

PROXIMATE, AMINO ACIDS, FATTY ACIDS, AND SENSORY PROPERTIES OF SMOKED YELLOWFIN TUNA (*Thunnus albacares*)

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Abstract

Smoking is one of the oldest and most widely used preservation methods, providing a distinctive taste and increasing shelf life due to the activity of antimicrobial components and the production of specific color, taste, aroma, and appearance. This study aimed to determine the effect of smoking whole fish (asar) and fillets (fufu) on the chemical characteristics, including the proximate composition, fatty acid profile, and amino acid content, as well as the organoleptic properties of smoked yellowfin tuna. Amino acid analysis was performed using LC-MS, the fatty acid profile was assessed using GC-MS, and organoleptic evaluation was performed using the hedonic test. The study design used two forms of smoked fish: whole (asar fish) and fillet (fufu fish). Chemical content data were analyzed by ANOVA with DMRT advanced test, while hedonic data were tested by Kruskal–Wallis with Mann-Whitney advanced test. The results showed that the asar and fufu smoking methods significantly affected the moisture, ash, and protein content, but did not significantly affect the fat and carbohydrate content. Fresh, asar, and fufu yellowfin tunas have nine essential and nine nonessential amino acids. The essential amino acids are lysine, histidine, leucine, valine, isoleucine, phenylalanine, threonine, methionine, and tryptophan, whereas the nonessential amino acids are glutamic and aspartic acids, arginine, alanine, glycine, proline, serine, tyrosine, and cysteine. Fresh yellowfin tuna contains omega-5, omega-6, omega-7, and omega-9 fatty acids; however, omega-5 is not found after smoking. Fufu yellowfin tuna had higher hedonic scores for aroma, taste, and texture than asar. The smoking method affects the chemical and hedonic content of smoked yellowfin tuna.

Keywords: asar fish, fufu fish, GC-MS, LC-MS, smoked fish

Karakteristik Proksimat, Asam Amino, Asam Lemak, dan Sensori Ikan Asap Tuna Sirip Kuning (*Thunnus albacares*)

Abstrak

Pengasapan merupakan salah satu metode pengawetan tertua dan paling banyak digunakan, memberikan cita rasa yang khas dan meningkatkan masa simpan karena adanya komponen antimikroba serta menghasilkan warna, rasa, aroma, dan penampakan yang spesifik. Penelitian ini bertujuan untuk menentukan pengaruh pengasapan ikan bentuk utuh (asar) dan filet (fufu) terhadap karakteristik kimia meliputi proksimat, profil asam lemak, dan asam amino, serta sifat organoleptik ikan tuna sirip kuning asap. Analisis asam amino dilakukan dengan metode LC-MS, profil asam lemak dinilai dengan metode GC-MS, dan evaluasi organoleptik dilakukan dengan uji hedonik. Rancangan penelitian menggunakan dua bentuk ikan asap, yaitu bentuk utuh (ikan asar) dan bentuk filet (ikan fufu), data kandungan kimia dianalisis Anova dengan uji lanjut DMRT, sedangkan data hedonik diuji Kruskal Wallis dengan uji lanjut Mann-Whitney.

Hasil penelitian menunjukkan bahwa produk pengasapan berbeda, yaitu asar dan fufu memberikan pengaruh nyata terhadap kandungan proksimat, yaitu kadar air, abu, dan protein, tetapi tidak berpengaruh nyata terhadap kadar lemak dan karbohidrat. Ikan tuna sirip kuning fufu, asar, dan segar memiliki sembilan asam amino esensial dan sembilan asam amino non-esensial. Asam amino esensial adalah lisina, histidina, leusina, valina, isoleusina, fenilalanina, treonina, metionina, dan triptofan, sedangkan asam amino non-esensial adalah asam glutamat dan aspartat, arginina, alanina, glisina, prolina, serina, tirosin, dan sistein. Tuna sirip kuning segar memiliki asam lemak omega-5, omega-6, omega-7, dan omega-9, namun omega-5 tidak ditemukan setelah proses pengasapan. Tuna sirip kuning fufu memiliki skor hedonik yang lebih tinggi untuk parameter aroma, rasa, dan tekstur dibandingkan dengan asar. Bentuk pengasapan memberikan pengaruh terhadap kandungan kimia dan hedonik ikan tuna sirip kuning asap.

Kata kunci: ikan asar, ikan fufu, GC-MS, LC-MS, pengasapan ikan

INTRODUCTION

Fish is a highly perishable food item that requires proper handling and preservation to maintain its quality for human consumption (Nunoo *et al*., 2019). Various methods are used to preserve fish, such as freezing, cooling, drying, salting, smoking, and canning (Nunoo *et al.,* 2019). One of the traditional preservation methods commonly used in Indonesia is smoking, which offers diversification opportunities, produces high-added-value products, and serves as an alternative when fresh fish is not available (Gómez-Guillén *et al*., 2009). Smoking is one of the oldest and most widely used preservation methods (Theobald *et al*., 2012; Ledesma *et al*., 2015). It provides a distinctive taste and increases the shelf life of fish due to the activity of the antimicrobial components of the smoke (Nithin *et al*., 2015), adding a specific color, flavor, aroma, and appearance to the fish (Fasano *et al*., 2016).

Fish smoking has evolved from traditional methods to more modern and hygienic systems. There are three primary methods of fish smoking: traditional (conventional), semi-mechanical, and liquid smoking. Traditionally, smoking fish by hanging them directly above the smoke source is low-cost; however, quality control is difficult, and the product is not uniform (Robianto & Utomo, 2021). Traditional smoking is generally performed by generating smoke from wood (Visciano *et al*., 2008; ~~Duedahl-Olesen *et al*., 2010)~~. Smoke is generated from the thermal pyrolysis of wood when access to oxygen is limited (Purcaro *et al*., 2013). Semi-mechanism smoking uses a drum or closed smoking room with a temperature controller and smoke ventilation that can reduce tar contamination and is more time-saving than conventional methods (Adawyah, 2023). Liquid smoking utilizes a liquid smoke solution infused with fish, making it more efficient and hygienic than other smoking methods. Although it lacks the authenticity of smoking in terms of taste, it has great potential on an industrial scale because it can control toxic compounds such as PAHs (Ramadhan, 2021).

Several important factors that affect the results of fish smoking include the type of wood, type and size of fish, humidity, temperature of the smoke, and smoking duration. Hardwoods such as teak, mahogany, guava, and mango are preferred because they produce stable smoke, a distinctive aroma, and minimal tar production (Putra *et al*., 2024). Consumer preferences are closely tied to specific smoked fish aroma profiles, which are influenced by the type of wood used (Owusu *et al*., 2025). Excessively high temperatures can cause incomplete combustion and produce excessive tar. The ideal temperature for smoking fish is between 60°C and 80°C. Controlling the temperature and humidity can prevent PAH (polycyclic aromatic hydrocarbons) contamination. The duration of smoking affects the color, texture, and product durability. Smoking for too long can make the fish texture hard and potentially dry. The size of the fish affects the smoking time and temperature required to achieve optimal results. Large fish require more time for the smoke to penetrate evenly (Hudi *et al*., 2024).

Tuna is an essential commodity, particularly originating from the waters of Papua and West Papua in eastern Indonesia. It has a high nutritional content, including protein and fat, along with omega-3 fatty acids (ω3), such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which are essential for human health (Apituley & Loppies, 2019). Furthermore, polyunsaturated fatty acids (PUFAs) prevent and cure cardiovascular diseases, including hypertension, arthritis, inflammation, autoimmune disorders, and cancer (Regulska-Ilow *et al*., 2013). Yellowfin tuna (*Thunnus albacares*) is used as a raw material for traditional smoking methods in Papua and West Papua. Based on their shape, there are two types of smoking: asar (whole form) and fufu (fillet form).

Asar fish is a smoked fish originating from eastern Indonesia, specifically the regions of Maluku and Papua. Generally, skipjack tuna or tuna is smoked using a hot smoking technique until partially dry, which extends its shelf life and adds a distinctive smoked flavor to its whole form (Swastawati, 2018). Fufu fish was a processed fish product processed through traditional smoking methods, especially from skipjack tuna or tuna, which were commonly found in eastern Indonesia, such as Maluku, North Sulawesi, and Papua. The term "fufu" comes from the Ternate language, which means "smoked" (Swastawati, 2018; Febriyanto, 2024). Fufu fish is an important form of local food diversification, rich in omega-3 fatty acids and iron due to its concentration during smoking (Sutrisno, 2023). It is also rich in nutrients, which extends its shelf life (Febriyanto, 2024).

The process of making asar fish involves cleaning the fish of gills and stomach contents, washing, soaking in a salt solution (10-15%), draining, smoked for 4-6 hours after which it cooling (Swastawati, 2018). The process of making fufu fish involves cutting the fish in half, seasoning it with spices, clamping it using bamboo tongs (often called "kawangkoan"), and smoking it for 6-8 hours over coconut coals. This fish is not only smoked but also formed using a unique technique that gives it an attractive appearance, savory smoky taste, and long shelf life (Swastawati, 2018). Fufu fish has the potential to contribute to food security because of its nutritional content and the practicality of its distribution (Sutrisno, 2023).

Previous research has reported the fatty acid profile of tuna (Thunnus albacares) loin treated with filtered smoke (Loppies *et al*., 2021). The highest saturated fatty acid content of smoked tuna (*Thunnus* sp.) using the liquid smoke method in tuna meat is palmitic and stearic acids (Amahorseja & Noya, 2019). In contrast, the highest unsaturated fatty acid is oleic acid (Amahorseja & Noya, 2019). Smoked skipjack tuna (*Katsuwonus pelamis*) has nine essential and nine non-essential amino acids, with seven main components of fatty acids, namely C14:0, C15:1 (cis-10), C16:0, C17:1 (cis-10), C18:0, C18:2 (all trans-9,12), and C20:0 (Sayuti *et al*., 2022). Existing research has not provided information on the chemical characteristics of smoked yellowfin tuna in whole and filleted forms. Therefore, this study aimed to determine the effect of smoking whole fish (asar) and fillets (fufu) on the chemical characteristics, including the proximate composition, fatty acid profile, and amino acid content, as well as the organoleptic properties of smoked yellowfin tuna.

MATERIALS AND METHODS

Sample Handling and Smoking

The material used in this study was fresh yellowfin tuna sourced from fish auction sites in Sorong City. The fish were then placed in Styrofoam boxes filled with ice to maintain freshness until they reached the processing facility. The hot smoking method was used with two different treatments: whole (asar fish) and filleted (fufu).

The process of making smoked fish begins with washing the fish and removing its gills and viscera. To prevent the fish from being crushed and facilitate easier handling during smoking, bamboo was inserted from the mouth to the tail to act as a buffer for the fish. The fish were then immersed in a mixture of water and salt (10% salt solution), followed by draining and smoking. A total of 100 yellowfin tuna were smoked using coconut coir and shell smoker. The smoking process was carried out in a furnace with a length of

6 m, a width of 4 m, a height of 60 cm, and a duration of 5 h until the fish was cooked and appeared silver to golden in color (Nabilah *et al.*, 2022).

The process of making fufu begins with washing the fish and removing the gills and innards. The fish is then split along the backbone, and the eyes, bones, and tail are removed. Each piece was sliced in the middle to approximately 20 cm along the lateral line, keeping the head and tail intact, and then washed until completely free from blood and foreign matter. The fish meat was skewered with four to six small bamboo sticks that had been prepared and pulled to the side, forming an ellipse, and clamped with a 50 cm long bamboo. The prepared fish was then arranged on the burning grill with the meat side facing the fire (bottom) at a slope of about 70-80^{o}. Coconut fiber was burned around the fish, but the flame did not come into contact with it. After the fire smoldered to produce smoke, it was pushed evenly to the center. Depending on the fish maturity level, the smoking process was carried out for 2-3 hrs. The burning temperature ranged between 120-150^{o}C, and the temperature in the middle of the fish reached 80-100^{o}C. After the fish was slightly cooked, heating was continued with the coals of fire, which were gradually reduced until they were completely extinguished. The cooked fufu fish acquired a silver to golden color and was then allowed to cool for 1-2 hrs (Sayuti *et al.*, 2022). Both the asar and fufu fish samples were subsequently frozen for further analyses.

Proximate Analysis

Moisture, protein, fat, and ash contents were analyzed according to the Association of Official Analytical Collaboration (AOAC) International method (AOAC, 2005) at the Integrated Research and Testing Laboratory (LPPT) of Gadjah Mada University.

Analysis of Amino Acids

Amino acid testing of fresh, asar, and fufu yellowfin tuna was performed using Liquid Chromatography-Mass Spectrometry (LC-MS) at the Integrated Research and Testing Laboratory (LPPT) of Gadjah Mada University. The type of LC column used was a C18 reverse phase column, with a particle size of 3–5 μm, column dimensions of 2.1 × 100 mm, and a column temperature of 30–40 °C. The preparation process involves first processing the sample (centrifugation, filtration, and concentration), then extracting it using the liquid-liquid extraction (LLE) or SPE method, redissolving it in the mobile phase solvent (usually a mixture of air + acetonitrile/methanol), and finally filtering it using a 0.22 μm membrane filter. The sample was then injected into the LC-MS autosampler at a volume of 5–10 μL (Sayuti *et al.*, 2022).

Analysis of Saturated and Unsaturated Fatty Acids

Saturated and unsaturated fatty acids in fresh, asar, and fufu yellowfin tuna were tested using Gas Chromatography-Mass Spectrometry (GC-MS) Instruments the Integrated Research and Testing Laboratory (LPPT) of Gadjah Mada University. Chromatography was performed on an HP-5MS column (30 m long, 0.25 mm inner diameter, 0.25 μm film thickness, 5%-Phenyl-methylpolysiloxane stationary phase). The GC temperature was typically programmed for an initial oven temperature of 60°C, held for 2 min (Ramp 1: Ramp 10°C/min to 200°C, Ramp 2: Ramp 5°C/min to 280°C), then held for 10 min, with a total run time of ~30–35 min, an injector temperature of 250–280°C (split/no split mode), a transfer line temperature of 280°C, and an MS source temperature of ~230°C. Electron impact ionization (EI) was used as the ionization mode. The sample was homogenized using a blender or vortex and then extracted using methods such as liquid-liquid extraction (LLE) and solid-phase microextraction (SPME). The sample was then derivatized using BSTFA and MSTFA and filtered using a 0.22 μm membrane filter. The sample was then placed into an autosampler vial with septa and injected using the split/splitless mode (Sayuti *et al.*, 2022).

Hedonic Test

The sensory properties were analyzed using a hedonic test with a scale beginning from 1 for immensely dislike and 9 for extremely like, based on the SNI 2346:2015 Indonesian National Standard (Badan Standardisasi Nasional, 2015). A total of 30 panelists participated in the hedonic test.

Data Analysis

The statistical data in this study were analyzed using Microsoft Excel and the SPSS 22 program. The The research data are presented in a table (fresh, asar, and fufu fish). The proximate test data were analyzed using the Student T-test, while the hedonic test data were analyzed using the Mann-Whitney test to compare asar and fufu.

RESULTS AND DISCUSSION

Proximate Analysis of Fresh Yellowfin Tuna, Asar and Fufu

Proximate testing on fresh, asar and fufu includes testing of moisture, ash, fat, protein, and carbohydrates content. The results of proximate testing are presented in Table 1, which shows the chemical content of yellowfin tuna fresh, asar and fufu.

Asar and fufu fish yellowfin tuna had a significant effect on all proximate characteristics of moisture, ash, and protein content, except for fat and carbohydrate content. Fufu fish had a lower moisture content than asar, despite the shorter smoking time. This was because the fillet shape of the fufu fish delivered heat more evenly than the asar (whole form). Smoking was found to cause evaporation of moisture in the smoked fish. Sigurgisladottir *et al.* (2000) reported that processing treatments led to differences in the moisture content of smoked fish, and the reduced moisture content caused a decrease in the water activity (a_w) value. This reduction inhibited microbial growth and contributed to increased shelf life. The smoking duration, humidity in the chamber, and interaction between smoke and moisture content can affect the a_w value of the final product (Kostyra & Baryłko-Pikielna, 2006). Oduor-Odote *et al.* (2010) reported that different types of fuel used in the smoking process affect the physical, chemical, sensory, and microbiological characteristics of smoked fish.

The longer the smoking duration, the higher the amount of cek content released from the fish (Kumolu-Johnson *et al.*, 2010). The smoking process can also reduce the moisture content of fish meat, thereby inhibiting microbial activity (Fuentes *et al.*, 2010). Sayuti *et al.* (2022) reported that the average moisture content of smoked skipjack tuna (fufu fish) was 64.52%. The average moisture content of smoked asar fish is 67.8% (Sayuti *et al.*, 2021). Smoking in various forms also led to variations in ash content, namely 2.27% in fufu fish and 1.67% in asar yellowfin tuna fish (Toisuta *et al.*, 2014). Based on the results, the ash content of smoked skipjack tuna ranged from 1.36-5.66%. Table 1 also shows an increase of 30.46% in the protein content of fufu fish and 25.83% in asar compared to the raw material for yellowfin tuna. The longer the fish is smoked, the higher the protein content and the lower the moisture content (Huda *et al.*, 2010). The average protein content of skipjack tuna smoked with wood ranges from 15.4% to 31.5% (Gehring *et al.*, 2011). According to a previous study, the type of smoking material significantly influences the protein content of smoked fish. Additionally, fish protein can change due to interactions with smoke components (Effendi, 2012). Different smoking ingredients cause increased protein and reduced moisture content (Wibowo, 2017).

Several factors affect the process of smoking fish, including the type of firewood, smoke density, temperature, air humidity

Table 1 The proximate test results of fresh and smoked yellowfin tuna

Parameters	Moisture (%)	Ash (%)	Fat (%)	Proteins (%)	Carbohydrates (%)
Fresh	72.55±0.71[c]	1.12±0.13[a]	0.75±0.26[a]	23.30±0.03[a]	2.29±0.84[a]
Asar	68.78±0.04[b]	1.68±0.12[b]	1.64±0.03[b]	25.83±0.08[b]	2.07±0.05[a]
Fufu	64.00±0.49[a]	2.27±0.04[c]	1.78±0.17[b]	30.46±0.57[c]	1.49±0.04[a]

The score was derived from the average of±standard deviation expressed three times on a wet weight basis

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and circulation, and smoking time (Kumolu-Johnson *et al.*, 2010). The types of wood suitable as fuel are hardwoods such as turi, sawdust, teak, coir, and coconut shells, which contain relatively high phenolic compounds and organic acids. Smoke should not be produced from combustion above 175-205°C, as this can result in a bitter taste and the formation of carcinogenic substances in the product (Huda *et al.*, 2010). Smoking at high temperatures can also lead to poor product outcomes, causing surface hardening of the meat due to evaporation inhibition (Purcaro *et al.*, 2013). The smoke absorption process significantly affected air humidity, indicating the need for adequate control. High humidity prolonged the smoking time and increased the concentration of smoke absorbed by the fish meat, culminating in a strong taste; however, the product was not dry (Lingbeck *et al.*, 2014).

However, excessively low humidity during smoking inhibits smoke absorption. An air humidity of 60% facilitated faster smoke absorption than other relative humidity levels. According to a previous study, good air circulation in the smoking room led to the perfect quality of smoked fish because the temperature and humidity of the room remained constant during smoking (Huda *et al.*, 2010). The smooth and continuous flow of smoke ensured that the particles adhered evenly to the fish, thereby effectively distributing the flavor (Jónsdóttir *et al.*, 2008).

Amino Acid Content of Fresh Yellowfin Tuna, Asar and Fufu

Amino acid testing on fresh, fufu, and asar fish included testing of essential and non-essential amino acids. The results of amino acid testing are presented in Table 2, which shows that both fresh fufu and asar have the same amino acids with different concentrations.

Table 2 Amino acid profile of fresh yellowfin tuna, asar and fufu.

No	Parameters	Fresh (%)	Asar (%)	Fufu (%)
Essential amino acids				
1	L-Histidine	2.74	2.19	4.00
2	L-Lysine	4.16	5.98	5.51
3	L-Phenylalanine	1.03	1.38	1.22
4	L-Isoleucine	1.22	1.6	1.46
5	L-Leucine	2.07	2.58	2.31
6	L-Methionine	0.75	0.98	0.90
7	L-Valine	1.37	1.84	1.66
8	L-Threonine	1.02	1.33	1.23
9	L-Tryptophan	0.05	0.05	0.06
Non-essential amino acids				
1	L-Arginine	1.76	2.49	2.05
2	L-Tyrosine	0.83	1.08	0.97
3	L-Proline	0.92	1.24	1.08
4	L-Glutamic acid	3.01	3.38	3.7
5	L-Aspartic acid	1.94	2.56	2.35
6	L-Cysteine	0.15	0.16	0.15
7	L-Serine	0.82	1.11	1.02
8	L-Alanine	1.29	1.7	1.57
9	L-Glycine	0.88	1.32	1.1

Table 2 shows that fresh, asar, and fufu yellowfin tuna had nine essential and nine non-essential amino acids. The essential amino acids were lysine, histidine, leucine, valine, isoleucine, phenylalanine, threonine, methionine, and tryptophan, whereas the nonessential amino acids were glutamic and aspartic acids, as well as arginine, alanine, glycine, proline, serine, tyrosine, and cysteine. Given that the human body cannot produce essential amino acids, they must be obtained from external sources (Nadiah *et al*., 2014). The essential amino acids for adults are lysine, leucine, isoleucine, threonine, methionine, valine, phenylalanine, and tryptophan, whereas those for children are arginine and histidine (Erkan *et al*., 2010). Based on the results, the primary amino acid compositions of fufu, asar, and fresh yellowfin tuna were lysine, glutamic acid, histidine, aspartic acid, leucine, and arginine. Fufu fish yellowfin tuna had 5.51% lysine, 3.7% glutamic acid, 4% histidine, 2.35% aspartic acid, 2.31% leucine, and 2.05% arginine, whereas asar had 5.98% lysine, 3.38% glutamic acid, 2.19% histidine, 2.56% aspartic acid, 2.58% leucine, and 2.49% arginine. This suggests that smoking asar and fufu fish increases the lysine, glutamic acid, aspartic acid, leucine, and arginine content. However, there was a difference in the histidine content, with asar having a decreasing effect, while fufu had an increasing effect, which was attributed to the effects of smoking. According to a previous study, smoking fish increases almost all amino acids, with the highest amount being the essential amino acid (EAA) group (Cieślik *et al*., 2018). Yellowfin tuna in fresh and canned treatments contains the main amino acids glutamic acid, lysine, leucine, arginine, and alanine (Nasri Tajan & Seifzadeh, 2022). Eighteen amino acids were identified in yellowfin tuna and bigeye tuna (*Thunnus obesus*), with glutamic acid being the most dominant (12.45% in yellowfin tuna and 11.28% in bigeye tuna) (Peng *et al*., 2013). The main amino acid content of yellowfin tuna eyes is glycine, followed by glutamic acid and aspartic acid (Renuka *et al*., 2016).

Fatty Acid Content of Fresh Yellowfin Tuna, Asar, and Fufu

Fatty acid testing was conducted on fresh, asar, and fufu, including testing for saturated and unsaturated acids. At the same time, the results of fatty acid content are presented in Table 3, which shows the

Table 3 Fatty acid profile of fresh yellow fin tuna, asar, and fufu

Compound	Concentration (% relative area)		
	Fresh	Asar	Fufu
C13:0	3.49	9.21	6.93
C14:1	0.87	-	-
C15:1 (cis 10)	58.28	51.36	49.92
C16:0	12.34	11.58	8.31
C16:1	1.68	1.84	2.34
C17:0	0.88	0.71	8.02
C17:1 (cis -10)	4.94	5.63	15.42
C18:0	12.1	13.3	3.06
C18:2 (cis, cis -9,12)	2.7	2.85	1.89
C20:0	1.23	1.85	3.45
C20:1 (cis 11)	0.48	0.36	0.66
C22:0	0.44	0.54	-
C20:4 (all cis -5,8,11,14)	0.58	0.77	-
Total	100.	100 .	100 .

differences in fatty acid content among fresh fish, fufu fish, and asar fish.

Table 3 shows that fufu yellowfin tuna fish contained 10 fatty acids, with the main components being C15:1 (cis 10) (Cis-10 Pentadecenoic acid methyl ester), C17:1 (cis -10) (cis-10- Heptadecenoic acid methyl ester), C16:0 (methyl palmitate), and C17:0 (methyl heptadecanoate) at 49.92%, 15.42%, 8.13%, and 8.02%, respectively. Asar contained 12 fatty acids, with the main components being C15:1 (cis 10) (Cis-10 Pentadecenoit acid methyl ester), C18:0 (methyl octadecanoate), and C16:0 (methyl palmitate) at 51.36%,13.3%, and 11.58%, respectively (Figure 2). The fresh yellowfin tuna was found to contain 13 fatty acids, with the main components being C15:1 (cis 10) (Cis-10 Pentadecenoit acid methyl ester), C18:0 (methyl octadecanoate), and C16:0 (methyl palmitate) at 58.28%, 12.1%, and 12.34 %, respectively (Figure 3). Fresh yellowfin tuna contains omega-5, omega-6, omega-7, and omega-9 fatty acids. However, omega-5 fatty acids were no longer detected after smoking, indicating that the process affected the fatty acid composition of the fish. The total MUFA content of some smoked marine fish ranged from 26.0% to 39.8%, whereas the total PUFA content was between 31.9% and 45.4% (Regulska-Ilow *et al*., 2013). Yellowfin tuna contains docosahexaenoic acid (DHA/PUFA) polyunsaturated fatty acids (head: 26.63 ± 0.19%, back: 34.71 ± 0.72%, tail: 31.27 ± 0.90%), followed by saturated fatty acids; palmitic acid (SFA) (head: 22.52 ± 0.22%, back: 20.14 ± 0.47%, tail: 20.72 ± 0.20%) and higher omega-3 content than omega-6 (Jayaweera *et al*., 2024). The main fatty acids of yellowfin tuna are C16:0, C18:1, C22:6 (DHA), and C18:0, where the DHA concentration is 20.22% of the total fatty acids (Peng *et al*., 2013). Yellowfin tuna meat is rich in docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Biji *et al*., 2016)

Hedonic Test Results

The quality of the asar and fufu products was evaluated using a hedonic test, which measured the panelists' level of preference for appearance, aroma, taste, texture, and overall acceptability (Table 4). The hedonic test in this study used a nine-point scale, where panelists rated each attribute as follows: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike (neutral), 6 = like slightly, 7 = like moderately, 8 = like very much, and 9 = like extremely.

Based on the hedonic test results for appearance parameters, Asar yellowfin tuna received an average rating of 7.31, while fufu scored 7.54; both were included in the moderately liked category (Table 4). The Kruskal–Wallis test results for appearance parameters obtained a P>0.05, indicating that there was no significant difference between the form and appearance of asar and fufu yellowfin tuna. The smoked yellowfin tuna had a golden yellow appearance, which is in line with the findings of Sulistijowati *et al.* (2011), who stated that good quality smoked fish should produce a golden yellow color. This color formation might be due to the potential chemical reaction between the carbonyl compound and the amino acid group (Jamilatun *et al*., 2016). The different

Table 4 Consumer preference test data for smoked asar and fufu fish

Parameter	Asar fish	Fufu fish
Appearance	7.31±0.28^{a}	7.54±0.51^{a}
Aroma	7.28±0.32^{a}	7.59±0.50^{b}
Taste	7.24±0.30^{a}	7.63±0.57^{b}
Textures	7.27±0.31^{a}	7.60±0.55^{b}
Overalls	7.27±0.30^{a}	7.59±0.53^{b}

Values are mean±SD;
Different letters in the same rows indicate significant differences (p<0.05).

colors of smoked fish products are caused by the amount of carbonyl and the type of smoked raw material used (Swastawati, 2008). Additionally, smoking duration affects the color and overall acceptance of smoked fish (Fatmawati & Mardiana, 2014).

Based on the hedonic results (Table 4), the parameters for asar yellowfin tuna were aroma 7.28, taste 7.24, and texture 7.27, while those of fufu were 7.59, 7.63, and 7.60, respectively, all of which were included in the moderately like category. The Kruskal–Wallis test results for aroma, taste, and texture parameters showed a significant difference between the whole (asar) and fillet (fufu) smoked yellowfin tuna due to the variation in the conditions of the fish. The Mann–Whitney test results revealed a preference for the aroma, taste, and texture of fufu yellowfin tuna, which was considered superior ($P<0.05$) compared to that of asar. Overall, the hedonic results showed an average score of 7.27 for the asar yellowfin tuna, while fufu scored 7.59, both of which fell into the moderately liked category. The Kruskal–Wallis test produced a P-value <0.05, indicating a significant difference between the two smoked fish forms. The Mann–Whitney test results showed that the preference for asar was lower than that for fufu yellowfin tuna.

Fufu yellowfin tuna was preferred over asar because of its aroma, taste, and texture. The characteristic color, taste, and smell of smoked products are due to carbonyl and phenolic compounds, as well as their derivatives. Phenolic compounds produce specific organoleptic characteristics, especially in the aroma of smoked fish (Martinez *et al.*, 2007). In another study, phenol and carbonyl compounds contained in liquid smoke were attributed to the unique taste of the final product (Saloko *et al.*, 2013). Compounds such as guaiacol, 4-methyl guaiacol, and 2,6-dimethoxy phenol contribute to the aroma of smoke (Varlet *et al.*, 2006). Furthermore, carbonyl and phenol compounds in smoke cause changes in the flavor and aroma of smoked fish (Kostyra & Baryłko-Pikielna, 2006). Guaiacol and syringol are essential to the taste of smoked fish, as they provide specific organoleptic characteristics (Kjallstrand & Petersson, 2001; Cardinal *et al.*, 2006; Martinez *et al.*, 2007; Jónsdóttir *et al.*, 2008; Oduor-Odote *et al.*, 2010). The varying levels of absorption due to differences in smoking duration and the number of smokers used caused an increase in the smoke component attached to the fish, culminating in different colors, tastes, and aromas (Isamu *et al.*, 2012). The smoking duration influenced the texture of the smoked fish, and the more prolonged the duration, the stronger the appearance, texture, and smell, which might not be favored by the panelists (Sumartini *et al.*, 2014). According to a previous study, fish smoked in a closed smoking room produced a strong aroma (Dotulong & Montolalu, 2018). The method and concentration of liquid smoke affect consumer acceptance of the smell (Swastawati *et al.*, 2018). Moreover, phenolic compounds contribute significantly to the aroma of smoked products preserved by smoking (Saloko *et al.*, 2013). The amount of smoke absorbed directly impacts the taste of smoked fish (Lombongadil *et al.*, 2013). The formation of a specific pleasant taste in smoked fish is caused by the reaction of proteins with carbonyl components (Apituley & Loppies, 2019). This reaction leads to the loss of ammonia compounds and damage to some proteins on the fish surface. Although phenolic compounds significantly contribute to the formation of taste, they function together with other components, such as carbonyl and acids, which are relatively smaller in number (Cieślik *et al.*, 2018).

Similar to taste, the formation of color in smoked fish is based on the reaction between the protein and carbonyl component. The primary factor in color formation is the carbonyl-amino reaction, which is more physical than chemical (Fuentes *et al.*, 2010). Certain amino acids, particularly lysine, play an important role in color formation, while arginine and histidine may be lost or damaged in this reaction (Huda *et al.*, 2010). High temperatures increase the decomposition of smoke but also cause damage to essential amino acids, such as lysine (Isamu *et al.*, 2012). Although methanal is one of the most reactive amino groups, it did not affect the color formation (Martinez *et al.*, 2007).

Other chemical compounds that play a role in color formation are glycolic aldehydes, 2,3-butadiene, and pyruval. In cold smoking, artificial dyes are usually added when soaking in salt water to enhance the attractiveness of the color of smoked fish (Essumang *et al*., 2013). The use of these dyes must comply with the regulations of each country, whereas turmeric and honey can also be used as coloring agents.

CONCLUSIONS

The smoking methods of whole fish (asar) and fillets (fufu) influence the chemical characteristics of the yellowfin tuna. Both forms had similar proximate compositions but differed in moisture, ash, and protein content. Each had nine essential and nine nonessential amino acids, with L-lysine being the most abundant essential amino acid and L-glutamic acid being the dominant nonessential amino acid. Fufu contained ten fatty acids, whereas asar contained twelve. Sensory evaluation revealed significant differences in aroma, taste, and texture, indicating that the fish form during smoking affects its chemical composition and sensory quality.

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