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THE EFFECT OF USING DIFFERENT CONCENTRATIONS OF TAPIOCA FLOUR ON THE QUALITY OF BARRACUDA FISH CRACKERS (*Sphyraena jello*)

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ABSTRACT

Barracuda (*Sphyraena jello*) is a fishery commodity with high potential for value-added processing, including fish crackers. Tapioca flour serves as the primary binding agent, influencing the product's physical, chemical, and sensory qualities. This study aims to evaluate the effect of varying tapioca flour concentrations on the quality of barracuda fish crackers and to determine the optimal formulation. The study was conducted experimentally in a laboratory using a Completely Randomized Design (CRD) with four tapioca flour treatments (0%, 10%, 20%, and 30%) and three replicates. The parameters tested included moisture content, protein, fat, ash, crispness, and sensory evaluation, in accordance with SNI 8646:2018. The results showed that variations in tapioca flour concentration had a significant effect ($p<0.05$) on all observed parameters. Moisture content ranged from 1.14–1.56%, protein content from 2.51–4.66%, fat content from 21.55–34.50%, ash content from 3.54–7.30%, and crispness from 1112.76–1995.11 gf. Based on the sensory test results, the treatment with 30% tapioca flour addition yielded the highest scores for appearance (8.60 ± 0.81), texture (8.53 ± 0.86), odor (8.27 ± 0.98), and taste (8.80 ± 0.61), with an overall average of 8.55 ± 0.22 (highly preferred category). Thus, a 30% tapioca flour concentration was determined to be the optimal formulation for producing barracuda fish crackers with superior physical, chemical, and sensory quality in accordance with SNI 8646:2018 standards.

Keywords: Barracuda; Tapioca Flour; Fish Crackers; Crispness; Ingredient Formulation

INTRODUCTION

Barracuda (*Sphyraena jello*) is one of the marine capture fishery commodities with great potential to be developed as a raw material for high-value processed products. Although national capture fishery production has exceeded 7 million tons per year, with a positive growth trend, the utilization of barracuda as a food ingredient remains limited. Most of the catch is still sold fresh, so the value added has not yet been maximized. This situation underscores the need for product innovation to enhance fisheries product diversification, including the production of fish crackers, a ready to eat, dried food product favored by people for its savory flavor and crisp texture (Azizah *et al*., 2021; Sali *et al*., 2020).

In the processing of fish-based products, the use of binding agents, such as tapioca flour, is crucial to the products' physical, chemical, and sensory quality. Tapioca flour is known to have a high starch content, particularly amylose and amylopectin, which can impart a distinctive texture and create air pockets during frying (Kusuma *et al*., 2013). However, excessive use of tapioca can increase moisture and carbohydrate content while reducing protein content due to a lower proportion of fish meat in the batter (Costa & Manihuruk, 2021). Therefore, determining the balance between the amount of fish meat and tapioca flour is a crucial aspect for producing fish crackers with a crisp texture and optimal nutritional value.

Several previous studies have investigated the effects of tapioca flour on various processed fish products, including barracuda nuggets (Sali *et al*., 2020), snakehead fish crackers (Purnomo *et al*., 2019), and catfish surimi meatballs (Indra *et al*., 2016). However, most of these studies used relatively high concentrations of tapioca flour (50–70%), resulting in increased moisture content and reduced protein content in the products. Meanwhile, research on the use of lower tapioca flour concentrations (10–30%) with a more dominant fish meat content remains limited. However, such formulations have the potential to produce products with better nutritional characteristics and crispness, similar to the fish chips developed by Abou-Taleb *et al*. (2019). Thus, this study holds a strategic position in addressing this scientific gap by evaluating the effects of varying tapioca flour concentrations on the quality of barracuda fish crackers and serves as part of the innovation roadmap for diversifying fishery products, focusing on enhancing economic value and food quality based on local marine resources. By processing barracuda into crackers with a low tapioca flour ratio, it is hoped that a food product can be produced that is not only highly nutritious but also meets national quality standards (SNI 8646:2018) and is competitive in the processed fishery products market.

Based on this background, this study was conducted to evaluate the effects of varying tapioca flour concentrations on the physical, chemical, and sensory characteristics of barracuda fish crackers, and to determine the optimal formulation capable of producing a product that meets the SNI 8646:2018 quality standards in a measurable and validated manner.

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RESEARCH METHOD

Time and Location

This study was conducted at the Fishery Products Processing Laboratory, Department of Fishery Products Technology, Faculty of Fisheries and Marine Sciences, Diponegoro University, Semarang, from May to July 2025. The study was conducted experimentally using a Completely Randomized Design (CRD) with four treatments of tapioca flour concentration (K [0%], A [10%], B [20%], and C [30%] of the total ingredients), each with three replicates. The percentage of tapioca flour was calculated based on 100 g of minced meat per treatment.

Materials and Equipment

The main ingredient used was fresh barracuda (*Sphyraena jello*) meat obtained from Rejomulyo Market, Semarang. Other ingredients included tapioca flour as a binding agent, salt, garlic, and oil.

The main equipment used included *a chopper* (Kirin) for mincing the fish meat, a digital analytical scale (VKTECH) for weighing ingredients, a steamer (stainless steel), a food dehydrator (LT–28; 6 trays) for drying into raw crackers, and a texture analyzer (Lloyd TAPlus) for measuring crispness. Proximate analysis was performed using the Kjeldahl method for protein content, the Soxhlet method for fat, and the ash content test (BSN, 2010). Color measurement was performed using a Colorimeter (NH310), while amino acid analysis was conducted using UPLC-PDA (The Acquity UPLC PDA Detector).

Research Procedure

Barracuda fish fillets were deboned and skinned, then ground into a fine paste. The cracker dough was prepared by mixing the fine fish paste with tapioca flour according to the treatment levels (0%, 10%, 20%, and 30%), adding 1.5% salt, 3% garlic, and sufficient oil to form a homogeneous dough. The dough was kneaded for approximately 10 minutes until smooth, then manually shaped into cylinders by hand with a diameter of 3.5 cm and steamed for 60 minutes. After steaming, the dough was cooled to room temperature, then thinly sliced (approximately 2 mm) and dried in *a food dehydrator* at 70°C for 8 hours. The dried crackers were then fried in hot oil for approximately 6 seconds until fully puffed, then cooled to room temperature before analysis. The 0% treatment was designated K, the 10% treatment A, the 20% treatment B, and the 30% treatment C.

The analysis included proximate analysis, namely moisture content (BSN, 2015), protein content (BSN, 2006), fat content (BSN, 2017), and ash content (BSN, 2010), as well as texture analysis (crispness) using a Texture Analyzer according to the method of Ramesh *et al*. (2018), color tests (*L*, a*, b** values) using a Colorimeter, and amino acid tests using UPLC-PDA according to SMM-SIG standards. Sensory testing was conducted in accordance with SNI 8646:2018, with evaluation of appearance, aroma, taste, and texture attributes by 30 semi-trained panelists using a 5-, 7-, and 9-point hedonic scale.

Data Analysis

Test results were analyzed using parametric and non-parametric analyses. Parametric analysis was applied to data from texture tests (crispness), proximate analysis (protein, fat, and ash content), and color profile tests (*a** and *b**). The method used was a Completely Randomized Design (CRD) in SPSS, including homogeneity tests and analysis of variance (ANOVA). ANOVA results indicating significant differences between treatments ($P < 0.05$) were followed by Duncan's multiple range test to determine differences among specific treatments.

Non-parametric analysis was used to process data from the proximate analysis (moisture content), *L** color profile, and sensory evaluation of barracuda fish crackers. The analysis employed the *Kruskal-Wallis* test followed by *Dunn's Multiple Comparison Test* in SPSS. The purpose of this analysis is to determine whether the treatments have a significant effect ($P < 0.05$) or not ($P > 0.05$). If the calculated χ-value is greater than the table χ-value or the probability is less than 0.05, the analysis may proceed using the Mann-Whitney test to identify significant differences among treatments for each parameter. If the calculated χ-value exceeds the table χ-value, or the probability is less than 5%, the analysis can proceed using the Mann-Whitney test to identify significant differences between treatments for each parameter.

RESULTS AND DISCUSSION

Texture (Crispness) of Barracuda Fish Crackers

The results of the analysis of the crispness of barracuda fish crackers (*Sphyraena jello*) with varying concentrations of tapioca flour are shown in Table 1.

Table 1. The Crispness of Barracuda Fish Crackers

No	Tapioca Flour Concentration	Crispness (gf)
1	0% (K)	1995.11 ± 64.84^{c}
2	10% (A)	1112.76 ± 65.56^{a}
3	20% (B)	1569.48 ± 74.16^{b}
4	30% (C)	1903.77 ± 55.65^{c}

Different superscript letters on the data indicate significant differences ($P<0.05$).

Based on Table 1, the control treatment without added tapioca produced the highest mean value of 1995.11 ± 64.84 *gf*. Conversely, Treatment A with a 10% tapioca addition showed the lowest value of 1112.76 ± 65.56 *gf*. The low crispness value in Treatment A is due to the high amylopectin content in tapioca flour, which results in a porous structure and a brittle texture. This explanation aligns with Wang *et al*. (2015), who stated that changes in starch during processing—such as water absorption, granule swelling, the formation of a viscoelastic paste, and the formation of a gel are influenced by the amylose amylopectin ratio, which directly impacts the texture of starch-based products.

The results of the statistical analysis in Table 1 indicate that as the concentration of tapioca flour used increases, the gelatinization process proceeds more effectively, forming a denser gel network and enhancing the mechanical strength of the crackers. This aligns with the findings of Reyniers *et al*. (2020), who emphasized that starch transformation during the processing of fried products particularly during gelatinization and drying plays a crucial role in determining the final product's crispness. Adding tapioca at a low concentration (10%) actually significantly reduced crispness, whereas at a high concentration (30%), texture quality improved again to levels approaching the control, with a firm level of crispness. This pattern aligns with the findings of a study by Allan *et al*. (2021), which reported that the amylopectin branches in sweet potato starch are associated with brittleness and crispness, underscoring the importance of the appropriate starch proportion for achieving optimal texture.

The processing steps also influenced the crispness test results for barracuda fish crackers. The steaming stage initiates starch gelatinization, which plays a role in determining the dough's structural density; the drying process then regulates moisture content; and the frying process is the primary factor determining crispness, as the appropriate frying temperature and duration create air pockets by releasing water vapor. Li *et al*. (2025) state that frying conditions significantly affect water loss, oil absorption, and the textural characteristics of fried fish products. Additionally, research conducted by Davoodi *et al*. (2025) confirms that moisture content and structural stability are key determinants of both crispness and shelf life in flour-based products. Palomino-Rincón *et al*. (2025) also noted that increased porosity resulting from ultrasonic treatment and the frying process is positively correlated with the perceived crispness of potato chips, as the porous structure formed affects both the product's mechanical properties and its sensory evaluation.

Sensory Evaluation of Barracuda Fish Crackers

Sensory testing is a method used to determine the level of acceptance of the produced product by panelists. This test uses each panelist's senses to analyze product quality against quality specifications such as appearance, texture, aroma (smell), and taste, in accordance with Indonesian National Standard (SNI) 8646:2018. The sensory value of barracuda fish crackers (*Sphyraena jello*) are presented in Table 2.

Table 2. Sensory value of Barracuda Fish Crackers

No	Tapioca Flour Concentration	Appearance	Texture	Odor	Taste
1	0% (K)	6.47 ± 1.04^{a}	6.73 ± 0.69^{a}	7.20 ± 0.81^{a}	7.13 ± 0.73^{a}
2	10% (A)	7.13 ± 0.73^{b}	7.00 ± 0.74^{a}	7.27 ± 0.87^{a}	7.60 ± 1.07^{b}
3	20% (B)	8.13 ± 1.01^{c}	8.07 ± 1.01^{b}	7.87 ± 1.01^{b}	8.60 ± 0.97^{c}
4	30% (C)	8.60 ± 0.81^{c}	8.53 ± 0.86^{b}	8.27 ± 0.98^{b}	8.80 ± 0.61^{c}

Different superscript letters on the data indicate significant differences (P<0.05).

Appearance

Based on the average scores in Table 2, the appearance score increased with increasing tapioca concentration, namely 6.47 in treatment K, 7.27 in treatment A, 8.13 in treatment B (20%), and 8.60 in treatment C (30%). These results indicate that the higher the tapioca content, the better the appearance rating, with treatment C (30%) receiving the highest rating from the panelists for a clean, very bright appearance. These test results are consistent with the findings of a study by Hadiwinata and Wulandari (2024), which found that formulations with higher starch content remain acceptable from a sensory perspective, including for appearance.

Using large amounts of tapioca flour not only yields a brighter final product but also improves its texture. The use of larger amounts of tapioca also contributes to other visual uniformities such as color, glossyness, and product consistency. Research by Zhu *et al*. (2024) showed that formulations with approximately 36% tapioca starch content achieved the highest scores in sensory tests for color uniformity and glossyness. These support the results of this study, which show that using 30% tapioca in barracuda fish crackers results in a more appealing appearance and is preferred by panelists. The type of starch used in food production also influences the visual characteristics of the resulting product. Nimitkeatkai *et al*. (2022) explain that adding tapioca tends to increase the product's darkness, while wheat flour provides greater brightness. This indicates that each type of starch contributes differently to color and brightness attributes.

In addition to being influenced by ingredient composition, processing stages also contribute to the appearance of barracuda fish crackers. Steaming facilitates starch gelatinization, making the dough more compact, while optimal drying can result in a brighter, more uniform color for the raw crackers. Gonçalves *et al*. (2023) reported that inadequate drying conditions can result in darker crackers and reduced panelist acceptance, whereas optimal drying enhances brightness and visual uniformity. During frying, oil quality and temperature significantly determine the product's appearance. Wang *et al*. (2021) emphasized that frying methods and temperatures greatly influence the color and sensory acceptance of starch-based foods: frying at a stable temperature with high-quality oil produces bright products, whereas the opposite conditions result in darker, less appealing colors.

Texture

The sensory texture scores for barracuda fish crackers (*Sphyraena jello*) are presented in Table 2. Table 2 show an improvement in texture quality as the tapioca concentration increases, where treatment K (0%) obtained a value of 6.73 ±0.69, then increased in treatment A (10%) to 7.00 ± 0.74, in treatment B (20%) to 8.07 ± 1.01, and reached the highest value in treatment C (30%) at 8.53 ± 0.86. The improvement in texture of barracuda fish crackers with the addition of tapioca flour indicates that the characteristics of starchy ingredients significantly determine sensory quality. Tapioca flour has a high amylopectin content, so during heating, it undergoes gelatinization, forming a finer, more porous network. The presence of these pores accelerates water evaporation during frying, ultimately resulting in a product with good expansion and higher crispness. According to Talib *et al*. (2024), the use of starch with a predominance of amylopectin increases crispness and panelist acceptance of fish-based products, findings that align with this study. In addition to starch components, barracuda fish protein also plays a crucial role in influencing the texture of the crackers. The protein acts as a structural enhancer, binds starch, maintains the stability of air pores, and strengthens the dough matrix after frying. The interaction between the proteins in the fish meat and the starch results in crackers that are not only crispy but also dense and resistant to crumbling. Ramesh *et al*. (2018) noted that the protein-to-starch ratio significantly determines both the chewiness and crispness of the crackers, as the balance of these two components affects structural stability during heating.

Odor

The sensory odor scores for barracuda fish crackers (*Sphyraena jello*) are presented in Table 2. Odor is one of the primary sensory parameters influencing consumer acceptance of barracuda fish crackers. Table 2 show an increase in odor intensity as the concentration of tapioca flour increases, with treatment K (0%) scoring 7.20, then increasing to 7.27 in treatment A (10%), treatment B (20%) at 7.87, and reaching the highest value in treatment C (30%) at 8.27. Based on the organoleptic test results, the odor scores ranged from moderately liked to liked, reflecting differences in panelists' perceptions due to variations in ingredient formulations. Baishak *et al*. (2020) explained that the type of fish primarily influences the odor of fish crackers, as protein and fat content produce volatile compounds during heating. Additionally, amino acid degradation contributes to the emergence of savory nuances that enrich the product's odor profile. Another contributing factor is the proportion of raw materials. Mahyuddin *et al*. (2024) reported that the ratio of fish to starch in the batter affects the odor quality of the crackers, with a balanced composition yielding a more acceptable, characteristic fishy odor. The use of tapioca flour, in addition to serving as a texturizer, also helps balance odor intensity by absorbing some of the excess volatile compounds.

The frying process also significantly determines the odor quality of fish crackers. Tokarczyk *et al*. (2025) reported that a higher frying temperature, specifically 180 °C, enhances product expansion and intensifies aroma by releasing volatile compounds from lipid oxidation. In addition to lipid oxidation, the Maillard reaction between amino acids and reducing sugars contributes to the characteristic savory aroma that is preferred. However, frying at excessively high temperatures can cause a rancid odor due to excessive oxidation of unsaturated fatty acids. In addition to ingredient formulation and frying, processing technology also influences the aroma quality of the crackers. Wang *et al*. (2021) found that variations in frying techniques result in different profiles of volatile compounds, including aldehydes, alcohols, and hydrocarbons from the degradation of fats and starch.

Taste

The sensory taste scores for barracuda fish crackers (*Sphyraena jello*) are presented in Table 2. Taste is one of the most critical sensory attributes determining consumer acceptance of barracuda fish crackers. The average taste scores in Table 2 show an increase in perceived taste as the concentration of tapioca flour increases, where treatment K (0%) scored 7.13, then increased to 7.60 in treatment A (10%), 8.60 in treatment B (20%), and reached the highest value of 8.80 in treatment C (30%). The composition of raw materials is the key factor in shaping the flavor profile. This is consistent with the findings of Maulida *et al*. (2025), who noted that adding fish meat in balanced amounts can enhance savory flavor and enrich sensory complexity. The protein and free amino acid content in barracuda fish contribute to the emergence of umami flavor. At the same time, fat components contribute to a savory impression by degrading lipid compounds during frying. In addition to fish meat content, additives such as tapioca flour also significantly influence the flavor quality of the crackers. Elida *et al*. (2025) explain that increasing the starch proportion in the cracker formulation can reduce the intensity of fishy odor while balancing the flavor profile, making it more palatable to panelists. Tapioca flour serves not only as a binding agent but also helps absorb some undesirable volatile compounds, resulting in a cleaner, savvier flavor.

Proximate Content of Barracuda Fish Crackers

Moisture Content

The final values obtained from the moisture content test of barracuda fish crackers (*Sphyraena jello*) with varying tapioca flour concentrations used in their production are presented in Table 3.

Table 3. Proximate Content of Barracuda Fish Crackers

No	Tapioca Flour Concentration	Moisture Content	Protein Content	Fat Content	Ash Content
1	0% (K)	1.56 ± 0.21^{a}	4.66 ± 0.21^{d}	34.50 ± 0.23^{d}	7.30 ± 0.09^{d}
2	10% (A)	1.19 ± 0.02^{a}	3.61 ± 0.30^{c}	26.54 ± 0.12^{c}	6.30 ± 0.27^{c}
3	20% (B)	1.15 ± 0.02^{a}	3.15 ± 0.03^{b}	22.48 ± 0.27^{b}	4.49 ± 0.21^{b}
4	30% (C)	1.14 ± 0.02^{a}	2.51 ± 0.16^{a}	21.55 ± 0.14^{a}	3.54 ± 0.23^{a}

Different superscript letters on the data indicate significant differences ($P < 0.05$).

Based on the average scores in Table 3, the moisture content decreased with increasing tapioca concentration, namely 1.56 in treatment K, 1.19 in treatment A, 1.15 in treatment B (20%), and 1.14 in treatment C (30%). However, statistically, as shown in Table 3, the addition of tapioca flour tends to maintain moisture content stability at the same level. The decrease in moisture content observed as tapioca flour is added, based on average values, is closely related to the physicochemical properties of starch, particularly the dominant amylopectin content in tapioca. During heating, amylopectin granules undergo gelatinization, forming a dense, elastic gel structure that reduces interparticle spacing and limits the presence of free water in the dough. Additionally, amylose molecules from tapioca can interact with fish proteins via strong hydrogen bonds, resulting in a more stable matrix. This structure enhances the retention of bound water while simultaneously accelerating the release of free water during drying and frying, resulting in a lower final moisture content in the product. The addition of tapioca also maintains moisture stability in the crackers by leveraging the gelatinization properties of the starch in tapioca flour, forming a stable network during steaming and preventing excessive evaporation.

This inhibits excessive water absorption, producing an ideal, stable cracker product. Baranwal *et al*. (2022) state that modifying the starch structure in tapioca can improve gelatinization efficiency and strengthen the polymer network formed, resulting in a reduction in residual moisture content. Meanwhile, Kupriy *et al*. (2021) suggest that adding tapioca to fish-based product formulations can reduce moisture content and improve texture stability by forming a homogeneous colloidal system within the protein matrix. Research results by Cankal *et al*. (2025) also show that increasing tapioca concentration to 30% effectively reduces moisture content below the SNI 8272:2016 threshold (<7%) and produces crackers with a lighter, crispier texture that remains stable during storage.

Protein Content

The protein content values obtained from the protein content test of barracuda fish crackers (*Sphyraena jello*) with varying concentrations of tapioca flour used in the production of barracuda fish crackers are presented in Table 3. Based on the data in Table 3, the protein content of the control barracuda fish crackers (K) without added tapioca was the highest, at 4.66%. In comparison, the lowest content was found in the treatment with 30% added tapioca (C), which reached only 2.51%. Treatments A (10%) and B (20%) fell between the two, with values of 3.61% and 3.15%, respectively. These findings indicate that as the concentration of added tapioca flour increases, the contribution of fish protein to the overall product composition decreases, even though the amount of fish used in each treatment remained the same. This aligns with the findings of Gunawan *et al*. (2025), who stated that increased starch use in fish cracker production can significantly reduce protein content. Beitane and Marisheva (2023) explain that the dominance of carbohydrate components in food formulations directly affects the measured decrease in protein content, while the study by Pedrali *et al*. (2022) reports that variations in filler ingredients in nut-based products result in significant differences in their protein content.

In addition to the influence of composition proportions, the decrease in protein content may also be attributed to molecular interactions between fish protein and starch during processing. The addition of large amounts of tapioca can form complex bonds with proteins, leading to some protein fractions not being optimally measured in proximate analysis. Talib *et al*. (2024) found that variations in starch usage in extruded fish products significantly impact protein content and product quality due to the formation of carbohydrate-protein interactions. Meanwhile, Ianiţchi *et al*. (2023) demonstrated that adding starch to meat emulsions can alter protein structure during heating, including denaturation, which ultimately contributes to a decrease in measured protein content.

Fat Content

The results of the fat content test for barracuda fish crackers (*Sphyraena jello*) are presented in Table 3. The results of the analysis in Table 3 show that the highest fat content was obtained in the control barracuda fish crackers (K) without tapioca addition, at 34.50%. This value decreased in treatment A (10%) to 26.54%, then further decreased in treatment B (20%) to 22.48%, until reaching the lowest level in treatment C (30%) at 21.55%. This reduction in fat content can be attributed to the shift in dough composition resulting from the addition of tapioca flour. This condition affects the presence of the fish's protein-fat matrix, which typically binds oil during frying. The control product, consisting solely of fish, still has a higher protein-fat content and thus absorbs more oil. In contrast, in treatments with higher tapioca concentrations, the amount of oil absorbed is relatively lower, making this fish cracker a healthier product with lower fat content. Guttifera *et al*. (2024) reported that changes in the composition of traditional fish crackers affect their chemical characteristics, including fat content, with starch dominance influencing the measured lipid content after heating.

High-starch products undergo more intensive gelatinization, resulting in a denser structure that limits the oil's movement into the matrix. Ndahawali *et al*. (2024) found that the combination of ingredient formulation and frying time can affect oil absorption in processed seafood products, while Mindarwati *et al*. (2024) showed that adding starchy ingredients to fish-based snack products affects fat content and the nutritional profile. Störmer *et al*. (2024) noted that oil migration and retention during frying are closely related to the physical properties of the matrices of the constituent ingredients.

Ash Content

The final results obtained from the ash content test are presented in Table 3. Ash content represents the total mineral content of a food product, including both macrominerals such as calcium and phosphorus, and microminerals such as magnesium and zinc. In this study, the fish bones were removed so that the ash content did not originate from the bones but rather from the natural minerals contained in the barracuda fish meat, such as phosphorus, potassium, sodium, and magnesium, as well as the salt added to the formulation. Salt was added at a rate of 1.5% uniformly across all treatments, so its contribution to ash content was constant. The proximate analysis presented in Table 3 shows that the control sample (0%) had the highest ash content at 7.30%, while the 30% tapioca treatment had the lowest at 3.54%. Barracuda, used as the main ingredient, is known to be rich in these minerals, so products with a dominant fish proportion tend to yield higher ash content. Conversely, tapioca flour has a low mineral content, so the more it is added to the formulation, the lower the product's ash content becomes.

These results align with those of Mutamimah *et al*. (2024), who reported that the use of starchy additives in fish cracker production reduces ash content by diluting natural minerals in the fish raw material. The processing method also influences the measured ash content. During frying, organic compounds in the batter degrade, leaving inorganic residues in the form of minerals, as measured by ash. Rico *et al*. (2024) emphasize that the retention and distribution of minerals in food products are influenced not only by the properties of the raw materials but also by processing treatments such as heating and exposure to sunlight, which can modify mineral content. Ash content decreases with increasing tapioca flour usage, even though the amount of fish remains the same across all treatments.

Additionally, the interaction between the protein in the fish meat and the starch-containing tapioca flour also affects the mineral distribution within the product matrix. The decrease in ash content as tapioca flour concentration increases indicates a diluting effect on minerals, given that tapioca flour has a relatively low ash content. Therefore, the differences in ash content between treatments are more due to changes in raw material composition than to the presence of fish bones. Resti *et al*. (2024) showed that the addition of fish protein increases ash content because animal protein provides significant minerals.

Color Profile of Barracuda Fish Crackers

Color is an aspect that influences consumers' perception of food product quality and visual appeal. Raharja *et al*. (2021) state that color is the first element observed by potential consumers and serves as an initial determinant of preference, even before evaluating a product's taste or texture. All results of the *L**, *a**, and *b** color profile tests for barracuda fish crackers are presented in Table 4.

*L** Color Profile

All results of the *L** color profile test for barracuda fish crackers are presented in Table 4. Based on the average scores in Table 4, the variation *in L** values indicates that tapioca flour concentration is the dominant factor influencing the brightness of the crackers. However, statistically, this did not reach significance as the amount of tapioca flour used increased. On average, the treatment without added tapioca (0%) yielded the lowest *L** value (39.14±0.82), while adding up to 30% tapioca resulted in the highest L* value (53.15±6.83). In the control treatment, the relatively dark natural color of barracuda fish meat still dominated the product's appearance. The addition of 10% tapioca began to increase the *L** value, in line with the role of tapioca's neutral white color in masking the fish pigments. This upward trend continued at a 20% concentration, while at 30% the *L** value reached its peak. This occurs because the increasing amount of amylopectin undergoes gelatinization, forming a transparent gel that reflects light more effectively, making the crackers appear brighter. Research by Cankal *et al*. (2025) demonstrated that tapioca-based crackers exhibit higher *L** values than those made with corn or potato starch, due to their lower protein content, which reduces the potential for Maillard browning. In line with this, Litaay *et al*. (2022) found that fortifying sago noodles with fish meal lowers the *L** value, as the increased protein content makes the product appear darker.

Table 4. Color Profile of Barracuda Fish Crackers

No	Tapioca Flour Concentration	*L**	*a**	*b**
1	0% (K)	39.14±0.82[a]	3.23±0.93[a]	9.61±0.40[a]
2	10% (A)	43.87±2.61[a]	8.02 ± 1.48 [b]	15.88 ± 2.21 [b]
3	20% (B)	47.94 ± 1.08 [a]	8.94 ± 0.81 [bc]	17.78 ± 1.49 [bc]
4	30% (C)	53.15 ± 6.83 [a]	10.77 ± 1.34 [c]	20.79 ± 2.51 [c]

Different superscript letters on the data indicate significant differences (P<0.05)

Mechanistically, the primary role lies in the starch composition present in tapioca flour. The interaction between gelatinized starch granules and fish protein also helps reduce the dominance of protein pigments, thereby increasing the *L** value of the color profile. Baig *et al*. (2024) confirm that starch with a high amylopectin content can form a clearer gel, thereby enhancing the optical properties and brightness of starch-based products. Processing stages also contribute, although to a lesser extent than formulation factors. Steaming supports starch gelatinization, while drying helps reduce moisture content, thereby maintaining color stability. Frying at high temperatures can cause a slight decrease in *L** values due to the Maillard reaction, although the effect is limited. According to Hoy *et al*. (2025), processed fish cracker-based products exhibit a decrease in *L** values during storage due to the oxidation of carotenoid pigments and non-enzymatic browning. However, frying can increase *L** values due to protein denaturation, resulting in a brighter appearance.

*a** Color Profile

The results of the *a** color profile test for barracuda fish crackers are presented in Table 4. Based on the average measurement scores in Table 4, there is variation in the *a** values among the treatments. The control treatment K (0%) yielded the lowest *a** value, namely 3.23±0.93, while treatments with the addition of tapioca flour at levels of 10% (A), 20% (B), and 30% (C) produced higher values, namely 8.02±1.48; 8.94 ± 0.81; and 10.77 ± 1.34.

This pattern confirms that adding tapioca at various concentration levels consistently enhances the red color intensity of the crackers. This change is likely related to the role of starch in enhancing chemical reactions during heating, thereby producing pigments that contribute to the reddish color. This phenomenon aligns with findings from other studies showing a positive correlation between increased starch content and higher *a** values in various fish-based and flour-based products (Putra *et al*., 2024). In addition to ingredient composition, processing stages also influence color formation. During steaming, starch gelatinization alters the dough structure while affecting the product's initial color.

Furthermore**,** drying reduces moisture content, which can affect color stability prior to the final cooking stage. The frying stage has the greatest impact, as the high heat absorbed by the product can trigger *Maillard* reactions between reducing sugars and proteins, as well as caramelization of starch components, which together can enhance the intensity of the reddish-brown color in the final product (Nawaz *et al*., 2021; Bayomy *et al*., 2023). The *Maillard* reaction is influenced by the increased availability of reducing sugars derived from tapioca flour, even though the protein content of the barracuda fish crackers in Table 3 is no longer a limiting factor in the reaction. The remaining fish protein still provides sufficient free amino groups to react with the reducing sugars, thereby increasing the a* color value.

*b** Color Profile

The final values of the *b** color profile for barracuda fish crackers are presented in Table 4. Based on the average measurement scores in Table 4, there is variation in the *b** values across the treatment levels. The control (K) without added tapioca flour produced the lowest *b** value, namely 9.61. The addition of tapioca at levels of 10% (A), 20% (B), and 30% (C) significantly increased the *b** values to 14.72, 19.54, and 20.79, respectively. This pattern confirms that higher tapioca concentrations tend to produce a more intense yellow hue, but significant differences are evident between the control and the tapioca-treated samples. These results align with the findings of Baishak *et al*. (2020), who described that the combination of fish meat and starch can enhance the intensity of the yellow color in crackers through ingredient interactions during heating. The research conducted by Kingwascharapong *et al*. (2024) also confirms that starch-based formulations can influence the *b** color profile characteristics of fish cracker products. The primary reactants in the Maillard reaction that form the *b** color profile stem from the ratio of protein to carbohydrate content in the tapioca, even though the protein content shown in Table 3 decreases as the addition of tapioca flour increases. This is due to the increased availability of reducing sugars derived from the tapioca flour, meaning that component is no longer a limiting factor in the reaction. The remaining fish protein continues to provide a sufficient amount of free amino groups to react with the reducing sugars, so an increase in the b* color value is still observed. The carbonyl groups from the carbohydrates contained in the tapioca flour react with the amino groups from the barracuda fish protein. The reaction between these two groups forms intermediate compounds, such as Amadori products, which degrade into yellowish furanic compounds, such as furfural and 5-hydroxymethylfurfural (HMF). These compounds are the initial products of the Maillard reaction and trigger an increase in the *b** value before developing into brown melanoidin pigments. The yellow color observed is influenced by the Maillard reaction, which produces yellow chromophores such as Amadori products, deoxyhexosone, furfural, and hydroxymethylfurfural (HMF). These compounds are formed as a result of the reaction between reducing sugar molecules from tapioca flour (glucose, maltose resulting from starch degradation) and the amino groups of barracuda fish protein. Research conducted by Nor *et al*. (2014) also reported that repeated heat treatment of crackers made from starch- and protein-containing fish can increase resistant starch content while influencing the product's yellow hue.

Amino Acid Content of Barracuda Fish Crackers

Amino acids are the basic building blocks of proteins and play a crucial role in determining the total nutritional value of food, including processed products made from fishery-based raw materials. Essential amino acids must be obtained through consumption because they cannot be synthesized by the body, whereas non-essential amino acids can be produced but still play a vital role in metabolic processes. Barracuda fish crackers (*Sphyraena jello*) are known to contain a variety of amino acids that not only provide nutritional value but also contribute to the sensory properties of the product, such as its savory flavor. This is supported by the findings of Zhao *et al*. (2025), who noted that the amino acid profile in fishery products reflects protein quality and can be influenced by the fish's biological condition and its living environment. The results of the amino acid content analysis of barracuda fish crackers are presented in Table 5.

Table 5. Amino Acid Content Testing of Barracuda Fish Crackers

Amino Acid Type	Amino Acid Content (mg/kg)	
	0% (K)	30% (C)
Essential Amino Acids		
L-Arginine	6710.45±136.54	3456.96±41.05
L-Histidine	12,586.14 ± 266.75	6,546.94 ± 9.63
L-Isoleucine	14,142.59 ± 207.65	8,199.36 ± 64.00
L-Leucine	11,838.67 ± 244.04	13,687.24 ± 16.34
L-Lysine	13,915.07 ± 168.48	7,436.31 ± 9.18
L-Valine	4,981.65 ± 82.50	3329.90 ± 5.47
L-Phenylalanine	33,119.53 ± 453.04	36,410.17 ± 141.28
L-Threonine	4,101.44 ± 61.86	2,156.95 ± 14.24
Non-Essential Amino Acids		
L-Alanine	7205.33 ± 64.62	3082.67 ± 25.22
L-Aspartic Acid	22,448.55 ± 342.88	11,669.31 ± 25.19
Glycine	5,624.23 ± 81.08	3305.92 ± 38.42
L-Glutamic acid	27,339.10 ± 347.52	14,576.42 ± 18.75
L-Proline	11,351.89 ± 152.37	4,267.35 ± 38.45
L-Serine	8,475.91 ± 135.59	4,261.35 ± 13.29
L-Tyrosine	5570.54 ± 107.57	3,406.01 ± 2.01

The data in Table 5 show variations in amino acid content due to differences in formulation. Lysine in the control was recorded at 13,915.07 ± 168.48, but decreased to 7,436.31 ± 9.18 in the treatment with 30% tapioca. Leucine, on the other hand, showed an increasing trend, from 11,838.67 ± 244.04 to 13,687.24 ± 16.34. Histidine decreased significantly from 12,586.14 ± 266.75 to 6,546.94 ± 9.63, while glutamate decreased from 27,339.10 ± 347.52 to 14,576.42 ± 18.75. These differences indicate an interaction between fish protein and starch during processing. The decrease in lysine may be due to its binding to starch or to degradation during heating, while the increase in leucine may be due to the release of amino acids during protein denaturation. In general, the decrease in most amino acid levels in treatment C (30%) can be explained by a dilution effect from the addition of tapioca flour, which has very low protein content. The increase in L-Leucine and L-Phenylalanine cannot be directly interpreted as a contribution of protein from the tapioca flour, given that this ingredient is not a source of amino acids. The increase in these two amino acids is related to changes in the relative proportions of the amino acid composition within the product matrix, as well as the characteristics of L-Leucine and L-Phenylalanine, which are relatively more stable under heat treatment and may be protected by the starch matrix.

Therefore, this phenomenon better reflects a change in the relative composition of amino acids rather than an absolute increase in protein content. Zhao *et al*. (2025) explain that certain amino acids can remain stable or even become more stable at high temperatures, so not all undergo degradation. This condition indicates that formulations with added tapioca not only affect total protein content but also alter the balance of amino acids.

Processing stages also contribute to these research findings. Steaming can cause protein denaturation and the release of amino acid fractions; drying can reduce the content of water-soluble amino acids; and frying can trigger the Maillard reaction, which can reduce lysine availability as it reacts with reducing sugars. Nasser and Amin (2025) demonstrated that modern drying methods for seafood snack products influence amino acid profiles through thermal changes and compound degradation. Kasyani *et al*. (2025) also reported that baking biscuits with tilapia flour substitution affects the presence of certain essential amino acids, including leucine and isoleucine. Antonets *et al*. (2024) further confirmed that interactions between proteins and starch under high-temperature conditions can form complexes that reduce the availability of some amino acids while simultaneously enhancing the stability of others.

CONCLUSION

Differences in tapioca flour concentration significantly affect the chemical, physical, and sensory characteristics of barracuda (*Sphyraena jello*) fish crackers. Based on sensory test results, the formulation with 30% tapioca flour addition yielded the highest scores for taste, aroma, and texture. It was therefore designated as the optimal formulation for further testing of amino acid content. The 30% treatment also showed the best balance between nutritional quality (high protein) and physical characteristics, making it the optimal formulation.

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REFERENCES

Abou-Taleb, M., S. Talab, A., A. Ibrahim, M., E. Genina, M., R. Anees, F., M. Mahmoud, M., & M. Abou-Taleb, S. (2019). Properties of frozen fish chips processed from some economically underutilized fish species. *Egyptian Journal of Aquatic Biology and Fisheries*, *23*(3), 493–502.

Allan, M. C., Marinos, N., Johanningsmeier, S. D., Sato, A., & Truong, V. D. (2021). Relationships between isolated sweet potato starch properties and textural attributes of sweet potato French fries. *Journal of Food Science*, *86*(5), 1819-1834.

Antonets, O. A., Kupriyanova, T. M., & Antonets, M. O. (2024). Feed and food quality of potato varieties. *Scientific Progress & Innovations*, *27*(4), 79-83.

Azizah, A., Purwandhani, S. N., & Laswati, D. T. (2021). Fortification of barracuda (Sphyraena jello) in the production of tortilla chips. *Agrotech: Journal of Agricultural Technology*, *3*(2), 18-26.

[BSN] National Standardization Agency. 2006[b]. SNI 01-2354.4-2006 – Chemical Test Methods – Part 4: Determination of Protein Content by the Total Nitrogen Method in Fishery Products. Jakarta: National Standardization Agency.

[BSN] National Standardization Agency. 2010. SNI 2354.1:2010 – Chemical Test Methods – Part 1: Determination of Ash and Acid-Insoluble Ash Content in Fishery Products. Jakarta: National Standardization Agency.

[BSN] National Standardization Agency. 2015[c]. SNI 2354.2:2015 – Determination of Moisture Content in Fishery Products. In National Standardization Agency (BSN) (SNI 2354.2:2015). Jakarta: National Standardization Agency.

[BSN] National Standardization Agency. 2018. SNI 8646:2018 – Ready-to-eat fish, shrimp, and mollusk crackers. Jakarta: National Standardization Agency.

Baig, M. A., Mostafa, H., Sivapragasam, N., Aslam, R., Zhou, W., & Maqsood, S. (2024). Investigating the role of starch in the structuring of meat alternatives from mung bean and pea protein isolates via heat-induced gelation. *Frontiers in Sustainable Food Systems*, *8*, 1473663.

Baishak, N. N., Islam, M. R., Moazzem, M. S., Ahmad, I., & Zzaman, W. (2020). Quality evaluation of nutritious fish crackers developed from three carp species. *Asian Food Science Journal*, *17*(1), 15–23.

Baranwal, J., Barse, B., Fais, A., Delogu, G. L., & Kumar, A. (2022). Biopolymers: A sustainable material for food and medical applications. *Polymers*, *14*(5), 983.

Bayomy, H. M., Alamri, E. S., Albalawi, A. N., Alharbi, R., Al-Maris, S., Rozan, M. A., & Shamsia, S. M. (2023). Formation of resistant starch and cracker products from leftover rice in Saudi Arabia. *Journal of Agriculture and Food Research*, *14*, 100832.

Beitane, I., & Marisheva, A. (2023). The potential of amaranth as a basic raw material for the production of pasta for a vegan diet. *Applied Sciences*, *13*(6), 3944

Cankal, Y. S., Berk, B., Köroğlu, E. E., Yorulmaz, H., Çavdaroğlu, E., & Ünlütürk, S. (2025). Influence of Tapioca, Corn, and Potato Starches on Physical and Textural Characteristics of Puffed Starch Crackers. *Academic Food*, *23*(2), 80–90.

Costa, W. Y., & Manihuruk, F. M. (2021). Chemical and Organoleptic Characteristics of Meat Crackers with Added Tapioca Flour and Different Steaming Times. *Jurnal AgroSainTa: Independent Educators Building the Nation*, *5*(1), 9-14.

Davoodi, M. G., Karimi, M., Naghipour, F., & Rahmanian, A. (2025). Investigating the Possibility of Increasing the Shelf Life of Fermented Doughnuts Using Edible Cellulose Films. *Journal of Food Science & Technology (2008-8787)*, *22*(163).

Elida, S., Palupi, E., Sulaeman, A., & Iwansyah, A. C. (2025). Innovative Mackerel Tuna Crackers: Sensory and Nutritional Quality, Digestibility, and Shelf-Life Estimation. *Future of Food: Journal on Food, Agriculture and Society*, *13*(1).

Gonçalves, E. M., Pereira, N., Silva, M., Alvarenga, N., Ramos, A. C., Alegria, C., & Abreu, M. (2023). Influence of air-drying conditions on quality, bioactive composition, and sensory attributes of sweet potato chips. *Foods*, *12*(6), 1198.

Gunawan, H., Handayani, L., & Maulidya, R. (2025). Characteristics of Baung Fish Crackers Made with Different Types of Starch. *Jurnal TILAPIA*, *6*(2), 47–59.

Guttifera, Rahmawati, L., Sari, S. R., Pratama, F., Widowati, T. W., Dewi, S., & Purwandoko P. B. (2024). Chemical characteristics of traditional fish crackers (kemplang) heated using a microwave oven. *Food Research*, *8*(4), 185-192.

Hadiwinata, B., Wulandari, P. S., Sumandiarsa, I. K., Ritonga, R. A., & Mahaji, T. (2024). Substitution of Mackerel (Scomberomorus commerson) Bone Meal in Fish Crackers. *Unram Fisheries Journal*, *14*(4), 2296-2309.

Hoy, J. M., Hamid, M. A., Ayub, M. S., Suratman, R., & Effendi, M. M. (2025). Development of Food Seasoning using Sub-standard Fish Crackers, Pumpkin (*Cucurbita moschata*), and Seaweed (*Kappaphycus alvarezii*). In *IOP Conference Series: Earth and Environmental Science* (Vol. 1446, No. 1, p. 012031). IOP Publishing.

Ianiţchi, D., Pătraşcu, L., Cercel, F., Dragomir, N., Vlad, I., & Maftei, M. (2023). The effect of protein derivatives and starch addition on some quality characteristics of beef emulsions and gels. *Agriculture*, *13*(4), 772.

Indra, R. W., Dewita D., & Sari, N. I.. (2016). The Effect of Different Levels of Tapioca Flour Addition on Consumer Acceptance of Dumbo Catfish (*Clarias gariepinus*) Surimi Meatballs. *Online Journal of Students, Faculty of Fisheries and Marine Sciences, University of Riau*, *3*(2), 1-13.

Kasyani, K., Mursyid, M., Perdana S. M., Ibnu, I. N., Kusmawan, D., Lanita, U., Alfridsyah, A., & Wazzan, H. (2025). Biscuit Formulation Substituting Wheat Flour with Tempeh Flour and Nile Tilapia Fish Flour as a Complementary Food to Prevent Stunting. Indonesian *Food Science and Technology Journal*, *8*(2), 245-252.

Kingwascharapong, P., Paewpisakul, P., Sripoovieng, W., Sanprasert, S., Pongsetkul, J., Meethong, R., ... & Rawdkuen, S. (2024). Development of a fish snack (Keropok) with reduced sodium using alternative salts (KCl and $CaCl_2$). *Future Foods*, *9*, 100285.

Kupriy, A. S., Dunchenko, N. I., & Voloshina, E. S. (2021). Scientific rationale for ingredient selection in functional fish pastes. *Theory and Practice of Meat Processing*, *6*(1), 66–77.

Kusuma, T. D., Suseno, T. I. P., & Surjoseputro, S. (2013). The effect of tapioca and wheat flour proportions on the physicochemical and organoleptic properties of celery crackers. *Jurnal Teknologi Pangan dan Gizi (Journal of Food Technology and Nutrition)*, *12*(1), 17–28.

Li, Y., Xia, X., & Yu, G. (2025). The Effect of frying conditions on the physical and chemical quality attributes of clearhead icefish (Protosalanx hyalocranius) during deep frying and air frying. *Foods*, *14*(6), 920.

Litaay, C., Indriati, A., Mayasti, N. K. I., Tribowo, R. I., Andriana, Y., & Amdriansyah, R. C. E. (2022). Physical, chemical, and sensory quality of noodles fortified with anchovy (Stolephorus sp.) flour. *Food Science and Technology*, *42*, e75421.

Mahyuddin, M., Rizal, A., & Afrizal, A. (2024). Organoleptic Quality and Nutritional Content of Crackers Made from Local Fish (Bleberan) as Snacks for Toddlers at Risk of Stunting. *Amerta Nutrition*, *8*(4).

Maulida, F., Safrida, S., Muhsin, S. W., & Febriansyah, M. I. (2025). Sensory and Chemical Characterization of Endemic Lumi-Lumi Fish Crackers (*Harpodon nehereus*) as a Local Wisdom Product. *Journal of Nutrition Science*, *6*(1), 6–11.

Mindarwati, E., Sedayu, B. B., Suryaningrum, T. D., Mardiyana, I., Prodiana, N., Supriyanto, A., ... & Ramadhan, W. (2024). Sustainable hybrid snack product: impact of dual fortification with Gracillaria seaweed and pressure-cooked milkfish broth by-products on nutritional, physical, textural, and sensory properties. *International Journal of Food Science and Technology*, *59*(9), 6111–6129.

Mutamimah, D., Arista, Y. L. V., Untari, D., & Liasari, A. (2024). Nutritional enrichment from Bali sardinella (Sardinella lemuru) head meal in fish crackers as emergency food. *Indonesian Journal of Fisheries Product Processing*, *27*(12), 1146-1155.

Nasser, A., & Amin, H. (2025). Impact of microwave-drying on the quality of innovative shrimp and clam snacks. *Egyptian Journal of Aquatic Biology and Fisheries*, *29*(1), 2779-2793.

Nawaz, A., Li, E., Khalifa, I., Walayat, N., Liu, J., Irshad, S., ... & Lorenzo, J. M. (2021). Effect of different processing methods on quality, structure, oxidative properties, and water distribution properties of fish meat-based snacks. *Foods*, *10*(10), 2467.

Ndahawali, D. H., Ticoalu, F., Wewengkang, I. D., Tumanduk, N. M., Hariyoto, F. D., & Soeharso, A. P. (2024). Standardization of ingredients and frying time for the squid stick home industry. In *BIO Web of Conferences* (Vol. 87, p. 03002). EDP Sciences.

Nimitkeatkai, H., Pasada, K., & Jarerat, A. (2022). Effects of tapioca starch and wheat flour on the physicochemical properties and sensory attributes of meat-based snacks made from beef scraps. *Foods*, *11*(7), 1034.

Nor, M. Z. M., Talib, R. A., Noranizan, M. A., Chin, N. L., & Hashim, K. (2014). Increasing resistant starch content in fish crackers through repetitive cooking-chilling cycles. *International Journal of Food Properties*, *17*(5), 966-977.

Palomino-Rincón, H., Ramos-Pacheco, B. S., Buleje Campos, D., Guzmán Gutiérrez, R. J., Yauris-Navez, E. M., & Alarcón-Quispe, E. (2025). Influence of Ultrasound Frequency as a Preliminary Treatment on the Physicochemical, Structural, and Sensory Properties of Fried Native Potato Chips. *Processes*, *13*(8), 2668.

Pedrali, D., Proserpio, C., Borgonovi, S. M., Zuccolo, M., Leoni, V., Borgonovo, G., Bernardi, A. M., Pagliarini, E., Giorgi, A., & Giupponi, L. (2022). Nutritional Characterization and Novel Use of “Copafam” Bean (*Phaseolus coccineus* L.) for the Sustainable Development of Mountainous Areas. *Sustainability*, *14*(20): 1–20.

Purnomo, P., Soetikno, N., Windari, W., & Adawyah, R. (2019). The Effect of Different Ratios of Fish Meat to Tapioca Flour on the Quality of Snakehead Fish

Crackers (Channa Striata). *Fish Scientiae*, *9*(2), 104-114.

Putra, H. B. P., Anandini, D. R., Amani, Z. N., & Arifin, M. H. (2024). The Effect of Spirulina platensis Addition on the Physicochemical and Hedonic Properties of Gluten-Free Cookies Made from Mocaf and Sorghum Composite Flour. *Int. J. Res. Public. Rev.*, *5*, 1070-1076.

Raharja, K. T., Rahayu, A. N., Sudarmayasa, I. W., & Handayani, A. M. (2021). Organoleptic Characteristics and Antioxidant Activity of Salak Seed Coffee Boba. *Jurnal Gizido*, *13*(May 1), 15–23.

Ramesh, R., Shakila, R. J., Sivaraman, B., Ganesan, P., & Velayutham, P. (2018). Optimization of gelatinization conditions to improve the expansion and crispiness of fish crackers using RSM. *LWT*, *89*, 248–254.

Resti, N., Ayustaningwarno, F., Nuryanto, N., Chasanah, E., Purwani, E. Y., Zhu, F., ... & Afifah, D. N. (2024). Physicochemical quality of dry noodles made from maize flour and fish protein hydrolyzate (Mizepi) as a potential emergency food. *Food Production, Processing and Nutrition*, *6*(1), 92.

Reyniers, S., Ooms, N., & Delcour, J. A. (2020). Transformations and functional role of starch during potato crisp making: A review. *Journal of Food Science*, *85*(12), 4118–4129.

Rico, D., Schorn-García, D., Aceña, L., García-Casa, M. J., Busto, O., Boqué, R., Mestres, M., & Martín-Diana, A. B. (2024). Exploring New Horizons for Wine Grapes: Modulating Functional Effects by Varying Harvest Timing and Solar Exposure. *Foods*, *13*(6), 1–20.

Sali, F., Asnani, A., & Suwarjoyowirayatno, S. (2020). Chemical and organoleptic quality of Barracuda (Sphyraena jello) fish nuggets with substitution of tapioca flour and carrot flour (Daucus carota L.). *Jurnal Fish Protech*, *3*(1), 1-8.

Störmer, A., Hetzel, L., & Franz, R. (2024). A critical review of test methods and alternative scientific approaches to compliance and safety evaluation of paper and board for food contact. *Frontiers in Chemistry*, *12*, 1397913.

Abu Talib, A., Russly, A. R., Bakar, J., Mahmud Ab Rashid, N. K., Ashari, R., & Shukri, R. (2024). Effects of different starches on the physicochemical and sensory characteristics of extruded fish snacks. *Food Research*, *8*(6), 57-70.

Tokarczyk, G., Bienkiewicz, G., Biernacka, P., Przybylska, S., Sawicki, W., & Tabaszewska, M. (2025). Effect of Frying Temperature on Lipid Binding, Fatty Acid Composition, and Nutritional Quality of Fish Crackers Prepared from Carp (Ciprinus carpio L.) and Tapioca Starch (Manihot esculentus). *Molecules*, *30*(5), 1139.

Wang, S., Li, C., Copeland, L., Niu, Q., & Wang, S. (2015). Starch retrogradation: A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety*, *14*(5), 568–585.

Wang, Y., Wu, X., McClements, D. J., Chen, L., Miao, M., & Jin, Z. (2021). Effect of new frying technology on starchy food quality. *Foods*, *10*(8), 1852.

Zhao, W., Zhang, Y., & Sun, H. (2025). Unlocking marine food potentials: empowering bioactive compounds, precision nutrition, and sustainable dietary solutions. *Frontiers in Nutrition*, *12*, 1674047.

Zhao, Y., Zhou, W., Li, M., Zhang, Y., Lv, W., Huang, W., ... & Li, M. (2025). Effects of Different Farming Models on Muscle Quality, Intestinal Microbiota Diversity, and Liver Metabolism of Rice Field Eel (Monopterus albus). *Foods*, *14*(13), 2383.

Zhu, J., Li, J., Wu, H., Zhu, Y., Dong, J., Huang, R., & Shen, R. (2024). Processing of Whole Kernel Tapioca Pearl and Milk Tea Boba from Fresh Highland Barley: Optimization of Processing Parameters and Quality Evaluation. *Foods*, *13*(6), 927.