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Undervalued tuna meat (*Thunus obesus* and *Katsuwonus pelamis lineaus*) to develop sausages

Carne infravalorada de atún (*Thunnus obesus* y *Katsuwonus pelamis linnaeus*) para desarrollar salchichas

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Abstract

Background: The tuna industry is one of the most essential sectors in global food production. Nevertheless, commercial meat known as "tuna loin" holds the utmost significance in producing and marketing its various products. Regrettably, fractions like tail and head meat have been overlooked and wasted due to their comparatively lower commercial value. Despite possessing notable technological value, this meat is typically reutilized into animal feed through flour production, missing the chance to create alternative high-value food products.

Objective: This study aimed to develop and evaluate the sausages produced with the underutilized cuts of tuna (tail and head meat).

Methods: The tuna utilized were Big-eye (*Thunus obesus*) and Skip-jack (*Katsuwonus pelamis lineaus*). Three (3) different types of sausages were formulated using 100% of Big-eye (BE), 100% of Skip-jack (SJ) tuna meat, and 100% of beef/pork meat (Control). The sausage pH changes during storage at $4 \pm 1^{o}C$ were analyzed and compared with the control. Proximal, microbiological, and sensory characteristics were evaluated.

Results: The pH of sausages showed that the values tended to decrease in control, while this value increased in two types of tuna. The formulated tuna sausages yielded 72% moisture, 18% protein, 4.1% lipid, 0.4% ash, 0.4 % fiber, and 4.5% carbohydrates. Sensory attributes showed excellent acceptance regarding color, smell, flavor, and texture. Overall acceptability was qualified as "liked," and the acceptability index ranged from 76% to 86%. During the refrigeration storage, the microbiological analyses indicated that the total coliform count was < 3 CFU/g. *Escherichia coli, Staphylococcus aureus*, and mesophilic aerobic bacteria in tuna sausage showed absence during 24 days of storage.

Conclusion: Using tuna tail and head meat enabled the development of gel-type emulsified products (sausages) that exhibited good nutritional, sensory, and microbiological quality.

Keywords: Tuna Sausages; Proximate Composition; Microbiological Quality; Sensory Characteristics

Resumen
Antecedentes: La industria atunera se erige como uno de los sectores más importantes en la producción mundial de alimentos. Sin embargo, entre sus diversos productos, la carne comercial conocida como "lomo de atún" ostenta la mayor importancia tanto en su producción como en su comercialización. Lamentablemente, fracciones de carne provenientes de la cola y la cabeza se han desperdiciado debido a su reducido valor comercial. A pesar de poseer un notable valor tecnológico, esta carne normalmente es utilizada en la alimentación animal mediante la producción de harina, perdiendo la oportunidad de desarrollar productos alimenticios alternativos con alto valor nutricional.
Objetivo: Este estudio tuvo como objetivo desarrollar y evaluar salchichas producidas con carne subutilizada de atún (carne de cola y cabeza).
Métodos: Las especies de atún utilizadas fueron Big-eye (*Thunus obesus*) and Skip-jack (*Katsuwonus pelamis lineaus*). Se formularon tres (3) tipos diferentes de salchichas usando 100 % de carne de atún Big-eye (BE), 100 % de Skip-jack (SJ) y 100 % de carne de res/cerdo (Control). Se analizaron los cambios de pH en las salchichas durante el almacenamiento a 4 ± 1 ºC y se compararon con el Control. También se evaluaron la composición proximal, calidad microbiológica y atributos sensoriales.
Resultados: El pH mostró que los valores tendieron a disminuir en relación a la muestra Control, mientras que este valor aumentó en los dos tipos de salchicha con carne de atún. Las salchichas con carne de atún mostraron un 72 % de humedad, 18 % de proteína, 4,1 % de lípidos, 0,4 % de ceniza, 0,4 % de fibra, 4,5 % de carbohidratos. Los atributos sensoriales mostraron buena aceptabilidad de los parámetros de color, olor, sabor y textura. La aceptabilidad general se calificó como "me gusta" y el índice de aceptabilidad osciló entre el 76 % y el 86 %. Durante el periodo de almacenamiento en refrigeración, los análisis microbiológicos indicaron que el recuento de coliformes totales fue < 3 UFC/g. No se evidenció la presencia de *Escherichia coli*, *Staphylococcus aureus* y bacterias aerobias mesófilas durante 24 días de almacenamiento.
Conclusión: El aprovechamiento de la carne de la cola y cabeza del atún permitió desarrollar productos emulsionados tipo gel (embutidos) que exhibieron buena calidad nutricional, sensorial y microbiológica.

Palabras clave: Salchichas de atún; Composición Proximal; Calidad microbiológica; Características sensoriales.

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Introduction

Modern food production processes depend on a wide range of preservation technologies responsible for ensuring the quality and acceptability of food from production to consumption [1, 2]. Recent consumer trends have focused on researching foods with potential health benefits [3-5]. Contemporary society strives to decrease the consumption of conventional foods that might increase cholesterol levels, hypertension, atherosclerosis, and the incidence of cardiovascular diseases, such as heart disease [6, 7]. The demand for foods with reduced fat, sodium, beef, and pork has experienced significant growth in consumer interest [8, 9].

Meat products such as bacon, ham, and sausages have been consumed and appreciated worldwide for their excellent flavor, texture, and characteristic color [10-12]. However, they have been classified as unhealthy due to their high-fat content, preservatives, and salt levels [13-15]. One of the most common meat products consumed worldwide is a different type of sausage [5]. This type of meat product is restructured foods prepared with minced and stuffed meat, generally in a balanced way [16-18]. Currently, sausage production has developed as an industry in many countries as an alternative to preserving fresh meat that cannot be consumed immediately [9, 17, 19]. Thus, sausage is one of the products in which different meat and non-meat products have been evaluated to increase nutritional value and reduce fat and salt content while ensuring and improving sensory attributes [20, 21]. Examples include the development of different sausages using non-conventional raw materials, such as a sausage enriched with concentrated chickpea protein [22]. The evaluation of apple pulp fiber on the characteristics of reduced-fat sausages [23]. The replacement of pork fat with makgeolli (Korean rice wine) dietary fiber in producing frankfurter sausages [24]. In the meat industry, fish sausage production from different species has been evaluated to improve raw materials and the nutritional characteristics of this meat product [25]. A fish sausage manufactured with sunflower oil and fish oil stabilized with fish roe protein hydrolysates was characterized [26]. Despite the nutritional limitations associated with sausages, the meat industry has been exploring new sources of raw materials; hence, incorporating alternative meats to produce sausages could improve their nutritional profile and commercial value [3, 27].

The use of fish or parts of fish could be a healthy option for food production and is an excellent option to satisfy the nutritional requirements of the population [17, 28, 29]. Tuna is a fish species that is highly accepted by the population. It has high nutritional components such as proteins, vitamins (A, D, and B3), and minerals (Potassium, Phosphorus, Sodium, Iron, and Magnesium) [30, 31]. It contains low levels of saturated fat acids and a high content of the unsaturated Omega 3 fatty acid. In this sense, tuna could benefit health and replace other types of meat [17, 32, 33].

Ecuador is one of the tuna-producing countries, and the total production volume of fisheries is expected to reach 2.5 million tons in 2025, compared to approximately 500,000 tons averaged between 2013 and 2015, according to the 2018 FAO report [34]. However, industrial production also generates many discards, such as tails and head meat, which are not used for industrial processes [35]. Improper management of these by-products poses a significant environmental contamination issue when not adequately treated [36]. In this sense, using underrated meat from the fishing industry generates an opportunity to develop fortified foods with different nutritional values than their conventionally produced counterparts [37-39]. Limited research is dedicated to assessing the quality and stability of fish sausages, and the existing studies rarely utilize discarded or underutilized parts within the tuna industry. Despite the studies on fish sausages, studies are still pending to evaluate the quality and stability of sausages made with underrated tuna meat. Therefore, the present study aimed to develop and evaluate the physicochemical, microbial, and sensory properties of sausages developed from the meat of tails and heads of tuna (*Thunus obesus* and *Katsuwonus pelamis lineaus*).

Materials and methods

Raw meats and fats

Fresh beef, pork meat, and pork back-fat were purchased from a local Manta City (Ecuador) market. Tuna heads and tails were obtained from a commercial tuna processing plant (Manta-Ecuador).

Tuna sausage preparations

Tuna and control sausages were produced according to a standard procedure (Figure 1).

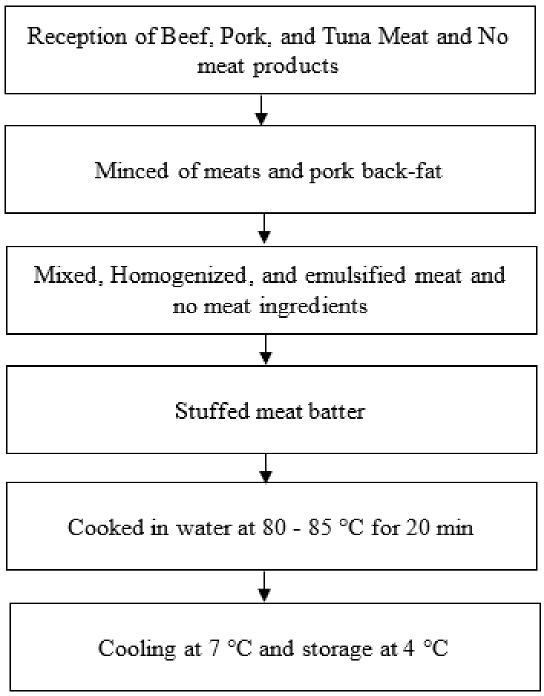

Figure 1. Sausages procedure scheme

The basis of the formulations was similar to the control and tuna formulations, except for meat for the control compared with tuna sausages (Table 1).

Beef, pork, tuna, and pork back-fat were minced separately through an 8 mm diameter disc using a meat grinder (PM-12, Mainca-Spain), then refrigerated at 4 °C. The ground beef, pork, and tuna meat used in each formulation was mixed, homogenized, and emulsified using a meat mincer (Mainca CM-21, Spain). The batter was chilled with ice (0°C) to maintain the temperature of the batter (4 °C). Then, additives, spices, and non-meat ingredients (Alitecno, Ecuador) were added to the meat and mixed. Finally, pork back-fat was added to the mixture, and the batter temperature was maintained below 10°C. The emulsified mix was stuffed into 12 mm diameter cellophane casing # 240, NIPPI Inc. (Tokyo, Japan), using a stuffer (FC-12, Mainca-Spain). Cooking was done in a water bath at 80-85 °C for 20 min until an internal temperature of 80 °C. Finally, the samples were cooled at ~7 ºC and stored at ~4 ºC until further analyses.

Table 1. Sausage formulations with different meat

Ingredients	**Treatments**		
	Control (%)	**BET6 (%)**	**SJT2 (%)**
Beef	35	-	-
Pork	35	-	-
Big Eye-Tuna	-	70	-
Skip Jack-Tuna	-	-	70
Pork back-fat	7	7	7
Frosty Ice	10	10	10
Cassava starch	3	3	3
Additives and spices	10	10	10

Control: sausage with beef, pork, and pork back-fat; BET6: sausage with Big Eye tuna meat and pork back-fat; SJT2: sausage with Skip Jack and pork back-fat.

Cooking loss

The losses in processing were determined during heat treatment. The sausages were cooked (approximately 0.5 kg) and weighed before and after cooking. Cooking loss was expressed as a percentage of the initial weight before cooking minus the final weight multiplied by one hundred after cooking. The tests were carried out in triplicate according to the methodology proposed by Salazar, Arancibia (2).

Proximate composition and pH analysis

Proximate composition (moisture, crude protein, crude fat, and crude ash) was performed according to the Association of Official Analytical Chemists (AOAC, 2005): Moisture was determined by drying in an oven at 105 ºC ± 2 ºC until constant weight; crude protein was evaluated by nitrogen content using Kjeldahl method, and content estimated by multiplying the nitrogen content by 6.25; crude fat content was determined by the Soxhlet method using petroleum ether; crude ash was determined by incineration in a muffle at 550 °C; The determination of fiber was carried out using the enzymatic-gravimetric method (AOAC 985.29) (PRT-701.03-019, 2011) (AOAC, 2005). The sample size was reduced to 0.5 g, and reagent volumes were reduced by half. Incubation with heat-stable alfa-amylase in a boiling water bath was extended to 30 min. The pH of the cooled assay solution was adjusted to 7.5 with 0.5 M NaOH. The pH of the suspension after protease incubation was adjusted to 4.5 with 0.5 M HCl. The residue and Celite were removed from the crucible, ground, and mixed well, and only portions (25 mg) were used for

micro-Kjeldahl Nitrogen determination. Carbohydrates were estimated by difference. All determinations were performed in triplicate using three samples for each treatment.
The pH of the samples was measured in a solution of sample and water using a digital potentiometer (HANNA HI 9126, Rhode Island, USA). All tests were carried out in triplicate.

Microbiological determinations

Samples of sausages were collected and weighed aseptically, homogenized, and grown in a specific medium. Mesophilic aerobic bacteria were determined and evaluated according to the official ISO 4833-1:2013 method. *Escherichia coli* by the ISO 7251:2005 method. *Staphylococcus aureus* is used by the official ISO 6888-3:2003 method and total coliforms by the official ISO 4832:2006.

Color determination

Color CIE Lab parameters, L* (lightness), a* (red/green), b* (yellow/blue), of cross-sections of sausages, were determined with a Hunter Lab Colorimeter (mini Scan 4500L EZ, Hunter Associates Laboratory INC, Reston, Virginia, USA) calibrated with an illuminator D65 (natural light) and standard observer D10. The results were expressed as Hue and Chroma values. The chroma polar coordinate or saturation C* was calculated from the expression $C^* = \sqrt{(a^{*2} + b^{*2})}$ and Hue (h°) = arc-tan (b*/a*) to a* and b* positives. Furthermore, the whiteness index was determined according to the equation $W = 100-[(100-L^*)^2 + (a^{*2} + b^{*2})]^{1/2}$. At least 15 measurements were performed in different sample areas.

Sensory attributes

The sensory properties were performed in the sensory laboratory equipped with individual cabins. The sausages were previously grilled until the internal temperature reached 90°C and kept at 70°C in an electric oven. Three pieces of 2 cm along the length of grilled samples without casing were provided with water at room temperature and salted crackers for palate cleansing. Sensory attributes such as smell, color, flavor, texture, and overall acceptability were evaluated by 20 semi-trained judges. They used a 5-point hedonic scale (5 – I liked very much; 4 - like moderately; 3 - neither liked nor disliked; 2– disliked moderately; 1 - *I do not like it*). Also, sausages were evaluated in hard texture using a scale of 1 for "*hard*" and 5 for "*very soft*." Attributes of smell, color, flavor, texture, and overall acceptability were evaluated. The acceptability index (AI) was calculated using Equation 1, according to the method proposed by Dutcosky (40).

$$AI = \frac{\text{average mark obtained for the}}{\text{maximum product score achieved}} * 100$$

Eq. 1

Statistical analysis

Data were presented as means and standard deviations (SD) and analyzed using the GraphPad Prism 5.0 program (GraphPad Software, San Diego, California, USA). One-way analysis of variance (ANOVA) and Tukey test with a significance level of P< 0.05 were done to determine the differences between samples. Shapiro and Wilks' test was applied to the data for sensory analysis to establish if the dates had a normal distribution, and the Friedman test was used for statistical analysis.

Results and discussion

Physicochemical properties

The pH of sausages shows a significant difference in storage time (p<0.05) during the 24-day storage period (Table 2). The pH showed different behavior between control and tuna sausages; in control, the values tended to decrease; in two types of tuna, these values increased. Control sausage started with a pH of 6.77, decreasing to 6.67 from 0 to 24 days. The decrease in pH values could be attributable to the lower quality characteristics of meat, such as water holding capacity, cooking loss, and emulsion stability because of decreased ionic strength between myofibrillar in meat protein (41-43). The pH started at 6.00 (BET6) and 5.69 (SJT2) and increased to 6.47 and 6.34 at the end of 24 days of storage. The increased pH values in tuna sausages could have occurred due to the growth and development of other types of bacteria competing with lactic acid bacteria, thus increasing the pH of sausages. For fish meat to be fit for human consumption, the pH must be below 6.8 (28). In concordance with this analysis, the tuna sausages would be fit for consumption for 24 days, which was the evaluation period. The behavior of tuna sausages was similar to those observed in sausages made with vongole (*Anomalocardia brasiliana*), with increasing values between 5.20 and 5.27 (44).

Table 2. pH values of sausages during storage time

Time (days)	Control	BET6	SJT2
0	6.77±0.01^{g}	6.00±0.07^{a}	5.69±0.01^{a}
3	6.72±0.02^{f}	6.09±0.02^{b}	5.82±0.01^{b}
6	6.72±0.02^{f}	6.15±0.03^{b}	5.95±0.01^{c}
9	6.70±0.03^{ef}	6.30±0.01^{c}	6.15±0.01^{d}
12	6.69±0.01^{de}	6.25±0.01^{cd}	6.19±0.01^{de}
15	6.67±0.02^{cd}	6.32±0.01^{cde}	6.22±0.01^{e}
18	6.65±0.01^{c}	6.38±0.01^{de}	6.31±0.01^{f}
21	6.61±0.01^{b}	6.41±0.01^{ef}	6.32±0.01^{f}
24	6.58±0.01^{a}	6.47±0.01^{f}	6.34±0.01^{f}

Control: sausage with beef, pork, and pork back-fat; BET6: sausage with Big Eye tuna meat and pork back-fat; SJT2: sausage with Skip Jack and pork back-fat. The results are the mean ± standard deviation. One-way ANOVA: different letters (a. b) in the same column indicate significant differences between samples (P < 0.05).

Cooking loss

The cooking loss was similar in tuna sausages and different from the control (p<0.05), although none differed more than 1% from the control, so these differences can be considered despicable (Table 3). The cooking loss obtained in this study was relatively low (~5%) and could be attributable to cassava starch content and a stable emulsion of components. The high cooking yield (<10% cooking loss) is indicative of the excellent quality of meat products because of the high water-holding capacity during cooking (45). A fish sausage from an unwashed minced blend of low-cost marine fish has a higher cooking loss (13.3%) (46). Likewise, when the effects of replacing pork with tuna levels were studied on the quality characteristics of Frankfurters, the cooking losses ranged from 12.86 to 16.77% (47). Other authors have observed different cooking losses in fish sausages because, generally, the cooking loss depends on the formulation, emulsion stability, and water holding capacity (48).

Proximal analysis

The results of the proximate composition analysis of the sausages are shown in Table 3. A significant difference was observed between tuna sausages and control in moisture content (P<0.05). Tuna sausages showed higher moisture content (~72 %) than the control (~ 59 %). The moisture content in tuna sausages was similar to that of Frozen South African hake (*Merluccius capensis*), which reported 72.9% (34). Tuna meat has high amounts of protein, balanced essential amino acid compounds, and good digestibility (49, 50). Thereby, meat products elaborated with meat fish tend to have good quality protein. In this sense, sausages prepared with the meat of Big Eye and Skip Jack tuna presented, on average, 18 % protein and were close to sausage prepared from marine catfish (*Sciades herzbergii*) stored under low temperatures (18.98%) (51), with meat from *Tetradon fahara* (18.61%) and *Clarias lazera* + *Tetradon fahara* (18.93%) (52), and fish sausages produced from fillets of crimson snapper (*Lutjanus erythropterus*) (19.7%) (53).

The variability of the composition of meat raw materials, the formulations, and the addition of fat could influence the amount of fat in the final product. The tuna sausages contained an average of 4.1% of fat. The higher fat content in the control sample could be attributable to the composition of pork meat that was not added to tuna sausages. Also, the fat results in the present work were low in contrast with sausages prepared with fresh bull's eye fish (*Priacanthus hamrur*) (5.62%) (54), sausages produced with fillets of crimson snapper (*Lutjanus erythropterus*) (12.2%) (53), and sausages with Pangas fish (*Pangasius Pangasius*) (10.70%) (55). No significant difference (P>0.05) was observed in ash, fiber, and carbohydrates. The Ecuadorian legislation (56) does not prescribe the ash concentration for sausage, so there is no way to compare the composition with any set limits.

Concerning the caloric content of sausages (Table 3), there were significant differences between control and tuna sausages (P<0.05). The samples BET6 and SJT2 had less caloric

content than the control. However, despite having the same proportion of fat in all formulations, the pork meat included in the control could have produced this difference. The lower caloric content obtained in this study is less than those reported in sausages with fat replaced with olive oil, flax, or konjac gels (up to 165 kcal/100 g product) (57), or about 139.30 kcal/100 g product with makgeolli lees fiber (24). The World Health Organization (WHO, 2003) recommends that for a balanced diet, the energy content should be composed of a variable contribution of 55-57% carbohydrates, 15-30% fat, and 10-15% protein.
Although each product consumed can have a dietary balance since a series of products are consumed daily, there is no doubt that some consumers consider meat products a vital source of their diet. So, achieving figures that allow reducing the energy content of fat (from 79.05% to 12.95% in tuna sausages) represents an essential advance to achieving foods whose caloric protein intake is more important than the caloric intake of fat.

Table 3. Proximate composition and caloric content (Kcal/100 g) of sausages

	Control	**BET6**	**SJT2**
Cooking loss (%)	5.4±0.05[a]	5.03±0.03[b]	5.7±0.05[b]
Moisture (%)	59.8 ± 0.06[b]	72.5 ± 0.25[a]	72.4 ± 0.23[a]
Protein (%)	10.2 ± 0.02[b]	18.5 ± 0.20[a]	18.3 ± 0.17[a]
Fat (%)	24. 8± 0.08[a]	4.1 ± 0.09[b]	4.1 ± 0.21[b]
Ash (%)	0.5 ± 0.03[a]	0.4 ± 0.01[b]	0.3 ± 0.02[c]
Fiber (%)	0.3 ± 0.03[a]	0.3 ± 0.04[a]	0.3 ± 0.02[a]
Carbohydrates (%)	4.5 ± 0.15[a]	4.4 ± 0.24[a]	4.6 ± 0.26[a]
Calories (Kcal/100g)	282.6 ± 0.40[a]	128.67 ± 1.6[b]	129.1 ± 1.8[b]
Fat Calories (Kcal/100g)	223.4 ± 0.69[a]	36.6 ± 0.81[b]	36.6 ± 1.87[b]
CH &F Calories (Kcal/100g)	18.5 ± 0.56[a]	18.1 ± 1.04[a]	19.2 ± 1.06[a]
Protein Calories (Kcal/100g)	40.8 ± 0.06[b]	74.0 ± 0.80[a]	73.3 ± 0.66[a]

Control: sausage with beef, pork, and pork back-fat; BET6: sausage with Big Eye tuna meat and pork back-fat; SJT2: sausage with Skip Jack and pork back-fat. The results were presented as mean ± standard deviation. One-way ANOVA: different letters (a. b) in the same column indicate significant differences between samples ($P < 0.05$). CH: carbohydrate, F: fiber, with the energetic contribution of each one.

Microbiological analysis and shelf life

Sausages showed a count of < 3 CFU/g during 17 days of evaluation for total coliforms. However, from this point of the analysis, the presence of this bacteria (9.2 CFU/g in BET6 and 6.4 CFU/g in SJT2) was detected. On the control sample, there was no coliform presence for 24 days. The results established that although adequate hygienic conditions were considered, sausages began to develop more rapidly at the end of the storage, inferring that this evaluation point defined the end of the lag phase. On the other hand, *E. coli* counts showed the absence of this microorganism during 24 days of chilling storage. The Ecuadorian Technical Standard NTE 1338:2012 establishes that the count of *E. coli* for cooked sausages shall be < 10 CFU/g. Therefore, tuna sausages stored for 24 days in refrigerated storage comply with the requirements. The results of *E. coli* were similar to those reported in sausages from Nile tilapia carcasses (*Oreochromis niloticus*) (42). The absence of *Staphylococcus aureus* during 24 days of tuna storage and control sausages was observed when refrigerated. The Ecuadorian Technical Standard NTE 1338:2012 allows up to 1,0x10^3 CFU/g of *Staphylococcus aureus* in cooked sausages. The results show that the sausages comply with hygienic procedures; the packaging and the refrigeration storage temperatures conserved and maintained the quality. The results of *S. aureus* were similar to those reported in sausages made from Nile tilapia carcasses (*Oreochromis niloticus*), which do not evidence the presence of *Staphylococcus aureus* (42). Also, in sausages produced with the meat of *Clarias lazera*, the S*taphylococcus aureus* counts during 30 days of storage at 5°C were imperceptible (52). Mesophilic aerobic bacteria count showed absence in tuna sausages, and in the control sample, there were 5 CFU/g at 24 days of storage. These results indicated the excellent quality of the tuna meat. The Ecuadorian Technical Standard, NTE 1338:2012 specifications for cooked sausages, recommend that these bacteria in food intended for human consumption do not exceed 5.0 *10^5 CFU/g. Studies of sausages produced with Indian sardines (*Sardinella longiceps*) found similar results for mesophilic aerobic bacteria (58). The microbiological results showed that the control of the tuna post-capture microbial load could be minimal to generate products of high quality from marine raw materials.

Color

The results of the color parameters of sausages are shown in Table 4. Lightness (L*) does not show significant differences (P>0.05) between the two types of tuna sausages, but they differed from the control. Lightness in control declined, being slightly darker and colorless. The redness (a*) was similar for all samples during the evaluation, which could be attributed to the red color added in all formulations. Regarding the yellowness (b*), there were no differences. However, the control showed a slightly higher value, while the BET6 and SJT2 exhibited the lowest. The Chroma and Hue do not show differences (P>0.05) between the treatments. The scarce difference in coloration among the different batches of sausages may be due to color differences in the mass formed by the emulsified muscle protein and the natural color added to the dough. The color values of tuna sausages reported in this study were similar to those reported in Frankfurter sausages with different tuna levels (47). The values reported in sausages with added surimi, fat, and water content were not significantly different (P>0.05) regardless of the addition of fish meat protein or fat.

Table 4. Color properties of sausages

Parameters	Control	BET6	SJT2
L	51.17±0.41[b]	53.33±0.52[a]	52.33±0.82[a]
a*	41.17±0.98[a]	41,50±0.55[a]	41.33±0.82[a]
b*	30.17±0.75[a]	29.67±1.03[a]	29.01±0.75[a]
C	51.04±0.78[a]	51.02±0.75[a]	50.71±0.61[a]
H	0.63±0.02[a]	0.62±0.02[a]	0.61±0.02[a]
IB	29.36±0.66[b]	30.86±0.79[a]	30.58±0.42[a]

Control (sausage with beef, pork, and pork back-fat), BET6 (sausage with Big Eye tuna meat and pork back-fat), SJT2 (sausage with Skip Jack and pork back-fat). The results are the mean ± standard deviation. One-way ANOVA: different letters (a. b) in the same column indicate significant differences between samples ($P < 0.05$).

Sensory analysis

The sensory analysis results were performed to establish the normality in dates, and the results showed, as was expected, no normal distribution. In this sense, dates were analyzed using the Friedman test to establish differences. The sensory results showed differences between tuna sausages and the control sample. The sensory attributes and acceptability results are shown in Figures 2A and 2B, respectively. The color of the sausages prepared with tuna meat was scored 4, "liked moderately"; also, the control sample was scored similarly. The acceptability index (AI) for the color parameter of the tuna sausages was 80%. Values above 70% indicate that the judges accept the product (40). The acceptability in the color parameter of this type of product is interesting because it is not a standard product in Ecuador. The judges could not compare it with the color of commercial fish sausage; they could only compare it with the control sample. The color acceptability of the sausages formulated in the present work was similar to Frankfurters with combined pork meat and yellowfin tuna (47) and sausages from marine catfish (*Sciades herzbergii*) (51).

The smell of sausages received a rating equivalent to "liked moderately." This result could be caused by the fact that spices were added to the dough commonly used in the production of sausages and contributed to developing a good smell in the final product. The result of "liked moderately" on the acceptability of the smell of the sausages was surprising because the premise with new products, especially with fish, is that consumers reject the new product. The rejection by the consumer could be expected because the smell of marine fish is usually powerful; in these species, more nitrogen components are not concentrated, which are low molecular weight volatile compounds (44). The tuna sausages smell was almost similarly appreciated to sausages from bull eye fish (*Priacanthus hamrur*) (38) and sausage from marine catfish (*Sciades herzbergii*) (51). The texture of the tuna sausages produced in the present work was scored as 4," liked moderately," and categorized as "soft moderately." The result in the hardness of texture of the tuna sausage was satisfactory because all procedures, raw materials, and conditions were adequate according to the standards for sensory evaluation. Regarding flavor and overall acceptability, the SJT2 sample scored the highest compared to BET6 and the control sample; the panelist qualification was "liked very much." This result is significant because the tuna meat used to produce tuna sausages comes from the head and tails of commercial tuna, which habitually needs to be more utilized.

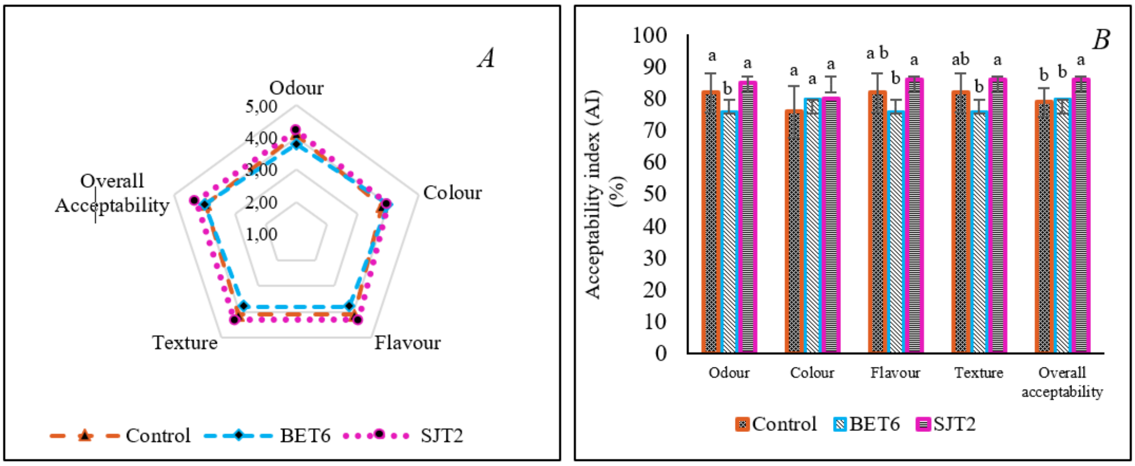

Figure 2. A) Sensory evaluation; B) Acceptability index. Control (sausage with beef, pork, and pork back-fat), BET6 (sausage with Big Eye tuna meat and pork back-fat), SJT2 (sausage with Skip Jack and pork back-fat). Different letters in AI (a. b) of each parameter indicate significant differences between samples (P < 0.05).

Conclusions

The production of sausages using underutilized tuna meat (tail and head tuna meat) is an excellent opportunity for the tuna industry. This new productive alternative adds value to less commercially viable meat, generating fresh and nutritious products with good nutritional quality, sensory appeal, and extended shelf life. The study results show that the sausages produced with tuna cuts have good-quality protein and less caloric content, principally due to the lower fat content. As production quality indicators, the pH and acidity show that sausages would be fit for consumption for 24 days. Regarding microbiological quality, sausages comply with hygienic procedures; the packaging and the refrigeration storage temperatures conserved and maintained the quality. There were no negative observations for taste or odor in the sensorial parameters, while the acceptability was assessed well. In conclusion, the results showed that tuna sausages have 24 days of shelf life stored at 4 °C without negatively affecting microbiological quality.

Conflict of Interest: The authors do not have any conflict of interest with any person or organization in publishing this article.

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References

1. Hassoun A, Cropotova J, Trif M, Rusu AV, Bobiş O, Nayik GA, et al. Consumer acceptance of new food trends resulting from the fourth industrial revolution technologies: A narrative review of literature and future perspectives. Front nutr. 2022;9:972154. DOI: https://doi.org/10.3389/fnut.2022.972154
2. Salazar D, Arancibia M, Calderón L, López-Caballero ME, Montero MP. Underutilized Green Banana (Musa acuminata AAA) Flours to Develop Fiber Enriched

Frankfurter-Type Sausages. Foods. 2021;10(5):1142. DOI: https://doi.org/10.3390/foods10051142
3. Salazar D, Arancibia M, Raza K, López-Caballero ME, Montero MP. Influence of Underutilized Unripe Banana (Cavendish) Flour in the Formulation of Healthier Chorizo. Foods. 2021;10(7):1486. DOI: https://doi.org/10.3390/foods10071486
4. Liu X, Le Bourvellec C, Yu J, Zhao L, Wang K, Tao Y, et al. Trends and challenges on fruit and vegetable processing: Insights into sustainable, traceable, precise, healthy, intelligent, personalized and local innovative food products. Trends Food Sci Technol. 2022;125:12-25. DOI: https://doi.org/10.1016/j.tifs.2022.04.016
5. Pérez L, Pincay R, Salazar D, Flores N, Escolastico C. Evaluation of the Quality and Lipid Content of Artisan Sausages Produced in Tungurahua, Ecuador. Foods. 2023;12(23):4288. DOI: https://doi.org/10.3390/foods12234288
6. Fróna D, Szenderák J, Harangi-Rákos M. The challenge of feeding the world. Sustainability. 2019;11(20):5816. DOI: https://doi.org/10.3390/su11205816
7. Kim TK, Hwang KE, Sung JM, Park JD, Kim MH, Jeon KH, et al. Replacement of pork back fat with pre-emulsion of wheat (Triticum aestivum L.) sprout and collagen and its optimization for reduced-fat patties. J Food Process Preserv. 2018;42(4):e13576. DOI: https://doi.org/10.1111/jfpp.13576
8. Chernukha I, Kotenkova E, Pchelkina V, Ilyin N, Utyanov D, Kasimova T, et al. Pork Fat and Meat: A Balance between Consumer Expectations and Nutrient Composition of Four Pig Breeds. 2023;12(4):690. DOI: https://doi.org/10.3390/foods12040690
9. Hwang K-E, Kim T-K, Kim H-W, Seo D-H, Kim Y-B, Jeon K-H, et al. Effect of natural pre-converted nitrite sources on color development in raw and cooked pork sausage. Asian-Australas J Anim Sci. 2018;31(8):1358. DOI: https://doi.org/10.5713/ajas.17.0767
10. Bis-Souza CV, Barba FJ, Lorenzo JM, Penna ALB, Barretto ACS. New strategies for the development of innovative fermented meat products: a review regarding the incorporation of probiotics and dietary fibers. Food Rev Int. 2019;35(5):467-84. DOI: https://doi.org/10.1080/87559129.2019.1584816
11. Prado N, Sampayo M, González P, Lombó F, Díaz J. Physicochemical, sensory and microbiological characterization of Asturian Chorizo, a traditional fermented sausage manufactured in Northern Spain. Meat Sci. 2019;156:118-24. DOI: https://doi.org/10.1016/j.meatsci.2019.05.023
12. Owusu-Apenten R, Vieira E. Meat. In: Nielsen BPIS, editor. Elementary Food Science. Food Science Text Series. Switzerland Springer; 2022. p. 602.
13. Gearhardt AN, DiFeliceantonio AG. Highly processed foods can be considered addictive substances based on established scientific criteria. Addiction. 2023;118(4):589-98. DOI: https://doi.org/10.1111/add.16065
14. Jiménez-Comenero F. Functional foods based on meat products. Boca Raton: Taylor & Francis; 2012.
15. Bolger Z, Brunton NP, Lyng JG, Monahan FJ. Comminuted meat products consumption, composition, and approaches to healthier formulations. Food Rev Int. 2017;33(2):143-66. DOI: https://doi.org/10.1080/87559129.2016.1149861
16. Djordjevic J, Pecanac B, Todorovic M, Dokmanovic M, Glamoclija N, Tadic V, et al. Fermented Sausage Casings. Procedia Food Sci. 2015;5:69-72. DOI: https://doi.org/10.1016/j.profoo.2015.09.017
17. Ninan G, Aswathy K, Joshy C. Development of dietary fiber-incorporated fish sausage. Cochin: Central Institute of Fisheries Technology, 2018.

18. Bilyk L, Popova N. Formation of quality and safety of offal sausages. Ukr J Food Sci. 2018:54. DOI: https://doi.org/10.24263/2310-1008-2018-6-1-8
19. Zhang Y, Zhang Y, Jia J, Peng H, Qian Q, Pan Z, et al. Nitrite and nitrate in meat processing: Functions and alternatives. Curr Res Food Sci. 2023:100470. DOI: https://doi.org/10.1016/j.crfs.2023.100470
20. Carballo J. Sausages: Nutrition, safety, processing and quality improvement. 2021;10(4):890. DOI: https://doi.org/10.3390/foods10040890
21. Bhattacharya S. Chapter 5 - Meat-, fish-, and poultry-based snacks. In: Bhattacharya S, editor. Snack Foods: Academic Press; 2023. p. 117-50.
22. Mokni Ghribi A, Ben Amira A, Maklouf Gafsi I, Lahiani M, Bejar M, Triki M, et al. Toward the enhancement of sensory profile of sausage "Merguez" with chickpea protein concentrate. Meat Sci. 2018;143:74-80. DOI: https://doi.org/10.1016/j.meatsci.2018.04.025
23. Choi Y-S, Kim Y-B, Hwang K-E, Song D-H, Ham Y-K, Kim H-W, et al. Effect of apple pomace fiber and pork fat levels on quality characteristics of uncured, reduced-fat chicken sausages. Poult Sci. 2016;95(6):1465-71. DOI: https://doi.org/10.3382/ps/pew096
24. Choi Y-S, Kim H-W, Hwang K-E, Song D-H, Choi J-H, Lee M-A, et al. Physicochemical properties and sensory characteristics of reduced-fat frankfurters with pork back fat replaced by dietary fiber extracted from makgeolli lees. Meat Sci. 2014;96(2):892-900. DOI: https://doi.org/10.1016/j.meatsci.2013.08.033
25. Berik N, Yilmaz D, editors. Fish Sausage Production from Different Fish Species. UARD Jubilee International Scientific Conference; 2018.
26. Hajfathalian M, Jorjani S, Ghelichi S. Characterization of fish sausage manufactured with combination of sunflower oil and fish oil stabilized with fish roe protein hydrolysates. J Food Sci Technol. 2020;57(4):1439-48. DOI: https://doi.org/10.1007/s13197-019-04179-6
27. Egea M, Álvarez D, Peñaranda I, Panella-Riera N, Linares MB, Garrido MD. Fat replacement by vegetal fibres to improve the quality of sausages elaborated with non-castrated male pork. Animals. 2020;10(10):1872. DOI: https://doi.org/10.3390/ani10101872
28. Jati SK. Quality characteristics of beef sausage reformulated with other protein sources. Yogyakarta: Universitas Gadjah Mada; 2019.
29. Racioppo A, Speranza B, Pilone V, Stasi A, Mocerino E, Scognamiglio G, et al. Optimizing liquid smoke conditions for the production and preservation of innovative fish products. Food Bioscience. 2023;53:102712. DOI: https://doi.org/10.1016/j.fbio.2023.102712
30. Boronat Ò, Sintes P, Celis F, Díez M, Ortiz J, Aguiló-Aguayo I, et al. Development of added-value culinary ingredients from fish waste: Fish bones and fish scales. International Journal of Gastronomy and Food Science. 2023;31:100657. DOI: https://doi.org/10.1016/j.ijgfs.2022.100657
31. Dutt Tripathi A, Agarwal A. Scope, nutritional aspects, technology, and consumer preferences toward seafood alternatives. Food Research International. 2023;168:112777. DOI: https://doi.org/10.1016/j.foodres.2023.112777
32. Boukid F, Baune M-C, Gagaoua M, Castellari MJEFR, Technology. Seafood alternatives: assessing the nutritional profile of products sold in the global market. 2022;248(7):1777-86. DOI: https://doi.org/10.1007/s00217-022-04004-z
33. Rueangwatcharin U, Wichienchot S. Development of functional canned and pouched tuna products added inulin for commercial production. J Food Sci Technol. 2015;52(8):5093-101. DOI: https://doi.org/10.1007/s13197-014-1589-y

34. FAO. El estado mundial de la pesca y la acuicultura (The world state of fisheries and aquaculture)2018. Available from: http://www.fao.org/3/V7180S/v7180s06.htm.
35. Ozogul F, Cagalj M, Šimat V, Ozogul Y, Tkaczewska J, Hassoun A, et al. Recent developments in valorisation of bioactive ingredients in discard/seafood processing by-products. Trends Food Sci Technol. 2021;116:559-82. DOI: https://doi.org/10.1016/j.tifs.2021.08.007
36. Sasidharan A, Rustad T, Cusimano GM. Tuna sidestream valorization: a circular blue bioeconomy approach. Environ Sci Pollut Res. 2023:1-19. DOI: https://doi.org/10.1007/s11356-023-28610-w
37. Cooney R, de Sousa DB, Fernández-Ríos A, Mellett S, Rowan N, Morse AP, et al. A circular economy framework for seafood waste valorisation to meet challenges and opportunities for intensive sustainability. J Clean Prod. 2023:136283. DOI: https://doi.org/10.1016/j.jclepro.2023.136283
38. Nurhayati, Agusman, Basmal J, Ikasari D, Kusumawati R, Munifah I. Effect of Kappaphycopsis cottonii powder/konjac composite on the characteristics of tuna (Thunnus sp.) fish balls. J Appl Phycol. 2024;36(1):421-31. DOI: https://doi.org/10.1007/s10811-023-03130-9
39. Wongsaichia S, Naruetharadhol P, Pienwisetkaew T, Gawborisut S, Ketkaew C. Unleashing customer empathy in the circular economy: Development of a high-calcium fish sausage prototype from fermented fish residue. Future Foods. 2024;9:100291. DOI: https://doi.org/10.1016/j.fufo.2023.100291
40. Dutcosky SD. Análise sensorial de alimentos. Pucpress, editor. Curitiba: Editora Universitária Champagnat; 2019. 540 p.
41. Ahn KI, Shim JY, Kim TK, Choi JH, Kim HW, Song DH, et al. Effects of Replacing Pork with Tuna Levels on the Quality Characteristics of Frankfurters. Korean J Food Sci Anim Resour. 2018;38(4):718-26. DOI: https://doi.org/10.5851/kosfa.2018.e10
42. Dallabona BR, Karam LB, Wagner R, Bartolomeu DAFS, Mikos JD, Francisco JGP, et al. Effect of heat treatment and packaging systems on the stability of fish sausage. Rev Bras Zootec. 2013;42(12):835-43. DOI: https://doi.org/10.1590/S1516-35982013001200001
43. de Sá Vieira PH, de Barrros CN, Mendes ES, Maciel MIS, de Andrade HA, de Oliveira Filho PRC. Development and characterization of fresh sausages made with marine catfish Sciades herzbergii (Bloch, 1794). Acta Scientiarum Technology. 2019;41:e40299. DOI: https://doi.org/10.4025/actascitechnol.v41i1.40299
44. Bispo EdS, de Santana L, Carvalho R, Andrade G, Leite C. Shellfish industrial utilization to produce sausage. Cienc tecnol aliment (Brazil). 2004; 24(4):664-8. DOI: https://doi.org/10.1590/S0101-20612004000400031
45. Choe J, Kim H-Y. Quality characteristics of reduced fat emulsion-type chicken sausages using chicken skin and wheat fiber mixture as fat replacer. Poult Sci. 2019;98(6):2662-9. DOI: https://doi.org/10.3382/ps/pez016
46. Nowsad A, Hoque M. Standardization of production of fish sausage from unwashed mince blend of low-cost marine fish. Asian Fish Sci. 2009;22(1):347-57. https://www.asianfisheriessociety.org/publication/downloadfile.php?id=170&file=Y0dSbUx6QTJOemcyTVRrd01ERXpOVFUzT1RnME5EWXVjR1Jt&dldname=Standardization%20of%20Production%20of%20Fish%20Sausage%20from%20Unwashed%20Mince%20Blend%20of%20Low%20Cost%20MarineFish.pdf
47. Ahn K-I, Shim J-Y, Kim T-K, Choi J-H, Kim H-W, Song D-H, et al. Effects of replacing pork with tuna levels on the quality characteristics of frankfurters. Korean J Food Sci Anim Resour. 2018;38(4):718. DOI: https://doi.org/10.5851/kosfa.2018.e10

48. Choi Y-S, Park K-S, Kim H-W, Hwang K-E, Song D-H, Choi M-S, et al. Quality characteristics of reduced-fat frankfurters with pork fat replaced by sunflower seed oils and dietary fiber extracted from makgeolli lees. Meat Sci. 2013;93(3):652-8. DOI: https://doi.org/10.1016/j.meatsci.2012.11.025
49. Balogun AM, Talabi SO. Proximate analysis of the flesh and anatomical weight composition of skipjack tuna (Katsuwonus pelamis). Food Chem. 1985;17(2):117-23. DOI: https://doi.org/10.1016/0308-8146(85)90080-9
50. Norhazirah A, Shazili N, Kamaruzzaman Y, Sim S, Ahmad A, Ong M. Heavy metals in tuna species meat and potential consumer health risk: A review. IOP Conf Ser Earth Environ Sci. 2020;494(1):012013. DOI: https://doi.org/10.1088/1755-1315/494/1/012013
51. Veloso R, dos Anjos B, Maciel M, Shinohara N, Andrade H. Development and evaluation of fresh sausage type of marine catfish (Sciades herzbergii (Bloch. 1794)) stored under low temperatures. Int Food Res J. 2019;26(2). http://www.ifrj.upm.edu.my/26%20(02)%202019/(28).pdf
52. Ahmed EO, Elhaj GA. The chemical composition microbiological detection and sensory evaluation of fresh fish sausage made from Clarias lazera and Tetradon fahaka. J Fish Aquac. 2011;2(1):11-6. https://bioinfopublication.org/files/articles/2_1_2_JFA.pdf
53. Al-Bulushi IM, Kasapis S, Dykes GA, Al-Waili H, Guizani N, Al-Oufi H. Effect of frozen storage on the characteristics of a developed and commercial fish sausages. J Food Sci Technol. 2013;50(6):1158-64. DOI: https://doi.org/10.1007/s13197-011-0441-x
54. Maheshwara K, Naik J, Balamatti A, Jagadish T. Biochemical and shelf life study of quality of fish sausage in ambient and refrigerated storage. Biochemical and Cellular Archives. 2017;Vol. 17, No. 1 pp. 265-70. DOI: https://connectjournals.com/file_html_pdf/2688601H_265A.pdf
55. Surasani VKR, Raju CV, Shafiq U, Chandra MV, Lakshmisha IP. Influence of protein isolates from Pangas processing waste on physico-chemical, textural, rheological and sensory quality characteristics of fish sausages. LWT. 2020;117:108662. DOI: https://doi.org/10.1016/j.lwt.2019.108662
56. Standardization EIo. Meat And Meat Products. Raw Meat Products, Cured Meat Products And Partially Cooked - Cooked Meat Products. Requirements. In: INEN, editor. NTE INEN 1338:2012. Ecuador: Ecuadorian Standarization Institute; 2012. p. 12.
57. Salcedo-Sandoval L, Cofrades S, Pérez CR-C, Solas MT, Jiménez-Colmenero F. Healthier oils stabilized in konjac matrix as fat replacers in n− 3 PUFA enriched frankfurters. Meat Sci. 2013;93(3):757-66. DOI: https://doi.org/10.1016/j.meatsci.2012.11.038
58. Ravishankar C, Setty T, Shetty T. Method for the preparation of sausages of acceptable quality from Indian oil sardine (Sardinella longiceps) and their shelf-life at different storage temperatures. Food Control. 1992;3(3):144-8. DOI: https://doi.org/10.1016/0956-7135(92)90098-U