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FUNCTIONAL TILAPIA PÂTÉ ENRICHED WITH GREEN BANANA BIOMASS AND CHITOSAN: QUALITY AND SENSORY EVALUATION

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Abstract: This study evaluated the consumer safety and quality of tilapia pâtés formulated with green banana biomass (GBB) and chitosan (Ch). Three formulations were prepared: F1 (control), F2 (2% GBB + 2% Ch), and F3 (3% GBB + 4% Ch). Microbiological, bromatological, and sensory analyses were performed according to Brazilian regulatory standards. All formulations complied with microbiological safety limits for fish-based products, with no detection of *Salmonella* spp., *Escherichia coli*, or *Staphylococcus aureus* above permitted levels. Formulation F3, containing 3% GBB and 4% Ch, exhibited a superior nutritional quality profile due to higher protein and fiber content, alongside reduced lipid and energy levels. Sensory evaluation demonstrated high consumer acceptability (AI > 75%) across all formulations. These findings indicate that GBB and Ch can be safely used as technological ingredients in fish pâtés, highlighting their potential as techno-functional ingredients.

Key words: *tilapia pâté, green banana biomass, chitosan, functional food, sensory evaluation, food safety*

INTRODUCTION

The development of novel food products enriched with bioactive compounds has become a major focus in food science and technology (Sorrenti et al., 2023). These innovations aim to improve nutritional quality and health (Wang, 2021).

Tilapia (*Oreochromis niloticus*), a freshwater fish widely consumed in tropical regions, is valued for its mild flavor, low cost, and ease of preparation. It is also an excellent source of high-quality proteins and omega-3 polyunsaturated fatty acids, nutrients associated with

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disease prevention and health promotion (Chu et al., 2021; Farming Association, 2026).

Despite these health benefits, tilapia consumption remains limited due to sensory barriers, consumer preferences, and the lack of convenient and attractive products (Barbosa et al., 2025). Thus, value-added fish products, such as pâtés, are a promising strategy to increase consumption. Among such ingredients, green banana biomass (GBB) and chitosan (Ch) have attracted growing attention as sustainable and techno-functional food components (Bertrand et al., 2024; Silva et al., 2024). GBB, obtained from unripe banana pulp, is rich in resistant starch that behaves similarly to dietary fiber, with physiological benefits (Lotfollahi et al., 2020).

Chitosan, a natural polysaccharide derived from crustacean exoskeletons, possesses antimicrobial and technological properties (Casariego et al., 2008). Previous studies have reported that Ch improves the technological properties of fish products, while GBB can act as a fat replacer, contributing to healthier formulations and improved product consistency (Pitak & Rakshit, 2011). Although both ingredients have been investigated separately in different food systems, demonstrating their techno-functional potential (Bertrand et al., 2024; Oliveira et al., 2024), to the best of our knowledge, no previous study has investigated the combined use of GBB and Ch as techno-functional ingredients in fish pâtés. This combination may enhance nutritional and technological properties.

Therefore, the objective of this study was to develop a tilapia pâté enriched with green banana biomass and chitosan, and to evaluate its compliance with food safety standards, nutritional quality, and consumer acceptance. His work contributes to consumer protection by assessing microbiological risks in accordance with RDC No. 60/2019, ANVISA, nutriational labeling requirements, and sensory thresholds that influence consumer choice. The findings aim to support the development of safer, healthier, and better-characterized fish-based products for the consumer market.

MATERIALS AND METHODS

The study was approved by the Ethics Committee of the Federal University of Recôncavo da Bahia (UFRB) under approval number 3.362.931. All experimental procedures were conducted at the Center for Agricultural, Environmental, and Biological Sciences (CCAAB) of UFRB, in Bahia, Brazil.

Preparation of fish pâté

Three formulations of tilapia pâtés (FP) were developed:

- F1 (control, without GBB and Ch),
- F2 (2.0% GBB + 2.0% Ch), and
- F3 (3.0% GBB + 4.0% Ch).

Microbiological and bromatological analyses were performed in triplicate. For the sensory analysis, 32 panelists participated, with each evaluator considered a replication. The experiment was conducted using a completely randomized design (CRD), with three treatments and 32 replications per formulation for the sensory evaluation. The proportions of GBB and Ch were determined based on preliminary trials.

Preparation of Green Banana Biomass (GBB)

The green bananas were obtained from a market in Cruz das Almas, Bahia. GBB was obtained from unripe bananas (stage 1 of ripeness). The bananas were washed under running water, immersed in a 100 ppm chlorine solution for 15 min, and pressure-cooked for 5 min after reaching full pressure. The cooked fruits were peeled, weighed, and processed in a blender until a smooth, homogeneous paste was obtained. The paste was cooled to room temperature and stored at 4 °C until use (De Oliveira Sena et al., 2020).

Preparation of Mechanically Separated Meat (MSM)

The MSM from tilapia (*Oreochromis niloticus*) was purchased commercially from Aquicultura e Agropecuária Lago Dourado LTDA - EPP, in Cabaceiras do Paraguaçu, Bahia. Tilapia MSM was prepared by rinsing the raw fish meat with potable water at 10 °C, followed by steaming at 100 °C for 5 min. The cooked and raw MSM portions were mixed in a 70:30 ratio (w/w) to balance texture and flavor characteristics.

Obtaining chitosan (Ch)

Chitosan (Ch) was obtained from POLYMAR Indústria e Comércio LTDA (Fortaleza, Ceará, Brazil) and had an 85% degree of deacetylation.

Table 1.
Ingredients used in the formulation of tilapia pâté enriched with green banana biomass and chitosan

Ingredients	Formulations*		
	F1	F2	F3
Tilapia MSM	50.0	50.0	50.0
Soy protein	1.50	1.50	1.50
Hydrogenated vegetable fat	5.00	3.00	2.00
Starch	2.00	0.00	0.00
Ice	25.0	25.0	25.0
Green banana biomass	0.00	2.00	3.00
Chitosan	0.00	2.00	4.00
Flaxseed gel	0.00	2.00	2.00
Monosodium glutamate	0.20	0.50	0.50
Sodium erythorbate	0.20	0.00	0.00
Sodium tripolyphosphate	2.00	0.00	0.00

** g per 100 g of product.*

Formulation and processing

Base ingredients for pate preparation are presented in Table 1. The preparation of the formulations was carried out as described by Delbem et al. (2012). After homogenization, samples were filled into sterilized screw-top glass jars, pasteurized in a water bath at 80 °C for 35 min, rapidly cooled in an ice-water bath, and stored at 7 °C until analysis.

In formulations F2 and F3, starch was replaced by green banana biomass due to its ability to act as a thickening and water-holding agent. Flaxseed gel was added for its emulsifying properties, helping maintain the pâté's texture.

Chitosan was used to reduce hydrogenated vegetable fat and replace sodium erythorbate and sodium tripolyphosphate, owing to its antioxidant and antimicrobial properties. Additionally, the concentration of monosodium glutamate was increased in formulations F2 and F3 to intensify the pâté's flavor.

Microbiological analysis

Microbiological quality was evaluated in accordance with the standards established by the Brazilian National Health Surveillance Agency (ANVISA) – Normative Instruction IN No. 161/2022 for fish-based products (ANVISA, 2022). The following were analyzed: *E. coli*, *S. aureus*, *Clostridium* spp., and *Salmonella* spp.

Analyses were performed according to the Bacteriological Analytical Manual (BAM) methodologies (BAM, 1998). Results were expressed as colony-forming units (CFU g^{-1}) or most probable number (MPN g^{-1}), as appropriate.

Bromatological analysis

Water activity (Aw) was determined using a calibrated Aw meter, with measurements taken at 25 ± 1 °C. Proximate composition — including moisture, crude protein, crude fiber, insoluble fiber, ether extract, non-nitrogenous extract, and ash — was determined according to AOAC (1997) official methods. All analyses were performed in triplicate (n = 3).

Total amino acid determination was performed as described by Machado et al. (2020). For tryptophan quantification, samples (150 mg) underwent alkaline hydrolysis with 4 M KOH at 110 °C for 6 h under an N_2 atmosphere. For the other amino acids, acid hydrolysis was performed using 6 M HCl at 110 °C for 24 h under an N_2 atmosphere to minimize degradation and oxidation of amino acids such as serine, threonine, and methionine. Following hydrolysis, the samples were centrifuged, an internal standard (norvaline) was added, and the samples underwent automated derivatization. All determinations were performed in triplicate. Total amino acids were determined by high-performance liquid chromatography (HPLC) using automated pre-column derivatization with o-phthalaldehyde (OPA/3-MPA) and 9-fluorenylmethyl chloroformate (FMOC).

Chromatographic separation was carried out on a ZORBAX Eclipse Plus C18 column (4.6 × 250 mm; 5 µm) maintained at 40 °C, using gradient elution with phosphate/borate buffer and a methanol: acetonitrile:water mixture at a flow rate of 1.5 mL min^{-1}. Detection of the derivatives was performed by fluorescence at specific wavelengths OPA (338 nm) and FMOC (262 nm).

The fatty acid composition was determined according to Nascimento et al. (2014). Initially, the lipids were subjected to methylation using a NaOH solution in methanol and boron trifluoride (BF_3), with heating in a water bath. After cooling, isooctane and a saturated NaCl solution were added to extract fatty acid methyl esters (FAMEs).

The obtained FAMEs were analyzed by gas chromatography with flame ionization detection (GC-FID). Fatty acid identification was performed by comparing retention times with standards (C4–C24, 18, 919-AMP; Sigma-Aldrich®), while quantification was performed using methyltricosanoate (C23:0) as an internal standard. Fatty acid composition was expressed as relative percentages of the total identified fatty acids.

Sensory analysis

The sensory acceptance tests were conducted with 32 untrained volunteers, who provided informed consent prior to participation. Each participant evaluated the three pâté formulations in a randomized order under controlled sensory evaluation conditions. Sensory attributes — flavor, texture, aroma, color, and overall preference — were assessed using a nine-point hedonic scale (1 = "strongly dislike" to 9 = "strongly like"), following Stevanato et al. (2007). Attitude and purchase intention were also evaluated.

The acceptability index (AI, %) for each attribute was calculated using Equation (1), as described by Dutcosky (2013).

$$AI\ (\%) = (A / B) \times 100 \quad \text{(Eq. 1)}$$

where A is the mean score for each attribute, and B is the highest possible score. The overall AI was obtained as the mean of all evaluated attributes.

Statistical analysis

Data from bromatological and sensory analyses were tested for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. Variables meeting these assumptions were analyzed by one-way analysis of variance (ANOVA), followed by Tukey's post hoc test at the 5% significance level. For variables that did not meet the assumptions of normality and/or homogeneity of variances (stearic acid (C18:0), oleic acid (C18:1 cis), and trans-linoleic acid (C18:2 trans)), the non-parametric Kruskal–Wallis test followed by Dunn's multiple comparison test with

Bonferroni adjustment was applied. Statistical analyses were performed using R software (version 4.2.3). Fatty acid and amino acid profiles were expressed as mean ± standard deviation, and statistical comparisons were performed when appropriate.

RESULTS AND DISCUSSION

Microbiological quality

All fish pâté formulations (F1, F2, and F3) complied with the microbiological standards established for fish-based products. No *Salmonella* spp. colonies were detected in any sample, and counts of *Escherichia coli* (< 3.0 MPN g^{-1}), *Staphylococcus aureus* (< 10 CFU g^{-1}), and sulfite-reducing *Clostridium* spp. were below the limits defined by Brazilian legislation, indicating adequate hygienic conditions.

Table 2.
Percentages of moisture, crude protein, ether extract, crude fiber, insoluble fiber, non-nitrogenous extract, and crude energy (kcal 100 g^{-1}) in fish pâtés, along with their respective p-values and coefficients of variation (C.V.)

Analyses	Formulations (%)				
	F1	F2	F3	*p value*	C.V. (%)
Moisture (%)	70.49 ± 1.12^{a}	67.00 ± 1.97^{b}	65.76 ± 0.42^{b}	0.012	1.97
Crude protein (%)	7.89 ± 0.45^{c}	9.98 ± 0.31^{a}	8.83 ± 0.07^{b}	0.001	3.63
Ether extract (%)	11.76 ± 0.08^{a}	11.73 ± 0.07^{a}	9.04 ± 0.03^{a}	0.194	0.60
Crude fiber (%)	11.24 ± 3.12^{b}	10.76 ± 2.41^{b}	17.50 ± 1.36^{a}	0.025	18.28
Neutral detergent fiber (%)	36.70 ± 1.24^{b}	46.04 ± 5.20^{a}	50.32 ± 3.07^{a}	0.006	8.08
Non-nitrogenous extract (%)	7.67 ± 0.78^{a}	6.11 ± 1.92^{a}	7.61 ± 0.51^{a}	0.292	17.38
Crude energy (kcal 100 g^{-1})	168.05 ± 0.87^{a}	169.82 ± 7.83^{a}	147.06 ± 1.85^{b}	0.001	2.89
Total[1] (%)	106.65	105.58	108.73		

[1]The sum exceeds 100% due to analytical variability and overlapping fractions inherent to proximate composition methods, particularly fiber and non-nitrogenous extract determinations. Means followed by the same letters on the same line do not differ significantly (p>0.05) according to the Tukey's test. F1: 0% GBB and 0% Ch. F2: 2.0% GBB and 2.0% Ch, and F3: 3.0% GBB and 4.0% Ch.

Water activity

The water activity (Aw) values of formulations F1, F2, and F3 were 0.94, 0.94, and 0.95, respectively. A statistically significant difference ($p < 0.05$) was observed only between and the other formulations, as F3 showed a slightly higher Aw value.

Bromatological composition

The centesimal composition of the fish pâtés is shown in Table 2. Significant differences ($p < 0.05$) were observed for moisture, crude protein, crude fiber, neutral detergent fiber (NDF), and gross energy, while the non-nitrogenous extract did not differ significantly among formulations. F2 showed the highest protein, while F3 had the lowest moisture, higher fiber, and lower energy.

Amino acid composition

The essential and non-essential amino acid profiles of the pâtés are presented in Table 3. Formulations containing GBB and Ch exhibited higher total amino acid content compared to the control. Formulation F2 showed the highest concentration of essential (19.02 mg g^{-1}) and non-essential amino acids (23.42 mg g^{-1}), representing an average increase of 28.7% and 18.8%, respectively, relative to F1. The most abundant essential amino acids across all formulations were leucine, lysine, and phenylalanine, while glutamic acid and aspartic acid (non-essential) were predominant among the NEAAs. The predominance of glutamic acid reflects the natural amino acid composition of the raw materials used in the formulations. These results indicate improved amino acid density, especially in F2, with a marked increase observed for certain amino acids, particularly tryptophan, which may reflect analytical variability or matrix effects and should be interpreted with caution.

The predominance of leucine, lysine, and phenylanine among the essential amino acids agrees with the amino acid profile commonly reported for fish proteins, in which lysine and leucine are consistently identified as major essential amino acids contributing to the high biological value of fish-derived proteins (Mohanty et al., 2014). Likewise, glutamic and aspartic acids were the predominant non-essential amino acids in the present study, a pattern frequently described for freshwater fish species and associated with the characteristic composition of fish muscle proteins (Lise et al., 2021). These findings indicate that incorporating green banana biomass and chitosan did not adversely affect the typical amino acid profile of tilapia pâté. Fish proteins are re-cognized as high-quality dietary proteins because they provide all essential amino acids required for human nutrition in balanced proportions (Mohanty et al., 2014). Although formulations F2 and F3 exhibited higher concentrations of essential and non-essential amino acids than the control, these differences are more likely attributable to changes in formulation composition and concentration effects than to direct amino acid contributions from green banana biomass or chitosan, since these ingredients are not significant protein sources. Nevertheless, the preservation of a favorable essential amino acid profile after ingredient incorporation demonstrates that the nutritional quality of the fish protein was maintained during formulation.

Table 3.
Content of essential and non-essential amino acids in mg g^{-1} of dry matter in fish pâtés (F1, F2, and F3).

Amino acids	Formulations (mg g^{-1})			*p value*	C.V. (%)
	F1	F2	F3		
Phenylalanine	1.69 ± 0.07^b	2.05 ± 0.05^a	1.93 ± 0.06^a	0.00005	3.30
Histidine	0.78 ± 0.04^b	0.93 ± 0.04^a	0.89 ± 0.02^a	0.00037	3.87
Isoleucine	1.45 ± 0.07^b	1.80 ± 0.05^a	1.72 ± 0.06^a	0.00003	3.53
Leucine	3.47 ± 0.15^b	4.30 ± 0.11^a	4.12 ± 0.13^a	0.00002	3.30
Lysine	3.05 ± 0.10^b	3.64 ± 0.06^a	3.62 ± 0.13^a	0.00002	2.96
Methionine	0.98 ± 0.04^b	1.18 ± 0.03^a	1.12 ± 0.04^a	0.00017	3.67
Threonine	1.39 ± 0.06^b	1.71 ± 0.04^a	1.66 ± 0.06^a	0.00003	3.46
Tryptophan	0.13 ± 0.01^b	1.40 ± 0.01^b	1.60 ± 0.01^a	0.00095	4.63
Valine	1.65 ± 0.08^b	2.01 ± 0.06^a	1.89 ± 0.06^a	0.00011	3.66
AAE total[1]	14.59 ± 1.13	19.02 ± 1.38	18.55 ± 1.34		
NEAA[2] total	18.70 ± 1.41	23.42 ± 1.77	20.80 ± 1.67		

Mean ± standard deviation. [1]EAA – essential amino acids. [2]Non-essential amino acids. F1: 0% GBB and 0% Ch. F2: 2.0% GBB and 2.0% Ch, and F3: 3.0% GBB and 4.0% Ch.

Table 4.
Relative percentage (%) of saturated, monounsaturated, and polyunsaturated fatty acids in total identified lipids (mono- and polyunsaturated) in the ether extract of fish pâtés (F1, F2, and F3)

Fatty acids	Formulations (%)			*p value*	C.V. (%)
	F1	F2	F3		
Myristic (C14:0)	1.65 ± 0.03^{b}	1.99 ± 0.13^{a}	2.01 ± 0.06^{a}	0.003759	4.68
Palmitic (C16:0)	32.15 ± 0.01^{a}	30.20 ± 0.67^{b}	29.28 ± 0.08^{b}	0.0000000001	1.97
Stearic (C18:0)[1]	0.00 ± 0.00^{a}	6.20 ± 0.06^{a}	3.26 ± 3.08^{a}	0.0552	—
Others	1.12 ± 0.02	1.33 ± 0.29	1.30 ± 0.29		
Total saturates	34.92	39.72	35.85		
Palmitoleic (C16:1)	2.83 ± 0.06^{c}	3.77 ± 0.13^{b}	4.05 ± 0.01^{a}	0.000004	2.36
Oleic (C18:1 cis)[1]	38.02 ± 0.20^{a}	37.08 ± 0.35^{ab}	21.25 ± 15.13^{b}	0.0273	—
Others	6.76 ± 0.06	1.73 ± 0.16	1.40 ± 0.16		
Total monounsaturated	47.57	41.98	26.49		
Trans-linoleic (C18:2 trans)[1]	0.00 ± 0.00^{a}	2.20 ± 0.00^{a}	20.49 ± 18.76^{a}	0.050	—
Linoleic (C18:2 cis)	15.03 ± 0.06^{a}	14.11 ± 0.04^{b}	13.74 ± 0.26^{b}	0.000163	1.11
Gamma-linolenic (C18:3n6)	0.43 ± 0.00^{b}	0.54 ± 0.04^{a}	0.59 ± 0.01^{a}	0.000659	5.00
Alpha-linolenic (C18:3n3)	1.01 ± 0.02^{a}	0.84 ± 0.01^{b}	0.81 ± 0.03^{b}	0.000110	2.64
Others	0.98 ± 0.15	0.02 ± 0.01	1.39 ± 0.24		
Total polyunsaturated	17.45	17.71	37.02		
ω6/ω3 ratio[2]	15.31	17.44	17.69		
Total unsaturated	65.02	59.69	63.51		

Mean ± standard deviation. F1: 0% GBB and 0% Ch; F2: 2.0% GBB and 2.0% Ch; F3: 3.0% GBB and 4.0% Ch. Values for individual fatty acids are expressed as mean ± standard deviation (n = 3). Summatory totals were calculated from the mean percentages of the component fatty acids and are presented for descriptive purposes only; therefore, separate standard deviations were not calculated. Means followed by different lowercase letters within the same row differ significantly (p < 0.05). [1]Stearic (C18:0), Oleic acid (C18:1 cis) and trans-linoleic acid (C18:2 trans) were analyzed using the Kruskal–Wallis test followed by Dunn's multiple comparison test with Bonferroni adjustment because the assumptions required for parametric analysis were not met. Consequently, coefficients of variation are not reported for these variables. [2]Calculated as (linoleic acid + γ-linolenic acid)/α-linolenic acid. The ratio is presented for descriptive purposes only and was not subjected to statistical analysis.

Similar observations have been reported for processed fish products, in which processing and formulation modifications did not compromise the nutritional value of the protein fraction (Pateiro et al., 2020; Lise et al., 2021).

Fatty acid profile

The distribution of saturated, monounsaturated, and polyunsaturated fatty acids (PUFAs) is summarized in Table 4. Distinct lipid patterns were observed among formulations. Formulation F2 showed the highest proportion of total saturated fatty acids (39.72%), whereas F1 presented the highest proportion of monounsaturated fatty acids (47.57%). Formulation F3 exhibited the highest proportion of total PUFAs (37.02%); however, the marked variability in trans-linoleic acid (C18:2 trans) limits interpretation of differences in PUFA content among formulations. Across all formulations, palmitic (C16:0), oleic (C18:1 cis), and linoleic (C18:2 cis) were the predominant fatty acids. Alpha-linolenic acid (C18:3n3) and gamma-linolenic acid (C18:3n6) were detected in all formulations, resulting in ω6/ω3 ratios ranging from 15.31 to 17.69.

Sensory evaluation

The mean sensory scores for the hedonic and attitude attributes are shown in Table 5, while the overall acceptance distribution is illustrated in Fig. 1.

No significant differences (p > 0.05) were observed among formulations for any evaluated attribute, including flavor, aroma, color, texture, appearance, overall impression, or purchase intention. Mean hedonic scores ranged from 6.7 to 7.3, corresponding to "slightly liked" to "moderately liked," indicating broad consumer acceptability of all formulations.

The acceptability index (AI%) was 83.9% for F1, 80.4% for F2, and 77.7% for F3, confirming high sensory approval across treatments. Although F3 exhibited a minor reduction in hedonic score, its acceptance level remained above 75%, which is generally considered satisfactory for consumer products. From a consumer-protection perspective, the absence of pathogenic microorganisms across all pâté formulations is a critical finding.

Table 5.
Averages of the attributes GI (hedonic), flavor, aroma, color, texture, appearance, GI (attitude), and GI (purchase intention) for the fish pâtés F1, F2, and F3, along with their respective p values and coefficients of variation (C.V.)

Attributes	**Formulations**			***p value***	**C.V. (%)**
	F1	**F2**	**F3**		
GI (hedonic)	7.3 ± 1.90[a]	7.2 ± 1.64[a]	6.7 ± 2.19[a]	0.418	27.28
Flavor	7.7 ± 1.49[a]	7.4 ± 2.06[a]	7.3 ± 1.95[a]	0.578	24.83
Aroma	7.5 ± 1.34[a]	7.2 ± 1.79[a]	6.7 ± 2.32[a]	0.269	26.09
Color	7.2 ± 1.51[a]	6.9 ± 1.82[a]	7.0 ± 1.85[a]	0.804	24.66
Texture	7.6 ± 1.45[a]	7.1 ± 1.91[a]	6.9 ± 2.08[a]	0.254	25.43
Appearance	7.8 ± 1.41[a]	7.6 ± 1.74[a]	7.1 ± 1.98[a]	0.305	23.04
GI (attitude)	5.8 ± 1.37[a]	5.5 ± 1.46[a]	5.0 ± 2.05[a]	0.127	30.35
GI (intention)	4.9 ± 1.79[a]	5.1 ± 1.59[a]	4.7 ± 2.09[a]	0.672	37.42

Mean ± standard deviation (n = 32), according to a nine-point scale, with the scores "6 – slightly liked" and "7 – moderately liked" expressed in the results. GI (hedonic) = global impression. Means followed by the same letters on the same line do not differ significantly (p>0.05) according to the Tukey test. F1: 0% GBB and 0% Ch. F2: 2.0% GBB and 2.0% Ch, and F3: 3.0% GBB and 4.0% Ch.

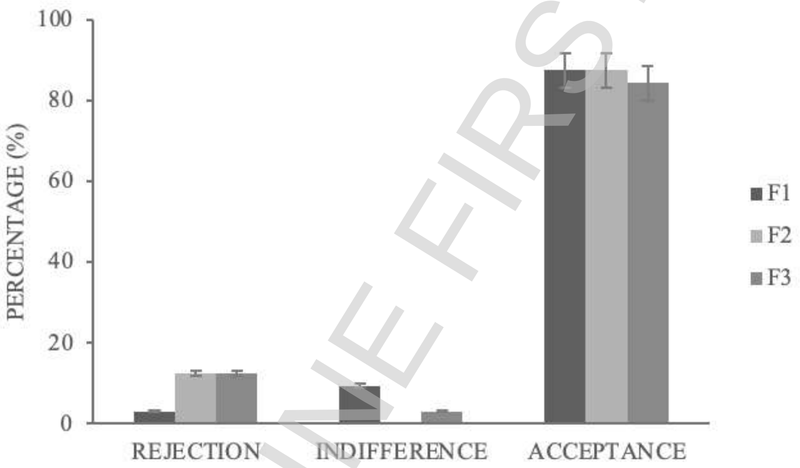

Figure 1. Distribution of overall acceptance for tilapia pâté formulations enriched with GBB and chitosan

All samples complied with the microbiological limits established by Brazilian food safety regulations Normative Instruction No. 161/2022 (ANVISA, 2022), demonstrating that the processing and ingredient selections were effective in ensuring product safety for consumers. The antimicrobial potential of chitosan (Ch) as a natural preservative may have played a decisive role in this outcome, particularly in formulations F2 and F3, which did not include synthetic preservatives such as sodium tripolyphosphate. Chitosan's cationic nature enables interactions with negatively charged microbial cell membranes, leading to disruption of cell permeability and inhibition of microbial growth (Arkoun et al., 2017). This property is particularly relevant for consumer protection, as it reduces reliance on chemical additives while maintaining microbiological safety.

The progressive reduction in moisture content from F1 to F3 reflects the hygroscopic and water-binding properties of both green banana biomass (GBB) and Ch, confirming their potential as technological ingredients to control water retention in emulsified fish products. These findings are consistent with previous studies showing that dietary fibers and chitosan increase water-holding capacity by promoting water immobilization and stronger interactions within the protein matrix, thereby modifying water distribution in emulsified meat products (Han & Bertram, 2017; Chattopadhyay et al., 2019; Auriema et al., 2022).

Although F3 exhibited lower moisture content, its water activity (Aw) was slightly higher than that of F1 and F2. Chitosan has been reported to improve water-holding capacity and emulsion stability by promoting interactions within the protein matrix, resulting in greater water immobilization and a more compact microstructure (Han & Bertram, 2017; Chattopadhyay et al., 2019; Wang et al., 2023). Because water activity is influenced not only by the amount of water present but also by its physicochemical state within the food matrix, the slight increase observed in F3 likely reflects changes in water distribution rather than differences in total moisture content.

The lower energy density observed in F3 is consistent with its higher fiber content and the replacement of part of the fat by green banana biomass and chitosan in the formulation. Green banana biomass is recognized as a fat replacer with a high water-holding capacity and thickening properties, thereby improving emulsion stability and product yield while reducing the fat content of emulsified meat products (Auriema et al., 2022; Oliveira et al., 2024). In addition, chitosan can interact with lipids and bile salts through physicochemical interacttions, potentially influencing lipid bioaccessibility (McClements, 2021). Together, these technological characteristics contribute to the development of fish-based spreads with reduced energy density while maintaining desirable structural properties.

Regarding crude protein, formulations F2 and F3 exhibited higher values than the control formulation. These differences are likely attributable to the overall formulation composition rather than to the direct protein contribution of green banana biomass or chitosan. Furthermore, because crude protein was estimated from total nitrogen, the presence of nitrogen-containing compounds such as chitosan may have contributed to the measured values. Variations in crude protein content among fish pâtés are also influenced by the raw material, processing conditions, and formulation characteristics (Matiucci et al., 2023). Considering that Nile tilapia typically contains 8–11% crude protein and that conventional fish pâtés average around 8% (Machado et al., 2020), the crude protein contents observed in the present study are consistent with values reported for fish-based products.

The lipid composition of the formulations largely reflects that of tilapia muscle and may vary according to anatomical region and processing conditions. Li et al. (2023) reported that the ventral portion of tilapia contains higher lipid content than the dorsal muscle, while successive washings during mechanical separation reduce total lipid levels. In the present study, formulation F3 exhibited the highest proportion of total polyunsaturated fatty acids (PUFAs); however, the marked variability in trans-linoleic acid should be considered when comparing lipid composition among formulations. Similar modifications in fatty acid composition have been reported after incorporating green banana biomass into emulsified meat products (Auriema et al., 2022), although the mechanisms underlying these changes may vary depending on the formulation and ingredients used.

Overall, palmitic, oleic, and linoleic acids remained the predominant fatty acids in all formulations, indicating that the incorporation of green banana biomass and chitosan preserved the characteristic fatty acid profile of the fish pâtés.

From a sensory perspective, the absence of significant differences among treatments for all attributes demonstrates that the inclusion of GBB and Ch did not compromise consumer perception of flavor, texture, or appearance. The relatively low concentrations used (≤3% GBB and ≤4% Ch) likely remained below the sensory detection threshold for structural and flavor alterations (Owusu-Apenten & Vieira, 2022). Comparable stability was reported by Ansorena et al. (2022), who found that incorporating 3–4% sunflower oil emulsion into bakery products did not significantly alter sensory acceptance. Therefore, the consistent hedonic scores observed here indicate incorporating GBB and Ch preserved the sensory acceptance of the pâtés while improving their nutritional characteristics, thereby supporting the development of healthier fish-based products without compromising consumer acceptability.

Therefore, these findings reinforce the potential application of GBB and Ch as multifunctional ingredients that integrate health promotion, waste valorization, and food innovation. Despite the promising results, this study has limitations, including the absence of shelf-life evaluation, a lack of detailed lipid oxidation analysis, and a lack of a more comprehensive nutritional lipid assessment beyond the ω6/ω3 ratio. Additionally, the relatively small sensory panel and the use of untrained assessors may limit the generalization of consumer acceptance findings.

CONCLUSIONS

This study demonstrated that green banana biomass (GBB) and chitosan (Ch) can be safely incorporated into tilapia pâtés while maintaining compliance with food safety regulations and consumer acceptability. The addition of these ingredients did not compromise microbiological safety, as all formulations met the standards established by the National Health Surveillance Agency (Brazil) for fish-based products.

Among the tested formulations, F3 (3% GBB and 4% Ch) exhibited the highest fiber content and lowest lipid and caloric values, while maintaining the characteristic fatty acid profile of the formulations.

These nutritional characteristics are relevant for consumer protection in the context of diet-related non-communicable diseases, as they support the availability of healthier processed food options.

From a consumer protection and food safety perspective, the enriched fish pâté formulations evaluated in this study showed potential for the development of nutritionally improved products while maintaining micro-biological quality and sensory acceptance.

Future studies should investigate the individual effects of formulation components and product stability under refrigerated storage to support the development of optimized formulations with extended shelf-life.

AUTHOR CONTRIBUTIONS

Conceptualization, writing – original draft, B.V.S; Investigation, B.V.S., M.A.L.C.M., A.S.R.B. and M.A.F.; Formal analysis, M.A.L.C.M., A.S.R.B., M.A.F., L.G.C., C.O.S. and P.C.G.C.; Visualization, L.G.C., C.O.S. and P.C.G.C; Writing – review & editing, S.M., M.B.P.P.O., P.C.G.C. and N.S.E.-B.; Supervision, S.M., M.B.P.P.O. and N.S.E.-B.; Funding acquisition, N.S.E.-B.

DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are available upon reasonable request.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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FUNKCIONALNA PAŠTETA OD TILAPIJE OBOGAĆENA BIOMASOM ZELENE BANANE I HITOZANOM: PROCENA KVALITETA I SENZORNA EVALUACIJA

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Sažetak: Ova studija je procenila bezbednost za potrošače i kvalitet pašteta od tilapije formulisanih sa biomasom zelene banane (GBB) i hitozanom (Ch). Pripremljene su tri formulacije: F1 (kontrolna), F2 (2% GBB + 2% Ch) i F3 (3% GBB + 4% Ch). Mikrobiološke, bromatološke i senzorne analize sprovedene su u skladu sa brazilskim regulatornim standardima. Sve formulacije su bile u skladu sa mikrobiološkim kriterijumima bez prisustva *Salmonella* spp., *Escherichia coli* ili *Staphylococcus aureus* iznad dozvoljenih granica. Formulacija F3, sa 3% GBB i 4% Ch, pokazala je superioran nutritivni profil zahvaljujući višem sadržaju proteina i vlakana, uz smanjen nivo lipida i energije. Senzorna analiza ukazala je na visoku prihvatljivost od strane potrošača (AI > 75%) kod svih formulacija. Rezultati ukazuju da GBB i Ch mogu biti bezbedno korišćeni kao tehnološki sastojci u ribljim paštetama, naglašavajući njihov potencijal kao tehno-funkcionalnih sastojaka.

Ključne reči: *pašteta od tilapije, biomasa zelene banane, hitozan, funkcionalna hrana, senzorna ocena, bezbednost hrane*

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