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THE USE OF TUNA BY-PRODUCTS IN CROISSANTS: INNOVATION, TECHNOLOGY, AND BENEFITS

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Abstract

Fish by-products have low economic value but present potential for use in increasing added value, reducing losses, and mitigating global food waste. The present study aims to develop innovative products that utilize tuna by-products by integrating them into human consumption. Thus, two types of butter croissants with tuna by-product fillings were created. The croissants were developed at the University of Agronomic Sciences and Veterinary Medicine of Bucharest in the Pilot Bakery Station. After creating the recipes and production technologies for the croissants containing fish by-products, consumer acceptance was assessed through sensory analysis tests. The evaluation criteria included taste, aroma, colour, overall appearance, and texture. The results showed that the created and tested products are suitable for large-scale consumption. The study`s findings demonstrated that the innovative products developed represent an effective alternative for valorising fish by-products.

Key words*: Blue transformation, consumer, fish, innovative product, nutritional value, sustainability.*

INTRODUCTION

The food industry generates a large amount of by-products which, when properly utilized, can become a sustainable source of raw materials. The valorisation of secondary products requires a new set of green technologies. For example, aquaculture, one of the fastest-growing sectors, uses only 30% to 40% of the fish for food, while the remaining 60% to 70% is considered a by-product (Fadda el al., 2024).

In 2022, global fisheries and aquaculture production reached a record 223.2 million tons, highlighting the essential role of aquatic foods in food security and the economy. Aquaculture has become the primary source of aquatic animals, surpassing capture fisheries for the first time, with a 51% share. Approximately 61.8 million people work in this sector, most of them in small-scale operations. International trade in aquatic products reached USD 195 billion, marking a 19% increase compared to the pre-pandemic period. Although capture fisheries production remains stable, only 62.3% of marine stocks are exploited sustainably. By 2032, aquatic animal production could increase by 10%, and per capita consumption could reach 21.3 kg (FAO, 2024).

Recently, the aquaculture sector has shown increasing interest in utilizing by-products from fisheries and aquaculture as valuable alternative raw materials (Newton et al., 2023).

Blue Transformation is a strategy that leverages existing knowledge and technologies to make aquatic food systems (both marine and freshwater) more sustainable, contributing to food security and nutrition. It aims to protect ecosystems, ensure the fair distribution of resources, and support adaptation to climate change. Transforming aquatic food systems requires a holistic and adaptive approach, focusing on socially, economically, and environmentally sustainable value chains. This process supports livelihoods, equitable benefit distribution, and the conservation of biodiversity and ecosystems. In a global context marked by food insecurity, climate change, and increasing food demand, Blue Transformation helps address these challenges by:

- Ensuring a sufficient supply of aquatic foods in a sustainable and equitable manner;
- Increasing access to safe and nutritious food, especially for vulnerable populations;
- Improving living conditions and incomes for communities involved in the sector;
- Enhancing the resilience of aquatic food systems to climate change and other dynamic factors (FAO, 2022).

FAO promotes the "Blue Transformation Roadmap" initiative for the sustainable development of the sector, with a particular focus on small-scale fisheries, which account for 40% of global catches and provide livelihoods for 500 million people. Effective policies and responsible investments are essential to protect aquatic resources and ensure a sustainable future (FAO, 2024).

The efficient utilization of fish by-products is a long-term strategy, considering the increasingly limited resources, high pollution levels, and the need to enhance economic profitability by exploiting unconventional raw materials (Toma (Enache) et al., 2023).

The fishing and aquaculture industry generates a large amount of by-products during processing and preservation operations, especially from tuna (Elhiss et al., 2024). Tuna, a migratory marine fish, is renowned for its high protein content (Thierry et al., 2021). The high nutritional value of tuna meat is due to its content of vitamins, minerals, and amino acids that meet human nutritional needs (Sasidharan et al., 2023). Consequently, there is significant interest in developing innovative methods to transform these by-products into value-added products (Xue et al., 2025).

The consumption of Atlantic bluefin tuna *Thunnus thynnus* (Linnaeus, 1758) provides multiple health benefits due to its rich content of essential nutrients. Atlantic bluefin tuna is an important source of omega-3 fatty acids, high-quality proteins, vitamins (such as vitamin D and the B-complex vitamins), and minerals (including selenium and iodine). The omega-3 fatty acids present in Atlantic bluefin tuna help reduce inflammation, promote cardiovascular health, and support cognitive function. High-quality proteins are essential for tissue repair and growth, while vitamins and minerals play crucial roles in various metabolic processes. Vitamin D plays a key role in calcium absorption, contributing to bone and dental health. It also supports immune system function and helps regulate mood, having a positive effect on depression prevention. The B-complex vitamins (B1, B2, B3, B6, B12) are essential for energy metabolism, the proper functioning of the nervous system, and red blood cell production. Vitamin B12, in particular, helps prevent anaemia and supports brain health. Selenium is a powerful antioxidant that protects cells from oxidative stress, contributes to proper thyroid function, and strengthens the immune system. Iodine is essential for the production of thyroid hormones, which regulate metabolism and support growth and nervous system development. Phosphorus helps maintain bone and dental health and plays an important role in DNA structure and cell membrane integrity. Magnesium contributes to muscle relaxation, blood pressure regulation, and the proper functioning of the nervous system (Chamorro et al., 2024).

As a result, in the context of leveraging the benefits of tuna meat, especially its by-products, we must be inventive in adding value through new products and reducing food waste. Innovation is the foundation of the food and beverage industry, enabling increased production to feed a growing population. However, investments in innovation in this sector have declined in recent years. For example, global launches of innovative food and beverage products accounted for 26% in the first five months of 2023, compared to 33% in 2019.

This decline can be attributed to several factors, including economic instability, which makes investors more reluctant to finance unvalidated products, and industry consolidation, which reduces competition and, consequently, incentives for innovation. Additionally, the emergence of artificial intelligence and e-commerce has lowered entry barriers for entering physical retail (RO.aliment, 2024).

MATERIALS AND METHODS

This paper represents an initiative to create and develop butter croissants filled with tuna by-

products, which were developed at the Bakery Pilot Station of the Faculty of Animal Productions Engineering and Management, University of Agronomic Sciences and Veterinary Medicine of Bucharest.

Croissants are food products made by incorporating a layer of butter or margarine into leavened dough, followed by successive folding to create a layered structure. In this structure, thin layers of fat and dough alternate, giving the final product its characteristic flaky texture (Grujic et al., 2008).

The proposed and developed products are represented by butter croissants filled with tuna and cheese cream (P1) and butter croissants filled with tuna and butter (P2).

These croissants differ from similar existing food products in that they contain tuna by-products in the filling composition, and the filling undergoes thermal treatment during the croissant baking process.

Ingredients used in the process of making butter croissants filled with tuna by-products

It is well known that in the food industry, the quality of products is directly influenced by the ingredients used. Careful selection of these ingredients not only determines the taste and texture of the final product but also impacts its appearance, shelf life, and nutritional value.

The animal-derived ingredients used in the production of butter croissants with tuna by-product filling contribute to their innovative character. These ingredients were: tuna (in the form of by-products obtained from processing tuna into steaks), butter, and cheese cream.

Tuna meat is valued for its high content of high-quality proteins, essential omega-3 fatty acids, and essential minerals, making it a valuable component in innovative bakery products. The nutritional composition of tuna meat per 100 g is characterized by an energy value of 350 kJ (82 kcal), a low fat content (0.11 g), of which 0.03 g are saturated fatty acids, and a carbohydrate content of less than 1 g, including negligible amounts of sugars (less than 1 g). Additionally, it provides a significant protein contribution of 19.9 g and a salt content of 1 g, both per 100 g tuna meat.

Butter gives the product a tender texture and rich flavour according with content of fats and specific aromatic compounds. The nutritional composition of butter, per 100 g of product, is characterized by an energy value of 3123 kJ (760 kcal), a fat content of 84 g, of which 60 g are saturated fatty acids, and the absence of carbohydrates and sugars (0 g). Additionally, butter contains 0.7 g of protein and 0.05 g of salt, both per 100 g butter.

Cheese cream provides smoothness and creaminess to the filling, enhancing both the consistency and flavour balance of the croissant. The nutritional composition of cheese cream, per 100 g of product, includes an energy value of 932 kJ (225 kcal), a fat content of 21 g, of which 14 g are saturated fatty acids. Also, it contains 4.3 g of carbohydrates, all in the form of sugars, 0.5 g of fiber, 5.4 g of protein, and 0.8 g of salt.

The combination of ingredients has been very important in creating innovative croissants, providing harmonization of taste, flavour, texture and increased nutritional value.

The composition of sample P1 is the result of a rigorous ingredient selection process and an optimized technological process designed to ensure a perfect balance between flavour, texture, and nutritional value. By carefully combining the fundamental components: flour (28.08%), butter (21.33%), grilled tuna (16.66%), cheese cream (15%), and water (12.92%), a product with a distinct organoleptic profile is obtained, where the finesse of the leavened dough harmoniously blends with the richness of the filling. Each ingredient plays a key role in defining the final characteristics of the product. Flour provides the dough structure, while high-quality butter ensures the characteristic tenderness of traditional croissants. The grilled tuna adds a deep umami note, complemented by the delicate creaminess of the cheese, which balances the taste and enriches the texture of the filling. Water, as a hydration element, contributes to gluten formation, influencing the dough's elasticity and stability. To achieve a refined taste and a well-defined aromatic profile, precise amounts of sugar (3.37%), salt (0.67%), and powdered milk (0.56%) are used, each significantly impacting the sensory perception. Sugar not only adds a subtle sweetness but also contributes to surface caramelization during baking, giving the croissants an appetizing

appearance and a golden crust. Salt, in addition to balancing the taste, enhances the natural flavours of the ingredients, while powdered milk improves texture and helps achieve a delicate and well-balanced aroma.

An important aspect of the manufacturing process is the dough proofing, ensured by the use of dry yeast (1.41%). This plays a crucial role in developing the airy and fluffy structure of the croissants, giving them volume and a light yet delicate texture. Controlled fermentation also contributes to the development of a complex aromatic profile, enhancing buttery notes and providing a pleasant aftertaste. Through a balanced combination of ingredients and adherence to strict technical parameters, the butter croissants filled with tuna and cheese cream achieve a high level of refinement. Each component plays a well-defined role in creating a sophisticated final product, where flavour and texture complement each other, delivering an exceptional gastronomic experience.

The composition of sample P2 is carefully crafted with the aim of achieving a balance between flavour, texture, and nutritional value. Each ingredient is carefully selected and proportioned to contribute to the refinement and complexity of the final product, transforming the simple act of tasting into an exceptional culinary experience. The essential components: represented by butter (29.66%), flour (28.08%), grilled tuna (23.33%), and water (12.92%), play a fundamental role in defining the organoleptic and nutritional profile of the croissants. Butter, with its high fat content, not only adds delicate tenderness and intense flavour but also contributes to creating a layered structure characteristic of fine pastry products. Flour, as a structural element, ensures the stability of the dough while providing the necessary elasticity to form the airy layers. The grilled tuna, with its juicy texture and intense flavour, enriches the filling, creating a harmonious contrast between the marine flavour and the creaminess of the butter. Water, essential in the hydration process, contributes to gluten development and ensures optimal consistency. To perfect the flavour balance, the composition is completed with sugar (3.37%), salt (0.67%), and powdered milk (0.56%). Sugar not only adds a subtle sweet note but also plays an important technological role, participating in the caramelization of the crust and enhancing the butter's flavour during baking. Salt, although used in small amounts, is crucial for highlighting the natural flavours and balancing the overall taste. Powdered milk, with its protein and lactose content, contributes to the dough's texture, adding a subtle smoothness and extra creaminess.

An essential element in the manufacturing process is the dry yeast (1.41%), which ensures the dough's leavening and the development of an airy structure, crucial for the flaky and light texture of the croissants. Controlled fermentation not only provides volume and flexibility to the dough but also contributes to the formation of a complex aromatic profile, subtly highlighting the butter and filling notes. Through this carefully balanced combination of ingredients, the butter croissants filled with tuna and butter become a sophisticated pastry product, where each component contributes to defining a unique tasting experience. The manufacturing process, combining technological expertise with a rigorous selection of raw materials, transforms this product into an expression of gastronomic excellence, where flavour, texture, and nutritional value harmoniously complement each other.

Obtaining grilled tuna meat from tuna by-products

The production of butter croissants filled with tuna required the development of an innovative raw material: grilled tuna meat obtained from tuna by-products. The technological process for obtaining this involves the careful processing of by-products resulting from the transformation of tuna into steaks. The main stages include the reception and qualitative inspection of the raw material, mechanical cleaning and washing to remove impurities, mechanical extraction of the meat, chopping and homogenizing, followed by thermal treatment at 180°C for dehydration and the improvement of sensory characteristics. After baking, the meat is rapidly cooled, hygienically packaged, and stored under controlled conditions. This technological process ensures a high-quality ingredient with optimized nutritional value and microbiological stability,

intended for use in innovative pastry products (Toma (Enache) et al., 2024).

The production of fillings for butter croissants with tuna by-products

To produce butter croissants filled with tuna by-products, fillings were created to highlight the fish by-products and to withstand thermal treatment during the baking process of the croissants.

For the preparation of the filling for sample P1, the grilled tuna, cheese cream, and high-quality butter were subjected to a careful mixing process until they formed a fine and homogeneous paste, in which each component was perfectly integrated, contributing to a uniform taste and delicate texture. After the filling was obtained, it was gradually cooled to reach an optimal refrigeration temperature, a process that allowed the preservation of the organoleptic and nutritional properties of the ingredients. The resulting filling was stored in a controlled environment, at the recommended refrigeration temperature, to prevent any deterioration or bacterial proliferation, and kept in optimal conditions until use. This step is essential to ensure consistent quality and to maintain the freshness of the filling.

To obtain the filling for sample P2, the grilled tuna and high-quality butter were carefully mixed and processed through kneading until they were transformed into a fine, perfectly homogenized paste. After obtaining the desired composition, the filling was allowed to cool to refrigeration temperature and stored under refrigeration conditions until use, just like P1.

Consumer acceptance

The sensory evaluation of butter croissants filled with tuna by-products (P1 and P2) aimed to determine the sensory effect of integrating these ingredients on consumer perception. The study sought to highlight to what extent the inclusion of tuna by-products influences the product's acceptability and its market potential.

For the analysis of sensory properties, several criteria were evaluated, represented by:

- Exterior appearance (Criteria 1) – Refers to the general visual characteristics of the entire product. It includes the evaluation of surface uniformity, the presence of any cracks or deformities, the level of browning, and the overall attractiveness of the product before consumption;
- Sectional appearance (Criteria 2) – Refers to how the product looks inside when cut or bitten into. It involves analysing the distribution of the filling, the layering of the dough, the porosity, and the internal structure of the croissant;
- Shape (Criteria 3) – Refers to the overall proportion and integrity of the product. This includes maintaining the characteristic shape of the croissant, symmetry and the absence of modelling defects;
- Colour (Criteria 4) – The colour evaluation is performed both on the outside and inside, focusing on the uniformity of the shade, the degree of baking, and any potential areas with discoloration or unattractive spots;
- Taste (Criteria 5) – Represents the overall taste characteristics perceived during chewing and afterward. The balance of flavours, taste persistence, and the compatibility of the ingredients used in the recipe are analysed;
- Smell (Criteria 6) – Refers to the olfactory perception of the product, determined by the characteristics of the volatile compounds. The intensity and pleasantness of the smell are evaluated both before and during consumption;
- Texture (Criteria 7) – Analysed both on the outside and inside. The crust's crunchiness is evaluated on the outside, while the softness, airiness, and layering of the dough, as well as the sensory experience during chewing, are assessed on the inside;
- Recipe originality (Criteria 8) – Refers to the innovative character of the product in terms of the combination of ingredients used, the balance between taste, colour, and appearance, as well as the boldness in creating a recipe distinct from traditional ones;
- Purchase decision – Participants expressed their willingness to consume this product again in the future based on the overall sensory experience. This criterion is essential for determining the commercial potential of the evaluated croissants.

These characteristics were assessed by participants using a 5-point hedonic scale, which allows measuring the degree of pleasure felt during consumption (Addo-Preko et al.,

2023). This scale ranges from 1 to 5, with each level reflecting a specific degree of acceptability:

- 0 – Very bad (Altered): The product shows severe defects indicating spoilage, and therefore, it is not subjected to tasting;
- 1 – Bad (With pronounced defects): The product has major defects that significantly affect its sensory characteristics, making it unsuitable for consumption;
- 2 – Unsatisfactory (With obvious defects): The product presents visible imperfections and deviations from the desired quality, negatively influencing the consumer experience;
- 3 – Satisfactory (With minor defects): The product is acceptable, with small imperfections that do not significantly affect the overall consumption experience;
- 4 – Good (Adequate qualities): The product meets quality requirements, has pleasant sensory characteristics, and is considered enjoyable by consumers;
- 5 – Very good (High quality): The product is of high quality, offering an optimal sensory experience, free of defects, and highly appreciated by consumers.

The sensory evaluation was conducted with the help of a diverse group of consumers, randomly selected, including individuals of different ages, genders, and from various socio-economic backgrounds, to obtain a representative perspective on general preference.

Nutritional values of the croissants

To evaluate the nutritional and energy content of butter croissants with tuna by-product filling, as well as to verify their integrity, it was necessary to determine their fundamental chemical composition. In this regard, essential parameters such as water content, proteins, lipids, carbohydrates, and mineral substances were analysed, as they influence both the nutritional quality and the stability of the product over time.

The sample analysis was conducted by an accredited laboratory, following industry-specific standards. The samples were prepared and sent to the laboratory, where specialized staff performed chemical assessments using validated analytical methods. These determinations are crucial for the detailed characterization of the product, optimizing the recipe, and verifying its compliance with safety requirements.

RESULTS AND DISCUSSIONS

Butter croissants with tuna by-product filling were created to meet consumer needs while also reducing food waste by utilizing fish by-products. They were analysed to assess consumer satisfaction, both in terms of the consumption experience and their impact on nutrition.

Until now, there is no additional information about croissants with tuna meat filling, because similar products have not been previously studied or documented in the literature. This innovation represents a new approach in the field of baking and pastry, unprecedented in previous research.

Furthermore, the products are being prepared for registration at the State Office for Inventions and Trademarks (OSIM). According to preliminary checks carried out both at OSIM and at EUIPO (European Union Intellectual Property Office) and WIPO (World Intellectual Property Organization), there are no similar products already registered within these intellectual property and patent protection bodies, thus underlining the innovative nature and uniqueness of this creation (https://www.osim.ro/, https://www.euipo.europa.eu/ro, https://www.wipo.int/portal/en/index.html). As such, the obtained results are unique and cannot be compared with other results from similar products.

The butter croissants with tuna by-product filling are characterized by a pleasant exterior appearance, similar to traditional butter croissants, but smaller in size. In section, two distinct areas can be seen in croissants P1 and P2: the dough area, which has a layered, porous appearance, and the filling area, which has a dense, creamy fish filling. The products retain the standard croissant shape and the typical golden colour.

The taste and smell of the products combine the characteristics of a rich butter croissant with the pleasure of consuming grilled fish (in the case of sample P1, the taste and smell of cheese

cream are also noticeable). The texture of the croissants is crispy on the outside, fluffy in the second layer, and creamy on the inside.

Production of butter croissants with tuna by-product filling

To efficiently utilize tuna by-products and increase their economic value, two variants of butter croissants with tuna by-product filling, P1 and P2, were created and developed.

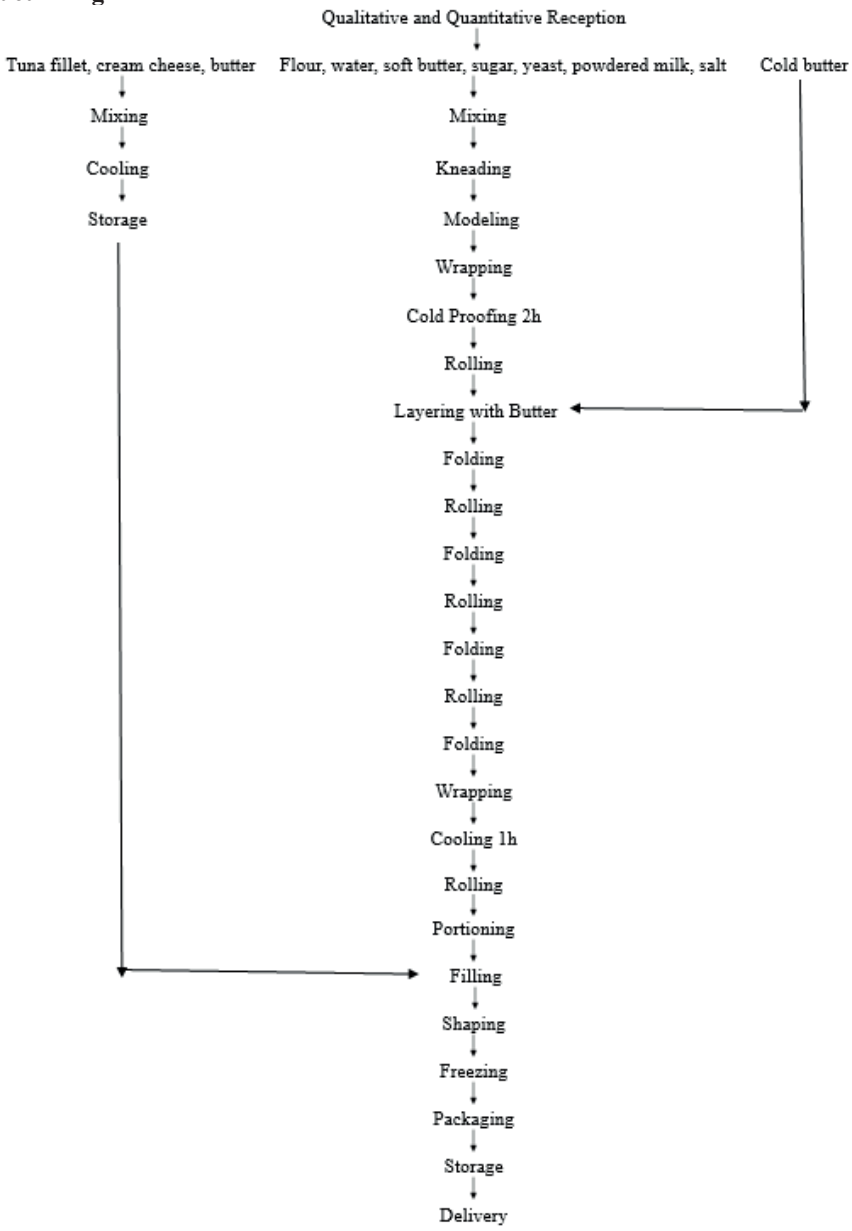

Figure 1. Technological scheme of P1

The process of making these innovative croissants (Figures 1 and 2) begins with the careful mixing of dry ingredients, such as salt, sugar, flour, and powdered milk, along with softened butter and yeast. This initial step aims to evenly combine the ingredients before

gradually adding water to form a homogeneous mixture. After the dough is formed, it is kneaded manually or mechanically to develop the gluten, which gives the final product elasticity and structure. The dough is then shaped into a rectangular form to facilitate the following stages of fermentation and folding.

The prepared dough is then wrapped and left to rise in a cool environment for two hours, allowing the yeast to act optimally. The cold fermentation process helps develop the flavours and ensures a light, airy texture.

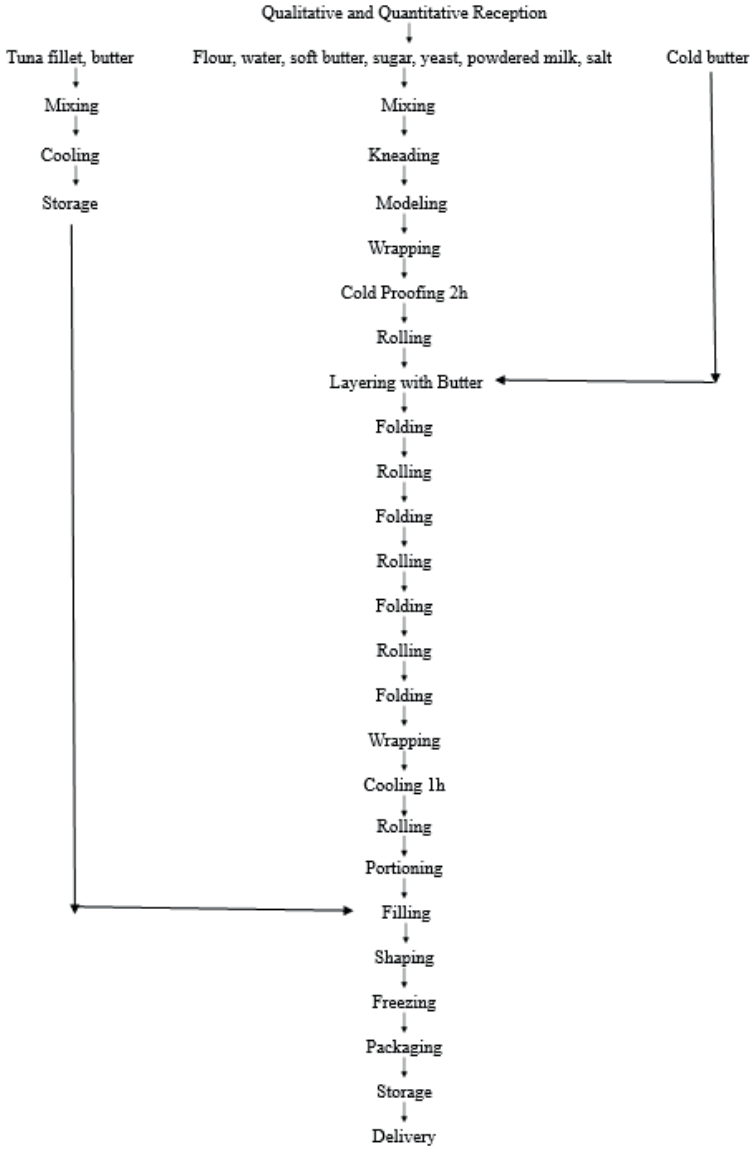

Figure 2. Technological scheme of P2

Figure 3. Croissant dough (Original)

After fermentation, the lamination process begins, where the dough is layered with cold butter, forming thin layers of dough and butter (Figure 3), which are essential for achieving a flaky and delicate texture. The dough is then folded and laminated four times through successive folds, creating multiple layers that give the croissants their characteristic layered and airy appearance.

After each lamination, the dough is chilled for an hour to allow the butter to firm up and prevent excessive blending of the layers. This step is crucial for ensuring a delicate and crispy texture when baking.

Figure 4. Filling the croissants (Original)

After cooling, the dough is laminated again, portioned, and filled (Figure 4) (using one of the two types of fillings mentioned earlier, depending on the desired variant).

Figure 5. Croissant shape (Original)

Next, the dough is shaped to achieve the final form of the croissants (Figure 5).

Subsequently, the croissants are rapidly frozen to preserve their flavour, texture, and quality. Immediate freezing helps maintain freshness, and the final product can be delivered in two forms: frozen, for the consumer to bake at home, or pre-baked, to offer an instant culinary experience. When marketed as a frozen product, after freezing, the croissants are carefully packaged to ensure they are protected from contamination and retain their characteristics until delivery. They are stored under optimal conditions to reach consumers in the best possible state.

For consumption, the croissants must undergo defrosting. After defrosting, the croissants will go through a proofing stage until they double in volume (Figure 6), and they will be brushed with a mixture of egg and milk. Once prepared, the croissants will be placed in a preheated oven at 170°C, well-ventilated, and equipped with a humidifying system. They will remain in the oven until fully baked (Figure 7).

Figure 6. Leavened croissants (Original)

Figure 7. Baked croissants (Original)

Sensory analysis of butter croissants with tuna by-product filling

Following the sensory analysis and the centralization of the results, it was found that the proposed products are considered suitable for large-scale consumption, having been positively evaluated by the assessors.

The sensory evaluation of sample P1 (Figure 8) (butter croissants with tuna and cheese cream filling) was conducted on a sample of 151 participants, who analysed the product based on essential criteria using the 5-point Hedonic scale. The results showed a high level of consumer appreciation, demonstrating that this innovative croissant variant has considerable potential for market acceptance.

Regarding the exterior appearance (Criteria 1), the P1 croissants received a score of 4.77, suggesting that the product was perceived as having an attractive presentation, with even baking, a well-browned surface, and no visible defects. A similar score was given for the cross-section appearance (Criteria 2) (4.79), indicating a balanced filling distribution, well-layered dough, and a visually pleasing internal structure.

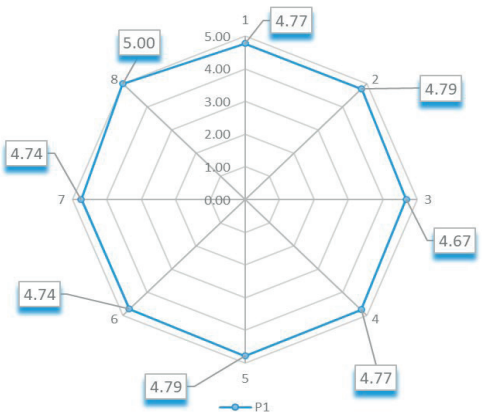

Figure 8. Sensory analysis of P1

The shape (Criteria 3) of the P1 croissants was rated 4.67, meaning the product maintained its proportions well, with minor variations in integrity.

Colour (Criteria 4) received a score of 4.77, confirming the uniformity of the shade both externally and internally, reflecting optimal baking.

One of the most important aspects of evaluating a food product is taste. In the case of sample P1, the taste (Criteria 5) was rated 4.79, indicating that participants found the combination of butter, tuna, and cheese cream to be well-balanced and pleasant. This high rating suggests that the ingredients blended harmoniously without any overpowering or unpleasant dominance.

Regarding smell (Criteria 6), product P1 was perceived positively, with a score of 4.74, suggesting that the overall scent was fresh and pleasant, without any indication of spoilage or incompatibility between the ingredients used.

The texture (Criteria 7) of sample P1 received a score of 4.74, indicating a well-balanced contrast between the crispy exterior of the croissant and the soft, airy, and well-layered interior.

A notable element of the P1 product evaluation is the originality of the recipe (Criteria 8), which received the maximum score (5.00). This result confirms that participants perceived the product as innovative and distinct from the classic options available on the market. The combination of butter, tuna, and cheese cream was considered bold and appealing, contributing to the product's uniqueness.

The most compelling proof of this product's success is the purchase decision, where 149 out of 151 participants (98.68%) stated that they would be willing to choose this type of croissant. This indicator confirms that the product was well received from a sensory perspective and also has real commercial potential, making it a viable option for market introduction.

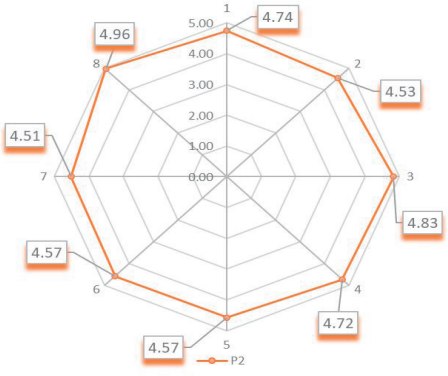

Figure 9. Sensory analysis of P2

The exterior appearance (Criteria 1) of the P2 innovative croissants (Figure 9) was rated 4.74, indicating that the product had a visually pleasing presentation, with even baking and an overall attractive look. The croissant's surface was perceived as well-browned, without evident defects or imperfections that could affect its aesthetic appeal.

The cross-section appearance (Criteria 2) of product P2 received a score of 4.53, suggesting a good internal structure with a uniform filling distribution. This result indicates that the dough developed well during proofing and baking, and the croissant's interior was properly layered. However, slight variations in consistency may have influenced the overall perception.

The shape (Criteria 3) of the P2 croissant was one of the most highly rated criteria, achieving a score of 4.83, which indicates good technological execution. Participants considered that the product maintained its proportions and integrity, having a well-defined shape without deformities or imperfections. This aspect is essential for the visual acceptance of the product and can contribute to a positive perception of its quality.

The colour (Criteria 4) of the P2 croissants was rated an average of 4.72, suggesting that it had a uniform shade both externally and internally. The even colour indicates proper baking and the use of quality ingredients, which contributed to an appetizing appearance.

The taste (Criteria 5) of the P2 croissants was rated an average of 4.57. The result reflects that participants perceived the combination of butter and tuna as balanced and pleasant, with no flavour notes negatively affecting the consumption experience. The ingredients were appreciated for their compatibility, and the product provided a pleasant taste sensation during chewing.

The smell (Criteria 6) of the P2 croissants received an average score of 4.57, suggesting that the product was perceived as having a fresh and well-balanced scent. This result indicates that the ingredients were of good quality and did not present any unpleasant olfactory notes, which is essential for the acceptance of a pastry product.

The texture (Criteria 7) of the P2 croissants was evaluated at an average of 4.51, reflecting a satisfactory consistency of the product. Although the obtained score is relatively lower, it suggests that certain aspects related to the dough's layering or the filling's distribution could be improved to enhance the perception of texture further.

A notable result was achieved in the originality of the recipe (Criteria 8), which received an average score of 4.96. This result demonstrates that participants perceived the product as innovative and different. This aspect distinguishes it from other croissants available on the market. The combination of ingredients was considered interesting and bold, offering a unique and appealing culinary experience.

Regarding the purchase decision, 41 out of the 47 participants in the sensory analysis (approximately 87.23%) stated that they would be willing to purchase the P2 croissant. This result confirms that the product was well received from a sensory perspective and has real commercial potential, making it attractive to consumers.

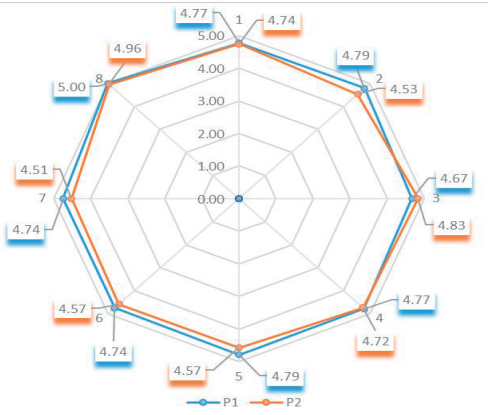

Figure 10. Comparative sensory analysis of P1 and P2

The comparative sensory analysis of the two types of croissants (Figure 10), P1 (with butter, tuna filling, and cheese cream) and P2 (with butter and tuna filling with butter), highlights high scores for both variants, demonstrating good consumer acceptability.

P1 has obtained slightly higher average scores for exterior appearance (4.77 vs. 4.74), cross-section appearance (4.79 vs. 4.53), taste (4.79 vs. 4.57), and texture (4.74 vs. 4.51), suggesting that this variant was well perceived, offering a well-integrated sensory balance.

On the other hand, P2 stood out with a higher score for shape (4.83 vs. 4.67), indicating better product integrity retention, and a closely comparable result for recipe originality (4.96 vs. 5.00), confirming that both variants were considered innovative.
Regarding the purchase decision, Sample 1 recorded a higher acceptance rate of 98.68% compared to Sample 2 (87.23%), suggesting a slightly stronger preference for the P1 variant.

Nutritional values of butter croissants with tuna by-product filling

Regardless of the commercialization method of the butter croissants with tuna by-products filling, their nutritional value must be determined for the baked product (in the state in which it will be consumed).
According to the results of the nutritional value analysis, P1 stands out with a nutritional profile (Table 1) characterized by a protein content of 11.86 g/100 g and a fat content of 26.03 g/100 g, a considerable proportion of which is represented by saturated fatty acids (20.95 g/100 g). Additionally, P1 contains 2.86 g/100 g of fiber, essential for supporting digestive health, and 28.39 g/100 g of carbohydrates, of which 2.91 g/100 g are simple sugars. Product P1 provides an energy value of 400.99 kcal/100 g and has a sodium level of 5182 mg/kg, equivalent to 1.30 g of salt/100 g. The moisture content is 30.86 g/100 g, which contributes to maintaining the product's stability and texture during storage.

Table 1. Nutrition declaration of butter croissants filled with tuna and cheese cream (P1)

Nutritional values per 100 g	
Energy	1677.74 kJ
	400.99 kcal
Protein	11.86 g
Fat	26.03 g
- of which saturates	20.95 g
Carbohydrate	28.39 g
- of which sugars	2.91 g
Fiber	2.86 g
Salt	1.30 g

Sample P2 is characterized by a nutritional profile (Table 2) with a higher protein content (14.45 g/100 g) than P1 and a lower fat content (20.22 g/100 g), with a considerable proportion represented by saturated fatty acids (16.03 g/100 g).
The fiber content is 2.32 g/100 g, while carbohydrates amount to 37.00 g/100 g, of which 2.55 g/100 g are simple sugars. The product has an energy value of 392.42 kcal/100 g and a sodium level of 5753 mg/kg, equivalent to 1.44 g of salt/100 g. The moisture content of 26.01 g/100 g significantly contributes to maintaining the product's stability and integrity throughout storage.

Table 2. Nutrition declaration of butter croissants filled with tuna and butter (P2)

Nutritional values per 100 g	
Energy	1641.89 kJ
	392.42 kcal
Protein	14.45 g
Fat	20.22 g
- of which saturates	16.03 g
Carbohydrate	37.00 g
- of which sugars	2.55 g
Fiber	2.32 g
Salt	1.44 g

Based on the nutritional comparison, it was observed that P1 has a higher energy value compared to P2. Sample P1 has a higher fat and fiber content than P2, but a lower level of proteins, carbohydrates and salt. The choice between them depends on nutritional priorities and individual preferences.

Benefits of consuming butter croissants with tuna by-product filling

P1 innovative croissant represents a nutritious and sustainable option, combining the benefits of fish consumption with the delight of a pastry product. P1 croissants offer an innovative way to integrate tuna by-products into human nutrition. The animal-based raw materials, namely tuna meat and cheese cream, provide a significant intake of proteins, vitamins (D, B12, E), and essential minerals (calcium, zinc, selenium) for the body. Butter ensures high-quality fats, offering a sustainable source of energy, while powdered milk complements the nutritional profile with calcium and magnesium, key elements for bone and nervous system health.
P2 innovative croissant is a tasty and nutritious alternative, incorporating fish into a refined pastry product. Just like P1, P2 croissants

provide an efficient way to utilize by-products resulting from fish processing, contributing to a responsible approach to food resource management.

The culinary innovations, P1 and P2, successfully meet the requirements of a balanced and delicious diet, combining unique ingredients into a versatile and appealing product. By using tuna, cheese cream, and butter alongside traditional pastry techniques, these croissants become a nutritious alternative, suitable for consumers who prioritize health and sustainability.

The two innovative products, P1 and P2, offer a more appealing alternative for fish consumption, including for children, who are often more selective about this food. Due to their unique characteristics, these products facilitate the integration of fish into the daily diet, providing a pleasant taste and a more enjoyable eating experience.

Moreover, the product supports the sustainability objectives promoted by the FAO's Blue Transformation initiative.

Designed for both end consumers and the bakery industry, P1 and P2 croissants offer innovative solutions for diversifying the range of additive-free products while also having a positive economic impact by creating new opportunities in the food industry.

The valorisation of tuna by-products generates economic advantages, fostering the growth of the food industry and contributing to the reduction of the negative environmental impact caused by disposing of by-products as waste.

CONCLUSIONS

The study conducted has demonstrated the feasibility of using tuna by-products in pastry products, offering an innovative and sustainable alternative for the valorisation of these resources. The two types of croissants developed exhibited organoleptic characteristics that were well-received by consumers, indicating high potential for market integration.

The sensory analysis highlighted a high level of acceptability, with the majority of participants awarding very good scores for appearance, texture, and originality. Overall, croissant P1 was rated more favourably in terms of sensory attributes compared to croissant P2.

The two innovative products, P1 and P2, provide a more appealing way to consume fish, including for children, who are often more selective when it comes to fish consumption.

Nutritional assessments confirmed that these products offer a good source of essential nutrients, providing high-quality proteins, essential fatty acids, and key minerals, thus contributing to a varied and sustainable diet.

By innovatively incorporating tuna by-products into pastry products, the study contributes to reducing food waste and promotes a sustainable model for utilizing aquatic resources.

The results obtained support the commercial potential of these products, offering opportunities for expanding the market for innovative pastry products with a positive impact on the environment and the circular economy.

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