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Functional dumplings made from lobster processing waste: nutritional, microbiological, and sensory characterization

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Abstract

This study aimed to develop functional dumplings from lobster processing waste, aiming to enhance the value of this by-product and create foods enriched with functional ingredients. Two formulations were developed: FBF1 (lobster waste, cassava, and wheat flour) and FBF2 (lobster waste, green banana biomass, and Peruvian maca), which were evaluated for their microbiological profile, centesimal composition, and sensory acceptance. Microbiological analysis revealed that both formulations were free of *Salmonella* spp., *Escherichia coli*, coagulase-positive staphylococci, and had low counts of mesophilic heterotrophic bacteria, in compliance with current legislation. Nutritionally, the FBF2 formulation had higher protein, lipid, and fiber content, while FBF1 maintained higher carbohydrate values. Sensory testing indicated wide acceptance for both formulations, with an acceptability index above 77%, although the FBF1 formulation achieved higher averages in flavor and overall acceptance. These results demonstrate that lobster waste dumplings offer microbiological safety, nutritional enrichment, and good sensory acceptance, making them a promising alternative for the food industry, which is focused on innovation, sustainability, and the development of functional products.

Keywords: Source of fiber, green banana biomass, maca flour, food sustainability.

Resumo - Bolinhos funcionais de resíduos do processamento de lagosta: caracterização nutricional, microbiológica e sensorial

Este estudo buscou desenvolver bolinhos funcionais a partir de resíduos do processamento da lagosta, visando a valorização desse coproduto e a criação de alimentos enriquecidos com ingredientes funcionais. Foram elaboradas duas formulações: FBF1 (resíduo de lagosta, aipim e farinha de trigo) e FBF2 (resíduo de lagosta, biomassa de banana verde e maca peruana), avaliadas quanto ao perfil microbiológico, composição centesimal e aceitação sensorial. Na análise microbiológica, ambas as formulações apresentaram ausência de *Salmonella* spp., *Escherichia coli*, estafilococos coagulase positiva e contagens reduzidas de bactérias heterotróficas mesófilas, atendendo à legislação vigente. Em termos nutricionais, a formulação FBF2 apresentou maior teor de proteínas, lipídios e fibras, enquanto a FBF1 manteve valores mais elevados de carboidratos. Os testes sensoriais indicaram boa aceitação para ambas as formulações, com índice de aceitabilidade superior a 77%, embora a formulação FBF1 tenha alcançado maior média nos atributos sabor e aceitação global. Esses resultados demonstram que os bolinhos de resíduo de lagosta apresentam segurança microbiológica, enriquecimento nutricional e boa aceitação sensorial, configurando-se como uma alternativa promissora para a indústria de alimentos voltada à inovação, sustentabilidade e desenvolvimento de produtos funcionais.

Palavras-chave: Fonte de fibras, biomassa de banana verde, maca peruana, sustentabilidade ambiental.

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Resumen - Empanadillas funcionales elaboradas a partir de residuos del procesamiento de langosta: caracterización nutricional, microbiológica y sensorial

Este estudio tuvo como objetivo desarrollar dumplings funcionales a partir de los desechos del procesamiento de langosta, con el fin de mejorar el valor de este subproducto y crear alimentos enriquecidos con ingredientes funcionales. Se desarrollaron dos formulaciones: FBF1 (desechos de langosta, yuca y harina de trigo) y FBF2 (desechos de langosta, biomasa de plátano verde y maca peruana), las cuales fueron evaluadas para su perfil microbiológico, composición centesimal y aceptación sensorial. El análisis microbiológico reveló que ambas formulaciones estaban libres de *Salmonella* spp., *Escherichia coli*, estafilococos coagulasa-positivos y tenían bajos recuentos de bacterias heterotróficas mesófilas, en cumplimiento con la legislación vigente. Nutricionalmente, la formulación FBF2 presentó mayor contenido de proteínas, lípidos y fibra, mientras que la FBF1 mantuvo valores más altos de carbohidratos. Las pruebas sensoriales indicaron buena aceptación para ambas formulaciones, con un índice de aceptabilidad superior al 77%, aunque la formulación FBF1 logró promedios más altos en sabor y aceptación general. Estos resultados demuestran que los dumplings de desechos de langosta ofrecen seguridad microbiológica, enriquecimiento nutricional y buena aceptación sensorial, constituyendo una alternativa prometedora para la industria alimentaria enfocada en la innovación, la sustentabilidad y el desarrollo de productos funcionales.

Palabras clave: Fuente de fibras, biomasa de plátano verde, harina de maca, sostenibilidad alimentaria.

Introduction

The valorization of food by-products has been established as an essential strategy for promoting sustainability and meeting the Sustainable Development Goals (SDGs) targets, as these by-products contain valuable compounds that can be reused, thereby reducing waste throughout the production chain (Coppola, Lauritano & Pascale, 2021). In the aquatic food sector, traditionally discarded by-products are increasingly being used to develop higher-value products, such as burgers, nuggets, and sausages. This approach helps mitigate environmental impacts, reduces pressure on natural resources, increases food security, and generates new economic opportunities for the industry (Pinto, Bezerra, Amorim, Valadão & Oliveira, 2017; FAO, 2024).

Although aquaculture outperforms fishing, it still maintains its strategic importance in the global supply of aquatic foods, with a production of 91 million tons in 2022. Of this total, marine capture contributed 80 million tons, representing 39.14% of global production. Among the most valuable resources are tuna, cephalopods, shrimp, and lobsters. In the case of lobsters, production had been impacted by the COVID-19 pandemic and market restrictions but recovered, surpassing 290,000 tons in 2022, although that is still below previous levels (FAO, 2024). This scenario reinforces the need for sustainable practices that include the use of waste to formulate new products, thereby aligning innovation with the principles of the circular economy.

Lobster processing waste has high nutritional potential, particularly due to its high-biological-value proteins, which are rich in essential amino acids and are easily digested and absorbed (Zhang, Ma, Songa & Farag, 2024). Beyond the nutritional aspect, the growing demand for functional foods reflects a health-oriented consumer trend, with a demand for products that offer specific benefits, such as reduced sodium, the presence of natural antioxidants, and added fiber (Safraid, Portes, Dantas & Batista, 2022).

Recent studies reinforce the functionality of lobster waste by highlighting its diverse composition and high added value. Its meat has a high protein content (up to 88%), essential for amino acid synthesis, tissue formation, and metabolic regulation. The carapace contains fibers derived from chitin and chitosan (approximately 6.28%), which are associated with beneficial effects, including immune modulation, cholesterol reduction, and anticarcinogenic activity. Furthermore, the carapace is notable for its high mineral content, including calcium, magnesium, iron, and phosphorus, which can be used in functional ingredients such as chitosan, glucosamine, and oligosaccharides (Karnila et al., 2024). Other ingredients such as Peruvian maca, green banana biomass, and propolis have also stood out as plant-based functional foods due to their observed health effects, and as sources of resistant starch, dietary fiber, protein, vitamins, phytosterols, carotenoids, and polyphenols (Wang & Zhu, 2019, Oliveira et al., 2024, Deng et al., 2025).

Replacing wheat flour with gluten-free ingredients in fish cakes, such as Peruvian maca, aims to appeal to consumers who associate these products with greater health benefits beyond those with celiac disease and non-celiac gluten sensitivity. Although these groups remain a minority, this market is growing and demands safe alternatives with technological and sensory qualities comparable to conventional foods (Grand View Research, 2024).

In this context, the technical and scientific challenge lies in developing innovative and sustainable foods made from lobster processing waste that are safe to eat, nutritionally enriched, and sensorially acceptable.

Therefore, this study sought to develop and characterize functional dumplings from lobster processing waste, evaluating their nutritional, microbiological, and sensory profiles.

Material and Methods

Obtaining lobster residue and ingredients

Lobster waste was obtained from a processing plant located in Alcobaça, in the extreme south of Bahia. The material was collected during the cleaning process, a stage designed to adjust the presentation of the muscle portion at the junction of the tail and cephalothorax. After collection, the residual meat was cleaned to remove impurities, then cooked in boiling water, and finally manually pressed through a sieve to remove excess water. The final product was packaged in polyethylene bags and stored refrigerated (4°C) until use.

The propolis, chitosan, and other ingredients (salt, seasonings, olive oil, wheat flour, and Peruvian maca) were purchased from certified suppliers. All ingredients were stored according to the manufacturer's recommendations, ensuring their integrity and quality until use.

Green banana biomass

Green banana biomass (GBB) was prepared according to a methodology adapted from Yap, Brennan, Jayasena & Coore (2017). The bananas were washed in running water, sanitized by immersion in a sodium hypochlorite solution (100 mg/L) for 10 minutes, and then rinsed in drinking water to remove excess chlorine. The bananas were then pressure-cooked for 15 minutes, cooled, drained, and ground (pulp and peel) in a stainless-steel food processor until a homogeneous puree was obtained.

Yeast hydrolysate

The residual yeast was supplied by a craft brewery located in Cruz das Almas, Bahia. The material underwent heat treatment at 98°C for 10 minutes to inactivate the cells, followed by washing in ice-cold water (1:1 w/v) and centrifugation at 6000 rpm for 5 minutes. The recovered cells were treated with 0.3% (w/v) NaOH for 30 minutes under agitation. Subsequently, eight cycles of washing (1:1 v/v) and centrifugation were performed to remove resins, tannins, and bitter compounds, as per Pinto (2011). The cleaned biomass was frozen at -18°C until use.

Making lobster dumplings

To prepare the functional lobster dumplings, two experimental formulations (FLD1 and FLD2) were established, as described in Table 1. During the preparation process, onion and garlic were sautéed in olive oil, followed by the addition of lobster meat. In formulation FLD1, cassava paste and wheat flour were used, while in formulation FLD2, cassava was replaced by GBB and wheat flour by Peruvian maca. Subsequently, chitosan, red propolis, yeast hydrolysate, salt, coriander, cumin, allspice, saffron, and smoked paprika were added. After homogenization, the dumplings were shaped, packaged in polyethylene bags, and frozen (-18°C) until analysis.

Microbiological analysis

The analyses of *Salmonella* spp., *Escherichia coli*, coagulase-positive staphylococci, and mesophilic heterotrophic bacteria were performed according to the Bacteriological Analytical Manual (BAM) described by Silva et al. (2010). The enumeration of mesophilic heterotrophic bacteria was performed by depth plating on Standard Count Agar (SCA). The analysis of *E. coli* was determined using the Most Probable Number (MPN) technique, which involves the cultivation of Lauryl Sulfate Tryptose Broth (LST), followed by confirmation in *Escherichia coli* (EC) broth and Eosin Methylene Blue Agar (EMB). The enumeration of coagulase-positive staphylococci was performed on Mannitol Salt Agar, where typical colonies were subjected to biochemical tests for catalase, coagulase, and fermentation of glucose and mannitol. The presence of *Salmonella* spp. was observed with pre-enrichment in Lactose Broth, selective enrichment in Tetrationate and Rappaport-Vassiliadis broths, followed by plating on MacConkey and *Salmonella-Shigella* Agar - SS.

Proximate composition

Moisture, ash, protein, lipid, insoluble dietary fiber, total carbohydrate, and caloric value analyses were determined according to the methodology of the Adolfo Lutz Institute (IAL, 2008). Moisture and ash determination were performed by the gravimetric method (105°C/6 hours) and muffle furnace incineration (550°C/4 hours), respectively. Crude protein was determined by the Kjeldahl method, using a conversion factor of 6.25 for nitrogen to protein. The ether extract was obtained by the Soxhlet method. NDF (neutral detergent

Table 1. Formulation of functional lobster dumplings.

Ingredients (g)	Formulations	
	FLD1	FLD2
Lobster waste	300	300
Cassava pulp	225	0
Green banana biomass	0	225
Wheat flour	30	0
Peruvian maca	0	30
Chitosan	6.0	6.0
Red propolis	0.3	0.3
Yeast hydrolisate	1.5	1.5
Salt	0.75	0.75
Onion	90	90
Garlic	30	30
Coriander	7.5	7.5
Cumin	3.0	3.0
Allspice	15	15
Olive oil	30	30
Saffron	1.5	1.5
Smoked paprika	1.5	1.5

fiber) was hot extracted with H_2SO_4 and NaOH. Total carbohydrate content was obtained by difference,subtracting the sum of the other components (crude protein, total lipids, and fixed mineral residue) from the dry matter content. For the caloric value, the sum of the caloric values of carbohydrates (4 kcal/g), proteins (4 kcal/g), and lipids (9 kcal/g) was used (Brazil, 2003). All analyses were performed in triplicate.

Sensory analysis

The sensory analysis of the cupcakes was conducted with 65 untrained tasters, randomly selected from teachers, students, and employees aged between 20 and 55 years, as approved by the Research Ethics Committee (CEP, no. 3,362,931) and who had signed the Free and Informed Consent Form.

The dumplings were baked in an air fryer at 180°C for 15 minutes (Figure 1). Each sample (15 g) was served on disposable plates, coded with random numbers, accompanied by sparkling water and crackers to neutralize the taste. Tests were applied to profile characteristics, attitude (whether or not to eat), and purchase intention.

The sensory characteristics profile was assessed using a nine-point affective scale, with extremes of 1 (extremely disliked) and 9 (extremely liked) for the attributes of flavor, aroma, color, texture, appearance, and overall acceptance. The attitude test was assessed using a seven-point affective scale, with extremes of 1 (would only eat if unable to choose another food) to 7 (would eat frequently), while the purchase intention test, if the product were available on the market to the consumer, was assessed using a seven-point affective scale, with extremes of 1 (would never buy) to 7 (would always buy) (Stevanato et al., 2007).

Acceptability index

The Acceptability Index (AI) was calculated based on the average of the attributes color, aroma, flavor, texture, and appearance, using the formula:

AI (%) $= \frac{A \times 100}{B}$, where

A = average score obtained for the product, B = maximum score given to the product. Dumplings with an AI score of 70% or higher were considered acceptable by the tasters (Stork, Nunes, Oliveira & Basso, 2013).

Statistical analysis

Data from the analyses were expressed as mean ± standard deviation. Analysis of variance (Anova) followed by the Tukey test was conducted using SISVAR 5.6 and SAS software to assess significant differences

Figure 1. Formulation FLD1 - Lobster dumplings with cassava and wheat flour. Formulation FLD2 - Lobster dumplings with green banana biomass and Peruvian maca.

.Results and Discussion

The microbiological results (Table 2) showed the absence of *Salmonella* spp., *E. coli*, and coagulase-positive staphylococci in the formulations, meeting the microbiological limits established by current legislation (Brazil, 2019). Mesophilic bacteria counts were well below the limits established (7.0 log CFU/g) by the ICMSF (2002). These findings confirm the microbiological safety of the dumplings, a direct result of the good handling practices employed and, most importantly, the prior heat treatment of the lobster residue.

Table 2. Microbiological characterization of functional lobster dumplings formulations.

Microorganisms	Formulations		Legislation (Brazil, 2019)
	FLD1	FLD2	
Escherichia coli (MPN/g)	< 3,0	< 3,0	50
Coagulase-positive staphylococci (CFU/g)	< 10	< 10	10^2
Salmonella spp.	Absence	Absence	Absence
Mesophilic bacteria (CFU/g)	4 x 10^2	2 x 10^2	10^7*

*ICMSF (2002). FLD1 (300g lobster, 225g cassava, 6g chitosan, 0.3g red propolis, 1.5g yeast, and 30g wheat flour). FLD2 (300g lobster, 225g GBB, 6g chitosan, 0.3g propolis, 1.5g yeast, and 30g Peruvian maca). CFU: Colony Forming Unit. MPN: Most Probable Number.

Regarding the centesimal composition (Table 3), the FLD2 formulation, which does not contain gluten, presented significantly ($p < 0.05$) higher levels of moisture, protein, lipids, and fiber. It also showed lower carbohydrate and calorie values compared to FLD1. The higher moisture content in FLD2 is associated with green banana biomass (GBB). Its water retention capacity contributes to the texture and yield of the products, as described by Oliveira et al. (2024). The increase in protein and lipid levels is attributed to Peruvian maca flour, which is rich in essential amino acids, primarily valine, leucine, and lysine, and fatty acids, including linolenic, palmitic, and oleic acids (Lovera, 2019; Wang & Zhu, 2019). These results corroborate the findings of Lovera (2019), who also observed higher protein and lipid content in gluten-free pizza dough supplemented with Peruvian maca. This demonstrates that using alternative flour sources other than wheat can substantially increase the nutritional value of traditionally consumed foods.

Table 3. Averages and standard deviations of the centesimal composition of functional dumpling formulations made from lobster processing waste.

Analysis (%)	Formulations	
	FLD1	FLD2
Moisture	56.97 ± 0.85^b	59.61 ± 0.34^a
Ash	3.86 ± 0.10^a	3.73 ± 0.12^a
Proteins	10.36 ± 0.34^b	11.64 ± 0.28^a
Lipids	8.17 ± 0.06^b	8.65 ± 0.26^a
Insoluble fiber (NDF)	10.68 ± 1.01^b	16.83 ± 0.90^a
Carbohydrates	20.64 ± 0.8^a	16.37 ± 0.58^b
Calorie value (Kcal/g)	197.54 ± 3.98^a	189.87 ± 1.59^b

Averages followed by the same letters on the same line do not show significant difference ($p<0.05$) by Tukey's test. FLD1 (300g lobster, 225g cassava, 6g chitosan, 0.3g propolis, 1.5g yeast, and 30g wheat flour). FLD2 (300g lobster, 225g GBB, 6g chitosan, 0.3g propolis, 1.5g yeast, and 30g Peruvian maca).

The fiber content was significantly ($p < 0.05$) higher in the FLD2 formulation. This increase is due to the combined contribution of GBB and Peruvian maca, both recognized sources of dietary fiber and resistant starch (Wang & Zhu, 2019; Auriema et al., 2021). Processed meat products are usually low in dietary fiber (Teo & Yan, 2021). Their addition not only represents a nutritional benefit but may also confer functional properties related to intestinal health (Oliveira et al., 2024). Anjos et al. (2021) reported that increasing GBB in tambaqui burgers raises fiber and resistant starch content. Furthermore, GBB is considered a functional food that can provide useful characteristics to lobster dumplings. Its use has also proven effective in reducing waste from fresh fruit production (Oliveira et al., 2024).

The growing consumers demand for healthier foods free from artificial additives has prompted the search for natural alternatives that can extend the shelf life of meat and fish products. In this context, chitosan and red propolis have been used as natural preservatives due to their functional properties. Chitosan, in addition to its recognized antimicrobial and antioxidant activity, acts as a physical barrier that slows lipid oxidation (Vieira et al., 2019) and has been used as a fat substitute in meat products (Amoli et al., 2021). Propolis, rich in flavonoids and phenolic compounds, is capable of inhibiting the growth of spoilage and pathogenic microorganisms (Santana et al., 2024). The combined application of these natural additives in lobster dumplings not only contributes to extended shelf life but also meets the trend toward safer, cleaner, and more sustainable products, representing an innovative strategy compared to the traditional use of chemical additives.

Another technological and sensory challenge for the food industry has been reducing sodium content, as salt plays a fundamental role not only in preservation but also in enhancing flavor and consumer acceptance. In this scenario, the use of yeast hydrolysate not only contributes to sodium reduction but also aligns with the clean label trend and the demand for healthier foods, without compromising the product´s sensory acceptance (Tao et al., 2023).

Regarding the sensory analysis of the formulations (Table 4), it was observed that there was no significant difference in most of the evaluated attributes, with average scores ranging from 6.83 (slightly liked) to 7.71 (moderately liked), indicating that the functional lobster cakes were tasty and well accepted by the evaluators. The acceptance of the cakes is further corroborated by the median, which obtained a score of 8 (very liked) in most of the formulation’s attributes.

Table 4. Assessment of the acceptability attributes of functional dumpling formulations made from lobster processing waste.

Attributes	Formulations			
	FLD1		FLD2	
	Mean	Median	Mean	Median
Flavor	7.49±1.53 [a]	8	6.85±1.95 [b]	7
Aroma	7.42±1.33 [a]	8	7.22±1.56 [a]	8
Color	7.42±1.26 [a]	8	7.18±1.73 [a]	8
Texture	7.43±1.46 [a]	8	6.83±1.96[a]	7
Appearance	7.35±1.44 [a]	8	7.00±1.74 [a]	8
Overall Acceptance	7.71±1.00 [a]	8	7.02±1.72 [b]	8
Attitude Test	5.57±1.3[a]	6	5.09±1.88[a]	6
Purchase Intent	4.94±1.41	5	4.57±1.90	4
AI (%)	83.00		77.94	

Average hedonic ratings + standard deviation. Averages followed by the same letters on the same line do not show a significant difference ($p<0.05$) according to the Tukey test. AI: Acceptability index. Scores 6 (slightly liked) and 7 (moderately liked). Attitude test (5 – would eat occasionally and 6 – would eat whenever I had the opportunity). Purchase intention (4 – would buy occasionally and 5 – would buy frequently). FLD1 (300g lobster, 225g cassava, 6g chitosan, 0.3g propolis, 1.5g yeast, and 30g wheat flour); FLD2 (300g lobster, 225g GBB, 6g chitosan, 0.3g propolis, 1.5g yeast, and 30g Peruvian maca).

The flavor and overall acceptance attributes in the FLD2 formulation, although different ($p < 0.05$) in relation to the FLD1 formulation (with cassava and wheat dough), also maintained average scores between 6.85 and 7.71. Different results were reported by Teo & Yan (2021) when proposing chicken nuggets containing GBB. For the authors, the scores of 4 (slightly disliked) and 5 (indifferent) obtained in most sensory attributes demonstrated a reaction of "food neophobia", which is the fear of trying new foods, which negatively affected the evaluators' response to the new flavor of the chicken nuggets.

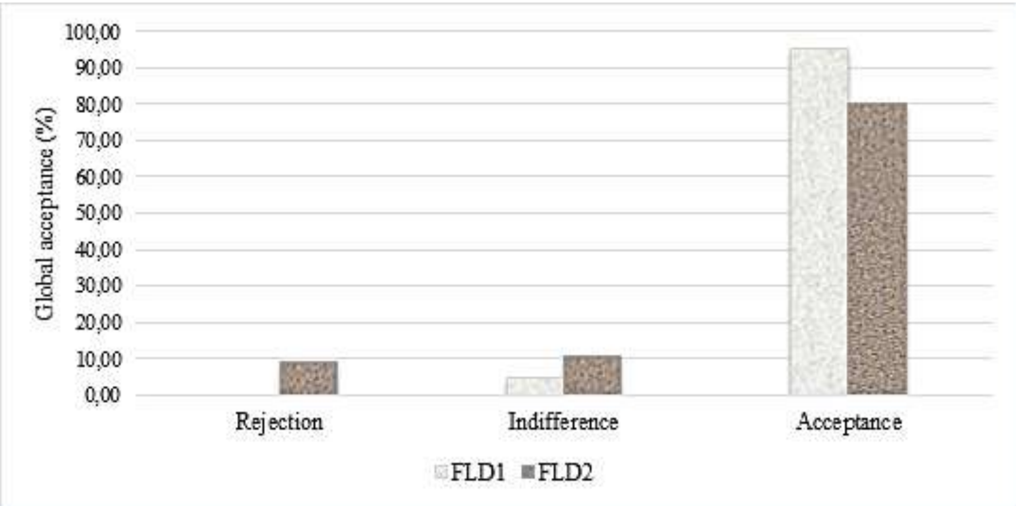
Although both formulations achieved an acceptability index (AI) above 70%, which is considered well accepted in the consumer market (Stork, Nunes, Oliveira & Basso, 2013), the FLD1 formulation achieved a higher AI (83.0%) when compared to FLD2 (77.9%), corroborating the order of preference of the samples, which was 57% for FLD1 and 43% for FLD2. This difference is related to the sensory characteristics of the GBB, which, despite being functional, altered the texture and flavor of the product, as indicated by some evaluators. GBB is not a commonly used ingredient among regular consumers, who typically use white potatoes or cassava to prepare fish dumplings. It was also observed that the replacement of sodium chloride with yeast hydrolysate was controversial for some evaluators, who reported a slightly salty product, and others an absence of sodium chloride.

The lower purchase intention index for FLD2 reinforces this trend. Contrary results were observed in the study by Anjos et al. (2021), who found that the increased addition of GBB to tambaqui burgers was well received by evaluators, demonstrating adequate harmonization of flavor and texture achieved by combining fish, GBB, chitosan, and liquid smoke.

Regarding the attitude and purchase intention tests (Table 4), no significant difference was found between the formulations. When observing the median scores, evaluators stated that they would "eat whenever they had the opportunity" for both FLD1 and FLD2 formulations. However, when asked about purchase intention, FLD1 stood out with a score of 5 "would buy frequently", while FLD2 received a score of 4 "would buy occasionally".

Overall, the acceptance of the functional lobster balls (Figure 2) was well received by the evaluators, with acceptance above 80%, demonstrating that the inclusion of GBB and Peruvian maca in the FLD2 formulation stands out as a relevant technological and nutritional alternative, meeting the demand for functional and gluten-free products, even with less immediate sensory acceptance among consumers not accustomed to such ingredients.

Figure 2. Percentages of approval, indifference, and rejection of the evaluated functional lobster dumplings.



Conclusion

The lobster processing waste dumpling formulations demonstrated satisfactory microbiological quality, meeting the standards established by current legislation, demonstrating the safety of the production process. From a nutritional perspective, the gluten-free formulation (FLD2), enriched with green banana biomass and Peruvian maca, stood out for its higher protein, lipid, and fiber content, as well as lower calorie content, constituting a functional alternative of interest to consumers with gluten restrictions. However, the traditional formulation (FLD1) achieved greater sensory acceptance and purchase intent, reflecting greater consumer familiarity with its composition.

These results demonstrate utilizing lobster processing waste to develop functional products is a promising strategy, combining sustainability, technological innovation, and nutritional value. The gluten-free formulation, despite having lower initial acceptance, represents a differentiated product with market potential in specific niche markets for restrictive gluten diets.

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