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Holistic Quality Assessment of Traditional Smoked Fish from the Sangihe Islands: Proximate, Sensory, and Microbiological Profiles

Eko Cahyono[1*], Frans Gruber Ijong[1], Yana Sambeka[1], Wendy Alexander Tanod[1], Frets Jonas Rieuwpassa[1], Novalina Maya Sari Ansar[1], Yosephina Margaretha Jawa Batafor[2]
[1]Fisheries Product Processing and Storage Study Program, Politeknik Negeri Nusa Utara
[2]Fisheries Product Technology Study Program, Institut Keguruan dan Teknologi Larantuka
*Email Corespondence: ekocahyono878@gmail.com

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ABSTRACT

This study characterized the chemical, sensory, and microbiological properties of four smoked fish products typical of the Sangihe Islands (*pinekuhe*, skipjack, *tinapa*, and *roa*). Twelve samples were collected from four production centers (n=3 per smoked fish type). Proximate analysis (moisture, ash, fat, protein, and carbohydrates) followed SNI standards; sensory evaluation involved 30 panelists using a 1–9 hedonic scale; and microbiological quality was measured via Total Plate Count (TPC). Data were analyzed using one-way ANOVA and Tukey's post-hoc test. Significant differences were found among products for all proximate parameters ($p<0.01$; $\eta^2=0.72–0.89$). Smoked *roa* fish had the lowest moisture content (17.46±0.31%) and the highest protein (23.78±0.16%) and ash (4.15±0.06%) contents. Smoked *tinapa* had the highest moisture content and was more prone to spoilage. Smoked skipjack had the highest fat content and the best appearance and texture scores, while smoked *pinekuhe* received the highest flavor score. All samples met the maximum ALT limit according to SNI (5.0×10^5 CFU/g). Each product has specific quality advantages; however, products with relatively high moisture content require better hygiene practices to improve safety and shelf life. These findings provide an initial scientific basis for efforts to improve the quality of local products in the Sangihe Islands and surrounding area.

INTRODUCTION

Fish smoking is one of the oldest food preservation techniques in the world, used since prehistoric times to extend shelf life and prevent spoilage[1]. As consumer awareness of healthy and safe eating patterns increases, global demand for traditional foods that meet modern nutritional and safety standards continues to rise [2]. In this context, traditional smoked fish products have great market potential if supported by adequate scientific documentation on their nutritional, sensory, and safety qualities.

Indonesia is known as the world's largest maritime country, with two-thirds of its territory comprising oceans and abundant fisheries, making it one of the largest global fish producers3. This enormous potential contributes significantly to food security, the national economy, and the welfare of coastal communities. However, inconsistent processing practices in small-scale fisheries often lead to variations in product quality and increase the risk of microbial contamination, thereby endangering consumer health and reducing product competitiveness in the market[4].

The Sangihe Islands are an archipelago at the northern tip of Indonesia known as a marine biodiversity hotspot, with rich coral reef ecosystems and abundant fishery potential[5]. The Sangihe community has a tradition of fish smoking passed down through generations, producing distinctive products such as *pinekuhe* (smoked fish cut using the butterfly technique), smoked skipjack tuna, smoked *tinapa* (smoked shark), and smoked *roa* (julung-julung fish). These products are not only an important source of protein for the local community, but also have high economic and cultural value.

Beyond the comparative quality assessment, the proximate values observed in this study have direct implications for public health nutrition in the Sangihe Islands. Smoked *roa*, with protein content of 23.78% and very low moisture (17.46%), represents a shelf-stable, protein-dense food resource that could be particularly valuable during the northwest monsoon season (December–March) when fishing activities are severely restricted. A 100 g serving of smoked *roa* provides approximately 23.8 g of protein, equivalent to 44-48% of the recommended daily intake for adults (based on 50-60 g protein/day reference). Similarly, smoked skipjack tuna offers not only protein but also a fat content of 6.32%, including omega-3 fatty acids beneficial for cardiovascular health, a relevant consideration given the increasing burden of non-communicable diseases in transitioning coastal communities in Eastern Indonesia[6]. This nutritional perspective elevates the study's relevance beyond food processing into the domain of community nutrition and food security.

Despite its strategic role, scientific documentation of Sangihe's distinctive smoked fish remains fragmented. [7]reported on the microbiological aspects of *Pinekuhe* smoked fish but did not examine its nutritional composition or sensory profile, leaving unanswered whether the identified *Staphylococcus aureus* contamination levels correlate with consumer rejection or product safety. Conversely, studies on smoked fish in Eastern Indonesia generally focus on proximate analysis without simultaneous sensory and microbiological assessment[8]. This fragmentation creates a critical knowledge gap: without integrated data, we cannot determine, for example, whether a product with high protein content (nutritionally desirable) also harbors high microbial loads (unsafe), or whether a product that consumers rate highly for taste also has excessive moisture content (short shelf life). The novelty of this study lies not merely in applying three analytical methods but in generating an integrated quality map that reveals trade-offs and synergies among nutritional value, consumer preferences, and food safety information, all of which are essential for evidence-based product diversification. To our knowledge, no previous study has simultaneously analyzed proximate, sensory, and microbiological parameters for this specific portfolio of Sangihe smoked fish products, nor explicitly linked these integrated findings to actionable diversification strategies.

This study aims to holistically characterise the chemical (proximate), sensory, and microbiological (Total Plate Count) characteristics of four types of traditional smoked fish from the Sangihe Islands: smoked *pinekuhe*, smoked skipjack tuna, smoked *tinapa*, and smoked *roa*. While previous studies have examined either the chemical quality of smoked *pinekuhe*[9] or the microbiological contamination of the same product[7] separately, no integrated assessment covering proximate, sensory, and microbiological parameters has been conducted for the diversity of Sangihe smoked fish products. Furthermore, smoked *tinapa* (shark) and smoked *roa* (garfish) have received little scientific attention despite their distinctive processing characteristics and potential for diversification. Therefore, this study offers a novel contribution not by introducing entirely new methodologies, but by applying a holistic assessment framework to a wider range of Sangihe specialty products and by explicitly linking quality profiles to product-specific diversification strategies. This geographical and comparative focus represents an incremental but meaningful advance over previous single-product or single-parameter studies.

MATERIALS AND METHODS

Time and Place

The research was conducted from August to December 2025. Sampling was conducted at the smoked fish production centre in Tahuna District, Sangihe Islands Regency, North Sulawesi. Proximate, sensory, and microbiological analyses were conducted at the Fishery Product Processing and Storage Laboratory at Nusa Utara State Polytechnic.

Tools and Materials

The main ingredients were four types of traditional smoked fish typical of the Sangihe Islands: smoked *Pinekuhe* (*Decapterus* spp.), smoked Skipjack tuna (*Katsuwonus pelamis*), smoked *Tinapa* (*Carcharhinus* spp.), and smoked *Roa* (*Hemirhamphus* spp.). Each sample consisted of 4 fish, each weighing 500 grams. Chemicals for proximate analysis (n-hexane, H_2SO_4, HCl, boric acid, indicators) were of analytical grade (Merck, Germany). The microbiological media used were Plate Count Agar (Oxoid, UK) and Buffered Peptone Water (Oxoid, UK). The main equipment included preparation equipment (stainless steel knives, cutting boards), electric oven (Memmert UN55, Germany), electric furnace (Thermolyne F6010, USA), soxhlet extractor, Kjeldahl apparatus (FOSS Kjeltec 8400, Denmark), laminar air flow cabinet (ESCO AC2-4S1, Singapore), autoclave (Hirayama HVE-50, Japan), incubator (Memmert IN55, Germany), and colony counter (Stuart SC6, UK).

Quality Control Measures.

The following quality control procedures were implemented throughout the study. For proximate analysis: All analytical balances were calibrated daily using certified standard weights (100 g ± 0.001 g). Oven temperature (105°C for moisture) and furnace temperature (550°C for ash) were verified weekly using calibrated thermocouples. For each batch of samples, a reagent blank (no sample) was analyzed alongside the samples to detect contamination from chemicals or glassware.

For microbiological analysis: Negative controls (sterile buffered peptone water plated on PCA) were incubated simultaneously with all sample plates to verify media sterility. Positive controls were not used because this was a quantitative enumeration (TPC) rather than a pathogen detection assay. All media were prepared according to manufacturer instructions, and each batch of PCA was tested for sterility by incubating 5% of the plates at 36°C for 48 hours prior to use. For sensory evaluation: Samples were served at room temperature (25±2°C) in white ceramic containers coded with three-digit random numbers. The serving order was randomized for each panelist using a Latin square design to minimize order effects. Panelists were instructed not to communicate during testing and to rinse their mouths with plain water between samples. General quality assurance: All glassware was washed with detergent, rinsed with distilled water, and sterilized in an autoclave at 121°C for 15 minutes before use. Analytical work for proximate and TPC was conducted in triplicate, and if the coefficient of variation (CV) exceeded 10%, the analysis was repeated.

Traditional Smoked Fish Processing Procedures

The smoked fish processing procedures were observed and documented in accordance with the traditional practices of the Sangihe community. Fresh fish were sorted by relatively uniform size, then cleaned of gills and entrails with stainless steel knives. Large fish (skipjack tuna, shark) were split lengthwise using the butterfly cut technique without separating the two sides of the fillet. The fish were washed with running water until clean. The fish were drained on bamboo racks at room temperature for 30 minutes, with one turning to reduce surface water. Smoking was conducted using a traditional stove fueled by a mixture of mango, coconut, and teak wood, along with coconut shells. The fish were arranged on bamboo racks with a distance of ±2 cm between each fish. The smoking process lasted for 6 hours. The smoking temperature was estimated to be 80-90°C based on traditional practices. The smoked fish was cooled to room temperature on a clean bamboo rack in a single layer for 2 hours, protected from dust and insects.

Parameter Testing

Organoleptic Test: Panelist selection and validation. Thirty untrained panelists (students from the Nusa Utara State Polytechnic) were recruited based on the following inclusion criteria: (a) aged 18–25 years; (b) non-smokers (or abstained from smoking for at least 2 hours before testing); (c) no self-reported cold, flu, or other conditions affecting taste or smell; (d) willing to consume fish products 10. Prior to the hedonic test, all candidates underwent a basic taste recognition test using solutions of sucrose (sweet), sodium chloride (salty), citric acid (sour), and quinine sulfate (bitter). Panelists consumed plain water before evaluating each sample to neutralize their taste buds. The sensory testing room was maintained at 22–25°C with white fluorescent lighting, in accordance with SNI 2725:2013 guidelines.

Proximate Analysis: Proximate analysis was performed in accordance with SNI 2354:2006. Moisture content was determined using the oven method at 105°C until a constant weight was reached. Ash content was determined by incineration in a furnace at 550°C for 6 hours. Fat content was analysed by the Soxhlet method using n-hexane as the solvent. The protein content was analysed using the Kjeldahl method (conversion factor 6.25). The carbohydrate content was calculated by difference (100% - % water - % ash - % fat - % protein).

Microbiology Analysis (Total Plate Count/TPC): TPC analysis was carried out in accordance with SNI 2332.3:2015. A total of 25 g of the sample was homogenised in 225 mL of sterile BPW, then diluted stepwise to 10^{-6}. One millilitre of suspension from each dilution was poured into a sterile Petri dish and mixed with approximately ±15 mL of PCA medium. Incubation was carried out at a temperature of 36±1°C for 48 hours. The colonies that grew were counted using a colony counter and were expressed as CFU/g. Negative controls (media without inoculation) were incubated simultaneously.

Data Analysis

Proximate data and TPC were analysed using one-way Analysis of Variance (ANOVA) with the help of SPSS version 26 (IBM, USA). Data were analyzed using one-way ANOVA and Tukey's post-hoc test. Organoleptic data were analyzed descriptively and presented as a radar diagram. All data are presented as means ± standard deviation.

RESULTS

Chemical Characteristics of Smoked Fish

The chemical composition of the four types of traditional smoked fish from the Sangihe Islands is presented in Table 1. Proximate analysis results showed significant variation among products across all parameters.

Table 1. Chemical characteristics of traditional smoked fish from the Sangihe Islands

Products	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Carbohydrate* (%)
Smoked *pinekuhe*	41.29 ± 0.52^{b}	1.76 ± 0.21^{b}	3.46 ± 0.26^{c}	22.18 ± 0.31^{b}	31.31 ± 0.55^{b}
Smoked skipjack	42.68 ± 0.14^{b}	0.33 ± 0.20^{d}	6.32 ± 0.28^{a}	22.39 ± 0.31^{b}	28.29 ± 0.46^{c}
Smoked *tinapa*	57.70 ± 0.08^{a}	0.89 ± 0.10^{c}	4.52 ± 0.02^{b}	15.46 ± 0.45^{c}	21.42 ± 0.47^{d}
Smoked *roa*	17.46 ± 0.31^{c}	4.15 ± 0.06^{a}	4.47 ± 0.20^{b}	23.78 ± 0.16^{a}	50.14 ± 0.06^{a}
ANOVA p-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**

**Carbohydrate by difference*

One-way ANOVA revealed significant differences among the four products for all proximate parameters ($p < 0.01$ for moisture, ash, fat, and protein). Post-hoc comparisons using Tukey's HSD test showed that smoked *roa* had significantly lower moisture content than all other products (mean difference = -24.22% to -40.24%, $p < 0.01$ for all pairwise comparisons), while smoked *tinapa* had significantly higher moisture than smoked skipjack and smoked *pinekuhe* (mean difference = +15.02% and +16.41%, respectively, $p < 0.01$). For protein content, smoked *roa* was significantly higher than smoked *tinapa* (mean difference = +8.32%, 95% CI: 7.89-8.75, $p < 0.001$), but not significantly different from smoked skipjack (mean difference = +1.39%, 95% CI: -0.28 to 3.06, $p = 0.092$). These confidence intervals indicate that with 95% certainty, the true protein difference between smoked *roa* and smoked skipjack lies between -0.28% and +3.06%, suggesting practical equivalence for nutritional purposes

Visual Appearance of Smoked Fish

The characteristics of smoked fish, such as skipjack tuna, *tinapa*, *pinekuhe*, and *roa*, vary depending on the smoking method and materials used, as shown in Figure 1.

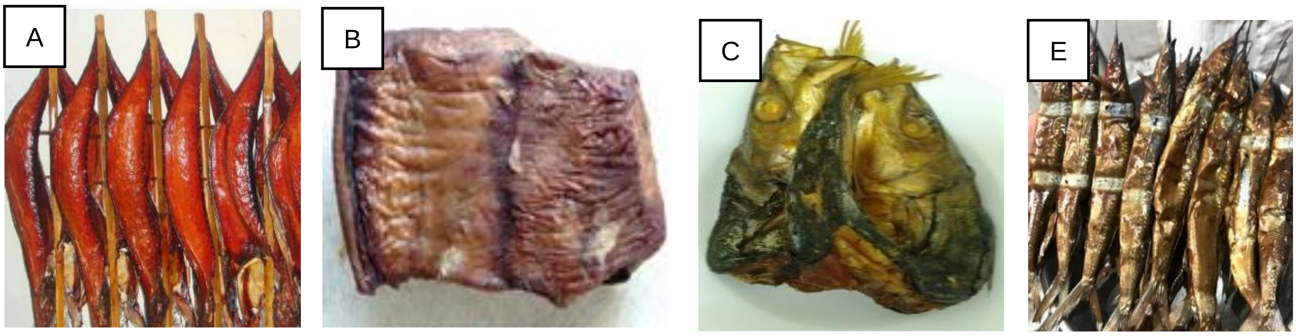

Figure 1. Visual of traditional smoked fish from the Sangihe Islands: [A] Smoked skipjack tuna with a distinctive golden-yellow colour and firm texture; [B] Smoked *tinapa* displaying firm meat fibers and a reddish-brown colour; [C] Smoked *pinekuhe* with a butterfly cut technique forming folds resembling a frog, a characteristic of Sangihe; [D] Small smoked *roa* with a golden-brown colour and natural skin luster.

Sensory Value of Smoked Fish

The sensory attributes of smoked fish include aroma, taste, texture, and overall appearance, as presented in Table 2.

Table 2. Sensory analysis of traditional smoked fish from the Sangihe Islands

Products	Appearance	Aroma	Taste	Texture
Smoked *pinekuhe*	6.90±1.21^{a}	7.11±1.35^{ab}	7.33±1.15^{a}	6.80±1.47^{ab}
Smoked skipjack	7.00±1.32^{a}	6.60±1.20^{a}	6.60±1.43^{ab}	6.60± 1.44^{a}
Smoked *tinapa*	6.70±1.49^{ab}	6.10± 1.53^{b}	5.60±1.58^{b}	6.60±1.48^{ab}
Smoked *roa*	5.33±1.49^{b}	6.00±1.41^{ab}	4.70± 1.40^{b}	4.60±1.43^{c}
ANOVA p-value	***p<0.01***	***p<0.01***	**p<0.01**	***p<0.01***

Total Plate Count

Total Plate Count (TPC) is an important microbiological parameter used to assess the quality and safety of food products by measuring the total number of live bacteria. The results are presented in Table 3.

Table 3. Total Plate Count of traditional smoked fish from the Sangihe Islands

Products	Test Results (CFU/g)	SNI 2332.3-2015
Smoked *pinekuhe*	2.4×10^5	5.0×10^5 (CFU/g)
Smoked skipjack tuna	2.5×10^5	
Smoked *tinapa*	1.4×10^5	
Smoked *roa*	1.5×10^3	

DISCUSSION

Chemical Characteristics of Smoked Fish

Smoked mackerel had the highest moisture content (57.70±0.08%), followed by smoked skipjack tuna (42.68±0.14%) and smoked *pinekuhe* (41.29±0.52%), while smoked *roa* has the lowest moisture content (17.46±0.31%). All products show highly significant differences ($p<0.01$). These differences are influenced by the characteristics of the raw materials and the duration of the smoking process. Shark (*tinapa*) has denser meat and tends to retain more water during smoking. The high moisture content of *tinapa* (>55%) classifies it as a high-moisture product[11], which implies a short shelf life and a higher risk of microbial growth. Conversely, the very low moisture content of *roa* reflects the intensive smoking process applied to small fish, resulting in a product with a firm texture and a long shelf life.

The highest ash content was found in smoked *roa* (4.15±0.06%), followed by smoked *pinekuhe* (1.76±0.21%), smoked *tinapa* (0.89±0.10%), and the lowest in smoked skipjack tuna (0.33±0.20%). The high ash content of smoked *roa* indicates a high mineral content, especially calcium and phosphorus from the fine bones of the julung-julung fish. This finding aligns with that of[12], who reported that small fish have a higher bone-to-meat ratio, resulting in higher ash content. Smoked skipjack tuna, with the lowest ash content, has a high meat-to-bone ratio and is free of fine bones.

Smoked skipjack tuna had the highest fat content (6.32±0.28%), followed by smoked *tinapa* (4.52±0.02%) and smoked *roa* (4.47±0.20%), while smoked *pinekuhe* had the lowest (3.46±0.26%). Fish species primarily determine this variation. Skipjack tuna is known as a fatty fish with high omega-3 fatty acid content[13]. The high fat content contributes to the formation of a distinctive aroma through lipid oxidation during smoking which aligns with the highest aroma score for smoked skipjack tuna (7.11±1.35).

Smoked *roa* had the highest protein content (23.78±0.16%), not significantly different from smoked skipjack tuna (22.39±0.31%) and smoked *pinekuhe* (22.18±0.31%), while smoked *tinapa* had the lowest (15.46±0.45%). The increase in protein content in smoked products is due to the concentration effect resulting from reduced water content[14]. Smoked *roa*, with the lowest water content, showed the strongest concentration effect. Protein plays an important role in flavour formation through the Maillard reaction and interactions with smoke compounds[15].

Because direct enzymatic measurement of available carbohydrates was not performed, we conducted a sensitivity analysis to assess how analytical errors might affect the calculated carbohydrate value for smoked *roa*. Assuming a conservative analytical error of ±2% for moisture and ±1% for ash, fat, and protein (typical for proximate analysis), the 95% confidence interval for carbohydrate-by-difference would range from approximately 43% to 57%. Even at the lower bound of 43%, this value remains unexpectedly high for a fish product. We therefore conclude that the elevated carbohydrate calculation likely reflects cumulative analytical error and the presence of unmeasured components (e.g., glycoproteins from fine bone matrix, potential carbohydrate-based glazes from traditional recipes). For accurate determination, direct enzymatic analysis is required in future studies.

The carbohydrate content, calculated by difference, was highest in smoked *roa* (50.14±0.06%), followed by smoked *pinekuhe* (31.31±0.55%), smoked skipjack tuna (28.29±0.46%), and smoked *tinapa* (21.42±0.47%). The very high value in smoked *roa* needs to be interpreted with caution. The by-difference method is cumulative, so it is prone to error if one of the measured parameters is inaccurate. Possible causes include the inclusion of non-protein, non-fat components, such as crude fibre from fine bones, or the addition of traditional seasonings that contain carbohydrates.

The Holistic Perspective for Product Diversification

The core contribution of this study is not merely the separate reporting of proximate, sensory, and microbiological data, but the integration of these three dimensions into a holistic quality assessment. Here we synthesize these findings to provide actionable insights for product diversification, recognizing that no single product excels in all dimensions simultaneously.

For smoked *roa*, the integration of high nutritional value (protein 23.78±0.16%, very low moisture 17.46±0.31%, suggesting long shelf life), with microbiological safety (lowest TPC at 1.5×10^3 CFU/g) presents a compelling case for positioning this product as a shelf-stable protein reserve for food-insecure periods, particularly during the northwest monsoon season when fishing is limited. However, the sensory trade-off is substantial: its low texture score (4.60±1.43) and low appearance score (5.33±1.49) indicate that consumers may not prefer it for direct consumption. The diversification implication is clear: smoked *roa* should be developed not as a ready-to-eat product, but as a protein-dense ingredient for further processing (e.g., rehydration in soups, incorporation into fish floss or fish crackers) or as an emergency food reserve where sensory considerations are secondary to nutritional security and shelf life. This dual positioning, as both a strategic reserve and an industrial ingredient, maximizes the value of its nutritional and safety advantages while mitigating its sensory weaknesses.

For smoked skipjack tuna, the integration tells a different story. This product achieves the highest sensory scores for appearance (7.00±1.32), aroma (7.11±1.35), and texture (6.60±1.48), combined with favorable nutritional attributes (protein 22.39±0.31%, fat 6.32±0.28% including likely omega-3 fatty acids). This makes it an excellent candidate for the development of premium ready-to-eat products. However, the food safety dimension raises a caution: its TPC value (2.5×10^5 CFU/g) approaches the SNI maximum limit of 5.0×10^5 CFU/g. The integration of these findings suggests that smoked skipjack tuna already has strong consumer acceptance and good nutritional value, but improvements in post-smoking hygiene (e.g., use of food-grade handling equipment, protection from dust and insects during cooling and packaging) are necessary to ensure its safety profile matches its sensory appeal. Without such improvements, the product's commercial potential cannot be fully realized.

For smoked *pinekuhe*, the highest taste score (7.33±1.15) is its primary asset. This suggests that taste-driven diversification, such as smoked fish floss (abon), fish crackers, or seasoned smoked fish products, would be most successful with this product. However, like smoked skipjack tuna, its TPC (2.4×10^5 CFU/g) approaches the safety limit, indicating that hygiene improvements are equally urgent. The butterfly cut technique, which is unique to Sangihe, provides a larger surface area for smoke penetration but may also increase exposure to post-smoking contamination. Diversification strategies for *pinekuhe* should therefore prioritize hygiene-certified processing while leveraging its superior taste profile.

For smoked *tinapa*, the integration reveals the most urgent concerns. Its high moisture content (57.70±0.08%), the highest among the four products, combined with the lowest taste score (6.03) and only moderate TPC (1.4×10^5 CFU/g), suggests that this product requires immediate intervention. The high moisture content increases the risk of spoilage and shortens shelf life. Diversification strategies could include: (a) post-smoking drying to reduce moisture to below 50%; (b) vacuum packaging to extend shelf life; (c) refrigeration requirements for distribution; or (d) repositioning as a product for immediate consumption rather than storage. Without such interventions, smoked *tinapa* will remain the most vulnerable product in the Sangihe smoked fish portfolio.

Visual Appearance of Smoked Fish

Visual differences between products reflect not only variations in raw materials but also specific processing techniques. *Pinekuhe*, with its distinctive butterfly cut, for example, not only serves an aesthetic purpose but also increases the surface area exposed to smoke, allowing for optimal penetration of flavour compounds[16,17].

Sensory Value of Smoked Fish

Products with a high appearance score, such as smoked skipjack tuna (7.00±1.32), had a uniform golden-brown colour, whereas those with a low appearance score, such as smoked *roa* (5.33±1.49), were either too dark or too pale. According to Wicaksono et al.[18], different smoking methods, such as hot smoking and the type of wood used, can cause significant differences in the colour of smoked fish. The characteristics of the raw materials also greatly affect the appearance of the smoked fish produced. According to Devadawson[13], characteristics inherent to raw fish, such as the presence of natural pigments like carotenoids and hemoproteins, play an important role in determining the colour of smoked fish products. A fish's diet and sex can influence these pigments; female fish often have higher carotenoid levels and more intense colouration. The smoking process does not involve the addition of dyes that can affect the appearance of smoked fish.

Products with a strong smoked fish odour (7.11±1.35) were preferred for their distinctive aroma. The characteristic aroma of smoked fish results from a complex interaction of volatile compounds. Consistent with previous reports, phenolic volatile compounds formed by the pyrolysis of wood lignin (e.g., guaiacol and syringol derivatives) are the most important group of compounds contributing to the smoky aroma[19]. However, our study did not measure these compounds directly. This is a limitation. The higher aroma score for smoked skipjack tuna (7.11±1.35) compared to smoked *tinapa* (6.27) may be related to its higher fat content (6.32% vs. 4.52%), as lipids are known to absorb and retain volatile smoke compounds — a relationship that should be confirmed by direct volatile compound analysis in future studies. 20reported that aldehyde compounds, such as hexanal and heptanal, are prominent in fresh and smoked fish and contribute to their distinctive aroma. [20] noted that fresh fish typically has higher alcohol concentrations, which can give off a fishy odour that is often masked or altered during the smoking process.

Taste value indicates the level of acceptance of a product's flavour. The study found that the highest taste value was in smoked *pinekuhe* (7.33±1.15). The taste of smoked fish is significantly influenced by its smoky, savoury, and authentic flavours, which arise from complex interactions among chemical compounds and processing techniques. According to Chen et al[22], fish contains various amino acids and nucleotides such as glutamate, aspartate, glycine, alanine, and arginine, which are often dominant as umami flavour carriers. The savoury aspect of *pinekuhe* is largely associated with the presence of umami compounds, naturally found in fish. In addition, the presence of other nutritional components, such as smoke-derived fats and phenolic compounds, can affect taste and preference. According to Nur et al[16], the use of coconut trunks, driftwood, and coconut husks produces a taste that meets standards. [19]added that components in wood produce major flavour compounds, including guaiacol, 4-methylguaiacol, syringol, 4-methylsyringol, cresol, and phenol, which contribute strongly to smoke attributes such as smoky, burnt, ashy, and creosote.

The best texture value was found in smoked skipjack tuna (6.60±1.43), and the lowest in smoked *roa* (4.60±1.43). This is thought to be influenced by several factors, including the smoking method, duration, smoking temperature, and packaging method. According to Odoli et al[23], traditional smoking methods often use high temperatures and rapid dehydration, causing denaturation and aggregation of myofibrillar proteins. This reduces protein solubility and alters muscle structure, resulting in a harder texture and decreased sensory quality. The smoking process carried out by the people of the Sangihe Islands brings the fish close to the heat source, which can cause parts of the fish to burn or become too dry, affecting the overall texture and appearance. According to Altan24, traditional smoking methods significantly reduce water content, which is crucial for maintaining the desired texture. The loss of moisture can make the fish taste dry.

Total Plate Count

All samples met the maximum TPC limit according to SNI 2332.3-2015 (5.0×10^5 CFU/g). However, the TPC values for smoked skipjack tuna (2.5×10^5 CFU/g) and smoked *pinekuhe* (2.4×10^5 CFU/g) were close to the threshold, indicating the need for improved process hygiene. The high TPC in these two products positively correlates with relatively high moisture content (42.68±0.14% and 41.29±0.52%, respectively), which supports bacterial growth[25]. Conversely, smoked *roa* with the lowest moisture content (17.46±0.31%) had the lowest TPC (1.5×10^3 CFU/g), confirming the critical role of moisture content in inhibiting microbial growth. Although still safe, the TPC values approaching the limit in skipjack tuna and *pinekuhe* require attention. Hygiene improvements can be achieved by ensuring that fresh fish is washed with clean running water, using food-grade equipment, avoiding direct contact between smoked products and dirty surfaces, and improving sanitation in the smoking room. This study only measured TPC as a general indicator of hygiene. For a more comprehensive food safety assessment, future studies should analyse specific pathogenic bacteria, such as Salmonella spp, Escherichia coli, and Staphylococcus aureus.

CONCLUSION

This study successfully established the holistic quality profile of four traditional smoked fish products from the Sangihe Islands. The key quantitative findings are as follows: (1) Smoked *roa* had the lowest moisture content (17.46±0.31%) and lowest Total Plate Count (1.5×10^3 CFU/g), indicating the longest potential shelf life, but received the lowest texture score (4.60±1.43/9); (2) Smoked skipjack tuna had the highest fat content (6.32±0.28%) and highest sensory scores for aroma (7.11±1.35/9), appearance (7,00±1.32/9), and texture (6,60±1.48/9), but its TPC (2.5×10^5 CFU/g) approached the SNI safety limit; (3) Smoked *pinekuhe* achieved the highest taste score (7,33±1.15/9) and moderate TPC (2.4×10^5 CFU/g); (4) Smoked *tinapa* had the highest moisture content (57.70±0.08%) and the lowest taste score (4,70± 1.40/9), requiring urgent handling improvements. All four products met the SNI TPC maximum threshold of 5.0×10^5 CFU/g. These findings provide an initial scientific reference for local quality improvement efforts in the Sangihe Islands. With appropriate caution regarding the limited geographical scope, the results can inform product-specific diversification strategies. Based on the limitations identified in this study, we recommend the following specific directions for future research: Pathogen-specific safety analysis. Quantitative analysis of Salmonella spp., Escherichia coli, Staphylococcus aureus, and Vibrio parahaemolyticus in all four products, following SNI or BPOM protocols, to provide complete food safety profiles.

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