International Journal of Gastronomy and Food Science 31 (2023) 100657

Contents lists available at ScienceDirect

International Journal of Gastronomy and Food Science

journal homepage: www.elsevier.com/locate/ijgfs

Development of added-value culinary ingredients from fish waste: Fish bones and fish scales

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ARTICLE INFO

Keywords:
By-products
Fish scales
Fish bones
Fish gelatine

ABSTRACT

Around 10% of the global fish catch (>90 million tonnes) is currently discarded, while by-products in fisheries account for up to 70% of the whole fish weight. From these, fish bones and scales represent 14–20% of by-products, which are also discarded. Therefore, there is an unmet need for valorising these by-products by transforming them into functional and nutritious ingredients. Towards this objective, we report herein different culinary processes to extract gelatine from fish scales, as well as fish flours from bones and scales, as innovative methods for waste valorisation in the food services industry. On the one hand, gelatine was extracted from demineralised and non-demineralised scales and their respective gelling and melting properties were analysed and compared in culinary elaborations. Both gelatines showed a lower melting point (23 °C) than pork gelatine (29 °C, used as control), which provided these gelatines with a smooth and creamy texture in mouth. On the other hand, financiers made of fish bone and fish scales flour were compared with those made with regular wheat-flour, resulting in no significant differences regarding their adhesiveness and springiness. These results showcase the potential of upcycling fish by-products into protein-rich value-added ingredients in the food services industry.

1. Introduction

The Food and Agriculture Organization of the United Nations (FAO) has reported that the total world production of seafood in 2018 was around 178 million tonnes, with wild fish catch representing 51% of the total. Of this figure, 10.1% become eventually discards (the portion of the fish catch that is thrown back into the sea) (FAO, 2020). Furthermore, during fish processing into fillets (the most common cut of fish) up to 70% of the total fish weight is discarded, which includes heads (9–12%), viscera (12–18%), skin (1–3%), bones (9–15%) and scales (5%). This large amount of by-products is sometimes used as animal feed, fishmeal, oil or plant fertiliser, but in most cases it is readily discarded (Gehring et al., 2011), (Gilman et al., 2020). In recent years, there has been an increased awareness of ocean sustainability and valorisation of current resources. In this regard, fish by-products are starting to be used as raw ingredients for human consumption (Islam et al., 2021). In addition to their lower environmental impact, the value of such upcycled ingredients has been shown to increase up to five times (Gildberg, 2002). According to the report published by Industry ARC (2022), the fish products market is estimated to grow at CAGR 4.8% between 2022 and 2027. In particular, the fish collagen market is expected to grow to $1994.7 million by 2032 (Future Market Insights, 2022). Hence, it highlights the huge potential of fish bones, scales, skin and muscles for the fish collagen obtention together with the relatively low price of such raw materials (Shaviklo, 2015).

Historically, the use of fish by-products dates back to >2500 years ago in north Africa, when the surplus from fish captures was used to elaborate fish ferments, which later were called “garum” by the Romans (Redzepi and Zilber, 2018), (Grainger, 2020). In current times, some of the more innovative applications in gastronomy are those developed by Ángel León (Aponiente, Spain) and Josh Niland (Fish Butchery, Australia). These innovations are largely based on the development of cold meats, such as fish sperm mortadella or fish morcilla, as well as garums and pâtés (Niland, 2019), (Niland, 2021). On the other hand, food industry innovations on the use of fish by-products have gained interest only recently, such as the production of ferments from

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https://doi.org/10.1016/j.ijgfs.2022.100657
Received 11 October 2022; Received in revised form 15 December 2022; Accepted 22 December 2022
Available online 23 December 2022

under-utilised fish parts (research funded by the FishFermPlus European project in 2012) (CORDIS: EU research results, 2015).

More conventionally, fish bones and scales are employed by the food industry as a source of collagen for gelatine extraction (Coppola et al., 2020). This gelatine can be used as thickener, emulsifier, stabilizer, or clarifying agent (Shen et al., 2019). As in the case of the gelatine extracted from land animal origin, fish gelatine is extracted from the type I collagen. However, they show different chemical compositions and denaturalization temperatures, being fish collagen the one with lower denaturalization temperature and thermal stability (Nomura et al., 1996), (Lin and Liu, 2006). Moreover, fish bones also represent an important collagen source (Muyonga et al., 2004). Their high protein percentage can be useful in food industry applications for the generation of peptides by enzymic hydrolysis (Morimura et al., 2002), while its high calcium content (30%) represents in some cases valuable source of a calcium (Shen et al., 2019). Fish bone flour has been used in different studies to fortify culinary elaborations. For example, Uthai (2021) reported the use of salmon fish bone powder as substitute for wheat flour in the elaboration of noodles, producing an increase of protein content in the final product. Although some differences in texture and appearance were observed, overall acceptance was not affected by the addition of 15% fish bone flour. Similar studies described that Ca and P content increased in fortified products with fish bone flour (Abdel-Moemin, 2015). In addition, fish gelatines can provide added value to the new products such as major flavour release, due to their lower melting point than pork gelatine (Gomez-Guillen et al., 2011; Choi and Regenstein, 2000). Although, previous studies reported collagen extraction methodologies, still there is a lack of studies in the culinary context (Darmanto et al., 2022; Huang et al., 2016; Nagai and Suzuki, 1999).

We report herein different culinary processes to extract and analyse gelatine from fish scales, as well as fish flours from bones and scales, as innovative tools for waste valorisation in the food services industry. The current study focuses on the valorisation of two important fish by-products, such as scales and fish bones, and their transformation into value-added ingredients for culinary applications. On the one hand, a culinary methodology for fish collagen extraction from fish scales will be established. On the other hand, key characteristics such as chemical compositions, melting temperatures and textures were thoroughly analysed, and their behaviours in different culinary preparations is presented and discussed.

2. Material and methods

2.1. Material

All fish by-products were obtained from the fish distributor enterprise GranBlau. For the study fish scales were collected from different fish species and fish bones from *Dicentrarchus labrax*. Lactic acid was purchased from ITW Reagents (US). The ingredients used in this study were: sodium chloride, pork gelatine powder, sunflower oil, cherry juice, heavy cream 35% (w/w), white sugar, whole milk, white wheat all-purpose flour, honey, ground almond, butter and pasteurized egg whites.

2.2. Methods

2.2.1. Gelatine

2.2.1.1. Scales demineralization process. 875 g of fish scales were washed in 10% w/v NaCl solution in a dry scale:solution ratio of 1:10 (w/w) for 24 h at 4 °C to remove unnecessary proteins. The solution must be changed every 8 h to improve the unnecessary protein removal (Muthumari et al., 2016). Then, scales were washed three times in a low mineralised water bath for 10 min at room temperature, changing its water each time. After, scales were strained and treated with 2 M lactic acid solution for 3 h in a dry scale: solution ratio of 1:10 (w/w). Afterwards, the demineralised scales were washed with low mineralised water until neutral pH was reached. The scales' weight after the demineralization process was 666 g, with a yield of 76%.

2.2.1.2. Gelatine extraction. 666 g of demineralised and 875 g of non-demineralised scales were boiled for 45 min at a dry scale:water ratio of 1:2 (w/w) and strained through a fine sieve. The resultant liquid was refrigerated at 4 °C for 2h until a gel was obtained. The gel was further dehydrated at 56 °C for 24 h in an oven (Distform MyChef, Spain) following a standard protocol described by (Boran and Regenstein, 2010). Then, the material was ground with a Robot Cook (Robot Coupe, France) and sieved with a 600 μm sieve until a fine powder was obtained. A total of 57 g of demineralised scales gelatine (DSG) and 85 g of non-demineralised scales gelatine (NDSG) were obtained. The extraction yield from demineralised and non-demineralised scales was 8.6% and 9.7%, respectively.

2.2.2. Flours

2.2.2.1. Fish bone flour (BF). 6 kg of raw fish bones from *Dicentrarchus labrax* were boiled for 30 min. Once cooked, the remaining meat that was sticked on the bones was removed and then, bones were dehydrated in an oven (Distform MyChef, Spain) at 90 °C for 24 h. Afterwards, they were ground with a Robot Cook (Robot Coupe, France) and sieved with a 600 μm sieve. A total of 800 g of BF was obtained.

2.2.2.2. Scales flour (SF). 592 g of non-demineralised scales (after gelatine extraction) were dehydrated in an oven (Distform MyChef, Spain) at 90 °C for 24 h. Afterwards, they were ground with a Robot Cook (Robot Coupe, France) and sieved with a 600 μm sieve. Afterwards, they were ground with a Robot Cook (Robot Coupe, France) and sieved with a 600 μm sieve. A total of 265 g of SF was obtained.

2.2.3. Chemical analysis

2.2.3.1. Food proximate. For centesimal composition, the ash content was determined by gravimetry using the incineration residue obtained by heating in a muffle furnace at 550 °C and, the moisture gravimetrically by drying in kiln at 110 °C to constant weight (Association of Official Analytical Chemists International, 2002). Protein content was determined by the Kjeldahl method (using a conversion factor of 5.95 as reported by Zhang et al., 2019), with an acid digestion, distillation of NH_3 over N/10 H_2SO_4 and titration with N/10 NaOH (Association of Official Analytical Chemists International, 1990). The lipid analysis was quantified by gravimetric method using acid hydrolysis by the Soxhlet extraction procedure (Association of Official Analytical Chemists International, 2005). The total carbohydrate content was estimated by subtracting the sum of moisture, ash, lipid, and protein content from 100 g. All of the analysis was following the standard of Official Methods of Analysis of AOAC International.

2.2.3.2. pH. pH of both flours was measured with a pHmeter (XS Instruments, Italy) according to the following procedure: 7.5 g of each flour (BF, SF and all-purpose wheat flour used as a control) were suspended in 150 g of low mineralised water using a hand blender. Then, pH was measured.

2.2.4. Gel properties

2.2.4.1. Gel preparation. 1.6 g of powder DSG gelatine and pork gelatine (used as control) and 3.2 g of powder NDSG was hydrated with 100 g of low mineralised water at 4 °C for 30 min. Then, it was heated in a bain-marie at 45 °C and allowed to cool down again at 4 °C for 3 h until completely jellified.

2.2.4.2. Gelling and melting temperature. 1.6 g of powder gelatine (DSG and pork gelatine, used as control) and 3.2 g of powder NDSG was hydrated with 100 g of low mineralised water at 4 °C for 30 min. Then, it was heated in a bain-marie at 45 °C and allowed to cool down again at 4 °C. The temperature of each jelly was recorded every 15 min with a thermometer until completely jellified. For the melting temperature (Tm) analysis, jellies were heated up in a bain-marie equipped with a thermometer and when the jellies began to melt, the temperature was written down. The hysteresis values were calculated as the difference between gelling and melting temperatures. Each analysis was done in triplicate.

2.2.5. Culinary applications of gelatines

2.2.5.1. Puffed gelatine. 5 g of dry gelatine (DSG and NDSG), obtained after dehydrating the gelatine blocks (without being ground) were deep-fried in a small pot using 400 g of sunflower oil at 185 °C for 5 s. Once fried, salt was added, and they were placed on absorbent paper to get off the oil excess.

2.2.5.2. Panna cotta. 2 g of DSG and CG and 4 g of the NDSG were hydrated with 50 g of heavy cream 35% (w/w) each for 30 min at 4 °C. In parallel, 120 g of heavy cream 35% (w/w) and 20 g of white sugar were added and heated to 80 °C in a small pot. The hydrated gelatines were heated to 45 °C and added to the previous mixture of heavy cream and sugar. Each mixture was divided in 3 cm diameter flan moulds and were allowed to cool down at 4 °C for 3h. Finally, they were removed from the moulds, and texture, flavour and structure analysis were performed.

2.2.5.3. Whipped gelatine. 8.2 g of DSG and CG and 16.4 g of the NDSG were hydrated with 100 g of whole milk each for 30 min at 4 °C. In parallel, 150 g of milk and 15 g of white sugar were mixed in a small pot and heated up to 80 °C. The hydrated gelatines were heated to 45 °C and added to the previous mixture of milk and sugar. The mixture was whipped with a Cooking Chef XL elite (Kenwood, UK) at low speed until a stiff foam was obtained. Finally, 5 g of each mixture was rationed with a pipping bag on a tray and were let to set for 3h at 4 °C. Further texture, flavour and structure analysis was carried out. Each whipped cream with the different gelatines were prepared in triplicate.

2.2.6. Culinary applications of flours

2.2.6.1. Financier. 107 g of butter was melted at 145 °C in a small pot. In a separate bowl, 129 g of white sugar, 43 g of the three flours (BF, SF and all-purpose wheat flour), 64 g of almond powder and 21 g of honey was mixed. 116 g of egg white was added to the previous mixture and finally, melted butter was slowly added. The mixture was set to rest at 4 °C for 30 min and then, it was rationed in silicon moulds (1 cm × 4.5 cm x 2.5 cm) using a pipping bag. All cavities were filled to the top and each one was weighted. Financiers were baked at 160 °C for 15 min in a mixed oven program (Distform MyChef, Spain) They were cooled down at −36 °C for 10 min in a blast freezer before being demoulded. Finally, the height and weight of each one was measured with a calliper.

The % of weight loss was calculated with the following formula: (1–(final weight/initial weight)) x 100; and the % increased height was calculated with the following formula: ((final height – initial height)/initial height) x 100.

2.2.7. Texture analysis

Texture analyser *TA-XT2* (Stable Micro Systems Ltd., England) with a 49 N load cell at a crosshead speed of 1 mm/s and a cylindrical plunger with a flat base of 35 mm of diameter (with a 75 mm compression platen), was used to determine hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness and resilience. For the texture profile analysis (TPA) of financiers, the samples were axially compressed to 35% of their original height and two compression cycles were done. Three financiers where tested: SF, BF and CF, as a control. The experiment was performed in triplicate.

2.2.8. Sensory analysis

Sensory evaluation of three types of financiers was conducted with untrained panellist to gain information on consumer acceptance of fish bone and scales flours as an alternative to wheat flour. 30 participants were recruited from CETT to perform the analysis. The test was conducted in individual sensory booths, random 3-digit codes were used to identify the samples and presented to the participants in a randomised order. Line scale was used for all ratings: external colour (brown intensity), colour uniformity, fishy flavour, graininess and sponginess. Eleven-point hedonic scale was used for the overall acceptance.

The acceptability index (AI) was calculated using the following equation: X/11*100, where X is the mean of the scores obtained for overall acceptance.

2.2.9. Statistical analysis

All data presented in this work are given as mean values ± standard deviation. Statistically significant differences between groups were analysed with one-way ANOVA test, followed by a post-hoc pairwise comparison using Tukey's test. The calculated p values were considered significant if $p \leq 0.05$. RStudio software (RStudio, Inc., USA) was used for statistical analysis and data processes.

3. Results

3.1. Chemical composition

Gelatine is obtained through thermal denaturalization of collagen that causes a destabilization of the triple helix of collagen (Alves et al., 2022). The result gives a mixture of peptides with different molecular weights, depending on the fractions of collagen content (α-chains, β-chains and γ-chains), which differ in molecular size (Boran and Regenstein, 2010). Its relative proportion will depend on the collagen source and production process (Alves et al., 2022). In fish scales, the collagen had low-molecular weight chains (α-chains and β-chains) (Muthumari et al., 2016). Protein quantification from demineralised scale fish gelatine (DSG) and non-demineralised gelatine (NDSG) showed a protein purity of 57.19 g/100 g and 43.37 g/100 g, respectively (Table 1). These differences could be attributed to the NaCl washing step performed on the demineralised scales for DSG extraction, which improved collagen extraction and yielded a purer gelatine, with less saline ions (Giménez et al., 2005). Compared with previous studies

Table 1
Chemical composition of products obtained and raw fish scales.

Products	Protein (g/100 g)	Fat (g/100g)	Carbohydrates (g/100 g)	Ash (g/100g)	Moisture (g/100g)
Fish bone flour (BF)	42.60 ± 9.89	0.85 ± 0.49	2.18 ± 0.01	49.01 ± 9.50	5.37 ± 0.09
Scales flour (SF)	34.74 ± 8.06	1.66 ± 0.95	28.03 ± 5.68	27.21 ± 5.27	8.36 ± 0.14
Demineralised scale fish gelatine (DSG)	57.19 ± 9.62	–	–	–	–
Non-demineralised gelatine (NDSG)	43.37 ± 8.59	–	–	–	–
Raw fish scales	33.74 ± 1.41	–	–	29.91 ± 0.40	–

reported by Maktoof et al. (2020), higher yields were obtained with the process reported in this study.

The nutritional compositions regarding the amount of protein was 42.60 g/100 g for fish bone flour (BF) and 34.74 g/100 g for fish scales flour (SF) (**Table 1**), in accordance with the values previously reported by Toppe et al. (2007). It is interesting to note that in the case of SF, the chemical analysis has been performed after gelatine extraction, even so 34.74 g/100g of protein were already extracted, which highlights the protein-rich content of fish scales. Fat content of BF and SF was low (0.85% and 1.66%, respectively), which agree with the low-medium fat composition in fishes like the ones used in this study (*Dicentrarchus labrax*) (Zhang et al., 2020). The main differences were observed in total carbohydrates, where SF contains about twenty times more carbohydrates than BF. Compared to wheat flour, which usually consists of 76.3% carbohydrates and 10.3% protein (Food Data Central - U.S. Department of Agriculture, 2019), SF would be slightly similar regarding carbohydrate content. However, protein amount in SF was three times higher than high-protein wheat flour, which could be useful to develop fortified food products or culinary elaborations with high amounts of protein. Total ash content ranged from 27.21% of SF to 49.01% of BF and 29.91% of raw fish scales (Table 1), in line with previous studies that report that fish scales are rich in calcium phosphate salts such as hydroxyapatite and calcium carbonate (Gomez-Guillen et al., 2011).

3.2. pH of fish bone and scale flours

The pH values of each flour were measured and the results obtained were pH 6.9 (all-purpose wheat flour), 7.6 (fish scale flour) and 7.2 (fish bone flour). The alkaline pH in both fish flours could be related to the hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) content, which accounts for 30–46% of scales' total weight (Shen et al., 2019; Liu et al., 2021).

3.3. Gelling and melting temperature of gelatines

The gelling temperature is defined as the temperature at which the process of gelation occurs. During this process, gelatine retains some of the collagen structures by recovering some cross-linkages (the greater the number of cross-linkages, the higher the gelling and melting temperatures) (Boran and Regenstein, 2010). The three gelatine solutions were initially heated to 45 °C and their gelling evolution was observed during the cooling time (Fig. 1). As shown in Table 2, control gelatine was completely jellified at 11.2 °C, while NDSG and DSG were still liquid and jellified at 10.1 and 8.5 °C, respectively. This effect is due because fish gelatines are less cross-linked and have less mechanical strength than mammal-origin gelatines (Coppola et al., 2020).

Regarding their melting temperature (Tm), the two scales-derived jellies showed lower Tm than the control, thus following the same tendency as the gelation process due to the formation of fewer cross-links

Table 2
Gelling temperature, melting temperature and hysteresis values of the three different gelatines. CG = pork gelatine, used as control, DSG = demineralised scales gelatine and NDSG = non-demineralised scales gelatine.

Gelatine	Gelling Temperature (°C)	Melting Temperature (°C)	Hysteresis (°C)
CG	11.2 ± 0.3	29.5 ± 0.7	11.2–29.5
DSC	8.5 ± 0.6	22.8 ± 0.4	8.5–22.8
NDSC	10.1 ± 0.1	23.5 ± 0.7	10.1–23.5

(Fig. 1) (Coppola et al., 2020). These results agree with previous studies, where lower Tm values reported for fish gelatines were around 17 °C for cold-water fishes, and 24–29 °C for warm-water fishes (compared to pork or bovine gelatines that show Tm values above 30 °C) (Gomez-Guillen et al., 2011).

Based on the results of gelling and melting temperatures, the hysteresis degree was measured (Table 2). Hysteresis is a very relevant property in gastronomy because it allows the handling of warm gels without melting if the temperature interval is wide. Comparing the results obtained from fish scales' gelatines with other gelling agents, the hysteresis range was low (Gomes et al., 2020), although it is similar to control pork gelatine.

3.4. Culinary applications

3.4.1. Puffed gelatine

Fig. 2 shows the manufacturing process of puffed gelatine made of DSG and NDSG, where a homogenous puffed gelatine was obtained with DSG. On the contrary, a heterogeneous puff was obtained with NDSG, due the lack of moisture uniformity in its structure, which is a consequence of its high minerals content (del Villar, 1994). This elaboration was not done with the CG because the puffed gelatine is the only elaboration requiring gelatine sheets.

3.4.2. Panna cotta

Panna cotta elaboration was selected to compare the gelling ability and stability of the obtained gelatines. Fig. 3 shows the three panna

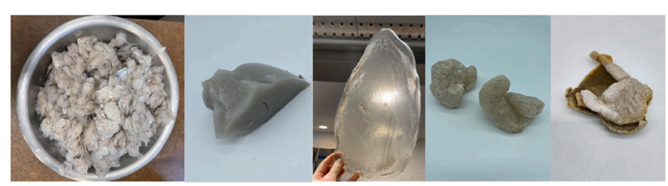

Fig. 2. Manufacturing process to obtain puffed gelatine. From left to right: fresh fish scales, DSG before dehydration, dehydrated DSG, puffed DSG and puffed NDSG.

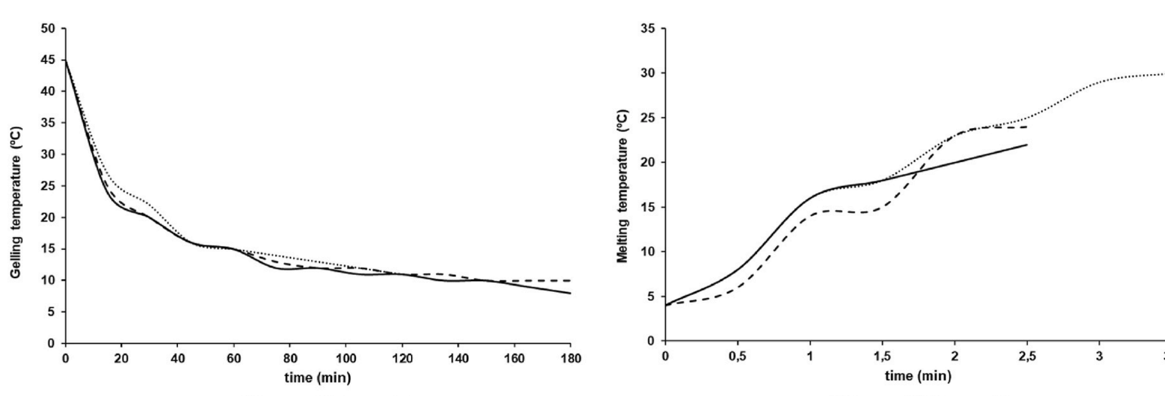

Fig. 1. Gelling and melting temperatures of demineralised scales gelatine (DSG), non-demineralised scales gelatine (NDSG) and pork gelatine used as control (CG).

Fig. 3. Demoulded panna cottas. From left to right: CG panna cotta, DSG panna cotta and NDSG panna cotta.

cottas made with significant differences among them. Panna cottas made of DSG and NDSG were smooth and creamy in mouth due to their lower melting temperature and they showed a weaker structure, which made them more difficult to removing them from the mould than the one made of CG. Regarding the aroma, panna cotta made of NDSG had a slightly fishy flavour, which was not present in the DSG product. This difference could be attributed to the demineralization process, which is known to decrease molecules causing this fishy odour (Huang et al., 2016). In addition, the DSG panna cotta had a higher release of lactic aromas than the CG panna cotta. These results agree with previous studies reported from Choi and co-workers, who observed that fish gelatines had a more desirable flavour and aroma release than gelatines with a higher melting point, such as pork gelatine (Choi and Regenstein, 2000).

3.4.3. Whipped gelatine

This elaboration was chosen to analyse the behaviour of each gelatine during the whipping and gelling processes. Whipped gelatine using CG generated a stiffer foam than the DSG and NDSG preparations (Fig. 4), due to its higher gelling temperature. Also, DSG and NDSG whipped gelatine melted faster in mouth, also due to this difference of melting point. In this application, the NDSG was also the only one that showed some fishy flavour.

3.5. Financiers characterization

3.5.1. Weight and height of financiers

CF financiers had higher weight loss than SF and BF products (Table 3), a result that could be attributed to a lower humidity absorption and, consequently, lower moisture content in the baked product. Thus, SF and BF financiers retained more water than CF financier. This effect could be due to the higher amount of protein of SF and BF, which was around 37 g/100g (Table 1), compared with regular wheat flour. These results agree with a previous study reported by Adeleke and Odedeji (2010), who showed that the protein content of fish flour caused a higher humidity in bread due to its high water-holding capacity. In addition, CF financiers had a higher increase in height than SF and BF products (Table 3). This may be due to the lack of carbon dioxide binding activity during raising in the SF and BF financiers. Starch, which is present in CF, is the responsible of gas binding that occurs during baking (Houben et al., 2012). In the case of SF and BF financiers, there is also an increase in height, albeit smaller than in the CF (Houben et al., 2012). Among SF and BF financiers, although the differences were subtle, BF had a lower weight loss and similar increased height, being moister and denser than the SF financier.

Fig. 4. Whipped gelatines. From left to right: CG whipped gelatine, DSG whipped gelatine and NDSG whipped gelatine.

Table 3
Characterization of financiers (weight and height). CF = control flour (regular wheat flour), SF = scale flour, BF = fish bone flour.

Type of flour	Before baking		After baking			
	Initial weight (g)	Initial height (mm)	Final weight (g)	Final height (mm)	Weight loss (%)	Increased height (%)
CF	14.0 ± 0.1^a	10.0 ± 0.1^a	10.7 ± 0.6^a	20.0 ± 0.8^a	23.9 ± 4.2^a	100.3 ± 8.2^a
SF	12.3 ± 0.6^a	10.0 ± 0.1^a	10.7 ± 0.6^a	15.0 ± 0.4^b	13.5 ± 4.5^b	50.4 ± 3.7^b
BF	12.7 ± 1.2^a	10.0 ± 0.1^a	11.7 ± 1.2^a	14.6 ± 0.7^b	7.9 ± 0.7^b	45.9 ± 7.4^b

a and *b* letters refer to significant difference ($p < 0.05$) between each flour and each measure.

3.5.2. Texture analysis of financiers

Significant differences in texture were observed in the financiers depending on the type of flour used (Table 4). The financier made of BF flour showed the lowest hardness, followed by SF, while the CF product exhibited the highest hardness. The hardness is associated with gluten development: a higher gluten content yields a higher hardness in the baked product (Fiszman et al., 2013). Also, these results could be related to the weight loss during baking (Table 3), which showed that CF financier had a higher weight loss than SF and BF financiers. These results agree with previous studies (Rahman and Al-Farsi, 2005), which reported that the hardness, chewiness, and resilience correlated inversely with the moisture content. Following the same tendency, using CF produced a chewier and gummier financier than using SF and BF. This could be associated with the gluten development and the consequent better network organization (Fiszman et al., 2013). In addition, the high carbohydrate (starch) content in CF can also cause a higher chewiness and gumminess compared with SF and BF (Table 1) (Carballo et al., 1995).

All financiers were significantly different between them across all measured parameters (Table 4) except adhesiveness and springiness. On the one hand, adhesiveness is defined as the negative force of the first compression, and it represents the energy necessary to remove the sample from the roof of the mouth after chewing (Kasapis, 2009). With regards to this property, SF and CF financiers were similar and significantly different to the BF financier. On the other hand, regarding springiness, SF and BF financiers showed a similar aerated structure as the CF financier (Liu et al., 2019). Finally, the highest cohesiveness was observed for the CF financier, a result that agrees with the findings of Houben et al. (2012) on gluten-free doughs being less cohesive than wheat flour doughs. In comparison, SF and BF financiers showed lower cohesiveness values and a crumblier texture (Fiszman et al., 2013).

3.6. Sensory analysis

Replacement of wheat flour by fish scale and fish bone flour had a

Table 4
Texture profile analysis (TPA) of the financiers made from the three different flours.

TPA parameter	Control flour (CF)	Scale flour (SF)	Fish bone flour (BF)
Hardness (g)	1101.2 ± 70.6^a	885.5 ± 71.9^b	534.6 ± 61.9^c
Adhesiveness (g·s)	−269.3 ± 12.6^b	−264.4 ± 48.8^b	−206.8 ± 32.5^a
Springiness (%)	0.74 ± 0.03^a	0.77 ± 0.05^a	0.78 ± 0.1^a
Cohesiveness	0.66 ± 0.01^a	0.60 ± 0.03^b	0.55 ± 0.02^c
Gumminess	731.2 ± 50.5^a	532.3 ± 36.4^b	291.2 ± 35.3^c
Chewiness (g)	539.4 ± 53.7^a	408.4 ± 54.7^b	229.7 ± 58.1^c
Resilience (%)	0.260 ± 0.01^a	0.21 ± 0.01^b	0.16 ± 0.01^c

a, *b* and *c* letters refer to significant difference ($p < 0.05$) between each flour and each TPA parameter.

significant effect on the overall acceptability of financiers (8.6, 6.9 and 4.2, respectively) (**Table 5**). Regarding the colour, significance differences were observed between the three samples, being the ones made of SF and BF of a darker brown (Fig. 5). This result could be related to the alkaline pH of these flours compared to wheat flour, as mentioned in section 3.2. As described by Ajandouz et al. (2008), a higher browning due to Maillard reaction is expected at higher pH (Ananda and Anggraeni, 2021). reported similar results replacing wheat flour by fish bone flour in cookies preparation. Otherwise, colour uniformity did not show significance differences between the three samples.

Regarding sponginess, consumers reported significant differences between SF and BF financiers compared with CF financiers. The higher sponginess in CF financier might be due to its capacity of retaining the air in its structure because of its higher starch content (Houben et al., 2012).

Concerning graininess, the CF financier showed the lowest value, which agrees with the cohesiveness results obtained in the TPA (Table 4). On the contrary, significant differences were observed between the BF and SF financiers, being SF the grainiest. This graininess could be attributed to the larger particle size in the SF product. Scales are harder than fish bones due to the higher hydroxyapatite content, which makes them more difficult to grind into a fine powder. Financiers made of SF showed better acceptability than BF-derived ones, and they present more graininess and sponginess. However, the use of BF led to a more pronounced fishy flavour perception in the product. Nevertheless, financiers made of SF showed an acceptability index of 63%, which is close to the minimum acceptability index necessary for a product (Lucas et al., 2018). In addition, panellists evaluated the overall acceptance of financier made from BF lower, especially due to the fishy flavour. Therefore, more research is needed to mask or even deodorize the flour. As highlighted previously, results on sensory analysis are preliminary and further studies using a larger group of panellists would be required.

Table 5
Sensory analysis of financiers made from the three different flours (n = 30).

Descriptor	Control flour	Scale flour	Fish bone flour
External colour (brown intensity)	4.2 ± 1.4^{c}	6.5 ± 1.6^{b}	7.6 ± 1.1^{a}
Colour uniformity	5.7 ± 1.9^{a}	6.3 ± 2.2^{a}	6.8 ± 2.2^{a}
Fishy flavour	0.8 ± 1.0^{c}	2.4 ± 2.0^{b}	7.0 ± 2.4^{a}
Graininess	2.0 ± 1.5^{c}	6.8 ± 1.9^{a}	4.5 ± 2.5^{b}
Sponginess	7.0 ± 1.9^{a}	4.9 ± 1.7^{b}	3.9 ± 2.5^{b}
Overall Acceptance	8.6 ± 1.2^{a}	6.9 ± 2.2^{b}	4.2 ± 2.3^{c}
Acceptability index (%)	78	63	38

a, *b* and *c* letters refer to significant difference ($p < 0.05$) between each flour and each descriptor.

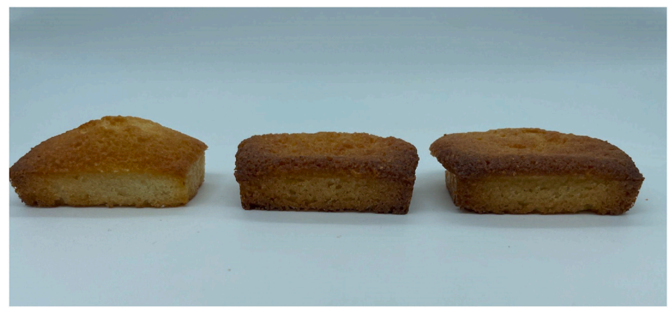

Fig. 5. Baked financiers. From left to the right: CF financier, SF financier, BF financier.

4. Conclusions

This study assessed four culinary elaborations made from fish waste; fish bones and fish scales. From these waste by-products, three distinct value-added ingredients were developed: fish scale flour, fish bone flour and fish scale gelatine, and their chemical composition was analysed. Protein quantification revealed a high protein concentration in these fish-derived flours, compared with regular wheat flour, which contributes to the texture of financier. Less spongy and harder financiers were related to higher amounts of water and their lower ability to retain the air inside the baked structure. However, financiers made of scale flour showed higher overall acceptance than those made of fish bone flour, due to the fishy flavour in the latter. Additionally, gelatine was isolated from fish scales using a demineralization process in order to obtain high-purity collagen and eliminate the fishy odour. We further showed that fish gelatine can be used as a substitute of pork gelatine, even though it has lower melting point and gelling temperatures. Nevertheless, fish gelatine provides as main advantages a smooth and creamy texture, as well as high flavour release of the elaboration. This research opens the door to new explorations on the extraction, valorisation, and culinary applications of functional ingredients derived from fish waste.

Implications for gastronomy

New value-added ingredients have been developed from fish by-products. On the one hand, fish bones and fish scale flours are developed and they are used to prepare financiers. On the other hand, two different culinary processes to extract gelatine from fish scale are described. The extracted gelatine is used as pork gelatine substitute in panna cota and whipped gelatine. In addition, its puffed ability is determined by frying it. The research reported in this article provides new culinary trends through the upcycling of fish by-products into protein-rich value-added ingredients in the food services industry. Furthermore, it opens the door to new explorations on the extraction, valorisation, and culinary applications of functional ingredients derived from fish discards.

Declaration of competing interest

None.

Data availability

No data was used for the research described in the article.

Acknowledgements

We thank Gran Blau for providing the fish ingredients. Dr. I. Aguiló-Aguayo thanks the National Programme for the Promotion of Talent and its Employability of the 'Ministerio de Economía, Industria y Competitividad' of the Spanish Government and the European Social Fund for her Postdoctoral Senior Grant 'Ramon y Cajal' (RYC-2016-2019 949)

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