CHEMICAL ENGINEERING TRANSACTIONS
VOL. 118, 2025

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Laura Piazza, Francesco Donsì, Giorgia Spigno, Paolo Ciambelli, Luca di Palma

ISBN 979-12-81206-19-9; **ISSN** 2283-9216

DOI: 10.3303/CET25118018

Valorisation of Atlantic bonito and Brassica By-Products in the Development of a Sustainable Pâté: Influence of Heat Treatment, Hydrocolloids and Brassica Concentration in a Factorial Design

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Fish is a highly nutritious food, rich in protein, unsaturated fats, vitamins, and minerals, and its consumption has increased due to the associated health benefits. However, fish processing generates substantial waste, accounting for more than 50% of the total weight of the fish, leading to economic losses. Utilising these by-products presents an opportunity to reduce waste while enhancing the nutritional profile of food products.
By-products from vegetable processing, like Brassica stalks and leaves, create economic and environmental issues, transforming them into flour provides a nutritious, fibre-rich, antioxidant source for food enrichment. The aim of this work was to develop a pâté formulation incorporating Atlantic bonito and Brassica byproducts. A 3-factor, 2-level, 3^2 factorial design was employed to assess the influence of key factors on the pâté's physicochemical, texture, and sensory properties. The factors evaluated included the concentrations of hydrocolloid (sodium alginate) at 0.5 and 1 % (w/w), Brassica at 1 and 2 % (w/w), and heat treatment temperature at 105 °C and 115 °C. There were significant differences between the different heat treatment temperatures and concentrations of brassica and hydrocolloid in texture, colour, pH, aw, moisture and ash. Sensory analysis identified the formulation containing 2 % Brassica and 1 % hydrocolloid, heat-treated at 115 °C, as having the most desirable characteristics, typical of a high-quality pâté. This study demonstrates the potential for utilizing fish and vegetable by-products to create a nutritionally enriched, sustainable food product.

1. Introduction

Fish is a globally consumed nutrient-rich food, although it is a highly perishable product that, if not handled and stored properly, can become unsafe for consumption due to microbial growth and biochemical alterations, including enzymatic and chemical degradation (Siddiqui et al., 2024). In recent years, the consumption of fish products has significantly increased due to their recognition as an essential part of a balanced diet and a healthy lifestyle. The circular bioeconomy, as a crucial aspect of the circular economy, plays a role in ensuring both resource sustainability and environmental preservation (Coppola et al., 2021). The fish processing results in the production of significant quantities of waste, the extent of waste production depends largely on the specific processing methods used, such as gutting, scaling and filleting (Arnaud et al., 2018). These processing activities lead to the accumulation of different by-products and discards, which mainly consist of muscle trimmings, skin and fins, bones, heads, viscera and scales. The efficient utilisation or management of these by-products is crucial to improving the sustainability of the seafood industry (Martínez et al., 2018). The Atlantic bonito (*Sarda sarda*) is a species of marine fish from the Scombridae family, commonly found along the coasts of the Atlantic

Paper Received: 7 May 2025; Revised: 6 July 2025; Accepted: 14 September 2025
Please cite this article as: Solinho J., Machado S., Pereira-Pinto R., Barros D., Vaz-Velho M., Vazquez M., Pinheiro R., 2025, Valorisation of Atlantic bonito and Brassica By-Products in the Development of a Sustainable Pâté: Influence of Heat Treatment, Hydrocolloids and Brassica Concentration in a Factorial Design, Chemical Engineering Transactions, 118, 103-108 DOI:10.3303/CET25118018

Ocean, the Mediterranean and the Black Sea. Compared to other common commercial species, it stands out for its beneficial aspects, such as its composition rich in lipid nutrients, proteins, high yield and characteristic flavour (Altan et al., 2022).
Cabbage (*Brassica oleracea var. acephala*) has dark green, curled leaves rich in sugars (fructose, glucose, sucrose), organic acids (malic, citric), and essential fatty acids (linoleic, α-linolenic). It contains amino acids like cysteine, histidine, methionine, and tryptophan, with glutamic and aspartic acids being most common. Its mineral content includes calcium, potassium, iron, zinc, and manganese, along with β-carotene, lutein, selenium, vitamin K1, folic acid, and ascorbate (Heimler et al., 2006; Vallejo et al., 2004). This cabbage is characterized by short, thick stems with wide leaves and veins. In agricultural terms, this cabbage gives high yields, is not very susceptible to pests and diseases, is well adapted to a wide variety of climatic situations (Ferreres et al., 2005). In addition to fish valorisation, Brassica by-products, like stalks and leaves, enhance food nutrition while reducing waste, promoting sustainability in food processing (Duarte et al., 2019)).
Pâté is a product with a gastronomic tradition and sensory characteristics that are much appreciated by the population and can be produced from different ingredients (Echarte et al., 2004).
Alginate, due to its biodegradable nature, gel-forming properties, encapsulation efficiency and availability, is extensively used in the food packaging industry, among others such as the pharmaceutical industry (Bilal & Iqbal, 2020; Carina et al., 2021).
Given the nutritional and functional benefits of both fish and Brassica by-products, this study aimed to develop a pâté formulation incorporating these ingredients and to evaluate the impact of heat treatment, hydrocolloid (sodium alginate), and Brassica concentration on its physicochemical, texture, colour and sensory properties.

2. Methodology

2.1 Raw materials

The raw materials used for the pâté formulation included surplus Atlantic bonito provided by Guimarpeixe (Commerce of Food Products), sodium alginate from Sosa Ingredients S.L. (Europe), and various seasonings such as garlic, onion, olive oil, pepper paste, salt, and black pepper obtained from a local market branch of Continente supermarket. Additionally, Brassica byproducts were supplied by UPN (Union of Horticultural Products of the North).

2.2 Experimental design

Table 1 presents the various pâté formulations created based on the factorial experimental design, which includes 3 factors at 2 levels (3^2 design). The factors are Brassica concentration, hydrocolloid concentration, and heat treatment temperature. The levels for each factor are as follows: Brassica concentrations of 1 % and 2 %, sodium alginate concentrations of 0.5 % and 1 %, and heat treatment temperatures of 105 °C and 115 °C. In total, 10 formulations were studied.

Table 1 – Factors and levels used in the experimental design for each assay performed using experimental design array in pate formulation.

Run	Temperature (ºC)	Brassica (% w/w)	Sodium alginate (% w/w)
1	1	1	1
2	1	2	1
3	1	1	2
4	1	2	2
5	2	1	1
6	2	2	1
7	2	1	2
8	2	2	2
9	1	0	0
10	2	0	0
Level	**Temperature (ºC)**	**Brassica (% w/w)**	**Sodium alginate (% w/w)**
1	105	1	0.5
2	115	2	1

2.3 Process production

The experimental pâté was formulated using fish byproducts, onion, olive oil, pepper paste, garlic, salt, and black pepper. The fish was cooked at 75 °C for 25 min, then ground using a blade mill (Retsch GRINDOMIX GM 200, Germany), colloid mill (Lab Colloid Mill, Shakti Pharmatech, India), and food processor (Termomix TM31, Vorwerk, Germany). Onion and garlic were cooked in olive oil at 100 °C for 2 min, followed by pepper paste, black pepper, and salt for 5 min. The minced fish paste was then added and ground for 15 sec at 10 rpm. The mixture was divided to incorporate brassica (1 and 2 %) and sodium alginate (0.5 and 1 %), then packed in glass containers and heat-treated at 105 and 115 °C for 10 min in an autoclave (Autoclave Trade Raypa, Spain).

2.4 Physicochemical analysis

For water activity determination a Novasina, AW Lab Set H were used. The pH values were measured using a pH meter (pH 25+, Crison, Spain). The moisture content was determined according to the AOAC method 925.10:1995 and ash content with AOAC method 938.08:1995. Protein was determined using AOAC method 955:04:1995 by the Kjeldahl method.

2.5 Texture and colour analysis

Texture properties firmness and adhesiveness were measured using the TA-XT2i Texture Analyser (Stable Micro Systems Ltd, United Kingdom). Pâtés were subjected to deformation using a stainless-steel cylindrical probe (P/10). The probe punched into the sample with a constant crosshead test velocity of 0.5 mm/s and a test distance of 8 mm. Six replicates were performed for each formulation, using different areas of the sample.
The colour of the samples was assessed using a Minolta CR300 (Konica Minolta, Japan) with the colour system CIE L*, a*, b*. Lightness (L *), redness to greenness (+a* to -a*) and yellowness to blueness (+b* to -b*). Fifteen replicates were performed, using different areas of the sample.

2.6 Sensory analysis

For sensory analysis, a quantitative descriptive analysis (QDA®) was carried out with seven semi-trained panellists, according to ISO 6658:2017. The attributes evaluated by the panellists were: fish odour, brassica odour, off odour, unctuousness, homogeneity, spreadability, fish flavour, brassica flavour, off flavour. These attributes were evaluated on an intensity scale of 10 points (1 - lowest intensity, 10 - higher intensity). In addition, the samples were classified in terms of general taste (1 to 5 points: 1 - very bad, 5 - excellent).

2.7 Statistical Analysis

Results were submitted to an analysis of variance (ANOVA), followed by a post-hoc Tukey test. Statistically significant differences were set at $p < 0.05$. Data mining was performed to investigate patterns using principal component analysis (PCA) with sensory analysis data. These statistical approaches were carried out using TIBCO® Statistica®, v.14.0.0, TIBCO Software Inc, Palo Alto, CA, USA.

3. Results and discussion

Table 2 shows the results of the physicochemical characterisation of the different formulations of Atlantic bonito pâté.

Table 2 - Results of the chemical characterisation (protein, moisture, ash, pH and aw) of the pâté (average ± standard deviation).

Formulations	Protein (%, w/w)	Moisture (%, w/w)	Ash (%, w/w)	pH	a_w
R1	15.40 ±0.68	66.41 ±0.21	3.47 ±0.03	6.29±0.02	0.958
R2	16.99 ±0.39	66.21 ±0.12	3.43 ±0.00	6.27±0.00	0.958
R3	16.12 ±0.04	66.33 ±0.31	3.42 ±0.01	6.29±0.02	0.957
R4	16.72±0.24	65.94 ±0.47	3.41 ±0.02	6.25±0.01	0.958
R5	16.62 ±0.09	66.28 ±0.27	3.36 ±0.04	6.25±0.01	0.960
R6	16.25 ±0.15	66.11 ±0.90	3.34 ±0.01	6.21±0.01	0.953
R7	15.82 ±0.13	65.91 ±0.48	3.45 ±0.01	6.21±0.01	0.951
R8	16.09±0.47	64.65 ±0.45	3.44 ±0.02	6.27±0.01	0.958
R9	16.04 ±0.14	67.58 ±0.31	3.16 ±0.07	6.33±0.01	0.961
R10	15.57 ±0.26	67.26 ±0.50	3.19 ±0.05	6.36±0.01	0.963

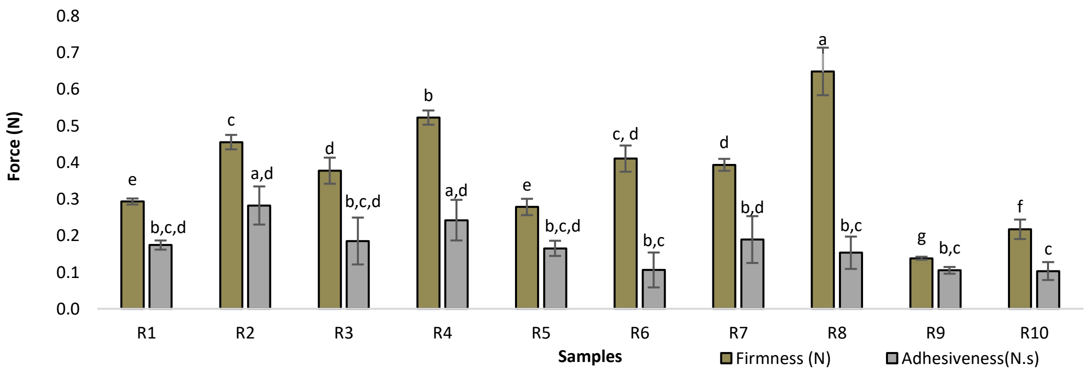
The protein content of the pâté was 16.11 %. Similar results, 14.13 %, were obtained by (Aquerreta et al., 2002), in the preparation of pâtés with mackerel (*Scomber scombrus*) and tuna liver (*Thunnus thynnus*). The results for moisture content showed a value of 66.30 %, the same value obtained by (Nielsen et al., 2020), in the production of salmon pâté with a reduced sodium content. According to the factorial analysis, it’s possible to verify that temperature, sodium alginate and brassica have a significant influence. However, the higher the concentration of brassica and hydrocolloid, the lower the moisture. Higher concentrations of Brassica and hydrocolloid resulted in lower moisture content, likely due to the water-binding properties of these ingredients, which reduce free water availability. The

Regarding the ash content, a value of 3.42 % was obtained, with similar values being obtained in the composition of commercialised fish pâté, which is made up of anchovies according to (Aquerreta et al., 2002). The factorial analysis carried out showed that temperature, sodium alginate and brassica had a significant influence.

The pH showed a value of 6.27 %, similar results were obtained by (Mancera-Rodriguez et al., 2022), for white pirapitinga (*Piaractus brachypomus*) pâté. The pH values remained within the typical range for fish pâté, with higher temperatures (115 °C) leading to slightly lower pH values, possibly due to protein denaturation and Maillard reaction by-products.

Concerning water activity (aw), an average value of 0.96 was obtained for all the formulations, which is typical for this food. The same value was obtained by (Mancera-Rodriguez et al., 2022), for white pirapitinga (*Piaractus brachypomus*) pâté. The factorial analysis revealed that temperature, sodium alginate, and Brassica concentration significantly influenced moisture, pH, water activity (aw), and ash content ($p < 0.05$). Finally, the factor analysis was carried out, identifying the parameters that had an influence on the final product, and in this case temperature and sodium alginate had an influence. The most important temperature was 115 ºC, where values differed between the different formulations.Given the known nutritional profile of Brassica spp. and Atlantic bonito by-products, the developed pâté is likely to be rich in proteins, dietary fibre, and natural antioxidants, which can enhance its functional value. Future studies should quantify these nutritional components in detail to support potential health claims.

Figure 1 - Results of the texture characterization (firmness and adhesiveness) of the pâté (average ± standard deviation). Means within the same column with different superscripts are significantly different at p < 0.05.



The texture profile analysis (Figure 1) showed that formulations containing higher sodium alginate and Brassica concentrations processed at 115 °C exhibited greater firmness ($p < 0.05$). This is attributed to sodium alginate's gelling properties, which contribute to structural stability, and the heat-induced protein coagulation effect. The sample with the highest firmness values was R8. Adhesiveness varied across formulations, with temperature being the most influential factor, suggesting that increased thermal processing affected protein interactions and moisture retention.

Table 3 - Results of the colour characterization (L, a and b*) of the pâté (average ± standard deviation).*

Formulations	L*	a*	b*
R1	49.70± 0.42	3.41± 0.24	20.22± 0.49
R2	49.77± 0.57	2.84± 0.21	20.23± 0.45
R3	50.03± 0.39	3.34± 0.12	20.44± 0.31
R4	48.94± 0.58	2.66± 0.23	19.79± 0.26
R5	49.88± 0.32	3.16± 0.21	20.34± 0.20
R6	49.19± 0.25	2.90± 0.32	20.18± 0.31
R7	49.38± 0.22	3.37± 0.10	20.33± 0.16
R8	49.00± 0.33	2.90± 0.23	20.04± 0.18
R9	50.76± 0.45	3.87± 0.13	20.79± 0.39

Table 3 shows the values obtained for the parameters analysed in the colour assessment. The L parameter, which ranges from 0 (darker) to 100 (lighter), exhibits slight variations among the formulations, with values between 48 and 50, indicating a tendency toward a lighter appearance. The a* parameter shows minor differences, particularly in R2 and R4, which have lower values than the other formulations. In contrast, the remaining formulations exhibit no significant variation in a* values. The b* parameter remains consistent across

all formulations. The statistics show that the brassica has an influence on the a* parameter, since this parameter refers to the red and green colour and, once brassica has been added to the pâté, it has a greenish colour.
In conclusion, colour analysis revealed that Brassica significantly influenced the a* parameter (red-green balance), as samples with higher Brassica content exhibited a greener hue, consistent with the presence of chlorophyll pigments. The L* (lightness) and b* (yellow-blue) values remained relatively stable, with minor variations attributed to differences in formulation composition and thermal processing.
Regarding the sensory analysis, a quantitative descriptive analysis (QDA®) was carried out with a panellist of semi-trained tasters to classify several attributes, namely fish odour, cabbage odour, off-odour, unctuousness, homogeneity, spreadability, fish flavour, brassica flavour and off-flavour.

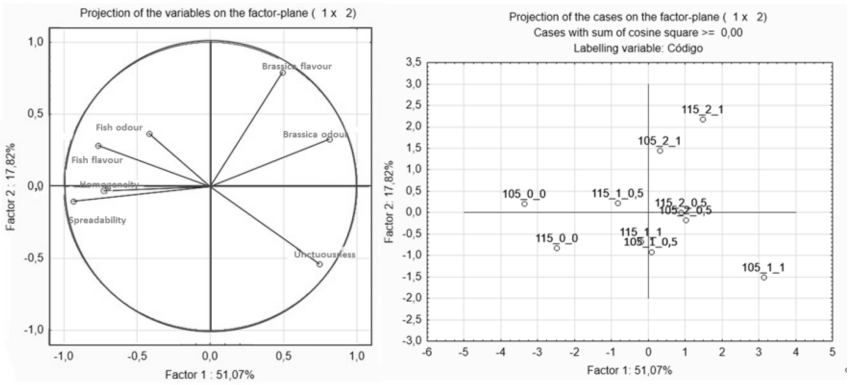


Figure 2 - Results of the statistical analysis carried out on the values obtained for the sensory analysis of the pâté (heat treatment temperature and concentration of brassica and sodium alginate).

Figure 2 presents the Principal Component Analysis (PCA) was employed to explore the relationships among sensory attributes, processing temperatures, and ingredient concentrations, PC1 (Factor 1) and PC2 (Factor 2) collectively accounted for approximately 69% of the total variance, effectively summarizing the majority of the dataset's informational content.
Samples R8 and R4 clustered closely due to their pronounced brassica flavour profiles. In contrast, samples R9 and R10 were positioned nearer to each other, reflecting their identical formulations, which excluded both brassica and sodium alginate. These omissions resulted in comparable levels of spreadability and homogeneity. Sample R3 distinguished itself with notably higher unctuousness compared to the other formulations.
The remaining samples are relatively close, exhibited similar sensory profiles, despite differences in brassica and sodium alginate concentrations, differing only in the temperatures they were subjected to.
The formulations R1, R2, R3, R5, R6 and R7 have similar values, with the score for general appearance being 4 points. Formulation R4 differs from the other formulations by the fact that its score is 3 points.
The R8 formulation obtained the highest score, with the characteristics "fish odour" prevailing, with a score of 6, "fish flavour", with a score of 8, "unctuousness", with a score of 6, "spreadability" and "homogeneity", with a score of 7, "odour" and "brassica flavour" scored 4, obtaining the maximum classification in the global appreciation, with a score of 5. The remaining attributes scored 1, as they referred to unfavourable attributes, i.e. off-odour and off-flavour.
Sensory evaluation showed that ‘’fish flavour’’ was the most appreciated and positively attribute, with sample R8, containing 2% Brassica, 1% sodium alginate and processed at 115 °C, achieved the highest overall score. This formulation was characterized by superior texture qualities, namely enhanced spreadability, homogeneity, and unctuousness, which are critical to consumer acceptance in pâté products.
The PCA analysis further confirmed that R8 clustered closely with formulations demonstrating that optimal texture and sensory appeal. In contrast, formulations with reduced levels of hydrocolloids or Brassica concentrations deviated from this cluster, largely due to the differences in texture and flavour intensity.
These results align with findings from similar studies on fish-based pâtés, indicating that optimizing hydrocolloid and vegetable by-product content enhances both sensory appeal and texture stability (Aquerreta et al., 2002).

4. Conclusions

This study demonstrates the potential of Atlantic bonito and Brassica by-products as valuable ingredients in the development of a sustainable and nutritious pâté. The factorial design analysis revealed that temperature, hydrocolloid, and Brassica concentration significantly influenced the physicochemical, texture, and sensory

attributes of the product. The formulation containing 2 % Brassica, 1 % sodium alginate, and processed at 115 °C (R8) exhibited the most favourable characteristics, making it a promising candidate for commercialization.
By incorporating fish and vegetable by-products into processed foods, this approach supports waste valorisation, circular economy principles, and improved food sustainability, offering an innovative strategy for the food industry. Further research could explore the shelf-life stability and consumer acceptance of such products under commercial storage conditions. While this study comprehensively evaluates the physicochemical and sensory properties of the formulations, aspects such as shelf life, microbiological safety, and long-term consumer acceptance remain to be studied. These are critical for commercial viability and will be the focus of future investigations. This type of product also offers strong marketing potential, aligning with consumer demand for clean-label, sustainable, and health-conscious food products.

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