Aquatic Food Studies 5(1), AFS286
https://doi.org/10.4194/AFS286

RESEARCH PAPER

Exploring the Potential of Upcycled Fish Trimmings in Burger Production: A Comparison of Fishburger and Commercial Mixed Burgers

Jacira Moreira de Campos[1], Jonatã Henrique Rezende-de-Souza[1,2,*], Geodriane Zatta Cassol[1,3], Luciana Kimie Savay-da-Silva[1]

[1]Federal University of Mato Grosso, Faculty of Nutrition, Department of Food Science and Technology, Cuiabá, Mato Grosso, Brazil.
[2]State University of Campinas, Faculty of Food Engineering, Department of Food Engineering and Technology, Campinas, São Paulo, Brazil.
[3]State University of Campinas, Faculty of Food Engineering, Department of Food Science and Nutrition, Campinas, São Paulo, Brazil.

How to Cite

Campos, J.M., Rezende-de-Souza, J.H., Cassol, G.Z., Savay-da-Silva, L.K. (2025). Exploring the Potential of Upcycled Fish Trimmings in Burger Production: A Comparison of Fishburger and Commercial Mixed Burgers. *Aquatic Food Studies*, 5*(1), AFS286*. https://doi.org/10.4194/AFS286

Article History
Received 24 April 2025
Accepted 05 August 2025
First Online 08 August 2025

Corresponding Author
E-mail: jonatarezendesouza@gmail.com

Keywords
Tambatinga
Hybrid fish
Co-product
Fish technology
Foodservice

Abstract

The fish processing industry generates up to 75% of residues, which are often underutilized or improperly discarded. Thus, a fishburger was developed using tambatinga trimmings from the filleting process and compared to two types of commercial mixed burgers: CB-A (poultry and beef) and CB-B (poultry, pork, and beef), focusing on nutritional and technological indicators. ANOVA and Tukey test were applied. The fishburger showed higher moisture content (74.21%) and lower levels of lipids (1.72%), ash (2.5%), carbohydrates (1.90%), and energy value (101.74 kcal) compared to the commercial burgers. Regarding carbohydrate content, only the fishburger presented values well below the Brazilian legal limit of 3% (1.90%), whereas CB-A showed levels close to the limit (3.63%) and CB-B exceeded it (4.10%). Although cooking loss and yield did not differ significantly among treatments, the fishburger showed a lower fat release rate (0.1%) and higher shear force (11.75 N), both influenced by the overall moisture and lipid content. Product colour was affected by both treatment and cooking, with commercial burgers appearing darker than the fishburger after cooking. The fishburger made from filleting trimmings offer a sustainable alternative to commercial options, providing nutritional benefits such as lower fat content while minimizing waste and additive use.

Introduction

The demand for convenient, healthy, and flavorful food is a current reality both in Brazil and worldwide. In this context, the food industry is constantly seeking alternatives to meet consumer expectations for safety and quality (Fung et al., 2018; Mota et al., 2021). Among the most popular meat products, the hamburger is widely consumed in various culinary preparations and stands out as one of the most important value-added meat products in the meat industry (Jadeja et al., 2022). These products can vary in size, weight, and composition, ranging from pure meat to blends with salt, assorted ingredients, or even vegetable proteins (Bolger et al., 2017; MAPA, 2022). However, fish-based products, such as the fishburger, are not yet widely adopted or consumed in Brazil. Conversely, several studies have highlighted the potential of different fish species for fishburger production (Branciari et al., 2017; Cavalcanti, 2017; Costa et al., 2019; Marengoni et al., 2009).

In Brazil, the main native species cultivated is the tambaqui and its hybrids, such as tambatinga (Peixe BR, 2025). Tambatinga (*Colossoma macropomum* × *Piaractus brachypomus*), a hybrid produced by crossing tambaqui (*C. macropomum*) with pirapitinga (*P.*

brachypomus), has gained ground in aquaculture due to its superior zootechnical performance compared to its parental lines (Hashimoto et al., 2012; Peixe BR, 2025). However, the prevalent commercialization of its fillet generates a high proportion of residues, accounting for approximately 75% of the total body weight (Andrade et al., 2014), which are often underutilized or improperly discarded by the food industry (Cunha et al., 2021; Rigueto et al., 2023).

Despite this underutilization, research has increasingly highlighted the nutritional relevance of fish for human health. Tambatinga meat, for example, contains high protein levels, typically around 20% and reaching up to 29%, along with a low lipid content generally ranging from 0.7% to 3% (Costa et al., 2025; Mariotto et al., 2024; Ritter et al., 2018). Fish in general are characterized by their high protein content, providing proteins of high biological value and essential amino acids, as well as fat-soluble vitamins A and D, B-complex water-soluble vitamins, and key minerals such as calcium, iron, magnesium, phosphorus, potassium, sodium, zinc, copper, manganese, and selenium (Sartori & Amancio, 2012; Tacon & Metian, 2013). Additionally, their fatty acid profile is predominantly unsaturated, offering health benefits such as anti-inflammatory effects and reduced risk of cardiovascular diseases (Ramos et al., 2016; Tacon et al., 2020). In the case of tambatinga, its lipid composition includes 43.12% unsaturated fatty acids and 10.78% polyunsaturated fatty acids, totaling 53.90% of its total lipid fraction (Mariotto et al., 2024).

Despite these numerous nutritional advantages, fish consumption in Brazil remains low, estimated at around 10.7 kg per capita in 2021, while the global average for the same year was 20.6 kg per capita, increasing slightly to 20.7 kg in 2022 (FAO, 2024; Peixe BR, 2025). This scenario is influenced by various factors, including age, gender, cultural habits, cooking difficulty, consumption preferences, point of sale, food safety, sensory attributes, price, and the lack of convenience in available products (Arbex et al., 2017; Maciel et al., 2019).

Therefore, several studies have evaluated to the potential of fishburger production as a strategy for promoting fish consumption and adding value to aquaculture by-products (Bainy et al., 2015; Branciari et al., 2017; Cavalcanti, 2017). This approach aligns with the concept of upcycling, which involves converting food processing residues into value-added products (Bangar et al., 2024; Rakesh & Mahendran, 2024). In the case of fish, upcycling represents an environmentally sustainable and economically viable solution, helping to reduce waste, minimize environmental impacts, and create new product opportunities for the food industry. Therefore, this study aimed to develop fishburger using tambatinga filleting trimmings and compare their nutritional and technological indicators with commercial mixed burgers.

Materials and Methods

Acquisition of Materials and Selection of Treatments

Trimmings from the filleting of hybrid tambatinga fish (*Colossoma macropomum* × *Piaractus brachypomus*) were purchased pre-ground and frozen from a commercial fish market in Cuiabá, Mato Grosso, Brazil. These trimmings consisted of fillet portions with a high concentration of intermuscular bones, commonly discarded during filleting, known as "espinhaço". These bones are attached to the vertebrae and have a Y-shaped configuration (Cassol et al., 2024). Other ingredients used in the development of the fishburger (FB), as well as the conventional hamburgers (frozen commercial products), were also obtained from local commercial establishments.

Two types of commercial hamburgers were analyzed: CB-A, a commercial hamburger made from a mixture of poultry and beef; and CB-B, a commercial hamburger comprising poultry, beef, and pork. The ingredient list on the CB-A label includes: chicken meat, pork fat, water (6.6%), beef, soy protein (*Agrobacterium* spp.) (4%), onion, salt, maltodextrin, potassium chloride, sugar, paprika, coriander, natural flavors (smoke, rosemary, meat, black pepper, and chili pepper), stabilizer (sodium tripolyphosphate), colorants (caramel IV and cochineal carmine), acidity regulator (sodium citrate), flavor enhancer (monosodium glutamate), and antioxidant (sodium erythorbate). The CB-B ingredient list consists of: chicken meat, pork meat, water (14.09%), pork fat, beef, soy protein (2.77%), collagen animal protein, salt, spices (onion, garlic, black pepper, and white pepper), hydrolyzed soy protein, maltodextrin, hydrolyzed corn protein, yeast extract, stabilizer (sodium tripolyphosphate), antioxidant (sodium erythorbate), flavor enhancer (monosodium glutamate), colorant (caramel IV), natural colorants (beet red and cochineal carmine), natural flavor (smoke), and nature-identical flavoring (meat).

Fishburger Preparation

Preliminary studies were conducted to define the final fishburger formulation used in this study. For this purpose, formulations previously described in studies developing fishburgers from different fish species were used as references (Bainy et al., 2015; Branciari et al., 2017; Cavalcanti, 2017; Costa et al., 2019; Marengoni et al., 2009).

Table 1 presents the list of ingredients used for fishburger production. After ingredient mixing, the mass was manually homogenized for 10 minutes to enhance myofibrillar protein extraction. The prepared mass was then molded into fishburger, each weighing approximately 30 g, using a 5.5 cm diameter hamburger mold. Subsequently, the products were frozen at −21°C and stored until analysis. The entire procedure was performed in six replicates.

Sample Preparation Prior to Analysis

Commercial burgers CB-A and CB-B were cut using a hamburger mold to obtain samples with size proportions equivalent to the fishburger (FB), approximately 30 g each, with a diameter of 5.5 cm. Analyses were performed on the samples after thawing at 22°C for approximately 30 minutes.

The analyses were segmented according to sample characteristics. In raw samples, proximate composition (total moisture, crude protein, total lipids, total ash, and total carbohydrates) and energy value determination were conducted, along with instrumental colour assessment. For cooked samples, technological quality assessments included yield and weight loss determination, fat release rate, instrumental texture, and instrumental colour.

All samples were cooked in a domestic oven (Esmaltec, Munique model) preheated to 270°C for 15 minutes. The cooking process occurred at 180°C for 30 minutes, with samples turned after the first 15 minutes to ensure uniform cooking.

Proximate Composition and Energy Value Determination

Moisture content was determined by gravimetry using an oven at 105°C. Total protein content was measured by the Kjeldahl method with a nitrogen correction factor of 6.25. Total lipid quantification was performed using hexane extraction via the Soxhlet method. Total ash content was determined by gravimetry in a muffle furnace at 550°C. The methods employed followed the guidelines established by Normative Instruction No. 25, June 2, 2011, regulating Official Physical-Chemical Analytical Methods for Fishery Product Control (MAPA, 2011).

Total carbohydrate content and energy value calculations were conducted following the guidelines of Resolution No. 360, December 23, 2003 (ANVISA, 2003) and Normative Instruction No. 75, October 8, 2020 (ANVISA, 2020). Calculation details are described in Equations 1 and 2, where 100 represents the percentage constant, TM is total moisture, TP is total protein, TL is total lipid, TA is total ash, TC is total carbohydrate content, and 4 and 9 are energy constants.

$$\text{Total carbohydrate (\%)} = 100 - \text{TM} - \text{TP} - \text{TL} - \text{TA}$$
Equation 1

$$\text{Energy value (kcal)} = (\text{TP} \times 4) + (\text{TC} \times 4) + (\text{TL} \times 9)$$
Equation 2

Weight Loss and Yield

Weight loss and yield evaluates followed the protocol established by Berry (1992), involving sample weighing before and after cooking. The percentages of weight loss and yield were calculated using Equations 3 and 4, where W_i is the initial sample weight, W_f is the final sample weight, and 100 is the percentage constant.

$$\text{Weight loss (\%)} = \left({}^{(W_i - W_f)}/_{W_i}\right) \text{x } 100$$
Equation 3

$$\text{Yield (\%)} = 100 - \text{wight loss}$$
Equation 4

Fat Release Rate

The fat release rate (FRR) was gauged in accordance with modifications to the methodology proposed by Cavalcanti (2017). Prior to the initiation of the study, Petri dishes and sheets of absorbent paper folded in half twice (so that they were larger than the raw product) were identified, dried in an oven at 105°C for 1 hour, cooled under vacuum in a desiccator for 30 min, and then weighed (tare).

The sample's cooking process was executed under the same conditions as previously outlined in item "Sample preparation prior to analysis", with minor adaptations. To do so, the samples were placed on a food rack and a pre-weighed and labeled Petri dish was placed below each sample (Figure 1A). The rationale behind this configuration was to collect the fat released during the roasting process. Subsequent to the completion of this period, each sample was transferred to a sheet of absorbent paper, which had been previously identified and weighed, where it remained for 2.5 minutes on each side, consistently on the same sheet of absorbent paper (Figure 1B).

Thereafter, the Petri dishes and absorbent paper sheets were dried again at 105°C for 30 minutes, cooled

Table 1. Composition of the tambatinga (*C. macropomum* × *P. brachypomus*) fishburger

Ingredients	**%**
Filleting trimmings	93.65
Soy flour	4.00
Sodium chloride	1.20
Garlic powder	0.20
Onion powder	0.20
Parsley powder	0.20
Black pepper powder	0.10
Cumin powder	0.05
Monosodium glutamate	0.10
Sodium tripolyphosphate	0.30
Total	100.0

under vacuum in a desiccator for 30 minutes, and finally weighed. The percentage FRR of the samples was calculated according to Equation 5, in which WP_i is the initial weight of the Petri dish, WAP_i is the initial weight of the absorbent paper, WP_f is the final weight of the Petri dish, WAP_f is the final weight of the absorbent paper, WS is the weight of the raw sample, and 100 is the percentage constant.

$$\text{FRR}\ (\%) = \left(\frac{(\text{WP}_\text{i} + \text{WAP}_\text{i}) - (\text{WP}_\text{f} + \text{WAP}_\text{f})}{\text{WS}}\right) \text{x}\ 100$$

Equation 5

Instrumental Texture

Cooked samples were cooled to 20°C and cut into rectangular pieces (2 × 4 × 0.5 cm; width, length, and height). Shear force tests were performed using a TA-XT Texture Analyzer (Stable Micro Systems) equipped with a Warner-Bratzler blade (1 mm thickness). The device was calibrated with a 5 kg standard weight and set to a pre-test speed of 2.0 mm/s, test speed of 2.0 mm/s, post-test speed of 10.0 mm/s, and a sample distance of 25 mm (Cavalcanti, 2017).

Instrumental Colour

Colorimetric parameters, including lightness (L*), redness (a*), and yellowness (b*), were assessed at three distinct points on both raw and cooked samples from all treatments. Measurements were performed using a Konica Minolta CR400 colorimeter with a 10° standard observer and D65 illuminant. To evaluate the impact of heat application on colorimetric parameters, the total colour difference was calculated using Equation 6 (Rezende-de-Souza et al., 2020), in which subscript values with *c* indicate cooked samples, and subscript values with *r* indicate raw samples.

$$\Delta\text{E} = \sqrt{(\text{L}_\text{c}^* - \text{L}_\text{r}^*) + (\text{a}_\text{c}^* - \text{a}_\text{r}^*) + (\text{b}_\text{c}^* - \text{b}_\text{r}^*)}$$

Equation 6

Data Analysis

Data were processed using Statistica software (version 10). For all nutritional and technological indicators, one-way analysis of variance (ANOVA) was applied, considering the product as the sole source of variation. For instrumental colour, a two-way ANOVA was applied, considering two fixed factors: the treatment (burgers) and the form of presentation (raw and cooked); when a significant interaction between the effects was indicated, a one-way ANOVA was applied. Tukey's post-hoc test was subsequently used (P<0.05).

Results and Discussion

The analysis of the evaluated treatments revealed a significantly higher moisture content in the FB samples compared to CB-B and CB-A, respectively (Table 2). This variability is a typical feature of processed meat

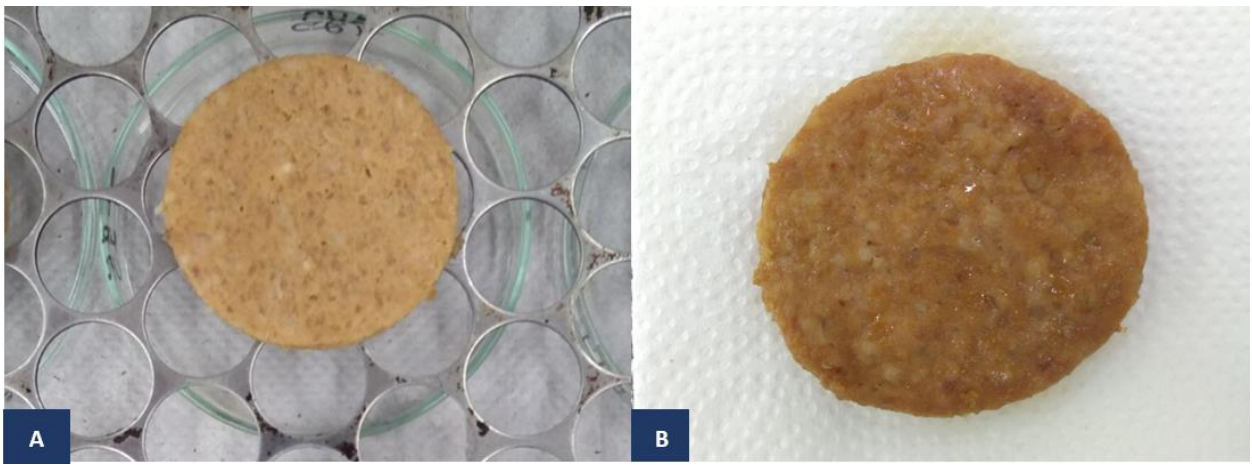

Figure 1. System for collecting fat released during cooking (A) and absorbing residual fat after cooking (B).

Table 2. Proximal composition and energy value of tambatinga (*C. macropomum* × *P. brachypomus*) fishburger (FB) and commercial burgers with mixed poultry and beef (CB-A) and poultry, beef and pork (CB-B)

Parameter	FB	CB-A	CB-B	Limit [1]	P value
Moisture (%)	74.21±0.05^{a}	59.38±0.19^{c}	64.45±0.56^{b}	-	<0.001
Protein (%)	19.66±0.13^{b}	21.26±0.55^{a}	20.13±0.23^{ab}	≥15	<0.01
Lipid (%)	1.72±0.07^{c}	11.85±0.12^{a}	8.33±0.12^{b}	≤25	<0.001
Ash (%)	2.50±0.02^{c}	3.88±0.01^{a}	2.99±0.10^{b}	-	<0.001
Carbohydrates (%)	1.90±0.18^{b}	3.63±0.58^{a}	4.10±0.29^{a}	≤3	<0.01
Energy value (kcal.100g^{-1})	101.74±0.45^{c}	206.19 ±0.88^{a}	171.89±2.54^{b}	-	<0.001

^{abc} Means (± standard derivation) with different letters on the same row differ by the Tukey's test (P<0.05). [1] Limit established by Brazilian legislation (MAPA, 2022).

products, as moisture levels are directly influenced by the type and proportion of ingredients used. In the FB, 93.65% of the composition was derived from fish meat, with the remaining 6.35% corresponding to other ingredients (Table 1). In contrast, the commercial burgers (CB-A and CB-B) did not fully disclose the quantitative composition of their ingredients. However, both declared the inclusion of soy protein: 4.0% in CB-A (fifth ingredient) and 2.77% in CB-B (sixth ingredient). Based on these values, it can be inferred that 96.0% and 97.23% of the total mass of CB-A and CB-B, respectively, consisted of meat and other non-specified ingredients, including fat and starch, which likely contributed to the differences in final moisture content. Fishburgers made with carp (*Cyprinus carpio*, Linnaeus), goldfish (*Carassius auratus*, Linnaeus), perch (*Perca fluviatilis*) and tench (*Tinca tinca*, Linnaeus) fillets had moisture contents ranging from 77.57% to 78.52% (Branciari et al., 2017), values close to those reported for FB samples in this study, but confirming the influence of the raw material used in the formulation on the composition of the final product.

According to the Brazilian Technical Regulation of Identity and Quality for burgers, the minimum protein requirement is 15% (MAPA, 2022). Although FB exhibited a slightly lower protein content than CB-A ($P<0,05$), all samples complied with Brazilian standard (Table 2). FB reached a protein content of 19.66%, which is notable considering that it was developed using filleting residues, by-products often underutilized or discarded by the fish processing industry. This protein level is comparable to, or even higher than, those reported in fishburgers made from whole fish or other species (Bainy et al., 2015; Branciari et al., 2017).

These findings highlight the potential of upcycling fish processing residues into value-added food products, aligning with circular economy principles (Rakesh & Mahendran, 2024). Beyond meeting nutritional and regulatory requirements, this strategy enhances waste valorization, optimizes resource use, and mitigates environmental impacts by reducing the volume of organic waste destined for landfills or incineration. In the metropolitan region of Cuiabá, one of Brazil's major commercial hubs for freshwater fish, 83.33% of fish retail establishments dispose of their processing residues as common waste (Cunha et al., 2021). Meanwhile, 11.11% of the surveyed 20 establishments reported selling or donating these residues to feed manufacturers, and only 5.56% rely on outsourced waste treatment services (Cunha et al., 2021). This scenario underscores the urgent need to advance upcycling initiatives in the seafood industry to harness these high-value nutritional by-products.

Moreover, fish proteins are well recognized for their high biological value, characterized by a favorable amino acid profile, excellent digestibility, and various health benefits (Sartori & Amancio, 2012; Tacon et al., 2020; Tacon & Metian, 2013). Thus, incorporating filleting residues into new formulations not only reinforces the nutritional significance of these co-products but also supports the sustainability of food systems.

In terms of lipid content, FB presented the lowest mean value among the samples, followed by CB-B, whereas CB-A exhibited the highest lipid concentration (Table 2). The differences observed may be explained by the intrinsic lipid content of the raw materials and the intentional addition of pork fat, which was absent in the FB formulation. In CB-A, pork fat was the second ingredient by order of predominance, while in CB-B it appeared in fourth position. The inclusion of such animal fats contributes not only to the lipid profile but also influences flavor, juiciness, and caloric density. However, all products remained within the legal limit of 25% lipids as specified by Brazilian legislation (MAPA, 2022), thus ensuring regulatory compliance.

The total ash content was significantly higher in the commercial burger samples, with CB-A registering the highest values, followed by CB-B (Table 2). The elevated ash content in commercial samples can be attributed to the presence of various food additives, including stabilizers, acidity regulators, flavor enhancers, and antioxidants, which are commonly incorporated to improve shelf stability and organoleptic characteristics. While there is no specific legal restriction for total ash in burgers, the total carbohydrate content is regulated in Brazil, with a maximum permissible value of 3% (MAPA, 2022). Both CB-A and CB-B exceeded this limit, indicating non-conformity with national standards, whereas the FB showed significantly lower carbohydrate levels and remained within the established limit. However, Brazilian legislation allows a 20% tolerance for analytical deviations, effectively increasing the maximum permissible carbohydrate content from 3.0% to 3.6% (MAPA, 2020). Considering this tolerance, CB-A meets the regulatory requirement, while CB-B remains non-compliant (MAPA, 2020).

No significant differences were observed among the three products regarding weight loss and cooking yield (Table 3). These mean values are consistent with those reported for burgers made from various species, typically ranging between 15% to 25% weight loss and 75% and 85% cooking yield (Bainy et al., 2015). However, during the cooking process, CB-A released more fat than CB-B, while FB exhibited the lowest fat release rate (Table 3). This phenomenon is directly associated with total lipid content, as higher lipid concentrations in the product lead to greater fat loss during cooking.

These technological characteristics are intrinsically linked to instrumental texture, as water and fat losses occur simultaneously during burger cooking. Consequently, a lower lipid content and therefore a reduced fat release, results in greater water loss, contributing to increased hardness. Accordingly, FB exhibited the highest hardness values, followed by CB-B and CB-A ($P<0.001$; Table 3). Additionally, fat performs a critical role in enhancing tenderness (Ordóñez, 2005),

further explaining the lower tenderness observed in FB compared to commercial burgers.

A significant interaction was observed between treatment (FB, CB-A, and CB-B) and product presentation (raw and cooked) for all colour parameters (Table 4). Cooking resulted in a general darkening of the samples, accompanied by increased redness and yellowness (P<0.001). These changes are attributed to the application of heat, which induces the Maillard reaction, a non-enzymatic browning process involving essential amino acids and reducing sugars that leads to the formation of highly pigmented compounds (Rodríguez et al., 2017).

Due to the significant interaction for all colour parameters, individual values are presented in Figure 2. In the raw samples, CB-A showed the highest lightness values, followed by CB-B, while FB samples were significantly darker (P<0.001). In contrast, after cooking, FB samples became the lightest, exhibiting the highest L* values, followed by CB-A and CB-B (P<0.001). This change in lightness in FB may be attributed to its meat matrix composition. The raw material used to produce FB is mainly fillet trimmings with a high content of red muscle fibers. White muscle fibers have fast contraction and glycolytic metabolism to provide energy in the live animal (SäNger & Stoiber, 2001), and are mainly found in the fillet area. Conversely, red muscle fibers, which were mainly used in the formulation of FB in this study, perform the function of slow contraction and oxidative metabolism in the living animal (SäNger & Stoiber, 2001); their colour is the result of the presence of myoglobin associated with oxygen (King et al., 2023).

Although pork and beef naturally contain higher levels of myoglobin than fish meat, the commercial

Table 3. Technological quality of tambatinga (*C. macropomum* × *P. brachypomus*) fishburger (FB) and commercial burgers with mixed poultry and beef (CB-A) and poultry, beef and pork (CB-B)

Parameter	FB	CB-A	CB-B	P value
Weight loss (%)	22.06±3.76^{a}	27.09±1.11^{a}	23.70±0.44^{a}	0.31
Cooking yield (%)	77.94±3.76^{a}	72.91±1.11^{a}	76.30±0.44^{a}	0.31
Fat release rate (%)	0.10±0.04^{c}	2.43±0.11^{a}	1.53±0.06^{b}	<0.001
Shear force (N)	11.75±0.26^{a}	3.09±0.16^{c}	9.64±0.18^{b}	<0.001

^{abc} Means (± standard derivation) with different letters on the same row differ by the Tukey's test (P<0.05).

Table 4. Instrumental colour of tambatinga (*C. macropomum* × *P. brachypomus*) fishburger (FB) and commercial burgers with mixed poultry and beef (CB-A) and poultry, beef and pork (CB-B)

	Treatment (T)			Cooking (C)		SEM	P value		
	FB	CB-A	CB-B	Raw	Cooked		T	C	T×C
L*	54.98^{b}	57.16^{a}	52.60^{c}	57.59^{a}	52.23^{b}	0.83	<0.001	<0.001	<0.001
a*	2.72^{c}	13.06^{a}	8.84^{b}	7.31^{b}	9.09^{a}	0.74	<0.001	<0.001	0.007
b*	14.12^{c}	26.25^{a}	19.83^{b}	17.65^{b}	22.49^{a}	1.03	<0.001	<0.001	0.002

L*, lightness; a*, redness; b*, yellowness; SEM, standard error of the mean. ^{abc} Means with different letters on the same row differ by the Tukey's test (P<0.05).

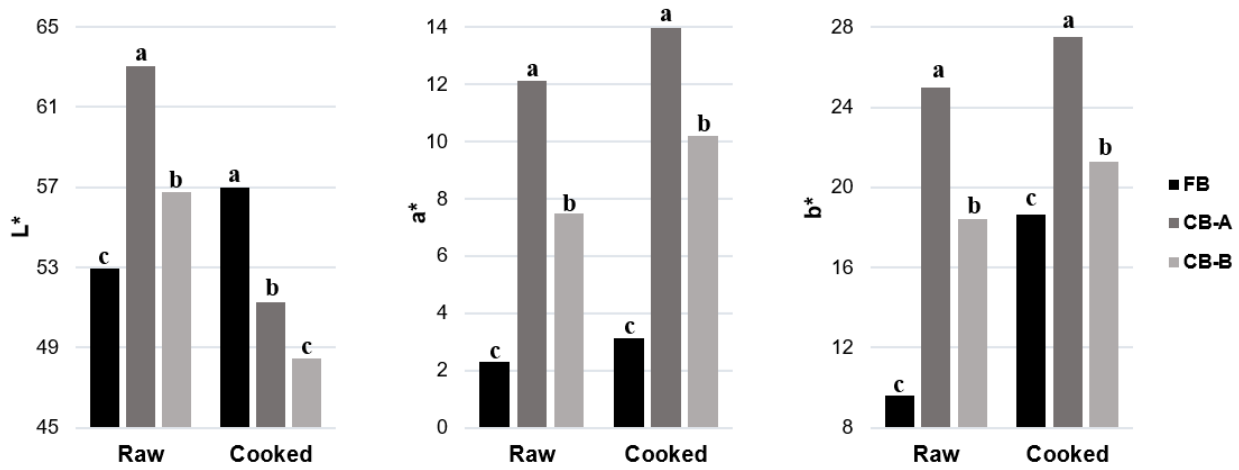

Figure 2. Interaction of fixed effects (treatment × presentation form) on the lightness (L*), redness (a*) and yellowness (b*) of raw and cooked samples. FB, tambatinga (*C. macropomum* × *P. brachypomus*) fishburger; CB-A, commercial burger with mixed poultry and beef; and CB-B, commercial burger with mixed poultry, beef and pork. ^{abc} Means with different letters between treatments of the same presentation (raw or cooked) differ by Tukey's test (P<0.05).

burgers (CB-A and CB-B) contained a lower proportion of meat and a variety of non-meat ingredients that significantly influenced their coloration. After cooking, FB samples became lighter in appearance, likely due to molecular changes in myoglobin and pigment degradation during heating. Additionally, the Maillard reaction may have been more intense in the commercial burgers due to their higher levels of reducing sugars. While raw meat typically contains minimal carbohydrates, commercial burgers often include added sugars and carbohydrate-rich ingredients such as garlic and onion powders, which enhance browning during cooking. These added ingredients may explain the greater darkening and the higher redness and yellowness observed in CB-A and CB-B compared to FB.

Another contributing factor to redness and yellowness in commercial burgers could be the use of spices and colorants, which are commonly added to enhance visual appeal and flavor but also influence instrumental colour. This highlights how both ingredient composition and thermal processing can influence final appearance. To complement the instrumental colour analysis, the total colour difference (ΔE) between raw and cooked samples was also calculated for each treatment (Figure 3). This parameter estimates how perceptible the colour difference would be to consumers. It is generally accepted that ΔE values below 1 indicate minor differences that are often imperceptible to the human eye, whereas values above 1 can be detected by most consumers. The greater the ΔE, the more perceptible the visual change from the raw samples to the cooked samples.

The results of this study extend beyond the technical field of fish science and technology, aligning closely with emerging trends in contemporary gastronomy, particularly in relation to sustainability, whole-ingredient utilization, and product innovation. The formulation of a fishburger using tambatinga filleting by-products exemplifies a concrete upcycling strategy that reflects the principles of the circular economy and sustainable gastronomy, both of which aim to reduce waste, valorize underutilized resources, and promote the development of healthier, more ethical foods.

The reuse of muscle trimmings, often discarded in the fish industry and food service establishments, demonstrates a shift in perception, whereby these non-prime cuts are used as nutritionally valuable and sensorially promising ingredients. Rather than being discarded, these by-products become raw materials for the creation of preparations with unique identity and adaptability to diverse culinary contexts. The fishburger developed in this study exhibited high moisture content, low levels of lipids and carbohydrates, and compliance with national regulatory standards. These characteristics not only support its potential in industrial and nutritional applications, but also position the product as a viable alternative for gastronomic use.

Technological parameters such as color, texture, and cooking yield indicate that freshwater fish-based products can be successfully adapted to popular culinary formats like burgers. Thus, from the perspective of creative gastronomy, incorporating fish filleting residues into new product formulations presents opportunities for chefs and culinary professionals to innovate with local ingredients, explore aquatic biodiversity, and adopt more sustainable practices. This approach is in alignment with concepts such as "root-to-stem" and "fin-to-tail", which promote for full utilization of animals, respecting the production cycle and minimizing environmental impact.

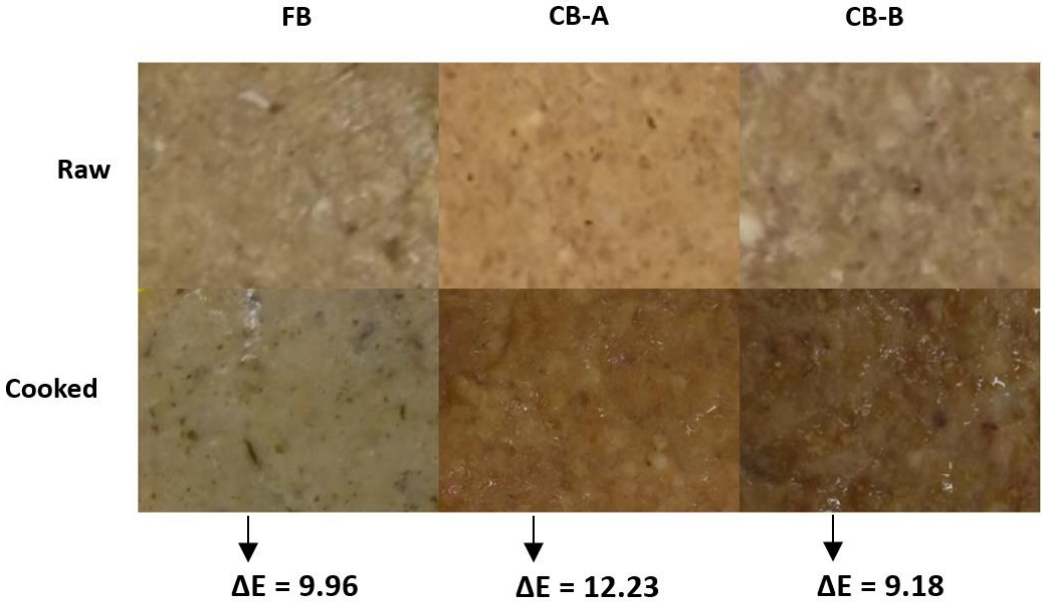

Figure 3. Color difference (ΔE) between the raw and cooked samples, individually by treatment. FB, tambatinga (*C. macropomum* × *P. brachypomus*) fishburger; CB-A, commercial burger with mixed poultry and beef; and CB-B, commercial burger with mixed poultry, beef and pork.

Conclusion

The present study highlights the potential of upcycling fish filleting trimmings into fishburger, providing insights into their nutritional, technological and colour characteristics when compared to commercial mixed burgers. By reintroducing high-value by-products, this approach not only reduces waste but also results in a product with balanced protein content and low lipid levels, leading to a lower energy value compared to commercial mixed burgers. This underscores the ability of upcycled ingredients, even from non-prime cuts, to yield distinct and desirable product characteristics while minimizing reliance on colour-modifying additives. The study emphasizes that upcycling fish trimmings is an environmentally conscious strategy, offering a sustainable alternative to traditional burger formulations. It also presents an opportunity for innovation in product development, reinforcing the circular economy in aquaculture and food processing systems.

Ethical Statement

Not applicable.

Funding Information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contribution

First Author: Conceptualization, Investigation, Methodology, Formal Analysis, Visualization and Writing –original, Writing -review and editing; **Second Author:** Investigation, Methodology, Data Curation, Formal Analysis, Visualization and Writing –original, Writing -review and editing; **Third Author:** Investigation, Methodology, Formal Analysis, Visualization and Writing -review and editing; **Fourth Author:** Project Administration, Resources, Supervision, Writing -review and editing.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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