).

Although fillet remains the most favored fish product among consumers (Silva et al. 2018), the processing of fish often results in wastage, including discarded carcasses and heads, leading to environmental concerns (Menegazzo et al. 2014). These residues can be utilized to obtain products with added value, such as the mechanically separated meat (MSM), achieved through a mechanized process that isolates the edible fraction, providing portions of meat without viscera, skin and bones from a single species or a mixture of fish species (Cavenaghi-Altemio et al. 2018). The MSM is an excellent raw material for fish derived products (Palmeira et al. 2016; Husein et al. 2020).

Breaded is the industrialized meat product obtained from the meat of different species, added of ingredients, molded or not, and coated with an appropriate coating that characterizes it (MAPA 2001). The coating process on breaded products represents, in general, the application of a layer of predust (pre-flouring), a layer of batter (suspension of solid in liquid) and breading (final coating) (Belusso et al. 2016). The nature, content, order, and number of layers can vary, which can still be combined in various ways, being that each one provides a specific function on the final product (Varela and Fiszman 2011).

The sensory characteristics taste, texture, odor, and appearance of these breaded products play a significant role in consumer perception and overall product quality (Veit et al. 2011; Kang and Chen 2014). Moreover, these coatings provide several functional benefits, including improved cooking properties (Chen et al. 2009; Praneetha et al. 2015), and protection against oxidation and dehydration during freezing, extending shelf-life (Osheba et al. 2013). Thus, it represents an important strategy to add value to the fish waste and fish of lower commercial value during the development of food products.

Different flours can be utilized in pre-dusting, battering, and breading. They are classified in white/plain grain, white/self-raising, wholemeal/plain, wholemeal/self-raising, bread-making mixes, gluten free, other refined grain, legume, other non-grain, and fruit/vegetable (Hughes et al. 2000). It underlines that some gluten-free flours can effectively replace wheat in various food applications due to their varied properties (Patil and Arya 2017). Some of their benefits are the higher fiber content, better digestibility, and potential for healthier food products (Culețu et al. 2021), beyond the adequacy for those with gluten sensitivities or celiac disease while the disadvantages may be related to texture and flavor, which may differ from traditional flour. The granulometry of the flour utilized in the breading can affect the final properties of the product, *e.g.*, texture and appearance, adhesion (pick-up), water and oil absorption, cooking time, color, uniformity, and consistency (Maskat and Kerr 2002, 2004; Adedeji and Ngadi 2011; Hera et al. 2013; Brannan et al. 2014; Pang et al. 2021; Sarkar and Fu 2022; Burešová et al. 2023). Therefore, the rising demand for gluten-free products has driven the investigation of the correlation between different types of flours and the resulting characteristics of the gluten-free breaded products (Burešová et al. 2023).

Considering specific dietary needs, individuals with celiac disease, intolerant to gluten, necessitate the development of specialized products to enhance their quality of life. This disease, characterized by an intolerance to gliadin in gluten, occurs in genetically predisposed individuals and results in intestinal mucosal lesions, hindering nutrient absorption at varied degrees of severity (Wang et al. 2017). It is important to underline that the structure of gluten does not change when it is roasted or cooked, so it must be removed from the diet and replaced by other options (César et al. 2006).

While fish products boast high nutritional value and functional properties, they lack dietary fiber. Integrating dietary fibers into restructured fishery products holds immense promise in creating functional foods that offer various health benefits beyond intestinal regularity (Sánchez-Alonso and Borderías 2008), including controlling blood glucose and cholesterol levels (Capuano 2017).

Thus, the aim of this work was to use mechanically separated meat of hybrid surubim to develop gluten-free fish fingers and to characterize them in terms of microbiological, physical (yield, shear strength, and color), chemical (proximate composition) and sensorial analyses. The goal was to provide a food alternative suitable for individuals with celiac disease.

Material and methods

Mechanically separated meat (MSM)

Hybrid sorubim (*Pseudoplatystoma reticulatum* × *Pseudoplatystoma corruscans*) carcasses were supplied by a local fishery processing plant. They were transported to the Laboratory of Bioengineering from the Federal University of Grande Dourados, Dourados, MS, Brazil, under refrigerated conditions, and immediately utilized to produce the MSM, in 3 mm particle size, by using a meat-bone separator (HT 250, High Tech, Brazil), operating at inlet 6 °C and outlet 10 °C (Cavenaghi-Altemio et al. 2013).

Fish fingers elaborated with MSM

The fish fingers were obtained by homogenizing the MSM of hybrid sorubim (94.90%) with sodium chloride (1.48%), spices (1.18%), stabilizer (0.55%), emulsifier (0.49%), ascorbic acid (0.49%), all supplied by Conatril Food Industry Ltda. (Rio Claro, SP, Brazil), and fiber of bamboo (Creasplend S20, Nutrassim Food Ingredients, Extrema, MG, Brazil) (0.91%), before rested for 24 h under refrigeration. Portions of 35 g were weighed, molded, and breaded, as shown in Table 1. Then they were stored under freezing. Coating flour and commercial liquid battering were supplied by Baptistella Alimentos Ltda (Itatiba, SP, Brazil). Wheat flour (Dona Santa, Dona Santa Alimentos Ltda, Dourados, MS, Brazil), maize flour flake type and cassava flour (Yoki™, General Mills Brasil Alimentos Ltda., São Bernardo do Campo, SP, Brazil) were purchased from the local commerce (Dourados, MS, Brazil).

Table 1. Treatments used for the coating of the fish fingers.

Treatment	Pre-dusting	Battering	Breading
T1	Wheat flour	Diluted wheat flour dough	Wheat flour
T2	Maize flour	Diluted maize flour	Fish meal
T3	Maize flour	Diluted maize flour	Corn flour
T4	Maize flour	Diluted maize flour	Mixture 1:1 of corn flour and cassava flour

Microbiological analysis

Microbiological analyses of the MSM of hybrid sorubim and the fish fingers elaborated with MSM of hybrid sorubim were performed for *Salmonella* sp., *Staphylococcus* positive coagulase and thermo-tolerant coliforms at 45 °C, in accordance with the methodology described elsewhere (USDA/FSIS 1998).

Physical analysis

Breading yield (pick-up)

During the breading process, the fish fingers were weighed without the cover (initial weight) and with the cover (final weight) for the calculation of the cover yield given by Eq. 1.

$$Breading\ yield = \frac{(Final\ weight - Inicial\ weight)}{Final\ weight} \times 100 \quad (1)$$

Shear force

Texture analysis of the fish fingers was carried out using a texture analyzer Model TAXTplus (Stable Micro Systems, Surrey, England) calibrated with a standard weight of 5 kg. Fish fingers kept at 2 °C were equilibrated at room temperature (28–30 °C) before analysis. Samples of 15 × 15 × 20 cm were cut, placed in the texture analyzer, and submitted to a cutting/shearing test (speed of 1.0 mm/s, distance of 30 mm) using a Warner-Bratzler shear blade (1 mm thick) to determine the shear force (N). A minimum of 50 replicates of each formulation were analyzed (Kang and Chen 2014).

Instrumental colour

The colour [CIE L*(lightness), a* (redness), b* (yellowness)] of the fish fingers elaborated with MSM of hybrid sorubim was evaluated using a colorimeter (Minolta Chroma Meter CR 410), with measurements standardized with respect to the white calibration plate (Jiménez and Gutiérrez 2001). Five readings were made from the samples. Color differences (Δ) were calculated to have a numerical comparison between the sample and the standard. The total color variation (ΔE) was expressed according to Eq. 2:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

Where: ΔL * = variation between lighter and darker (- = darker, + = lighter); Δa* = variation between green and red (- = greener, + = redder), Δb* = variation between blue and yellow (- = bluer, + = yellower).

Chemical analysis

Moisture, crude protein, and crude ash contents of the fish fingers elaborated with MSM of hybrid sorubim were determined in triplicate according to the methods described by AOAC (2012). Moisture was determined by the oven drying method at 105 °C until constant weight (method 950.46), protein by the Kjeldhal method (method 928.08), ash by using the muffle oven technique (method 920.153), and crude fiber by chemical digestion (method 978.10). The lipid content was obtained in triplicate by the extraction method with cold organic solvent (Bligh and Dyer 1959).

Sensory analysis

Sensory analyses of the fish fingers elaborated with MSM of hybrid sorubim were conducted by 50 non-trained panelists. A nine-points hedonic scale (9 = like extremely; 1 = dislike extremely) was used for evaluation of the attributes colour, odor, texture, taste, and overall acceptance. Samples were fried in soybean oil at 180 °C for 3 min., cut with edges of approximately 15 × 15 × 20 mm, stored in styrofoam box coated with aluminum foil for temperature maintenance, and presented in monadic form, randomly coded with three digits. In the same sheet, it was evaluated the purchase intention using a 5-point scale, where 5 = certainly would purchase, 4 = probably would purchase, 3 = perhaps would purchase / perhaps would not purchase, 2 = probably would not purchase and 1 = certainly would not purchase, which was expressed as the percentage of total score. For frequency of consumption of fish fingers, a 5-point scale was utilized, where 5 = weekly, 4 = 2 to 4 times a week, 3 = fortnightly, 2 = monthly, and 1 = rarely (Cavenaghi-Altemio et al. 2018). The acceptance index (AI) was calculated according to the following equation: AI = (average of the attributed grades / maximum attributed grade) × 100. The sample was considered accepted if the value was greater than 70% (Stone and Sidel 2004). A correlation coefficient (r) was calculated by the quotient of the sensory texture and the instrumental texture. A classification was made according to the following criteria: weak ($0.10 < r < 0.30$), moderate ($0.40 < r < 0.60$), and strong ($0.70 < r < 1$) (Carneiro et al. 2019).

Statistical analysis

Statistical results were evaluated through analysis of variance (ANOVA) and the Tukey test for comparison of means, at a level of 5% of significance, using the statistical software Statistica 7.0. The sensory attributes, the purchase intention and the consumption frequencies were analyzed in percentage.

Results

Microbiological analysis

Microbiological analysis of coliforms at 45 °C, coagulase positive staphylococci (CPS), and *Salmonella* sp. were carried out of for the fish fingers to guarantee the food security of judgers priori the conduction of the sensory analysis (Table 2). The results of the microbiological analysis were carried out for T1, T2, T3, and T4 containing hybrid sorubim and did not present difference between treatments ($p > 0.05$).

Chemical analysis

Proximate composition of the fish fingers is shown in Table 3. Results indicated that moisture from T3 differed from T1,

Table 2. Microbiological analyses of the fish fingers.

Treatment	Microbiological analyses		
	Coliforms at 45 °C	Coagulase positive staphylococci	*Salmonella* sp.
T1	<1.0 × 10^2 CFU/g est.	Negative	Absence in 25 g
T2	<1.0 × 10^2 CFU/g est.	Negative	Absence in 25 g
T3	<1.0 × 10^2 CFU/g est.	Negative	Absence in 25 g
T4	<1.0 × 10^2 CFU/g est.	Negative	Absence in 25 g

Treatments (T1, T2, T3, and T4) according to Table 1. CFU: counting forming units.

Table 3. Proximate composition of fish fingers.

Treatment	Proximate composition (%)				
	Moisture	Protein	Fiber	Lipids	Ash
T1	61.14^a ± 0.18	12.34^a ± 1.74	11.37^a ± 1.01	4.42^a ± 0.26	2.34^b ± 0.04
T2	60.24^a ± 0.16	14.25^{ab} ± 1.44	11.33^a ± 1.06	10.91^b ± 1.92	2.60^a ± 0.04
T3	59.73^b ± 0.16	10.60^{ac} ± 1.07	11.42^a ± 1.03	4.63^a ± 0.34	1.96^d ± 0.05
T4	60.34^a ± 0.23	11.05^a ± 1.12	11.00^a ± 1.42	6.99^a ± 0.93	2.17^c ± 0.04

Means with the same letter in the same column do not differ statistically at 5% (P > 0.05). Treatments (T1, T2, T3, and T4) according to Table 1.

T2 and T4 ($p < 0.05$), which did not differ from each other ($p > 0.05$) (Table 3). The treatments did not differ from each other ($p > 0.05$) in terms of protein content (Table 3). However, T2 differed from the other treatments for the highest protein content (14.25%) while T3 for the lowest protein content (10.60%) ($p > 0.05$). For the crude fiber content, there was no statistical difference ($p > 0.05$) between treatments (Table 3). For the lipid content, T2 differed ($p < 0.05$) from the other treatments (Table 3). For the ash content, there was statistical difference ($p < 0.05$) between treatments, with T2 presenting the highest concentrations (2.60%; Table 3).

Physical analysis

Coverage yield (pick-up), shear strength, and the instrumental color parameters luminosity (L*), redness (a*), yellowness (b*), and color difference (ΔE*) of the fish fingers were determined for the four coating treatments (T1, T2, T3, and T4) (Table 4). T1 was established as standard to measure due to the presence of gluten and wheat flour-based coverage (Table 1).

In relation to the pick-up, T2 obtained the lowest value (19.91%), differing from the other treatments ($p < 0.05$). T1 and T3 did not present statistical difference ($p > 0.05$) while T3 and T4 did not differ between them ($p > 0.05$) (Table 4). Fish fingers breaded according to T3 and T4 had the highest averages for shear strength (Table 4).

Regarding the instrumental color parameters, there was a statistical difference ($p < 0.05$) for luminosity (L*), redness (a*) and yellowness (b*) in all treatments. T2 presented a significantly lower average than the other treatments in relation to L* and b* ($p < 0.05$), and a significantly higher averages for a* (without differing from T4) ($p < 0.05$) (Table 4).

When calculating the color difference (ΔE*) between the standard treatment (T1) and the other treatments, results indicated that T2 was darker than T1, while T3 and T4 were lighter than T1. All treatments were redder and less yellow compared to wheat flour (T1). The higher ΔE* was observed for T2, followed by T3 and T4 (Table 4).

Table 4. Breading yield, shear force, and instrumental color of fish fingers.

Treatment	Breading yield (%)	Shear strength (N)	Instrumental color			
			L*	a*	b*	ΔE*
T1	27.15^a ± 2.55	5.75^b ± 1.20	50.42^a ± 1.96	3.69^c ± 0.23	28.34^a ± 1.00	-
T2	19.91^d ± 1.81	5.82^b ± 1.21	40.66^b ± 0.30	9.39^a ± 0.31	14.62^c ± 0.16	17.78
T3	24.71^{ab} ± 2.86	12.27^a ± 1.62	51.36^a ± 1.47	4.00^c ± 0.47	25.04^{ab} ± 0.91	3.44
T4	23.72^{bc} ± 1.77	13.51^a ± 1.72	52.15^a ± 2.34	5.09^b ± 0.14	21.87^b ± 2.27	6.99

L*: lightness; a*: redness, b*: yellowness, ΔE*: color difference. Means with the same letter in the same column do not differ statistically at 5% (P > 0.05). Treatments (T1, T2, T3, and T4) according to Table 1.

Sensory analysis

The means and standard deviations for the sensory attributes of color, taste, texture, odor, and overall acceptance of the fish fingers by the acceptance test are expressed in Table 5. The sensory attributes of taste, odor, texture, and overall acceptance did not differ statistically ($p > 0.05$). Regarding the color attribute, T1 differed ($p < 0.05$) and presented an average value higher than that obtained for T2, not differing from the other treatments ($p > 0.05$). The average scores of the sensory attributes varied from 6 (I liked it slightly) to 8 (I liked it a lot) on the hedonic scale, in an average range of 6.12 to 7.50. All treatments presented acceptances indexes above 70%, except for the color attribute of T2 (Table 5).

Fig. 1 shows the percentage of the purchase intention frequencies of the fish fingers prepared with mechanically separated meat of hybrid surubim in treatments with and without gluten. T4 had the highest percentage of purchase intention (40%) for "certainly would purchase", followed by treatments T3, T1 and T2. For the sum of the frequencies of the intentions "certainly would purchase" and "possibly would purchase" were 82, 62, 72, and 64% for T1, T2, T3, and T4, respectively, with a rejection index ranging from 6 to 14%.

Table 5. Sensory analysis of fish fingers.

Treatment	Sensory analysis					Correlation*
	Color	Taste	Texture	Odor	Overall acceptance	
T1	7.10ª ± 1.52 (78.89%)	7.40ª ± 1.39 (82.22%)	7.28ª ± 1.36 (80.89%)	7.24ª ± 1.27 (80.44%)	7.36ª ± 1.08 (81.79%)	0.21
T2	6.12ᵇᶜ ± 2.13 (68.00%)	6.98ª ± 1.67 (77.56%)	7.22ª ± 1.62 (80.22%)	6.52ª ± 1.83 (72.44%)	6.64ª ± 1.76 (73.78%)	0.19
T3	6.88ᵃᵇ ± 1.45 (76.44%)	6.90ª ± 1.79 (76.67%)	7.24ª ± 1.27 (80.44%)	6.96ª ± 1.84 (77.33%)	6.90ª ± 1.56 (76.67%)	0.12
T4	6.44ᵃᵇ ± 1.70 (71.56%)	7.50ª ± 1.34 (83.33%)	7.12ª ± 1.51 (79.11%)	7.26ª ± 1.50 (80.67%)	7.10ª ± 1.42 (78.89%)	0.07

Values in parenthesis are referred to the acceptance index (%). *Correlation between instrumental texture and sensory analysis. Treatments (T1, T2, T3, and T4) according to Table 1.

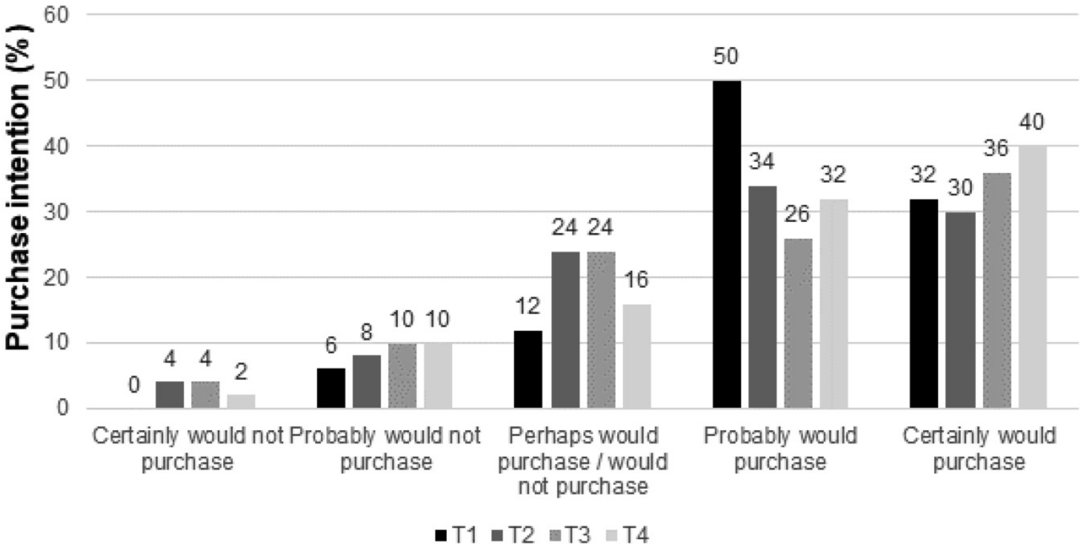

Figure 1. Purchase intention of the fish fingers. Treatments (T1, T2, T3, and T4) according to Table 1.

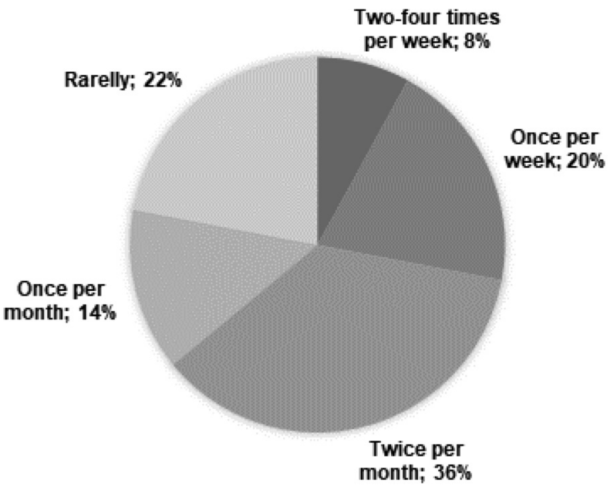

Figure 2. Frequency of consumption of breaded products.

Fig. 2 shows the frequency of consumption of breaded products by the judgers. It varied from 2 to 4 times a week, once a week, every 15 days or once a month. Most of the judges (36%) stated that they consume these products every 15 days. Adding it to the percentage of attendance “once a week”, a total of 56% is obtained, indicating that most of the judgers are regular consumers.

The sensory evaluators were asked to rate the samples for texture, which was also measured instrumentally through the shear strength, representing the same force that the teeth exert on the sample. Thus, it was possible to correlate both results through a correlation coefficient (Table 5). The texture attribute evaluated during the sensory analysis and that measured through the shear strength had positive weak correlations for T1, T2 and T3. However, T4 showed no correlation.

Discussion

Microbiological analysis

Regarding the coliform at 45 °C, the Brazilian Health Surveillance Agency establishes a maximum tolerance of 10^2 CFU / g for pre-cooked fish, breaded or not, chilled, or frozen (Brazil 2019). It was observed that the obtained values were below the maximum accepted according to the Brazilian legislation (Table 2). The same was observed for CPS, whose maximum tolerance is 5×10^2 CFU / g. The criterion of absence in 25 g of product was also attended for *Salmonella* sp. (Table 2). Therefore, the fish fingers were prepared according to the microbiological standards established for foods, thus considered safe for sensory analysis.

Chemical analysis

Literature reports 58.20–59.35% moisture for surubim (*Pseudoplatystoma corruscan*) nuggets (Silva et al. 2015), 56.08% for mandi-pintado (*Pimelodus britskii*) nuggets

(Veit et al. 2011), and 63.68% for pacu (*Piaractus mesopotamicus*), 65.84% for jundia (*Rhamdia quelen*), and 67.46% for Nile tilapia (*Oreochromis niloticus*) breaded steaks (Cortez Netto et al. 2010). Due to the relation between the hybrid sorubim and the related species, the former values were closer to those obtained here, which varied from 59.73 to 61.14% (Table 3).

Legislation determines a minimum of 10% of protein for breaded products (MAPA 2001), which was attended. Much high protein values were obtained for pacu (20.45%), jundia (20.09%), and tilapia (19.05%) breaded steaks (Cortez Netto et al. 2010). However, the values were much closer to those reported for surubim nuggets (13.18–13.74%) (Silva et al. 2015) and maldi-pintado nuggets (14.67%) (Veit et al. 2011). Thus, beyond the differences between fish species, the different values can also be explained by the addition of different concentrations of other ingredients in the formulations. In the present work, there was no addition of non-meat protein in the formulations.

The absence of statistical difference in fiber content may have occurred because all flours have approximately the same dietary fiber content, while the statistical differences observed for the lipid content may be explained by the use of fish meal as coating, since it is richer in lipids than the other flours. T1, T3 and T4 presented levels of lipids in a bit broader range than that determined for surubim nuggets (8.80–8.95%) (Silva et al. 2015).

Literature reports ash contents of 0.87–0.88% for surubim nuggets (Silva et al. 2015) and 2.7% for mandi-pintado nuggets (Veit et al. 2011). These differences in ash content between the obtained formulations and other studies may be explained mainly by the variable content of mineral in the flours utilized for breading. The addition of condiments and salts with inorganic residues have also contributed to the ash content (Cavenaghi-Altemio et al. 2013), despite these ingredients did not vary for the different formulations developed here.

Physical analysis

It was observed that products breaded with flours of larger particle sizes obtained high pick-up values (Table 4). It occurred because coarser particles have more irregular surfaces, providing greater areas for adhesion to the food surface, which may form a thicker and more textured coating on the food surface, increasing pick-up values, while finer particles create a smoother coating (Hera et al. 2013), which explains the results obtained in T3 and T4. However, the granulometry of the flour affects its ability to absorb moisture from the food's surface. Finer particles tend to absorb moisture more quickly, which can help create a crispier crust during frying by reducing the formation of steam bubbles (Burešová et al. 2023), which explains why in T1 the regular wheat flour, grounded into a finer texture compared to cassava and maize flours, presented a cohesive coating when used for breading. Fish meal does not have starch. Therefore, to increase the pick-up value of the fish meal, it is necessary to increase its granulometry or to obtain a mixture with other gluten free flour.

Fish fingers breaded according to T3 and T4 had the highest averages for shear strength (Table 4). The variation in shear force can also be explained by the granulometry of flour. It is because the size and shape of flour particles influence their ability to adhere to the surface of the food being breaded. Finer particles can adhere more tightly and evenly, enhancing the adhesion of the breading to the food item (Maskat and Kerr 2004; Pang et al. 2021). This may result in a smoother and more consistent texture with less variation in shear force. Moreover, the moisture that is absorbed by the finer particles helps to maintain a softer texture and a lower shear force (Hera et al. 2013). Thus, the products breaded with flour of larger particle sizes (T3 and T4) showed greater shear force and, consequently, great crispness (Maskat and Kerr 2002), which is very desired in fried products.

The higher color values observed for all treatments compared to T2 can be explained by the fact that the T2 coating was prepared with fish meal, providing a darker color. The higher luminosity obtained for T1 is explained due to the use of a finer flour, compared to the fish meal, which may form a more compact coating that reduces oil absorption, resulting in a lighter and less greasy final product (Brannan et al. 2014). However, it does not explain why T3 and T4, with coarser particles, did not differ from T1 in terms of color. Maybe the consistency obtained in the particle size distribution has ensured the uniformity in the breading process, leading to consistent appearance across all portions of the food item (Sarkar and Fu 2022).

Sensory analysis

Texture, flavor and appearance are some of the factors that most influence consumer's acceptance of fried products (Wang et al. 2023). Regarding the texture, the characteristics of crunchiness, tenderness, and mouthfeel are related to breading particle size. A thicker and crunchier coating may be preferred by some consumers, while others may prefer a thinner and more tender coating. Despite the observed differences observed for breading yield and shear strength, they did not influence the sensory evaluation of the texture. Differences in flavor were also not statistically significant between treatments. However, the color score obtained for T2, which was statistically lower than the other treatments, was the only sensory parameter that can explain the lower purchase intention for "certainly would purchase" and "possibly would purchase" (62%) obtained for T2.

For comparison, pacu, jundia, and tilapia breaded steaks developed by Cortez Netto et al. (2010) had a similar average range of attribute scores, which varied from 7.00 to 7.93. When the acceptance index is equal to or greater than 70%, the product is considered accepted (Stone and Sidel 2004). Thus, T2 would not be accepted in relation to color, as it presented a slightly lower value (68%).

Regarding the purchase intention survey, it was reported elsewhere averages of 60% for pacu, 73% for jundia

(73%), and 77% for tilapia breaded steaks (Cortez Netto et al. 2010). It was also reported similar studies where most of the judges have never consumed the evaluated product, *e.g.*, a study where 83.76% of the judgers never consumed fish nuggets (Lima et al. 2015). The low correlation values and even the null correlation can be explained by the lack of sensitivity of the judges during the sensorial analysis and the different temperatures between the samples submitted to the shear strength and the sensorial analysis.

Conclusions

The growing demand for gluten-free products has several practical implications for the food industry, starting with the development of gluten-free alternatives for popular food products that also meet consumer's expectations in terms of taste, texture, and nutritional profile. In general, granulometry and particle size distribution of flour played a crucial role in the breading properties and product characteristics. T2 showed the smallest pick up due to the lowest granulometry. T3 and T4 showed higher shear strength than T1 and T2. Therefore, they had greater crunchiness due to the type of flour used for final coating. T2 was darker and redder and less yellow compared to the other treatments. T3 was the only one that did not differ from treatment 1 in relation to parameters L*, a* and b*, therefore it presented the lowest ΔE^*. This same difference can be seen in the sensory analysis, whose results showed a significant difference ($p < 0.05$) only in relation to the color attribute for the T1 and T2. T1 had the highest acceptance index (>70%). T2 showed an acceptance index inferior to 70% because it was considered not accepted by consumers in relation to the color attribute. T4 had the highest purchase intention. The results of the frequency of consumption indicate that fish fingers are an alternative to meat protein intake. Physical and sensory analysis, purchase intention, and acceptance index indicated that T3 and T4 have similar and/or equal characteristics to T1 and are good alternatives to replace wheat flour, favoring celiac consumers. Thus, it concludes that both maize and cassava flour meet consumer's expectations for fish fingers. The fish meal, despite a valuable coproduct obtained from fish valorization and a gluten free raw material for food formulations, needs to be incorporated into formulations containing gluten free flour and/or improved in terms of granulometry to also meet these expectations.

Author's Contributions

Conceptual idea: Cavenaghi-Altemio, A. D.; Methodology design: Cavenaghi-Altemio, A. D.; Data collection: Cavenaghi-Altemio, A. D.; Data analysis and interpretation: Fonseca, G. G.; Writing and editing: Fonseca, G. G.

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