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Research article

Potential application of *carduma* (*Cetengraulis mysticetus*) and *plumuda* (*Opisthonema* spp.) fish paste for the development of a *leberkäse* (liver loaf) fish product: Physicochemical and functional properties

Jairo Humberto López Vargas [a], Adriana Patricia Muñoz Ramírez [b], Andrea Paola Rodríguez Triviño [c], Jesus Simal-Gandara [d,*]

[a] *Instituto de Ciencia y Tecnología de Alimentos, Universidad Nacional de Colombia, Sede Bogotá, Grupo de Investigación Aseguramiento de la calidad de alimentos y desarrollo de nuevos productos, Carrera 30 No. 45-03, Edificio 500A, Bogotá, Código Postal 111321, Colombia*
[b] *Facultad de Medicina Veterinaria y Zootecnia, Departamento de Producción Animal, Universidad Nacional de Colombia, Sede Bogotá, Grupo de Investigación UN-ACUICTIO, Carrera 30 No. 45-03, Edificio 561A, Bogotá, Código Postal 111321, Colombia*
[c] *Department of Food Technology, School of Food Engineering, University of Campinas (UNICAMP), 13083-862, Campinas, Brazil*
[d] *Food Science Laboratory, Analytical Chemistry and Food Science Department, Food Science and Technology Faculty, University of Vigo, Ourense Campus, E-32004 Ourense, Spain*

A R T I C L E I N F O

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Pelagic species
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Fish-meat product

A B S T R A C T

This study investigated the potential use of fish paste from two pelagic species (*Cetengraulis mysticetus* or *carduma* in Colombia and *Opisthonema* sp. or *plumuda* in Colombia), either separately or combined, as a substitute for external fat sources in a *Leberkäse* product. Three stages were analyzed, evaluating biometric proportions, body performance, and meat batters containing different concentrations of fish pastes. Physicochemical and instrumental characterization analyses were performed to determine the effect of the type of fish paste and the level of its inclusion in the final product. Results showed that *plumuda* fish paste had higher protein and ash content than *carduma* fish paste, and the inclusion of *carduma* fish paste in meat batters led to a greater loss of liquid and lower emulsion and gel stability values. The study also established selection criteria for the two pelagic fish species that could be useful for the fishing industry. Overall, the study demonstrated that *Leberkäse* can be produced using these pelagic species with a relatively simple processing technology.

1. Introduction

Aquaculture remains one of the world's best methods of producing foods. In many developing countries, aquaculture product processing has evolved from traditional methods to more advanced value-added processes, depending on the product and market value. In recent decades, per capita aquatic food consumption has been significantly influenced by increasing the supply, changing consumers, technological development, and rising incomes [1].

Small locally caught and traded native species represent an important source of micronutrients in the diets of economically

* **Corresponding author**.
E-mail address: jsimal@uvigo.gal (J. Simal-Gandara).

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vulnerable populations in developing countries due to their high nutrient content and bioavailability. Small fish, often consumed by rural populations, are nutritionally important even in small quantities [2]. Small pelagic fish species constitute the major species group that is fished and targeted for nonfood uses, including reduction into fish meal and fish oil to be used in formulations of animal feeds, for direct animal feeding, resulting in a significant proportion of this nutrient-rich source is lost to animal feed. Small fish also contain all the elements of a healthy and nutritionally optimal food source for humans ([3,4].

The production chain of fishery products in Colombia has the potential of gaining a prominent position among economic activities, generating an important role in the local economy of poor rural and coastal regions [5]. Pacific fishery resources include small pelagic species, called in Colombia *carduma* (*Cetengraulis mysticetus*), considered the main commercial species among small pelagic fishes and representing 35 % of all fish caught in Colombia in terms of volume, while *plumuda* (in Colombia) or (*Opisthonema* spp*)* is the second most important fishery resource of the Colombian Pacific, contributing 27 % of the total catch. The importance of *carduma* and *plumuda* is not only economic, but also ecological and biological [6,7].

Consumers are demanding healthier meat products that are low in fat, salt, cholesterol, and calories, while at the same time, containing bioactive components, unsaturated fatty acids, and fiber [8]. However, these inclusions or substitutions could alter the taste, appearance, and flavor of the final formulations. To meet consumer demands, fish processing technologies have recently been oriented towards technological improvements, added value, product diversification, and quality assurance [9]. In general, some functional properties such as emulsion stability and gelation properties have not been well documented in fish meat of carduma and *plumuda*. In addition, no studies have been reported for these properties by using a model system. The objective of this research was to provide an overview of the proximate composition, technofunctional and physicochemical analysis, and potential food application of *carduma* and *plumuda* species. Likewise, in this research carduma: *plumuda* mixtures of 100 %, 75 %, 50 % and 25 % were selected and studied based on preliminary tests related to the addition of these fish pastes to emulsified meat products.

2. Materials and methods

2.1. Materials

In this study we used approximately 120 kg of whole *carduma* (*C. mysticetus*) and *plumuda* (*Opisthonema* spp.) obtained from the Tumaco fish market (Nariño, Colombia), transported frozen by land (−18 °C) to the laboratory of the Food Science and Technology Institute of the National University of Colombia, Bogotá Campus. Both whole *carduma* (CAR) and *plumuda* (PLU) raw fish were labeled and stored in a deep freezer at temperatures between −30 °C and −35 °C for later use. Fish were characterized based on their biometric parameters: length, shape, and weight. To obtain the biometric measurements and body yields, the fish were weighed, measured, and cut for the separation and weighing of their body components (head, fins, tail, viscera and carcass: defined as a whole fish or a portion

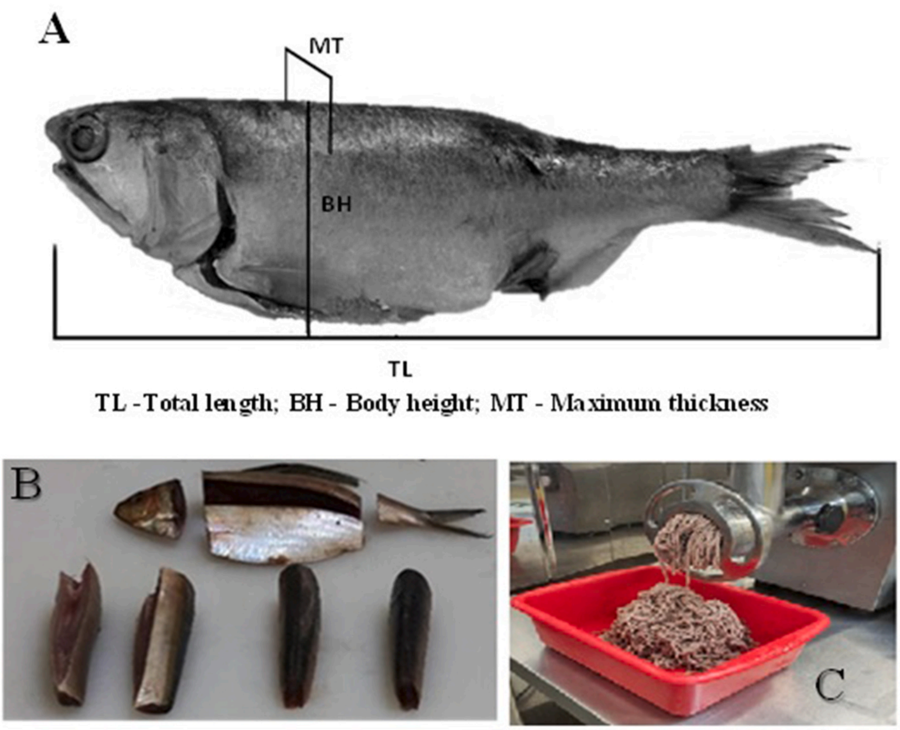

Fig. 1. Diagram of the biometric measurements of fishes (carduma and plumuda) (A), fish loins (B), and fish paste (C).

of a fish that has been gutted and/or gilled and the head and some or all of the fins have been removed).

For the preparation of *Leberkase* the following ingredients were used: refined salt (Refisal, Colombia); sodium nitrite (Tecnas, Medellin, Colombia); dietary fiber (IPF Ingredientes y Productos Funcionales S.A.S., Antioquia, Colombia); corn starch (Maizena® Fécula de Maíz, Colombia) and black pepper, onion powder, and garlic powder (Griffith Foods S A S, Marinilla, Colombia).

2.2. Biometric parameters and yield of carduma (C. mysticetus) and plumuda (Opisthonema spp.)

2.2.1. Biometric parameters

Three biometric parameters were used for data collection of the two species of fish. A total of 100 fish were sampled, 50 units for each species. The total length (TL) was defined as the longest dimension between the anterior and posterior edges of the fish. This measure was determined using vernier calipers on each fish from the tip of the snout to the caudal fin. The maximum body height or depth (BH) was measured in lateral view and in a straight line from the ventral edge to the dorsal edge of the body; the highest or deepest portion of the fish was the maximum thickness (MT), as shown in Fig. 1a [10]. All measurements were made with the concave (proximal) side of the fish facing down, to ensure that the anterior and posterior aspect of the fish were oriented on the same focal plane.

2.2.2. Percentage yield

We studied a total of 50 fish, CAR (Cetengraulis mysticetus) (n = 25) and PLU (Opisthonema spp.) (n = 25). We recorded the whole-body weight of the fish in grams using an electronic laboratory balance including both the carcass weight and carcass yield [(carcass weight/whole-body weight) *100]. We eviscerated the fish and the heads, fins, and tails were cut off with a sharp knife. We weighed the backs, heads, and tails separately, while we weighed the viscera, fins and scales together using an analytical balance. The mean of these weights was calculated and used to estimate their percentages in relation to weight of the whole fish. We collected the following data for the two fish: whole-body weight, viscera, fins, and scales weight and tail weight in grams.

2.3. Preparation and physicochemical characterization of fish pastes

2.3.1. Preparation of fish pastes

We prepared five batches of fish paste as follows: The carcasses were cut perpendicularly from the initial part of the dorsal fin to the caudal fin to obtain the loins (useful part) of each specimen (Fig. 1b and c). The loins were ground in a meat grinder (Javar, Colombia 3 mm disc) three times, until we obtained a homogeneous paste. We packaged the paste in plastic bags and stored them at −1±0,5 °C for later use.

2.3.2. Proximate composition, pH, and water activity

We carried out physicochemical analyses in triplicate on all samples. A proximate analysis was performed to determine moisture [11], protein [12], fat) [13] and ash [14]. The pH measurement was determined using pH meter Orion Star™ A211 (Thermo Scientific™); water activity (A_w) was measured using a HC2-A_w water activity meter (Rotronic, Swizterland).

2.4. Preparation and characterization of techno-functional properties of fish batters

2.4.1. Preparation of fish batters

The formulation of fish meat batters contained the following: pork back fat (20 % w/w) and NaCl (2.0 % w/w); ST1: 100 % fish paste (CAR); ST2: 100 % fish paste (PLU); ST3: 25 % fish paste (CAR) and 75 % fish paste (PLU); ST4: 50 % paste (CAR); and 50 % paste (PLU); ST5: 75 % paste (CAR) and 25 % paste (PLU). The raw fish meat and fat were kept at about 0 °C ± 2 °C. The preparation procedure was according to the procedure described in Ref. [15] with some modifications: First, fish paste or mixed pastes and sodium chloride were added at low speed for grinding in a food processor (CT680SS Series, Ninja® Intelli-Sense™, USA) for 3–4 min; subsequently, pork fat was added and mixed at high speed to form the emulsion. This process lasted until the fish meat batter reached 12 °C.

2.4.2. Emulsion stability of fish batters

The stability of the emulsion was reached according to Ref. [16] with some modifications: We transferred 50g of each standard formulations of fish meat batters to falcon tubes (three replicates) and these tubes were centrifuged at 4000 rpm for 5 min. Subsequently, we placed the tubes into a thermostatic bath at 40 °C for 15 min and the temperature was raised to 70 °C for 20 min. The tubes were left standing upside down in previously weighed beakers for 40 min to release the exudates. The total amount of liquid released was expressed as a percentage of the sample weight. We then dried the released liquid in an oven at 103 °C (16 h) and weighed it to determine the amount of fat released.

2.4.3. Gel stability of fish batters

We analyzed the gel stability of fish batters using the method described in Ref. [17] with modifications. We filled pre-weighed graduated falcon tubes (25 g) with paste and closed and heated the falcon tubes in a thermostatic bath for 30 min at a temperature of 70 °C. We then placed the falcon tubes upside down in beakers inside a desiccator for 50 min and weighed the tubes along with the sample and measured them in triplicate.

2.5. Preparation and physicochemical characterization of the leberkäse fish product

2.5.1. Preparation of the leberkäse fish product

We evaluated five experimental treatments with different concentrations of *carduma* and *plumuda* fish pastes and replaced them with dietary fiber. We used the following formulation of a *Leberkäse* fish product in the experiment: ice (29 %), salt (1.5 %), sodium nitrite (0.018 %), black pepper (0.20 %), dietary fiber (1.95 %), corn starch (1.95 %), onion powder (0.20 %) and garlic powder (0.20 %), as described in Table 1.

We mixed the fish pastes (*carduma* and/or *plumuda*), the ingredients, and the additives using a food processor (CT680SS Series, Ninja® Intelli-Sense™, USA) for 4 min; during the preparation the temperature of the mixture was kept below 10 °C. We filled aluminum trays with the mixture and baked them in a convection oven under the following conditions: first, the oven was preheated to 180°C for 10 min and, the trays were set to bake at a constant temperature. The required internal temperature (72°C) at the core of the product was obtained at 40 min under these conditions. The resultant samples were cooled at 2°C – 4°C until the temperature at the center of the samples was not higher than 4°C. After reaching 4°C we performed the analyses.

2.5.2. Physicochemical characterization of the leberkäse fish product

2.5.2.1. pH and A_w. We measured the pH and A_w of the *Leberkäse* according to the methodologies described in 2.3.2.

2.5.2.2. Cooking loss and cooking yield of the leberkäse fish product. We calculated cooking loss as the difference between fresh and cooked sample weight relative to the fresh meat sample weight, expressed in percentages [18], ((Eq. (1) and Eq. (2)).

$$\text{Cooking loss } (\%) = ((W1 - W2) / W1) \text{ X } 100 \tag{1}$$

$$\text{Cooking yield } (\%) = (W2 / W1) \text{ X } 100 \tag{2}$$

Following,
W1—Weight before cooking, g and W2—Weight after cooking, g.

2.5.2.3. Texture profile analysis (TPA). Eight cylindrical samples (20 mm length × 20 mm diameter) were cut for each treatment using a metallic cylinder. As a texture measure we used a TA.XTplus Texture Analyse (Stable Micro Systems, England), equipped with the texture 32 V1.0.0.68 software (Stable micro Systems), [19]. We carried out an instrumental texture profile with a P-35 probe (35 mm in diameter, stainless steel), the samples were compressed to 50 % of their original height at a crosshead speed of 1.5 mm/s. The load cell capacity used was 25 kg (250 N). The parameters determined were hardness (N), cohesiveness, gumminess (N) and chewiness (N mm).

2.5.2.4. Colour measurement. Colour was measured in a CM-5 spectrophotometer (Konica Minolta, Tokyo, Japan), according to Ref. [20]. We calculated according to Eq. (1) and Eq. (2), operating with D65 illuminant, 10° observation angle, SCE mode, and CIELab colour system for the evaluation of the parameters L*, a*, and b*. Chroma and hue angles.

$$\text{Chroma} = \sqrt{(a^*)^2 + (b^*)^2} \tag{1}$$

$$h_{ab} = tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{2}$$

We measured the colour in 5 inner and outer sections for treatment (n = 10/treatment) and we measured the samples at room temperature (25 °C).

2.6. Statistical analysis

We analyzed the data on morphometric measurements and body yields using descriptive statistics (mean, standard deviation, minimum and maximum) for both *carduma* (*C. mysticetus*) and *plumuda* (*Opisthonema* spp.*)*. We ran all experiments in triplicate and

Table 1
Treatments formulations of leberkäse fish product.

Samples	Treatments (%)[a]				
	T1	T2	T3	T4	T5
Fish paste carduma	100	–	25	50	75
Fish paste plumuda	–	100	75	50	25

[a] In the experimental batches different percentages of fish pastes were substituted. T1: Containing 65 % fish paste (carduma); T2: Containing 65 % fish paste (plumuda); T3: Containing 25 % fish paste (carduma) and 40 % fish paste (plumuda); T4: Containing 32.5 % fish paste (plumuda) and 32.5 % fish paste (carduma); T5: Containing 40 % fish paste (carduma) and 25 % fish paste (plumuda).

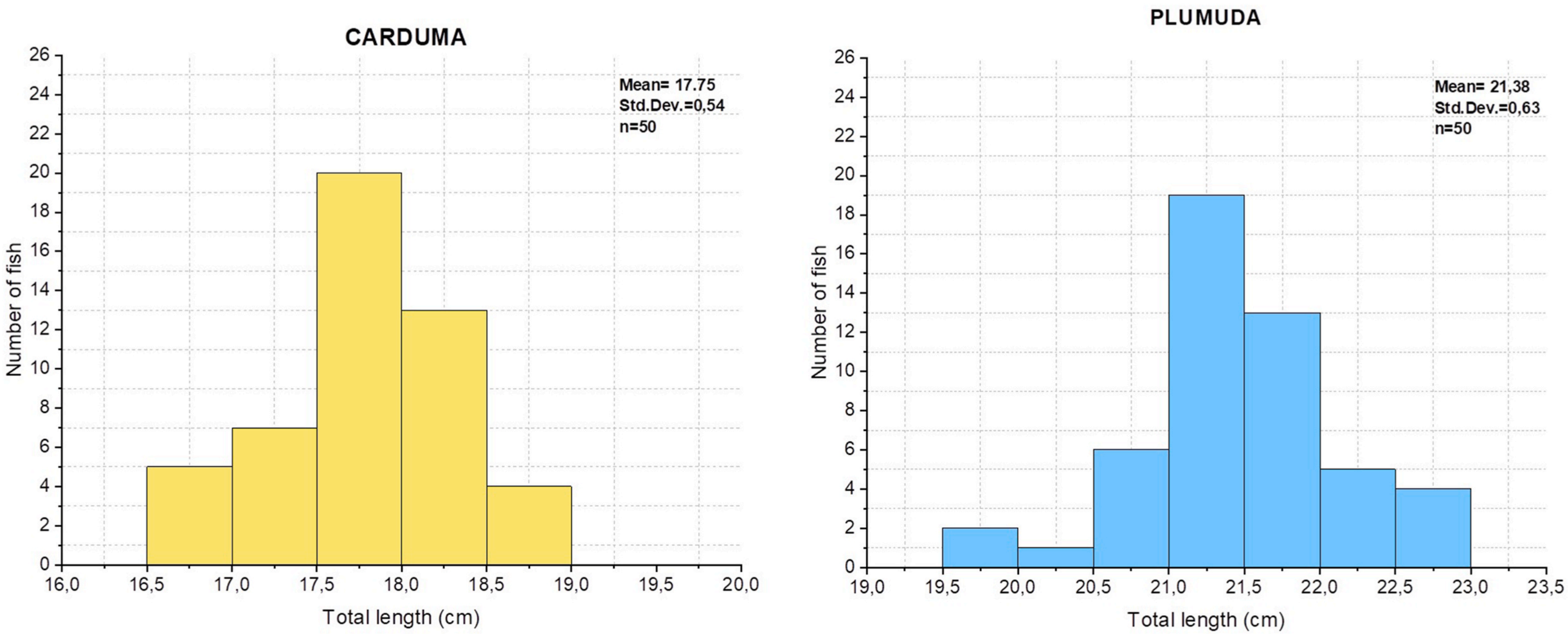

Fig. 2. Histogram showing the frequency distribution of total length for carduma (*C. mysticetus)* and plumuda (*Opisthonema* sp.*)*.

reported all mean values with standard deviations. We tested variances for homogeneity and normality; and, if they met the assumptions, we evaluated differences between groups by ANOVA. We used one-way analysis of variance (ANOVA) to evaluate the statistical significance ($p < 0.05$) of the effect of the *Leberkäse* fish product formulations, using the minitab statistical software 18 version (Minitab inc, version 18.1, USA). We used the least square differences (LSD) to compare mean values of formulations and significant differences ($p < 0.05$) between *Leberkäse* fish product formulations identified by a multiple comparison test by Tukey's.

3. Results and discussion

3.1. Biometric parameters and yields of carduma (C. mysticetus) and plumuda (Opisthonema spp.)

According to the histogram analysis, the 17.5–18 cm total length class had the highest abundance of specimens of *carduma* and the 21–21.5 cm class showed the highest abundance of specimens of *plumuda* (Fig. 2). Previous studies reported that the maximum size of the *plumuda* reaches at least 25.14 cm in the Colombian Pacific, representing a relative age of four years [21]. However, other. data [22] reported that, in relation to *carduma* length for 2009, specifically in the Tumaco (Colombia) region in the range of classes between 13 cm and 18 cm. The size class 16.5 was numerically dominant and constituted approximately 24 % of the total. Similar trends were reported in Ref. [23] in 2009 in samples of *C. mysticetus* in the Cauca-Nariño corridor, fished using artisanal methods, with lengths between 12.5 cm and 18.5 cm.

Maximum sizes reported in the case of *plumuda* appear superior compared to our maximum recorded size. Perhaps the presence of smaller individuals within the sampling is the cause of the smaller maximum size of this species. However, for *carduma* the lowest value reported within the distribution was lower than that found in our results, ranging from 16.5 cm to 29 cm. These records, compared to those reported by other authors, may also be associated with the different types of fishing gear with different mesh sizes used by local artisanal fishermen that could affect the frequency distribution of the total length of the individuals. Other possible factors could be variations in growth pattern linked to the aquatic habitat, differences in geographic location, season of the year, diseases, sexual maturity, food availability and phenotype of the species [24].

The yield of carcasses of the species were very proximate (Table 2). Carcass weight is over 50 % body weight for two specimens. However, *plumuda* had 1.49 % higher yield than carcasses *carduma*. Higher yields of head were also obtained in *plumuda*, totaling 23.25 ± 1.77 %. *Carduma* had the highest yield of viscera, tail, and fins.

3.2. Analysis of carduma (Cetengraulis mysticetus) and plumuda (Opisthonema sp.) fish pastes

Carduma fish paste had higher fat content in comparison with *plumuda* fish paste. Regarding moisture samples, we found values of 72.86 % and 71.21 % for *carduma* and *plumuda* pastes. We determined a lower value in this study than the one found in Ref. [25] that showed moisture values for *plumuda* of 75.60 % and 74.35 % for *carduma*. The *plumuda* fish paste had the highest protein content. Ash values were lower in the *carduma* pastes in our study (table S1). The pH value of the *plumuda* pastes was higher than that of *carduma*. The pH value is the measure of acidity or alkalinity of a product and pH varies from one food to another so an acceptable limit of pH value of 6.80–7.00 has been proposed for fresh fish products and the pH value for fresh fish meat was 6.00–6.50 [26,27]. Finally, the fish pastes had equal water activity (A_w) value.

Table 2
Biometric parameters and yields of carduma (Cetengraulis mysticetus) and plumuda (Opisthonema sp.).

	carduma		plumuda	
	X±SD	Min–Max	X±SD	Min–Max
Biometric measurements (cm)[a]				
TL	17.75 ± 0.56	16.5–19	21.38 ± 0.63	19.7–22.8
BH	4.40 ± 0.19	4.00–4.90	5.65 ± 0.34	4.16–6.53
MT	1.97 ± 0.13	1.80–2.30	2.45 ± 0.17	1.82–2.93
n	50		50	
Yield (%)[b]	**X±SD**		**X±SD**	
Body Weight (g)	58.21 ± 5.40		71.64 ± 6.93	
Head	18.83 ± 2.12		23.25 ± 1.77	
Viscera	7.19 ± 0.09		2.91 ± 0.00	
Tail	4.72 ± 0.93		1.33 ± 0.38	
Fins	5,55 ± 0.92		4.46 ± 0.43	
Scales	5.22 ± 2.71		7.17 ± 1.76	
Carcass[c]	58.58 ± 2.71		60.0 ± 2.30	
N	25		25	

[a] TL: Total length, BH: Maximum body height or depth; MT: Maximum thickness; n: The total number of individuals sized. Minimum (Min), maximum (Max), mean (X) and standard deviation (SD) values for the biometric parameters (cm).
[b] Yield in respect of the total weight.
[c] Carcass yield is a percentage of the carcass (without head, tail, fin and viscera) weight relative to whole fish weight.

3.3. Physical properties of fish batters

Results of emulsion stability (%) and gel stability (%) of fish batters are summarized in Table 3. The differences in emulsion stability of fish batters formulated with different levels of fish pastes were significant ($P < 0.05$). The emulsion stability of the batter with 75 % paste (*carduma*) and 25 % paste (*plumuda*) (ST5) resulted in the highest liquid and fat exudation, thus decreasing the stability of the emulsion. The batter with 100 % (ST2) of *plumuda* had a significantly lower fluid loss than batters prepared with *carduma* in higher percentages. The gel-forming capacity of proteins determines the textural attributes of the finished products. Also, the addition of salt generally improves gel-forming capacity by solubilizing myofibrillar proteins. Nevertheless, the gel-forming capacity of fish varies from one species to another [28]. For t**he** gel stability parameter, we found non-significant differences ($p < 0.05$).

3.4. Physicochemical properties of leberkäse

We present treatments used in preparing *Leberkäse* containing fish levels (100 %–25 %) in Table 1. We present the pH results for samples of *Leberkäse* prepared with fish paste (*carduma* and *plumuda*) at different concentrations in Table 3. The pH values in 75 % (CAR)/25 % (PLU) samples were higher than those of other treatments; this could be because in both fish pastes, the *carduma* and *plumuda* had a wide range of pH (from 5.9 to 6.2). Similar trends in pH values are reported in Ref. [29], showing that pH was above 6.0 in both minces and cooked fish sausage. The water activity in the different formulations did not differ significantly (P>0.05) and ranged between 0.970 and 0.973. Statistically significant difference was observed ($P > 0.05$) in cooking loss results, the lowest ones reported for treatments T1 and T5 the highest for T2 (Table 3). For T5 the addition of fiber and starch showed significantly ($P < 0.05$) reduction of cooking losses. Starch is commonly added to fish processed products to improve the texture and to allow more water retention [30,31]. Iyengar and Gross [32] reported that the use of fiber improves the cooking yield and texture of food products due to its high water-holding capacity and fat-binding properties [33].

3.4.1. Texture analysis and colour parameters

Regarding texture parameters of the *Leberkäse* fish product (Table 3), the addition of plumuda (T2) significantly ($P > 0.05$) increased hardness 10.67 ± 0.65 N. Similar results were found for gumminess and chewiness, for the same treatment. Dincer and Cakli [34] reported similar mean values of hardness in sausages prepared from frozen fillets, the lowest being 17.7 N. High moistness and lower hardness in samples could be because of the interactions between myofibrillar protein in meat and water, with the formation of a stable hydrophilic interaction, increasing the water holding capacity [35]. The replacement of pork back fat resulted in a decrement of the hardness product [36]. The total collagen content of the fish, lower than that of terrestrial animals, also has an influence [37].

Fig. 3 shows the colour parameters of the *Leberkäse* fish product. Inner colour samples in all treatments had higher L* values when compared to outer samples. That increase was more noticeable in the samples with a major percent of *carduma* versus *plumuda* (T5), but the inner colour of the two did not show a significant difference ($P > 0.05$) among treatments. However, the decrease in lightness at

Table 3
Chemical composition and physicochemical properties.

	Treatments					
	ST1[a]	ST2	ST3	ST4	ST5	*P*-value
Physicochemical properties of batter						
Emulsion stability of batter (%)	10.66 ± 1.73[bc]	7.31 ± 0.67[c]	11.40 ± 1.61[abc]	13.10 ± 0.83[ab]	15.20 ± 1.25[a]	0.002
Total liquid exudation	8.72 ± 1.67[ab]	4.40 ± 0.78[c]	8.24 ± 2.13[b]	10.34 ± 0.54[ab]	11.84 ± 0.73[a]	0.000
Fat exudation	1.94 ± 0.07[b]	2.91 ± 0.26[ab]	3.15 ± 0.66[ab]	2.77 ± 0.30[ab]	3.36 ± 0.86[a]	0.055
Gel stability of batter (%)	88.92 ± 2.04	90.62 ± 1.49	90.12 ± 1.13	90.92 ± 3.09	89.19 ± 2.10	0.718
	T1[b]	**T2**	**T3**	**T4**	**T5**	***P*-value**
Physicochemical properties of leberkäse						
pH	6.29 ± 0.01[b]	6.36 ± 0.08[b]	6.34 ± 0.06[b]	6.35 ± 0.06[b]	6.61 ± 0.02[a]	0.000
A_w	0.972 ± 0.006	0.971 ± 0.003	0.971 ± 0.001	0.970 ± 0.003	0.973 ± 0.004	0.801
Cooking loss (%)	9.28 ± 0.10[b]	13.66 ± 1.27[a]	11.45 ± 0.23[ab]	11.62 ± 0.09[ab]	9.43 ± 0.48[b]	0.004
Cooking yield (%)	90.72 ± 0.10[a]	86.34 ± 1.27[b]	88.55 ± 0.23[ab]	88.38 ± 0.09[ab]	90.57 ± 0.48[a]	0.004
Textural parameters						
Hardness (N)	4.49 ± 0.38[c]	10.67 ± 0.65[a]	5.83 ± 0.53[b]	2.96 ± 0.24[d]	3.96 ± 0.35[c]	0.000
Cohesiveness	0.29 ± 0.03[ab]	0.28 ± 0.02[abc]	0.26 ± 0.01[c]	0.30 ± 0.01[a]	0.28 ± 0.01[bc]	0.001
Springiness (mm)	0.40 ± 0.03[c]	0.47 ± 0.03[a]	0.44 ± 0.05[abc]	0.45 ± 0.04[ab]	0.41 ± 0.02[bc]	0.001
Gumminess (N)	1.31 ± 0.20[bc]	3.03 ± 0.31[a]	1.54 ± 0.18[b]	0.90 ± 0.08[d]	1.09 ± 0.11[cd]	0.000
Chewiness (N mm)	0.52 ± 0.12[bc]	1.42 ± 0.20[a]	0.68 ± 0.14[b]	0.41 ± 0.06[c]	0.45 ± 0.06[c]	0.000

[a-c]Means with the different letter in the same row are significantly different ($p < 0.05$). Data are presented as the mean values ± SD.

[a] In fish meat batter; ST1: 100 % fish paste (CAR); ST2: 100 % fish paste (PLU); ST3: 25 % fish paste (CAR) and 75 % fish paste (PLU); ST4: 50 % paste (CAR) and 50 % paste (PLU); ST5: 75 % paste (CAR) and 25 % paste (PLU), following were also added to all formulations pork back fat (20 % w/w) and NaCl (2.0 % w/w).

[b] In the experimental batches of the leberkäse fish product, fish pastes were substituted in different percentages; T1: Containing 65 % fish paste (CAR); T2: Containing 65 % fish paste (PLU); T3: Containing 25 % fish paste (CAR) and 40 % fish paste (PLU); T4: Containing 32.5 % fish paste (CAR) and 32.5 % fish paste (PLU); T5: Containing 40 % fish paste (CAR) and 25 % fish paste (PLU).

T2 (values inner/outer values) was due to the decrease in water content in this treatment. Significant differences ($P < 0.05$) in coordinate a* values were observed for the inner and outer values. The lowest a* value was similar in treatments T1 and T5 (outer color values) and a significant peak was observed in sample T1 (inner values). Therefore, the presence of *carduma* fish paste increases the a* value for the inner colour.

The colour saturation (C*ab value) of the *Leberkäse* T1 "inner" was significantly lower than T4, whose saturation was similar to that of the T4 "outer". One suggestion is that colour variations in low-fat sausages are more susceptible if air bubbles are generated that are then trapped in the batter during processing. This lighter colour will be reflected on the surface of the product due to scattering, so that the product appears lighter and has a higher hue value [38].

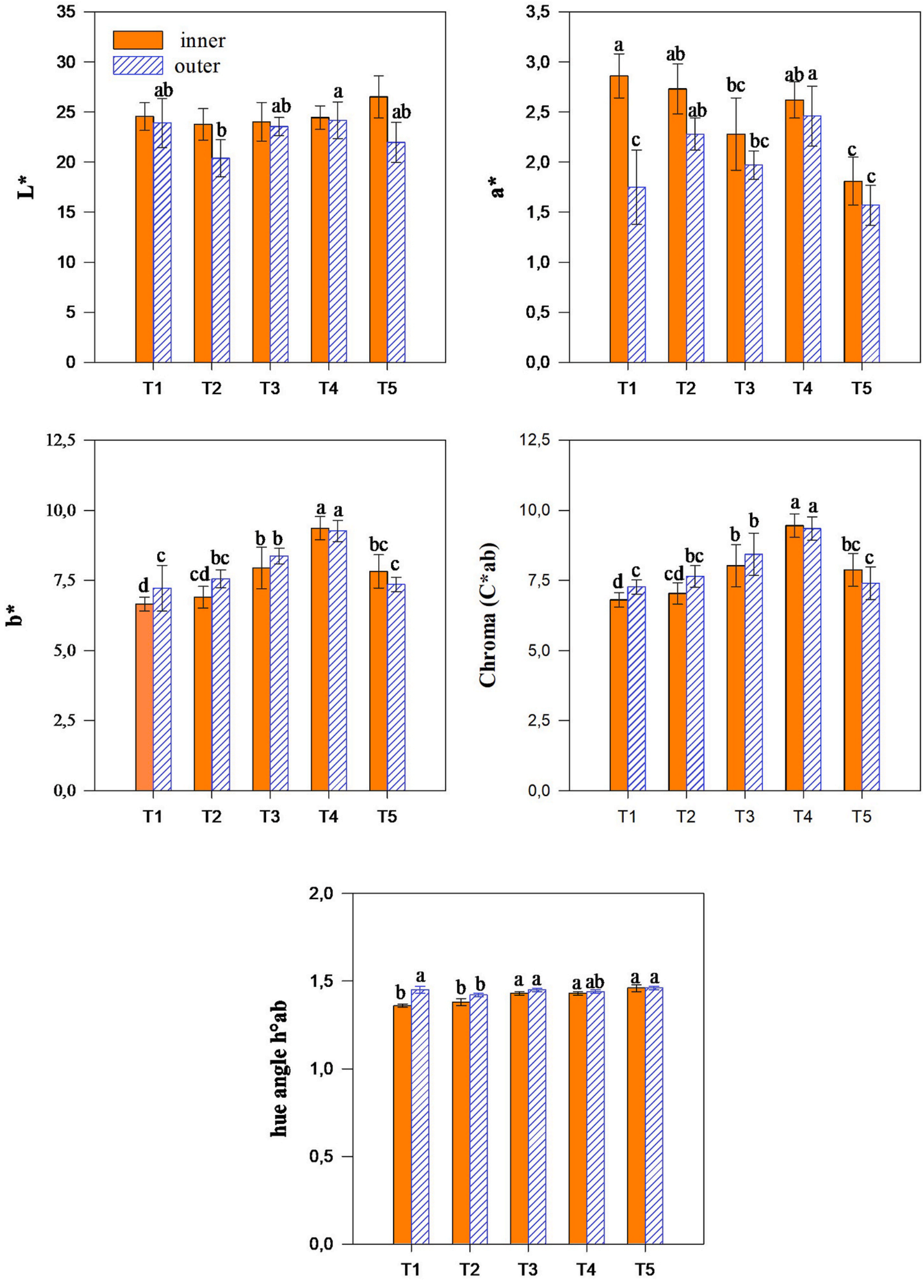

Fig. 3. Colour parameter of leberkäse fish meat product. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

4. Conclusions

The evaluated parameters in body weights, yields, and body length could serve as indirect selection criteria in the search for fish with favorable carcass characteristics. The results of the physicochemical and technological evaluation indicated that fish pastes from *carduma* and *plumuda* (pelagic species) could be used to produce *Leberkäse* or other types of fish products. This highlights the opportunities to develop value-added products by using species from fishery resources of low commercial value that are normally destined for uses other than the human diet.

4.1. Future directions

Looking ahead, it is imperative to address limitations in terms of analysis for this study, especially in the development of a product such as *Leberkäse* for pelagic species. An essential step is to perform sensory analysis in further studies, which unfortunately, due to the scope of the research project, was postponed to a second phase. These considerations are crucial and will be considered in future work in the development of similar products. Additionally, the absence of fatty acid composition analysis in this product was due to the predetermined scope of the project that unfortunately did not include such analysis. As researchers, the importance of this analysis for a comprehensive understanding of the nutritional profile and overall quality of the product is fully recognized. However, due to the constraints and focus of the initial phase of the project, resources and time were allocated to other aspects considered more pertinent at the time. While recognizing the importance of fatty acid composition analysis, priority was given to aspects crucial to viable product development within the constraints of the project. Considering the limitations of this work, future research can provide a deeper understanding of the sensory properties and compositional characteristics of fish *Leberkäse*, providing elements for its optimization and commercial viability.

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Additional information

No additional information is available for this paper.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jairo Humberto López Vargas: Investigation. **Adriana Patricia Muñoz Ramírez:** Investigation. **Andrea Paola Rodríguez Triviño:** Investigation. **Jesus Simal-Gandara:** Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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