

## EFFECT OF LIQUID SMOKE CONCENTRATION AND IMMERSION DURATION ON PROXIMATE AND SENSORY CHARACTERISTICS OF SMOKED CATFISH (*Clarias* sp.)

Pengaruh Konsentrasi dan Lama Perendaman Asap Cair terhadap Karakteristik Proksimat dan Sensoris Lele (*Clarias* Sp.) Asap

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### ABSTRACT

Smoked catfish is a widely consumed fish product; however, conventional smoking using direct combustion of wood or coconut shells is associated with prolonged processing, inconsistent product quality, and the potential formation of carcinogenic compounds. Liquid smoke offers a practical alternative that can provide more uniform flavor while reducing the formation of polycyclic aromatic hydrocarbons (PAHs). This study evaluated the effects of liquid smoke concentration and soaking duration on the proximate composition and sensory acceptance of smoked catfish and assessed product compliance with the Indonesian National Standard (SNI) 2725:2013. The experiment was conducted at the Laboratory of the Freshwater Aquaculture Study Program, Rejang Lebong State Community Academy, using a factorial Completely Randomized Design with two factors: liquid smoke concentration and soaking duration. Each treatment was replicated twice, with commercially smoked catfish serving as the control. Sensory evaluation was performed by 20 semi-trained panelists based on appearance, odor, taste, and texture. Data were analyzed using one-way ANOVA followed by Duncan's Multiple Range Test at a 5% significance level. The results indicated that the treatments significantly affected appearance, odor, and taste. The combination of 5% liquid smoke and 10-minute soaking produced the highest sensory scores across all parameters and the highest protein content. All samples met the SNI moisture requirement, whereas three samples treated with 10% liquid smoke exceeded the 20% fat limit. Thus, 5% liquid smoke with 10-minute soaking is recommended as the optimal treatment.

**Keywords:** Catfish, Liquid Smoke, Proximate, Sensory.

## ABSTRAK

Ikan lele asap merupakan produk olahan perikanan yang banyak dikonsumsi masyarakat. Pengasapan konvensional menggunakan pembakaran langsung kayu atau tempurung kelapa memiliki beberapa keterbatasan, seperti waktu pengolahan yang relatif lama, mutu produk yang tidak seragam, dan potensi terbentuknya senyawa karsinogenik. Asap cair dapat menjadi alternatif karena lebih praktis dalam penggunaannya, menghasilkan cita rasa yang lebih seragam, dan berpotensi mengurangi pembentukan hidrokarbon aromatik polisiklik (PAHs). Penelitian ini bertujuan mengetahui pengaruh konsentrasi dan lama perendaman asap cair terhadap komposisi proksimat dan tingkat kesukaan panelis terhadap lele asap serta mengevaluasi kesesuaiannya dengan SNI 2725:2013. Penelitian dilakukan di Laboratorium Program Studi Budidaya Perikanan Air Tawar, Akademi Komunitas Negeri Rejang Lebong, menggunakan Rancangan Acak Lengkap (RAL) faktorial dengan dua faktor, yaitu konsentrasi asap cair dan lama perendaman, masing-masing dua ulangan. Lele asap komersial digunakan sebagai kontrol. Uji organoleptik melibatkan 20 panelis semi-terlatih dengan parameter kenampakan, bau, rasa, dan tekstur. Data dianalisis menggunakan ANOVA satu arah dilanjutkan dengan uji Duncan pada taraf 5%. Hasil menunjukkan perlakuan berpengaruh nyata terhadap kenampakan, bau, dan rasa. Kombinasi asap cair 5% dan perendaman 10 menit menghasilkan nilai organoleptik tertinggi serta kadar protein tertinggi. Seluruh sampel memenuhi persyaratan kadar air SNI, sedangkan tiga sampel dengan konsentrasi 10% memiliki kadar lemak di atas batas maksimum 20%. Kombinasi 5% dan 10 menit direkomendasikan sebagai perlakuan optimal.

**Kata Kunci:** Asap Cair, Ikan Lele, Organoleptik, Proksimat.

## INTRODUCTION

Smoked fish is one of the processed fisheries products favored by the Indonesian public because of its distinctive flavor produced through the smoking process. In addition to imparting a specific aroma and taste, smoking also extends fish shelf life through the preservative effect of compounds contained in smoke. One type of fish widely processed into smoked products is catfish (*Clarias sp.*), given its abundant availability, affordable price, and relatively high nutritional content. Catfish flesh is known to contain up to 19.03% protein, 8.10% fat, 1.5% ash, and 71.3% moisture (Abdel-Mobdy *et al.*, 2021).

Traditional fish smoking is generally carried out through the direct combustion of coconut shells or wood as a smoke source. Although this practice has long been used, it has several drawbacks, including a relatively long processing time, inconsistent product quality, difficulty in controlling smoking temperature, and the risk of contamination with carcinogenic tar compounds (Lokollo *et al.*, 2012).

As an alternative, the use of liquid smoke is considered capable of overcoming the various drawbacks of conventional smoking. Liquid smoke is obtained through condensation of the pyrolysis products of high-carbon materials such as wood, yielding phenolic, carbonyl, and organic acid compounds with antimicrobial properties that play an important role in the formation of product color and flavor (Lingbeck *et al.*, 2014). Simon *et al.* (2005) further noted that smoking using liquid smoke offers advantages in ease of application, more consistent product flavor, efficient use of smoking agents, and the ability to eliminate most carcinogenic polycyclic aromatic hydrocarbon compounds.

Chemically, liquid smoke contains three main groups of compounds, namely phenolics, carbonyls, and organic acids, each of which plays a specific role in the quality of smoked products. Phenolic compounds such as guaiacol and syringol act as antioxidants and are the main contributors to the characteristic smoky aroma; carbonyl compounds are responsible for the formation of the golden-brown color through a Maillard-like reaction with amino groups of

surface meat proteins, while organic acids contribute to the antimicrobial effect and reduction of product pH (Baroutian *et al.*, 2026). These three groups of compounds work synergistically, but their effectiveness is highly dependent on the applied concentration, as excessively high concentrations tend to produce overly intense smoke flavor and aroma, thereby reducing consumer acceptance despite an increase in antimicrobial and antioxidant activity (Baroutian *et al.*, 2026). Chemical characterization of commercial liquid smoke by Montazeri *et al.* (2013) further confirms that the proportion of phenol and carbonyl compounds largely determines the intensity of color and smoky aroma formed on the surface of smoked products.

Research on the application of liquid smoke to various smoked fish products has been widely conducted with variations in fish species, liquid smoke source, concentration, and immersion duration, as summarized in Table 1.

Table 1. Previous studies on the application of liquid smoke to smoked fish products

| Researcher (Year)               | Object and Liquid Smoke Source                       | Concentration (%) and Duration (minute)        |
|---------------------------------|------------------------------------------------------|------------------------------------------------|
| Suroso <i>et al.</i> (2018)     | Indian mackerel, redistilled rubberwood liquid smoke | 10, 15, 20 ; 10, 15, 20                        |
| Fauzi <i>et al.</i> (2022)      | Catfish, dried banana leaf liquid smoke              | 10, 15, 20; 5, 15, 25                          |
| Rakhmayeni <i>et al.</i> (2024) | Tandipang fish, coconut shell liquid smoke           | 1, 3, 5; 15, 30, 45                            |
| Ikhwan <i>et al.</i> (2025)     | Milkfish, coconut shell liquid smoke                 | 3; 15                                          |
| Anggraini <i>et al.</i> (2022)  | Baung fish, liquid smoke                             | 2, 4, 6; single immersion                      |
| Khamidah <i>et al.</i> (2019)   | Manyung fish, durian peel liquid smoke               | Fixed concentration; varied immersion duration |
| This study                      | Catfish, coconut shell liquid smoke                  | 5, 10; 10, 20, 30                              |

Research on the combination of concentration and immersion duration of coconut shell liquid smoke specifically applied to catfish remains limited, as shown in Table 1. This study was therefore conducted to complement this information and to address the need for scientific data on the balance point between concentration and immersion duration that produces the best sensory and nutritional quality. Specifically, this study aimed to: (1) analyze the effect of liquid smoke concentration and immersion duration on panelist preference for the parameters of appearance, odor, taste, and texture of smoked catfish; (2) determine the proximate composition (protein, fat, moisture, ash, and carbohydrate content) of smoked catfish under the best treatment combination for each level of concentration and immersion duration; and (3) compare the fat content, moisture content, and sensory quality of the resulting product with the quality and safety requirements of SNI 2725:2013 on smoked fish, so that the optimal treatment combination can be recommended for production-scale application.

## METHODS

### Time and Place of Research

The research was conducted from June to December 2025 at the Laboratory of the Freshwater Fisheries Aquaculture Study Program, Rejang Lebong State Community Academy, Rejang Lebong Regency, Bengkulu Province. Proximate composition testing was carried out at the Animal Husbandry Laboratory of the University of Bengkulu, while organoleptic testing was carried out at the Laboratory of the Freshwater Fisheries Aquaculture Study Program, Rejang Lebong State Community Academy.

### Tools and Materials

The tools used included knives, scales, cutting boards, basins, an oven, a timer, a camera, plastic plates, and office stationery. The materials used included fresh catfish, commercial smoked catfish as a control, water, salt, and coconut shell liquid smoke.

### Research Design

This study was conducted based on previous research on the use of liquid smoke in smoked fish products. The study used a Factorial Completely Randomized Design (FCRD) with two treatment factors. The first factor was liquid smoke concentration, consisting of two levels, K5 (5%) and K10 (10%). The second factor was immersion duration, consisting of three levels, P10 (10 minutes), P20 (20 minutes), and P30 (30 minutes). Each treatment combination was replicated twice, yielding twelve experimental units, plus one commercial smoked catfish sample as a comparison (control).

### Research Procedure

The research stages began with gutting fresh catfish, washing, and soaking in a salt solution to impart a base flavor. After being rewashed and drained, the fish were immersed in a liquid smoke solution according to the concentration and duration combination of each treatment. The product was then cooked in an oven until done, characterized by a golden-yellow to brownish color.

### Parameters and Data Analysis

Organoleptic testing was conducted using a hedonic score sheet referring to SNI 01-2346-2006 on a 1–9 scale, covering the parameters of appearance, odor, taste, and texture, and involved 20 semi-trained panelists. Samples with the best organoleptic values from each treatment combination were subsequently tested for proximate composition, including crude protein, fat, moisture, ash, and carbohydrate content (Amrullah *et al.*, 2019). The organoleptic and proximate data were tested for variance homogeneity using Levene's test, followed by one-way analysis of variance (ANOVA). When the treatment had a significant effect ( $P < 0.05$ ), the analysis was continued with Duncan's Multiple Range Test at the 95% confidence level using SPSS software. The proximate test results were then compared with the quality and safety requirements for smoked fish according to SNI 2725:2013.

## RESULTS

### Organoleptic Test

The mean organoleptic values of smoked catfish products for each combination of liquid smoke concentration and immersion duration are presented in Table 2.

Table 2. Mean organoleptic values of smoked catfish under various treatments (scale 1–9)

| Treatment            | Appearance | Odor/Aroma | Taste | Texture |
|----------------------|------------|------------|-------|---------|
| K5P10 (5%, 10 min)   | 9.000      | 8.750      | 8.750 | 8.750   |
| K5P20 (5%, 20 min)   | 8.625      | 8.375      | 8.500 | 8.750   |
| K5P30 (5%, 30 min)   | 9.000      | 8.375      | 8.375 | 8.750   |
| K10P10 (10%, 10 min) | 9.000      | 7.250      | 7.750 | 8.375   |
| K10P20 (10%, 20 min) | 9.000      | 8.000      | 7.500 | 8.375   |
| K10P30 (10%, 30 min) | 8.875      | 7.375      | 7.000 | 8.500   |
| Control (K0)         | 5.750      | 3.500      | 3.750 | 7.250   |

Overall, all samples subjected to liquid smoke treatment obtained higher organoleptic values than the control across all four parameters tested. The highest values for appearance, odor, taste, and texture were consistently obtained in the treatment with 5% concentration and

10-minute immersion duration (K5P10), while the lowest values for all parameters were found in the control sample.

Further examination of Table 2 shows a fairly consistent pattern of decreasing organoleptic values with increasing immersion duration at the same concentration, particularly for the odor and taste parameters. At 5% concentration, the odor value decreased from 8.750 (K5P10) to 8.375 (K5P20 and K5P30), while the taste value decreased from 8.750 (K5P10) to 8.500 (K5P20) and 8.375 (K5P30). A similar pattern was observed at 10% concentration, with the taste value decreasing from 7.750 (K10P10) to 7.500 (K10P20) and 7.000 (K10P30). In contrast, the appearance parameter remained relatively stable within the range of 8.875–9.000 for all liquid smoke treatment combinations, indicating that the color and surface appearance of the product were less sensitive to variation in immersion duration compared with the odor and taste attributes.

### ***Analysis of Variance and Duncan's Test***

The results of the variance homogeneity test and one-way analysis of variance for the four organoleptic parameters are presented in Table 3.

Table 3. Results of variance homogeneity and analysis of variance (ANOVA) for organoleptic parameters

| Parameter  | Levene | Sig. Levene | F-calculated | Sig. ANOVA |
|------------|--------|-------------|--------------|------------|
| Appearance | 13.549 | 0.000       | 28.256       | 0.000      |
| Odor       | 1.385  | 0.188       | 5.679        | 0.000      |
| Taste      | 3.667  | 0.000       | 5.871        | 0.000      |
| Texture    | 1.557  | 0.119       | 1.120        | 0.354      |

The analysis of variance showed that the treatment had a highly significant effect ( $P < 0.05$ ) on appearance, odor, and taste, but no significant effect ( $P > 0.05$ ) on texture. Duncan's test for appearance, odor, and taste consistently placed the control sample in the subset with the lowest values, clearly separated from all treatment samples, while the liquid smoke treatment samples were mostly grouped in subsets with relatively high and overlapping values. This pattern indicates that the significant difference detected by the variance test was mainly driven by the contrast between samples given liquid smoke treatment and the control sample, rather than by large differences among combinations of concentration and immersion duration themselves. For the texture parameter, all samples, including the control, were relatively uniform, and the further test therefore did not reveal a clear subset separation.

The results in Table 3 also show that the variance of the data for appearance and taste was not homogeneous (Sig. Levene  $< 0.05$ ), largely attributable to the much lower and more variable control values compared with the liquid smoke treatment samples. Nevertheless, the calculated F-values for both parameters far exceeded the critical value, so the conclusion of a significant treatment effect can still be upheld, given the large effect size resulting from the sharp contrast between the control and treated samples. A different condition was shown by the odor and texture parameters, which satisfied the assumption of variance homogeneity (Sig. Levene  $> 0.05$ ), so the ANOVA results for both parameters can be interpreted directly without concern about violation of statistical assumptions.

### ***Proximate Test***

Samples with the best organoleptic values from each treatment combination were tested for proximate composition. The results of protein, fat, moisture, ash, and carbohydrate content testing are presented in Table 4.

Table 4. Proximate composition of smoked catfish under various treatments (% wet weight)

| Sample     | Protein | Fat   | Moisture | Ash | Carbohydrate |
|------------|---------|-------|----------|-----|--------------|
| 1. K5P10   | 33.54   | 18.98 | 25.24    | 7.9 | 9.59         |
| 2. K5P20   | 29.04   | 18.91 | 28.24    | 7.2 | 11.92        |
| 3. K5P30   | 29.47   | 17.99 | 28.85    | 4.9 | 13.84        |
| 4. K10P10  | 26.29   | 22.13 | 26.36    | 6.8 | 12.83        |
| 5. K10P20  | 24.36   | 20.71 | 23.17    | 5.0 | 22.71        |
| 6. K10P30  | 27.42   | 21.64 | 22.50    | 6.8 | 18.69        |
| 7. Control | 32.01   | 18.83 | 26.52    | 2.9 | 13.42        |

The highest protein content was obtained in the K5P10 sample (33.54%) and the lowest in the K10P20 sample (24.36%). Fat content showed the opposite pattern, with the highest value in the K10P10 sample (22.13%) and the lowest in the K5P30 sample (17.99%). Moisture content ranged from 22.50% (K10P30) to 28.85% (K5P30), while ash content ranged from 2.9% (control) to 7.9% (K5P10). The highest carbohydrate content was obtained in the K10P20 sample (22.71%).

When examined by concentration, protein content in the 5% concentration series tended to decrease with increasing immersion duration, from 33.54% (K5P10) to 29.04% (K5P20) and 29.47% (K5P30), whereas in the 10% concentration series the pattern of protein decrease was inconsistent, as the lowest value was actually found at the medium duration (K10P20 = 24.36%). Unexpectedly, the highest ash content was found in the sample with the shortest immersion duration (K5P10 = 7.9%) and decreased at longer durations at the same concentration, a pattern contrary to the general expectation that longer immersion would increase mineral absorption from the salt and liquid smoke solution. Carbohydrate content, calculated by difference, showed values inversely related to protein and ash content, so that the increase in carbohydrate content in several samples (particularly K10P20 and K10P30) more likely reflects a decrease in other components than an actual increase in carbohydrate content.

### ***Comparison with SNI Smoked Fish 2725:2013***

A comparison of the fat and moisture content of the smoked catfish products from this study with the quality and safety requirements for smoked fish under SNI 2725:2013 is presented in Table 5.

Table 5. Comparison of fat and moisture content with SNI smoked fish 2725:2013

| Sample                    | Fat Content (%) | Moisture Content (%) | Conformity with SNI |
|---------------------------|-----------------|----------------------|---------------------|
| 1. K5P10                  | 18.98           | 25.24                | Compliant           |
| 2. K5P20                  | 18.91           | 28.24                | Compliant           |
| 3. K5P30                  | 17.99           | 28.85                | Compliant           |
| 4. K10P10                 | 22.13           | 26.36                | Fat non-compliant   |
| 5. K10P20                 | 20.71           | 23.17                | Fat non-compliant   |
| 6. K10P30                 | 21.64           | 22.50                | Fat non-compliant   |
| 7. Control                | 18.83           | 26.52                | Compliant           |
| SNI 2725:2013 requirement | Max. 20.0       | Max. 60.0            | —                   |

The moisture content of all research samples met the requirements of SNI 2725:2013, being well below the maximum limit of 60.0%. The fat content of the K5P10, K5P20, K5P30, and control samples also met the requirements, whereas the three samples with 10% liquid

smoke concentration (K10P10, K10P20, and K10P30) exceeded the maximum fat content limit of 20.0%. The sensory scores of all treatment samples were above 7 on the 1–9 scale, thus meeting the minimum sensory requirement of SNI, while the control sample fell below this value for the appearance, odor, and taste parameters.

Overall, of the seven samples tested, only the K5P10, K5P20, K5P30, and control combinations met all the requirements of SNI 2725:2013 for fat and moisture content, whereas the three samples with 10% concentration met the moisture content requirement but not the fat content requirement. When the SNI conformity criteria and sensory values are considered together, the K5P10 combination is the only treatment that simultaneously meets all SNI quality requirements while achieving the highest organoleptic values across all four parameters tested, making it the most suitable to recommend as a reference treatment for processing smoked catfish using coconut shell liquid smoke.

## DISCUSSION

The treatment of 5% liquid smoke concentration with a 10-minute immersion duration consistently produced the highest organoleptic values across all parameters tested. This pattern indicates that lower concentration and shorter immersion duration tended to be preferred by panelists compared with higher concentration and longer duration. This finding is consistent with Simon *et al.* (2005), who noted that although liquid smoke can impart a uniform flavor, its use at excessive concentration or exposure has the potential to produce an overly sharp taste and aroma due to the accumulation of phenolic compounds, thereby reducing the level of consumer preference. A similar tendency was reported by Fauzi *et al.* (2022) for smoked catfish using dried banana leaf liquid smoke, in which a longer immersion time did not always increase the product's preference score.

The high appearance score obtained under the K5P10 treatment can be explained by the mechanism of color formation characteristic of smoked products. Carbonyl compounds in liquid smoke react with amino groups of proteins on the surface of fish flesh through a reaction resembling the Maillard reaction, producing a golden-yellow to brownish color characteristic of smoked fish products (Fikri *et al.*, 2022). This reaction is reinforced by the interaction between phenolic compounds in liquid smoke and the proteins and reducing sugars in fish flesh, which further contributes to color intensity and the formation of the characteristic smoky aroma (Muri *et al.*, 2023). At 5% concentration with 10-minute immersion, the amount of carbonyl and phenolic compounds absorbed into the flesh tissue is presumed to be at an optimum level for forming color and aroma preferred by panelists, whereas at 10% concentration the accumulation of these compounds tends to be excessive, resulting in an overly sharp aroma and taste, as reflected in the decline in odor and taste values from samples K10P10 to K10P30 in Table 2.

A different pattern was reported by Rakhmayeni *et al.* (2024) for smoked tandipang fish, which instead obtained better preference scores at longer immersion durations. This difference is presumed to be related to differences in flesh characteristics and muscle structure among fish species that affect the rate of liquid smoke penetration into the tissue, so that the optimal immersion time cannot be generalized across commodities and must be determined specifically for each fish species.

The moisture content of all samples, ranging from 22.50–28.85%, indicates that the drying process during the oven-baking stage proceeded satisfactorily and consistently met SNI requirements, so that variation in moisture content among treatments was more influenced by differences in the absorption of liquid smoke and salt solution than by the efficiency of the cooking process itself. Overall, the results of this study reinforce the recommendation to use 5% liquid smoke concentration with a 10-minute immersion duration as the best treatment, as

this combination provides an optimal balance among sensory acceptance, protein content, and conformity with the quality requirements of smoked fish SNI.

The finding that the combination of low concentration and short duration (K5P10) provides the highest sensory acceptance is in line with the comprehensive review by Baroutian *et al.* (2026), which concluded that the antimicrobial and antioxidant effectiveness of liquid smoke indeed increases at higher concentrations, but the threshold for consumer sensory acceptance is generally reached well before that concentration, resulting in a trade-off between food safety and taste preference. A similar finding was reported by Hadanu and Lomo (2019) for smoked fish immersed in coconut shell liquid smoke, in which a low concentration (3%) with an adequate immersion duration actually produced better consumer acceptance than higher concentrations. The consistency of these findings across different species and liquid smoke sources reinforces the argument that the optimum threshold for liquid smoke concentration in smoked fish products generally lies in the low-to-moderate range rather than at the maximum concentration that theoretically provides the best preservation effect.

In this study, the absence of a significant treatment effect on texture indicates that the muscle protein structure of catfish is relatively stable against exposure to liquid smoke compounds within the range of concentrations and durations tested. This finding is consistent with Setyastuti *et al.* (2021) for smoked catfish with coconut shell liquid smoke, who reported that product texture is primarily determined by protein solubility and moisture content in muscle tissue, whereas significant texture changes were only observed after the product underwent frozen storage for a certain period due to gradual protein structure degradation. Thus, at the initial processing stage examined in this study, texture changes due to smoking are more strongly determined by the cooking process—namely thermal protein denaturation from oven heat—than by variation in liquid smoke concentration and immersion duration themselves.

In terms of chemical composition, the increase in liquid smoke concentration from 5% to 10% tended to be accompanied by an increase in fat content and a decrease in protein content in most samples. This trend is consistent with the findings of Ikhwan *et al.* (2025) for smoked milkfish and sardines, which showed that exposure to liquid smoke at higher concentrations also affected the product's fat content due to interaction between phenolic compounds and lipid components on the surface of the fish flesh. A similar finding was reported by Muri *et al.* (2023) for skipjack tuna floss treated with liquid smoke at various concentrations, in which fat content tended to increase with increasing liquid smoke concentration because phenolic and carbonyl compounds in liquid smoke can interact with the lipid layer on the flesh surface, although this effect was not always statistically significant across the entire range of concentrations tested. The increase in fat content at 10% concentration caused three samples in this study to fail to meet the maximum fat content requirement of SNI 2725:2013, although all three still obtained acceptable sensory scores.

The decrease in protein content in treatments with longer immersion duration, observed in samples K5P20 and K5P30 relative to K5P10, is presumed to be related to the leaching of water-soluble sarcoplasmic proteins from the flesh tissue into the salt and liquid smoke immersion solution. The leaching of soluble components due to longer immersion time was also reported by Litaay *et al.* (2021) for anchovy flour soaked in sodium bicarbonate solution, in which longer immersion times increased the likelihood of water-soluble components such as proteins and minerals migrating from the fish tissue into the immersion solution owing to the concentration gradient between the tissue and the immersion medium. Although the type of immersion solution differs, this mass-transfer principle is relevant for explaining the pattern of decreasing protein content in samples with longer immersion durations in the present study. These findings indicate a trade-off among preference level, nutritional content, and product quality conformity with national standards, so that the determination of liquid smoke

concentration and immersion duration at a production scale needs to consider the balance among sensory, nutritional, and food quality regulatory aspects.

The significant effect of treatment on protein content observed in this study differs from the findings of Anggraini *et al.* (2022) for smoked baung fish (*Mystus gulio*), who reported that liquid smoke concentration had no significant effect on protein or ash content, although it significantly affected moisture and fat content. This difference is likely related to differences in muscle structure and intramuscular fat content among fish species, as well as differences in treatment design, since this study combined variations in concentration and immersion duration factorially, allowing the effect of protein leaching due to immersion duration to also be observed. Consistent with this, Khamidah *et al.* (2019) for smoked manyung fish (*Arius thalassinus*) also confirmed that liquid smoke immersion duration plays an important role in determining final product quality, even when the type and concentration of liquid smoke used are the same, reinforcing the need to optimize the combination of concentration and duration simultaneously rather than considering either factor alone.

The increase in fat content with increasing liquid smoke concentration observed in this study is also consistent with the findings of Hutomo *et al.* (2015) for smoked eel (*Monopterus albus*), who reported that higher liquid smoke concentration affected the quality and lipid composition of the product due to interaction between phenolic and carbonyl compounds and the fat layer on the flesh surface. Chemical characterization of commercial liquid smoke by Montazeri *et al.* (2013) further explains that the proportion of phenol and carbonyl compounds in liquid smoke varies considerably depending on the source and production process, so that the intensity of color and aroma, as well as their interaction with the lipid and protein components of fish flesh, may also differ among types of liquid smoke. Considering all these results, the selection of 5% liquid smoke concentration with a 10-minute immersion duration in this study was based on sensory and nutritional considerations.

## CONCLUSION

Liquid smoke concentration and immersion duration significantly affected the appearance, odor, and taste of smoked catfish, but had no significant effect on texture. The highest organoleptic values across all parameters were obtained under the treatment with 5% concentration and 10-minute immersion duration, which also produced the highest protein content (33.54%) among all treatments. The moisture content of all samples met the requirements of SNI smoked fish 2725:2013, whereas the fat content in the 10%-concentration treatments exceeded the required maximum limit. Based on all parameters tested, the combination of 5% liquid smoke concentration with a 10-minute immersion duration is recommended as the best treatment for processing smoked catfish using coconut shell liquid smoke.

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