Formaldehyde detection and quality evaluation of Tambaqui (*Colossoma macropomum*) to ensure food safety in the Coastal Region of Kalianda

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Abstract. Food safety is a critical component of the national food system, particularly for fishery commodities that are highly perishable and require proper post-harvest handling. In coastal regions such as Kalianda, South Lampung, limited cold chain infrastructure and inadequate post-harvest handling systems can contribute to a decline in fish quality and the potential for substandard practices, including the use of non-recommended additives. This study aimed to analyze the freshness and formaldehyde content of tambaqui (*Colossoma macropomum*) in the fish supply chain in Kalianda. Sampling was conducted from April to June 2025 at the Fish Auction Site (TPI) at Dermaga Bom and traditional markets in the region. The parameters analyzed included organoleptic attributes, pH, Total Volatile Base (TVB), Trimethylamine (TMA), natural formaldehyde (FA), and dimethylamine (DMA). The results indicated that fish obtained from collectors exhibited better quality (average organoleptic score of 7.2) compared to market samples (average score of 5.9). TVB levels in market samples reached 14.12 mg N/100g, higher than the 8.82 mg N/100g found in collector samples; TMA, FA, and DMA values were also higher in market-sourced fish. These findings indicate quality degradation and potential contamination during distribution in traditional markets. Therefore, strengthening the cold supply chain, providing education to stakeholders, and enforcing strict monitoring of hazardous additive usage are essential to ensure the quality and safety of fishery products.

1 Introduction

Food safety plays an integral role in national food systems, particularly concerning fishery commodities, which are highly perishable and demand meticulous post-harvest handling to preserve quality and ensure consumer safety. In coastal regions like Kalianda, South Lampung, the absence of adequate cold chain systems and proper handling procedures may contribute to rapid degradation of fish quality and create conditions that enable the use of improper preservation methods, including potentially hazardous additives.

Fish spoilage is often evaluated using physicochemical and sensory parameters. Total Volatile Base Nitrogen (TVB-N) is widely recognized as a robust spoilage indicator, as it reflects the accumulation of ammonia, trimethylamine (TMA), and other nitrogenous

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compounds during degradation [1]. pH changes also provide valuable information about the freshness status of fish muscle, with increases typically correlating with microbial activity [2]. Trimethylamine oxide (TMAO), abundant in marine fish, can be enzymatically or microbially reduced to dimethylamine (DMA) and TMA, compounds responsible for characteristic off-odors and closely associated with spoilage progression.

Formaldehyde in fish may occur naturally as a result of TMAO degradation during storage, particularly in cold conditions, or may be illegally added as a preservative to prolong shelf life. Natural formaldehyde concentrations in marine species are generally low and vary by species, size, and storage conditions [3]. However, levels exceeding natural thresholds can indicate contamination from external sources, posing a significant health hazard due to its carcinogenic potential.

Tambaqui (*Colossoma macropomum*) is widely consumed in coastal Lampung, yet there is limited information on its post-harvest quality and formaldehyde content across different supply chain nodes. To address this gap, this study evaluates freshness and formaldehyde levels in tambaqui obtained from both fish collectors at Dermaga Bom landing site and local traditional markets. Parameters include organoleptic properties, pH, TVB, TMA, natural formaldehyde (FA), and dimethylamine (DMA). Findings from this investigation will offer insights into the integrity of the fish supply's supply chain, inform food safety protocols, and support policy and infrastructure improvements in coastal fisheries.

2 Methods

2.1 Research materials and equipment

The research was conducted from March to June 2025 , with sample collection carried out at the Fish Auction Site (TPI) Dermaga Bom and traditional markets in Kalianda, South Lampung . Sample preparation was performed at the Way Muli Aquaculture Center, Rajabasa, South Lampung. The sample freezing stage was carried out in cold storage at PT. Iandv Bio Indonesia, Rajabasa, South Lampung. Chemical testings were conducted at the Laboratory of Aquatic Product Raw Material Characteristics and the Biochemistry Laboratory, Department of Aquatic Product Technology, as well as the Fish Nutrition and Feed Technology Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University, Bogor.

The study utilized fresh tambaqui (*Colossoma macropomum*) as the primary material, along with analytical-grade reagents including ammonium acetate, glacial acetic acid, acetylacetone, distilled water, 7.5% TCA solution, Nessler reagent, H_3BO_3 solution, saturated K_2CO_3 (3 N) solution, neutral 10% formaldehyde, 0.0105 N HCl, copper ammonia solution, 5% CS_2–toluene solution, 30% acetic acid, and anhydrous Na_2SO_4 (all Merck or equivalent). The equipment employed included organoleptic score sheets, a pH meter, homogenizer, analytical balance, knives, spatulas, Conway dishes, incubator, ELISA reader, microplates, micropipettes, microtips, glass pipettes, pipette fillers, test tubes, measuring cylinders, glass funnels, filter papers, vortex mixer, ice gels, and styrofoam boxes. These materials and instruments were selected to ensure the precision and reliability of physical and chemical analyses.

2.2 Research stages

The research procedure began with sampling, followed by physical and chemical testing, and concluded with data analysis. Fish samples were collected from two different locations, namely from a collector at the Dermaga Bom fish auction site and a seller at the Kalianda traditional market. The selection of tambaqui from these two sources was considered to represent the actual conditions at each location, so it could be categorized as a representative form of sampling. The samples were then stored in a cool box containing flake ice and ice gel to maintain the quality of the fish until the testing process was carried out.

2.2.1 Sample collection and storage

A total of nine fish were obtained, with three used for organoleptic testing in triplicate and the remaining six processed into homogenized samples for chemical analyses, including pH, TVB, TMA, FA, and DMA. The samples were stored in styrofoam boxes containing ice flakes at a 1:2 fish-to-ice ratio with added ice gel to maintain quality prior to testing. Additionally, interviews with collectors and market vendors were conducted to gather information about fishing and storage practices.

2.2.2 Sample preparation

Morphometric measurements of tambaqui samples, including body height, body width, standard length, and total length, were taken using two precision rulers, and the results were systematically recorded to build a complete dataset. The fish samples were selected based on uniform body proportions to ensure consistency in the analysis. Organoleptic tests were then conducted using human senses to evaluate taste, odor, color, and texture in accordance with the Indonesian National Standard No. 2729 of 2013.

2.2.3 Freezing and transporting samples

The fish samples were transported the next day from Lampung to Bogor during a 10-hour journey, starting at 11:00 a.m. to 9:00 p.m. Western Indonesian Time. The fish samples were transported in a styrofoam box containing flake ice with a ratio of fish to ice of 1:2 and ice gel to maintain the quality of the fish.

2.2.4 Chemical testing

The chemical testing procedure for food involves several systematic steps. pH testing is carried out to determine the acidity or alkalinity of a sample, which affects its quality and safety. The Total Volatile Base (TVB) test measures ammonia and other volatile nitrogen compounds as indicators of freshness, while the TMA test evaluates fish quality by detecting spoilage-related compounds. Natural formaldehyde testing is performed to identify the presence of potentially harmful formaldehyde, and dimethylamine testing is used to further assess product quality, particularly in fish, as it reflects deterioration and spoilage.

2.3 Analysis

2.3.1 Organoleptic assessment

Following the guidelines in Indonesian National Standard No. 2729 of 2013 for fresh fish [4], sensory evaluation was conducted using a score sheet with a nine-point scale. Assessments were based on human sensory perception of several attributes, including the eyes, gills, surface mucus, flesh, odor, and texture. Three trained panelists were engaged to perform the evaluations.

2.3.2 pH measurement

The acidity level (pH) of the fish was determined using a calibrated pH meter applied to three body regions—dorsal, ventral, and caudal—to ensure consistent data. Approximately 5 g of fish flesh was weighed, minced, and homogenized with 45 mL of distilled water using a homogenizer. The pH reading was recorded once the meter displayed a stable value, following the method described by [5].

2.3.3 Total Volatile Base (TVB) analysis

TVB content, which indicates protein decomposition, was measured using the Conway microdiffusion method with Nessler reagent. A 15 g sample was blended with 45 mL of 7.5% TCA, homogenized, and filtered to obtain a clear extract. The extact was placed in the outer chamber of a Conway dish alongside saturated K_2CO_3, while 3% H_3BO_3 was placed in the inner chamber. After sealing, the dish was incubated at 37°C for 2 hours before titrating the boric acid solution with 0.02 N HCl until a pink endpoint appeared. The TVB concentration was calculated using the titration data.

2.3.4 Trimethylamine (TMA) analysis

TMA determination followed the Conway microdiffusion method [7]. In this test, TMA was reduced to TMA, which was then quantified through gas diffusion and titration. The sample extract was combined with neutral formaldehyde and saturated K_2CO_3 in the outer chamber, while 3% H_3BO_3 was placed in the inner chamber. After sealing, the setup was incubated for 60 minutes at 37°C, and the boric acid solution was titrated with 0.02 N HCl until the green color shifted to pink. The TMA concentration was calculated from titration results.

2.3.5 Natural Formaldehyde (NF) analysis

Natural formaldehyde content was measured using the Nash reagent method [8], which involves a solution of ammonium acetate, glacial acetic acid, and acetylacetone. Five grams of fish flesh were homogenized with 15 mL of 7.5% TCA, filtered, and mixed with an equal volume of Nash reagent. The mixture was incubated at 40°C for 30 minutes, cooled to room temperature, and then its absorbance was measured at 412 nm using an ELISA reader. FA levels were calculated based on a standard curve ranging from 0 to 20 ppm.

2.3.6 Dimethylamine (DMA) analysis

DMA quantification, following the method of [9], involved mixing 5 g of sample with 15 mL of 7.5% TCA, then reacting 2 mL of the extract with copper-ammonia solution and CS_2-toluene. The mixture was incubated at 50°C for 2 minutes, combined with 30% acetic acid, and vortexed for 1 minute. The toluene layer was separated into a tube containing anhydrous Na_2SO_4, and absorbance was measured at 440 nm using an ELISA reader. DMA levels were determined using a standard curve (0–19 ppm).

2.4 Data analysis

The procedure for processing physical and chemical test results, including organoleptic test, pH, TVB, TMA, natural formaldehyde, and dimethylamine, were carried out using a parametric approach with Microsoft Excel 2021. This software served as a tool to process data systematically so that more measurable results are obtained. Through this application, the total value, average, and standard deviation of each test parameter was calculated.

3 Result and discussion

3.1 Aquatic Product Supply Chain in Kalianda

The tambaqui fish (*C. macropomum*) belongs to the family *Serrasalmidae*. The tambaqui fish prefers habitats in whitewater, blackwater, and clearwater rivers with flooded forests during part of the year, migrating in large schools during spawning season. tambaqui are commonly caught using gillnets made of multifilament nylon with mesh sizes ranging from 150 to 240 mm stretched. Gillnets account for about 70% of the catches, and other methods include mixed gear (gillnets combined with castnets), drift nets, long lines, and castnets [10].

Morphometric measurements of freshwater pomfret (*C. macropomum*) were recorded to characterize the physical dimensions of the sampled fish. The average total length was 17.50 ± 0.44 cm, with a standard length of 13.93 ± 0.65 cm. The mean fork length was 15.30 ± 0.46 cm, while the average body height was 9.60 ± 0.92 cm. These measurements were used as baseline data to ensure uniformity of the fish samples analyzed in subsequent physicochemical and sensory quality assessments.

Field interviews conducted in the coastal area of Kalianda show a fairly structured distribution pattern in the supply chain for capture fisheries products, which operates on a daily cycle. Fishing activities generally begin when fishermen leave the dock at night to go out to sea. The catch is then brought back to shore in the early morning and immediately distributed to the fish auction site. At the fish auction site, the fresh fish are immediately auctioned to collectors or wholesalers, and the transaction process usually takes place on the same day. This auction process allows fishery products to immediately enter the formal distribution channel, both for local consumption and for supply to other regions, thereby maintaining the freshness and market value of the commodity.

The distribution pattern for fish entering traditional markets is slightly different. These fish generally come from fishing activities conducted by fishermen the previous afternoon. To maintain quality and slow down the degradation process, the catch is immediately stored in insulated containers such as cool boxes equipped with ice as a passive cooling medium. This low-temperature storage aims to suppress the activity of spoilage microorganisms and extend the shelf life of the product until distribution and sale the following day. This storage and distribution pattern highlights the importance of the cold chain in maintaining the quality of fresh seafood throughout the supply chain, as well as illustrating the adaptation of fishermen and traders to fishing times and market demand. An illustration of the supply chain for aquatic products in Kalianda is attached in Figure 1. Documentation of fish handling at the TPI and traditional markets in Kalianda is attached in Figure 2.

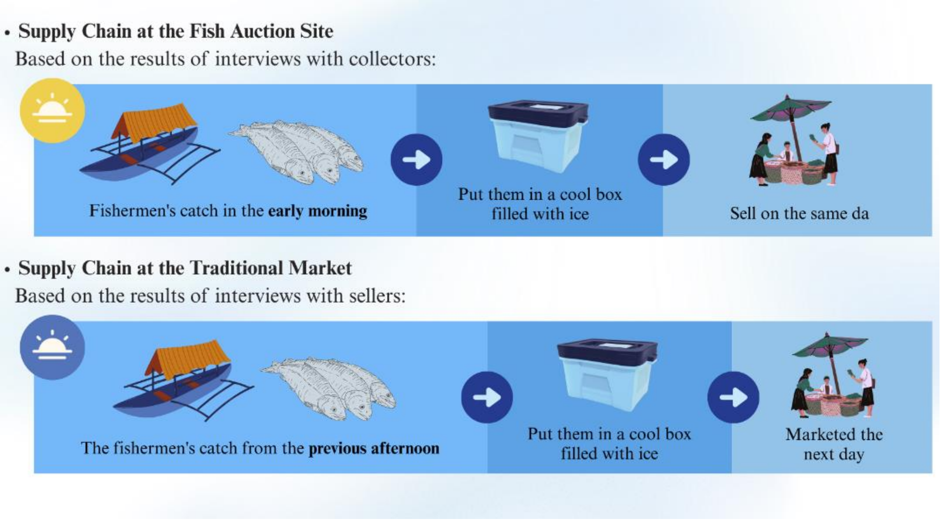

Fig. 1. Aquatic product supply chain in Kalianda.

A B

Fig. 2. Fish Handling at the Fish Auction Site and Traditional Market in Kalianda. Description: A = Dermaga Bom Kalianda Fish Auction Site, B = Kalianda Traditional Market.

3.2 Organoleptic Test

Based on field observations, tambaqui (*C. macropomum*) delivered to the Fish Auction Site (TPI) were generally caught by local fishers the night before and promptly placed by collectors into containers filled with water and ice blocks. In comparison, fish sold in traditional markets were typically obtained from collectors the previous afternoon and stored overnight by vendors in insulated boxes with crushed ice. This method of storage is consistent with recommendations, who emphasized that maintaining fish quality begins at the point of acquisition by using crushed ice as a cooling medium and keeping the product in insulated boxes to sustain low temperatures. The differences in organoleptic quality scores between tambaqui (*C. macropomum*) from collectors and those from markets are illustrated in Figure 3.

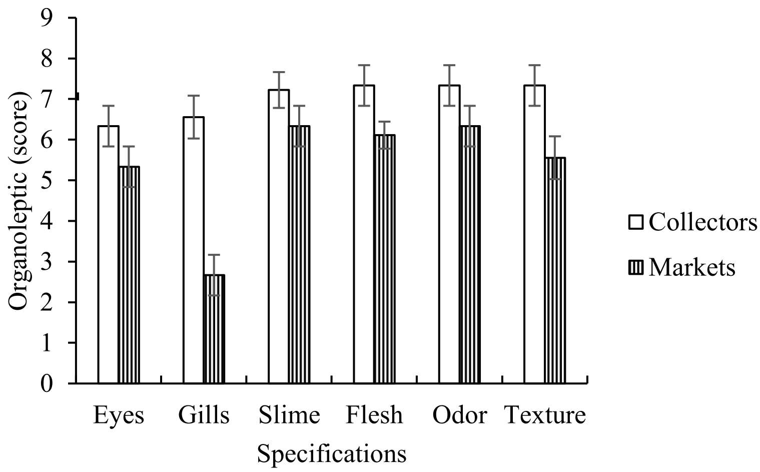

Fig. 3. Sensory quality parameters of Tambaqui (*Colossoma macropomum*). The dotted-line indicates the cut-off value of fresh fish.

Sensory assessments, which examined attributes such as eye brightness, gill coloration, surface mucus, firmness of flesh, odor, and texture, were carried out by three trained panelists and revealed notable quality disparities. Statistical evaluation confirmed that tambaqui obtained directly from collectors at the TPI had significantly higher organoleptic scores than those purchased from market vendors, reflecting greater freshness as a result of more recent harvesting and better handling practices. Similar trends were reported by Rachma *et al.* [11], who found that black tambaqui landed directly by seine net fishers in Kendal Regency retaine d higher freshness levels due to swift post-catch handling and shorter storage durations. Among the sensory indicators, odor was the most decisive factor, as the development of ammonia-like smells was associated with the onset of spoilage. A shorter supply chain proved to be instrumental in preserving the sensory quality of fresh fish products.

3.3 pH

Acidity testing is an instrumental approach to assessing the quality and freshness of fish, carried out using a pH meter after the fish meat has been homogenized with distilled water. This measurement aims to identify the level of acidity or alkalinity of muscle tissue, which directly reflects the post-mortem physiological status of the fish. Fresh fish typically exhibit a pH range of 6.0 to 7.0; deviations from this range indicate quality degradation, with a pH above 7 indicating intensified decomposition processes due to microbial activity, while a pH below 6 indicates quality deterioration due to the accumulation of acidic compounds during storage. The pH values of fish obtained from collectors and market vendors are presented in Figure 4.

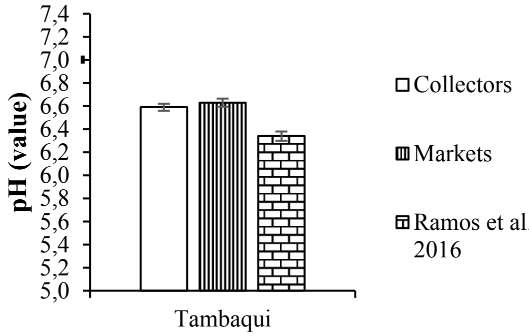

Fig. 4. pH of Tambaqui **(***C. macropomum***).** The dotted-line indicates the cut-off value of fresh fish.

The pH values of Tambaqui (*C. macropomum*) from collectors (6.59) and markets (6.63) showed only a slight difference, indicating that both sources maintained the fish in relatively fresh condition. Fresh fish muscle generally exhibits a near-neutral pH around 6.0-7.0 (the dotted line), which initially decreases post-mortem due to lactic acid formation before gradually increasing as microbial and enzymatic activity progresses, producing basic compounds such as ammonia and trimethylamine [12]. The observed pH levels are within the range reported for fresh fish and suggest that the market samples, despite undergoing additional handling and storage, have experienced only minimal biochemical changes compared to collector samples. This pattern aligns with previous findings that slight pH elevation is an early indicator of spoilage progression, emphasizing the utility of pH as a rapid and non-destructive freshness assessment parameter in fish quality monitoring.

3.4 Total Volatile Base (TVB)

Total Volatile Base testing is one of the most commonly used parameters in assessing the quality of fishery products, especially seafood. TVB measurement includes the determination of trimethylamine levels produced by spoilage bacteria activity, dimethylamine formed as a result of enzymatic autolysis during frozen storage, and ammonia produced through amino acid deamination and nucleotide catabolism. In addition, TVB also includes other volatile base nitrogen components that are closely related to the spoilage process in fishery products. The TVB levels of fish obtained from collectors and market vendors are presented in Figure 5.

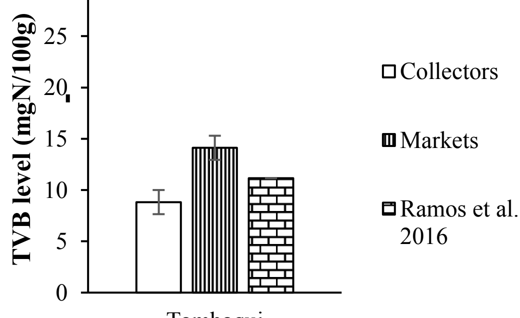

Fig. 5. TVB of Tambaqui (*Colossoma macropomum*). The dotted-line indicates the value of spoiled fish.

Figure 3 illustrates that Tambaqui (*C. macropomum*) samples sourced directly from collectors exhibit notably lower total volatile base (TVB) values (~8 mg N/100 g) compared to those obtained from markets (~14 mg N/100 g), indicating less protein degradation in the former. The dotted line in the figure represents the maximum allowable TVB value of 20 mg N/100 g, as stipulated in SNI 2354.8:2009. Elevated TVB concentrations—comprising ammonia, dimethylamine (DMA), and trimethylamine (TMA)—are linked to microbial and enzymatic spoilage and serve as established indicators of fish freshness, with values above 15 mg N/100 g often signaling the onset of spoilage [13]. The significant disparity between collector and market samples corroborates findings reported before, indicating that TVB-N levels exceeding approximately 35 mg N/100 g reliably reflect advanced spoilage stages. This underscores the necessity of minimizing storage duration and maintaining proper cold chain protocols to preserve sensory and biochemical quality in fish products.

3.5 Trimethylamine (TMA), Natural Formaldehyde (NF), and Dimethylamine (DMA)

The trimethylamine test on fish is used to assess freshness and detect spoilage, as bacteria, particularly in the visceral area, can reduce trimethylamine oxide into trimethylamine, a volatile compound that decreases sensory quality. The natural formaldehyde test identifies and measures endogenous formaldehyde formed during quality degradation, especially under low-temperature or frozen storage. Meanwhile, the dimethylamine test serves as an important molecular parameter to evaluate the decline in quality and freshness of fish, while also helping distinguish between naturally occurring and artificially added formaldehyde. TMA, NF, and DMA values for both sources are shown in Table 1.

Table. 1. Trimethylamine (TMA), Natural Formaldehyde (NF), and Dimethylamine (DMA) of Tambaqui (*Colossoma macropomum*)

Source of Fish	TMA (mgN/100g)	NF (ppm)	DMA (ppm)
Collector	8.24 ± 0.59	0.26 ± 0.02	0.57 ± 0.02
Market	9.22 ± 0.90	0.34 ± 0.03	0.60 ± 0.02

The statistical analysis indicated that the fish from collector had significantly lower TMA, NF, and DMA levels than the one from the market, suggesting superior freshness. Microorganisms use oxygen from TMAO under anaerobic conditions to produce TMA, a process mainly driven by gram-negative bacteria that dominate the microbial community in degrading fish tissue. Natural formation of formaldehyde occurs through the reductive mechanism of trimethylamine oxide catalyzed by the enzyme TMAOase, producing formaldehyde and dimethylamine as by-products [14]. The naturally formed formaldehyde, together with dimethylamine, contributes to protein rigidity, and the extent of protein denaturation is generally proportional to the ratio of natural formaldehyde to dimethylamine [15].

4 Conclusion

The comparative evaluation of *Colossoma macropomum* quality parameters between collectors and market sources revealed consistent trends across physicochemical and sensory indicators. Organoleptic assessment showed significantly higher scores for fish obtained directly from collectors, reflecting superior freshness and minimal sensory deterioration. This finding was supported by pH measurements, where both sources exhibited values within the acceptable freshness range, but collector samples maintained slightly lower pH, indicating reduced microbial and enzymatic activity. Total Volatile Base (TVB) levels were markedly higher in market samples, signifying greater protein degradation, while TMA concentrations followed a similar pattern, with lower values in collector samples corresponding to delayed conversion into volatile amines. Formaldehyde (FA) and dimethylamine (DMA) contents were also significantly elevated in market-sourced fish, suggesting more advanced spoilage and possible risks associated with natural or external contamination. Collectively, these results demonstrate that fish obtained directly from collectors exhibit superior quality and freshness compared to market samples, emphasizing the importance of effective cold chain management, rapid distribution, and strict monitoring to ensure the safety and quality of fishery products.

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