Development of a Traceability System for Fresh Tuna Loin (Thunnus sp) Quality Based on Various Handling Temperatures at FPU XYZ Using Quick Response (QR) Codes

ABSTRACT

This study aims to: (1) identify the supply chain at FPU XYZ in Gorontalo City; (2) determine the quality of fresh tuna loin at each stage of the supply chain based on handling temperatures; (3) evaluate the validity of the QR Code during scanning; and (4) analyze the implementation of a QR Code-based traceability system for fresh tuna loin. The research methodology involved surveys and laboratory tests. Sampling was conducted using non-probability purposive sampling, with 19 respondents from a total population of 30, comprising fishermen, collectors, and FPU staff. Laboratory results were obtained using a completely randomized design and analyzed with ANOVA. The results indicate that: (1) the traceability of fresh tuna loin quality at FPU XYZ involves three supply chain stations: fishermen, collectors, and FPU; (2) laboratory test results on histamine content, Total Plate Count (TPC), and Salmonella based on different handling temperatures and samples across the supply chain meet the standards of SNI 2354.10:2016, SNI 2332.3:2015, and SNI 01-2332.2-2006; (3) information from laboratory tests formatted as QR Codes has been validated by expert validators and deemed valid based on three assessment aspects; (4) the traceability system for fresh tuna loin quality based on QR Code can be accessed anytime and anywhere.

Keywords: Traceability, Mutu, Tuna Loin, QR Code

1. INTRODUCTION

Gorontalo Province is one of the key producers of tuna in Sulawesi Island, with its catch being exported to various countries (Lamasigi *et al*., 2022). According to Pratiwi *et al*. (2021), the export markets for Indonesian tuna, including the United States, the European Union, and Japan, require a traceability system in each Fish Processing Unit (FPU) that cooperates as an importing country. The traceability system is a concept established to address food safety issues, which have become a serious global concern in recent years (Lin *et al*., 2018). Therefore, this system is crucial for FPUs, including FPU XYZ, which until now have relied on manual paper-based recording. This method risks being damaged or lost due to staff negligence.

The advent of technology as a system capable of maintaining accurate traceability records is essential, enabling direct access to information by buyers. Consequently, FPU XYZ can enhance buyer trust in the safety of its exported products. Traceability refers to the system's ability to trace the raw materials of food products, including feed and additives, throughout the production chain, from the receipt of raw materials to distribution. This system also ensures rapid and efficient clarity of the origin and treatment history of products, particularly at critical points in the supply chain to guarantee food safety (Eka Putra & Labasariyani, 2018). Traceability can also be understood as risk management for business organizations, facilitating the recall of identified unsafe products or goods (Prasatia *et al*., 2020).

In the study by Hasibuan *et al*, (2021), traceability was implemented using a paper-based system that coded the date of shipment, quantity of products shipped, destination, and delivery paperwork. The coding for internal traceability has been designed in the form of a 1D barcode consisting of 12 digits, starting from the stage of raw material receipt to staffing. The implementation of the traceability system has also been applied to dragon fruit products using a tracing and tracking system in a fishery company capable of monitoring each stage of the production process (Harahap dan Wisudari, 2020).

Although traceability systems have been widely implemented, they rarely include information on quality content. Hence, in the event of unexpected risks such as contamination by undesirable compounds (Salmonella and histamine), immediate management is not possible. Changes in quality content may occur due to temperature increases, which accelerate bacterial growth and the process of biochemical decomposition (Irianto, 2008). A rapid rise in histamine levels is also a result of the optimal growth of histamine-producing bacteria (Nento *et al*., 2015).

Bacterial contamination can occur during the handling of fishery products, from capture to distribution to consumers. Therefore, it is crucial to implement traceability with a system that utilizes technology to reduce the risk of damage and loss of important export documents, which has traditionally been done manually. One technology that can be utilized is the Quick Response Code (QR Code), which can store more information, is smaller in size and can be scanned both vertically and horizontally, unlike traditional barcodes (Sujana & Putra, 2022). In Japan, QR Codes have been widely used in marketing activities since the early 1990s, thanks to their ability to create direct interactions with consumers.

Therefore, this study aims to develop a traceability system for the quality of fresh tuna loin products in the supply chain, from capture and landing to FPU XYZ, based on different temperatures, utilizing QR Code technology. This will enhance product marketing security and increase buyer trust.

2. MATERIAL AND METHODS

This study used both quantitative and qualitative methods with survey and laboratory testing approaches. The quantitative method emphasized the analysis of numerical data processed using statistics, while the qualitative method focused on analyzing the thought processes and dynamics of relationships among observed phenomena (Priadana & Sunarsi, 2021). Quantitative data were obtained from laboratory tests on the Salmonella content, histamine, and Total Plate Count (TPC) of product samples, whereas qualitative data were derived from interviews with fishermen, collectors, and Fish Processing Units regarding the handling practices of fish at each supply chain stage.

The population of the study consisted of 30 individuals including fishermen, collectors, and Fish Processing Unit staff, with criteria selecting those currently or previously working as suppliers of raw materials to FPU XYZ. These criteria formed the basis for sample selection using purposive sampling. According to Priadana & Sunarsi (2021), purposive sampling is a technique where subjects are selected based on specific criteria set by the researcher. In this study, the sample size was 19 individuals, comprising fishermen, collectors, and FPU staff, based on the established criteria.

The research flow is depicted in Figure 1, starting from data collection, sample collection, sample testing, data analysis, QR Code design, and QR Code testing.

2.1 Data Collection

Data collection was conducted using three techniques: observation, interviews, and documentation. Observations were made directly to monitor the activities of fishermen, collectors, and Fish Processing Units from the handling of tuna at the capture sites to fish processing on board, as well as the processing, labeling, and shipping by the Fish Processing Units. Interviews were conducted with 19 respondents, consisting of fishermen, collectors, and Fish Processing Unit staff. Documentation involved gathering data in the form of written notes, photographs, and videos taken directly at the research sites.

2.2 Sampling

Sampling of raw tuna fish material began by first checking the spine temperature, followed by collecting samples from three parts: tail, middle, and chest, using gloves according to the applicable Standard Operating Procedure (SOP). After cutting, the fish was wrapped in 0.5/30 (T/L) sized plastic loin, neatly packed into styrofoam boxes, and topped with crushed ice as needed until the raw material temperature reached the set standards (4°C, 5°C, and 6°C), monitored using a thermometer. Tuna samples were collected from three points in the supply chain: fishermen (on the boat), collectors (fish gathering places), and the Fish Processing Unit (production site). At each location, three samples of tuna were taken from the three points (tail, middle, and chest), each weighing 1 kg per piece.

2.3 Sample Testing

Sample testing in the laboratory was aimed at obtaining data on histamine levels (SNI 2354.10:2016), Total Plate Count / TPC (SNI 2332.3:2015), and the presence of Salmonella (SNI 01-2332.2-2006) in tuna loin meat. Samples were taken from three supply chain points (fishermen, collectors, and Fish Processing Unit), and each sample weighing 1 kg per piece was tested 15 times. Sample data grouping was done based on temperature: Sample 1 at 4°C, Sample 2 at 5°C, and Sample 3 at 6°C. All testing was conducted according to applicable procedures and referenced SNI 2354.10:2016.

2.4 Data Analysis

Quantitative data analysis used the One-Way Analysis of Variance (ANOVA) method to determine whether there was an effect due to different temperature treatments on the test parameters and the mean difference among the three sample groups at different temperatures.

2.5 Design and Testing of QR Code

The results of the interviews and laboratory tests were presented in PDF format, and QR Codes were then generated for these files. The validity of these QR Codes was tested by IT experts based on three aspects: accessibility and navigation, communication and display quality, and overall media functions, using a formula developed by Mahardhika & Wahyuni (2023).

$$V_a = \frac{T_{SE}}{T_{SM}} \times 100\%$$

Explanation:
V_a = Expert Validation
TSE = Empirical Score achieved (expert assessment)
T_{SM} = Maximum Score (expected)

The expert validation values were then averaged according to the validity aspect items, using the following formula.

$$V_a = \frac{V_{a1} + V_{a2} + V_{a3}}{3}$$

Explanation:
V_a = Total average of expert validations
V_{a1} = Expert validation value for validity aspect item 1
V_{a2} = Expert validation value for validity aspect item 2
V_{a3} = Expert validation value for validity aspect item 3

The criteria used in the validity assessment percentages are based on Table 1, where a QR Code is considered valid if it meets the criteria ranging from 70% to 100%.

Table 1 Criteria for Validity Assessment Percentages

Percentage (%)	Criteria
90.01% - 100.00%	Highly Valid
70.00% - 90.00%	Valid
50.01% - 70.00%	Invalid
25.00% - 50.00%	Highly Invalid

3. RESULTS AND DISCUSSION

Based on the traceability system that employs a survey method through interviews and questionnaires, FPU XYZ has a supply chain consisting of fishermen, collectors, and the FPU itself. FPU XYZ purchases raw materials directly from fishermen, while fishermen sell to collectors. The current supply chain of FPU XYZ is depicted in Figure 2.

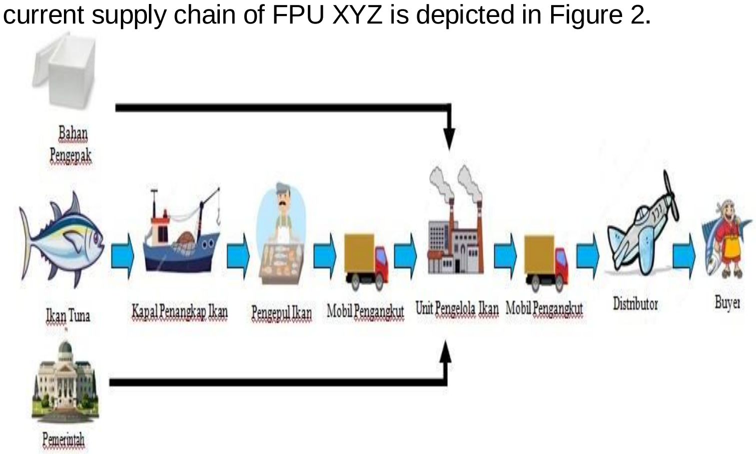

Figure 1. FPU XYZ Supply Chain

As shown in the Supply Chain (Figure 1), FPU XYZ obtains its primary raw material, tuna for export, directly from collectors who cooperate with fishermen. In addition to obtaining raw materials at a cost-effective price to maximize profits, FPU XYZ can easily implement a traceability system to track the origin of raw materials from producers before they are marketed to consumers.

3.1 Traceability System

The Traceability System is divided into two types: Internal Traceability and External Traceability (Hasibuan *et al.*, 2021). At FPU XYZ, Internal Traceability has been implemented and can track information from the FPU to the collectors. However, currently, fishermen and fishing locations cannot be traced. Therefore, in this study, the author conducted research on the development of a traceability system to trace fresh tuna loin raw materials from upstream to downstream. Traceability information at the fishermen's level includes the fishing location, duration of catch, type of fishing gear, and methods of handling tuna on the boat. At the collector's level, the information traced includes the origin of the raw materials and methods of handling tuna. At the FPU level, handling methods adhere to the HACCP system. Furthermore, this study also tested the quality of the fish to determine the meat quality as information accessible to FPU XYZ and buyers anytime and anywhere.

3.1.1 Traceability System at the Fishermen Level

Based on interviews with fishermen regarding the location of the catch, 71% of the total sample population reported that tuna fishing only occurs in the waters of Tomini Bay or WPP715, while others can fish outside Tomini Bay depending on the weather and the abundance of tuna as the target catch.

The duration of tuna fishing operations for 71% of the total population is less than 24 hours in the Tomini Bay or WPP715 area, while others can operate for more than 24 hours. This is supported by the capacity of larger boats to carry ice as a preparation in case the location of the target fish cannot be predicted, necessitating continuous searching to find the target fish. Meanwhile, fishermen with smaller boats cannot operate for extended periods like those with larger boats, due to the boat's capacity not being able to carry sufficient ice for cooling large quantities of fish, thus requiring them to return within 24 hours.

The fishing gear used by the fishermen all employ environmentally friendly methods, specifically using hand lines. According to Chailuddin, *et al*, (2019) as cited in Tomasila *et al*, (2020). hand lines are considered environmentally friendly fishing gear. Besides being eco-friendly, hand lines can also operate at various depths, from surface waters to the seabed, and are suitable for both coastal and deep-sea waters.

Interview data from the entire sample population involved in data collection agreed on the importance of proper handling of tuna on boats to maintain quality, thereby fulfilling the desired grade required by collectors. Handling practices include the use of non-rusting and sterile loining knives to prevent bacterial contamination, with tools being washed before and after use.

Based on laboratory test results from three fishermen samples with fifteen repetitions, the total Total Plate Count (TPC) at 4°C was 4.08 CFU/gram, at 5°C was 4.12 CFU/gram, and at 6°C was 4.15 CFU/gram. These results indicate that the fish samples still meet the consumable TPC standard of 4.40 CFU/gram (SNI 2332.3:2015). This aligns with the fishermen's practice of sterilizing equipment before and after use, thereby minimizing the risk of bacterial contamination.

After capture, fishermen instantly kill the fish by striking their heads, then load the fish onto boats and process them into loins. The processed fish are then sectioned into four parts and placed into boxes with a 1:3 to 1:5 ice-to-fish ratio. According to Litaay *et al*. (2020), handling fish on boats without adequate storage facilities can result in a 20-30% spoilage rate from the ship to the landing center. Factors affecting the quality of tuna include biological factors (age, species, sexual maturity, diseases) and non-biological factors (capture techniques, handling, cooling, and storage).

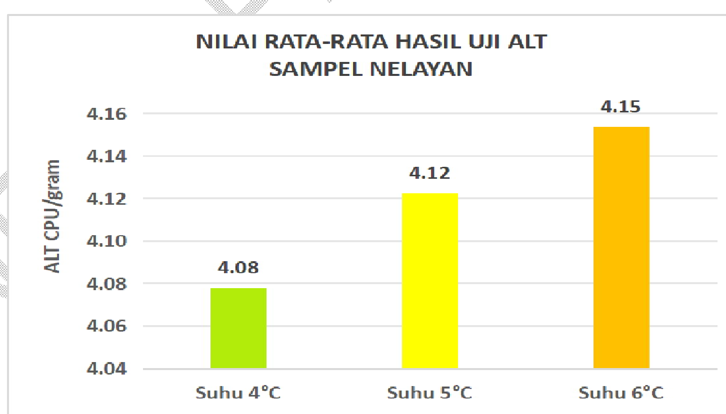

Figure 2. Average Total Plate Count (TPC) Values in Fisherman Samples

Laboratory tests on tuna samples from fishermen, repeated 15 times, showed an average histamine content of 32.40 ppm/gram at 4°C, 35.84 ppm/gram at 5°C, and 39.84 ppm/gram at 6°C. These levels are still below the maximum limit of 100 ppm/gram as per SNI 2354.10-2009, indicating that the tuna is safe for consumption. Fishermen maintain the fish temperature by sprinkling ice at a 1:3-1:5 ratio. According to Abdullah and Tangke (2021), histamine formation is inhibited at temperatures of 0°C or lower, and at 4.4°C, the formed histamine is 0.5-1.5 mg/100 grams of fish, still within the SNI limit of not exceeding 5 mg/100 grams of fish. During sampling, the fish temperature in the styrofoam box with a 1:3 ice concentration was between 1.3°C and 1.9°C, well below the SNI standard.

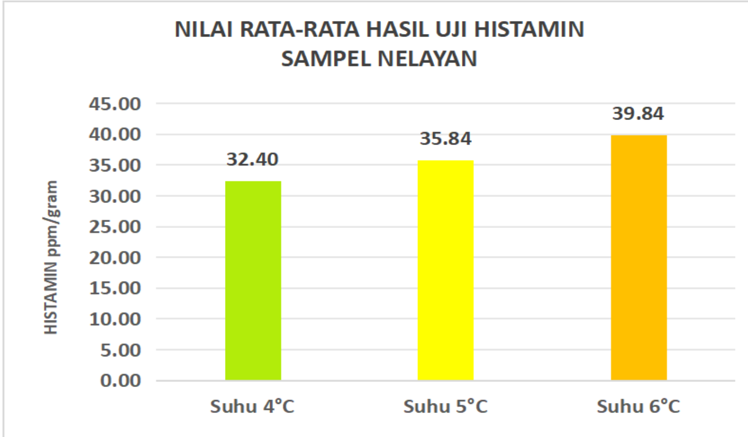

Figure 3. Average Histamine Test Results in Fisherman Samples

The results from tuna sample tests from fishermen indicated negative Salmonella content at 4°C, 5°C, and 6°C, complying with the SNI 01-2332.2-2006 standard which requires raw fish materials, particularly tuna, to be free from Salmonella. Inadequate post-harvest handling can accelerate fish spoilage due to high environmental temperatures and the activity of enzymes and microbes (Mailoa *et al*., 2019). The negative Salmonella results indicate that the fish were handled properly. Fishermen reported that they mitigate quality degradation by immediately processing the fish into loins after harvest, wrapping the fish in plastic to prevent microbial contamination, and preserving them in styrofoam boxes with ice in a 1:3 to 1:5 ratio.

Table 2. Salmonella Test Results in Fisherman Samples

SAMPLE	TEMPERATURE	FISHERMAN
Salmonella	4^0C	Negative
	5^0C	Negative
	6^0C	Negative

3.1.2 Traceability System at the Collector Level

Collectors are part of the supply chain following fishermen who provide raw tuna materials to FPU XYZ, ranging from loin to whole fish. One concept and instrumentation of food quality and safety recommended to support and ensure food quality is the provision of complete information about the position of a product and the distribution path it follows, facilitating easier product tracing (Harahap & Wisudari, 2020).

Collectors of fresh tuna loin have demonstrated a thorough understanding of the origin of raw materials and the fishermen supplying the tuna. All collectors have agreed that handling tuna loin on the boats is a crucial factor in maintaining fish quality, and they have also attended training on proper handling techniques. There is a high awareness of the importance of the quality of the fish being sold, as all collectors acknowledge that the quality directly impacts the selling price.

However, there are several challenges faced by collectors concerning the standards of temperature that must be maintained to preserve the freshness of the fish. Although all collectors have monitored temperatures and handled tuna loin according to maximum temperature standards, only 25% truly understand the precise temperature standards required. Moreover, although all collectors claim to have monitored temperatures, they cannot provide evidence of the temperature monitoring devices used, indicating potential issues in the oversight and documentation of this process.

Going forward, enhancing understanding regarding optimal temperature standards and the implementation of measurable temperature monitoring systems will be crucial steps to ensure that the quality of tuna remains preserved. With increased knowledge and awareness, collectors will be better able to ensure that the quality of fresh tuna loin remains excellent, which will ultimately have a positive impact on selling prices and customer satisfaction.

Laboratory test results from three samples from collectors, repeated fifteen times, showed that the total Total Plate Count (TPC) at 4°C was 4.18 CFU/gram, at 5°C was 4.22 CFU/gram, and at 6°C was 4.28 CFU/gram. These figures still meet the acceptable TPC standard of 4.40 CFU/gram (SNI 2332.3:2015), indicating that the tuna is still fit for consumption. This aligns with the collectors' statements about sterilizing equipment before and after use, thus significantly reducing the risk of bacterial contamination. If tuna is detected to contain microbial or chemical contaminants exceeding the SNI thresholds, the product would be considered contaminated and must not be marketed (Sipahutar *et al.*, 2021).

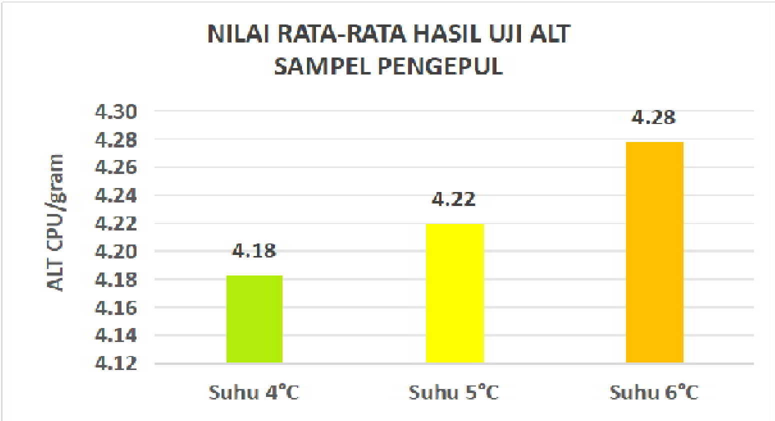

Figure 4. Average TPC Test Results in Collector Samples

Laboratory tests on histamine content in three tuna samples from collectors, each tested 15 times, yielded average results of 43.01 ppm/gram at 4°C, 48.15 ppm/gram at 5°C, and 54.29 ppm/gram at 6°C. These histamine levels in the tuna samples at the temperatures of 4°C, 5°C, and 6°C do not exceed the SNI maximum standard of 100 ppm/gram (SNI 2354.10-2009). The raw tuna materials are still classified as good quality since the histamine content remains below the established SNI limit. This outcome aligns with the collectors' statement during interviews, where they reported having handled tuna loin by sprinkling ice in a 1:3 to 1:5 ratio to control temperature increases in the raw tuna loin materials. This practice was also supported by the researchers who measured temperatures during sample collection at the collectors, finding that when measuring the temperature of the fish samples at the collectors, with a cooling concentration of fish and ice from 1:3 to 1:5 in a styrofoam box, temperatures ranged from 1.2°C to 1.5°C, far below the SNI standard of 100 ppm/gram (SNI 2354.10-2009). Therefore, this tuna loin raw material is still considered to be of high quality.

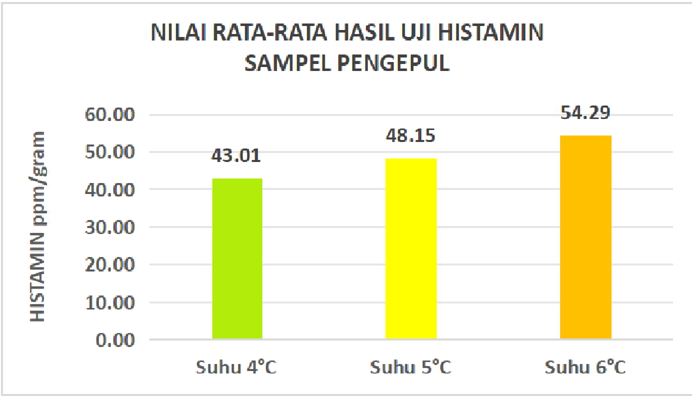

Figure 5. Average Histamine Test Results in Collector Samples

The results of tuna sample tests from collectors showed that Salmonella content was negative at temperatures of 4°C, 5°C, and 6°C, complying with the SNI 01-2332.2-2006 standard, which requires that raw fish materials, particularly tuna, must be free from Salmonella. Improper handling of fish post-harvest can lead to damage due to high temperatures and contamination from poorly sanitized equipment (Mailoa *et al*., 2019; Ratnaningtyas *et al*., 2023). The negative Salmonella results indicate that the tuna has been handled properly. Collectors reported maintaining quality by sterilizing equipment before and after use, thus minimizing the risk of bacterial contamination.

Table 3. Salmonella Test Results in Collector Samples

SAMPLE	TEMPERATURE	COLLECTOR
Salmonella	4^0C	Negative
	5^0C	Negative
	6^0C	Negative

3.1.3 Traceability System at the FPU Level

FPU XYZ has effectively implemented a Hazard Analysis and Critical Control Point (HACCP) system, evidenced by the successful documentation of the HACCP manual and the proper execution of all procedures. Through this system, FPU XYZ can trace the origin of the tuna raw materials in detail, including identifying the fishermen who supply them. Moreover, FPU XYZ only accepts raw materials that meet quality standards, specifically those kept at temperatures below 4.4°C, to maintain the freshness and quality of the fish. Temperature control is also rigorously applied at every stage of the tuna loin production process, with the use of temperature measuring devices ensuring the consistency of raw material temperatures throughout the process.

The traceability system in place allows FPU XYZ to track all processing stages, although current record-keeping still utilizes traditional paper documentation. Although this recording system has not yet transitioned to digital, it does not diminish its effectiveness in maintaining product quality. According to Harahap and Wisudari (2020), inadequate implementation of traceability systems in each industry could lead to rejection risks, resulting in losses. Therefore, to date, FPU XYZ has not received any complaints from buyers requiring product recalls, indicating high customer satisfaction and compliance with international quality standards. The effective implementation of HACCP and traceability systems contributes to buyer confidence in FPU XYZ's tuna loin products.

Laboratory test results from FPU samples show that the total TPC at 4°C is 4.23 CFU/gram, at 5°C is 4.28 CFU/gram, and at 6°C is 4.31 CFU/gram. These values are still below the SNI standard limit of 4.40 CFU/gram (SNI 2332.3:2015), classifying the tuna loin as high quality. FPU XYZ has performed sterilization of equipment before and after use to maintain fish quality and prevent bacterial contamination. Furthermore, FPU XYZ has also implemented a Hazard Analysis Critical Control Point (HACCP) system, a quality management system focused on food safety by identifying and monitoring critical control points during the production process (Abdullah and Tangke, 2021).

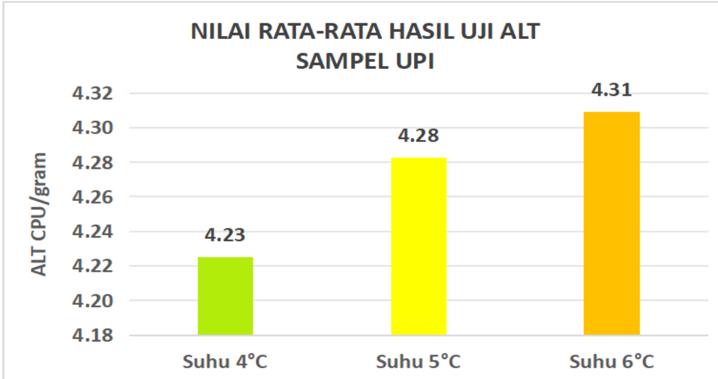

Figure 6. Average Total Plate Count (TPC) Results in FPU Samples

Laboratory tests on tuna samples at FPU XYZ show that the average histamine content at 4°C is 26.09 ppm/gram, at 5°C is 32.38 ppm/gram, and at 6°C is 37.86 ppm/gram. These values are well below the maximum limit of 100 ppm/gram as per SNI 2354.10-2009, indicating that the tuna is safe for consumption. Histamine poisoning can occur if fish with more than 70 mg/100 grams is consumed. Histamine forms from bacterial activity that converts histidine into histamine and is often an indicator of fish spoilage, especially in scombridae species (Ginantaka, 2023; Lasmi *et al*., 2021). FPU XYZ maintains the quality of the fish by sprinkling ice in a ratio of 1:3-1:5 to keep the raw materials at the correct temperature. Temperature measurements taken during sampling show that the raw materials were between 1.3°C and 1.7°C, well below the SNI standards, reflecting proper handling at FPU XYZ.

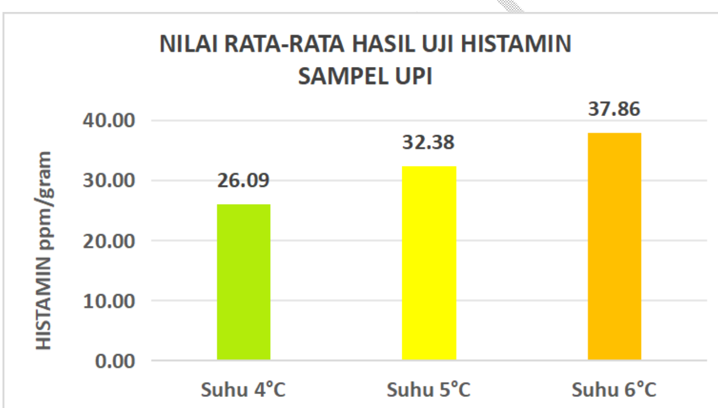

Figure 7. Average Histamine Test Results in FPU Samples

Salmonella content tests on tuna samples at FPU XYZ returned negative results at temperatures of 4°C, 5°C, and 6°C. This complies with SNI 01-2332.2-2006 standards, which require that raw fish materials, especially tuna, be free from Salmonella. These results confirm that the handling and processing of tuna loin have been performed adequately. FPU XYZ has implemented a HACCP system to ensure quality, thereby greatly minimizing the risk of bacterial contamination. Proper processing must follow Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP) (Siahaan *et al*., 2022).

Table 4. Salmonella Test Results in FPU Samples

SAMPLE	TEMPERATURE	FPU
Salmonella	4^0C	Negative
	5^0C	Negative
	6^0C	Negative

3.2 Designing a Quick Response Code

The process of designing the Quick Response Code Traceability consists of two stages: the creation of the Quick Response Code and its validation by a validator.

3.2.1 Creation of Quick Response Code

In the first stage of creating the QR Code, all relevant information about the traceability system is incorporated into a PDF document. The QR Code is generated using the QR Generator website, which can be accessed at me-qr.com. The information encoded in the QR Code includes the fishing location, fishing gear, date of capture, processing on the ship, temperature monitoring, date of ship landing, transport vehicle number, weight, grade, production date, shipping date, country of origin, destination country, and results of chemical and biological parameter tests (TPC, Histamine, and Salmonella) from the LPPMHP Gorontalo Laboratory.

Figure 8. Quick Response Code Traceability for FPU XYZ

3.2.2 Validation Results of Quick Response Code

The validation results of the QR Code Traceability performance test are presented based on each aspect.

3.2.2.1 Validity Aspect of Accessibility and Navigation (V_{a1})

The validity aspect of Accessibility and Navigation (V_{a1}) consists of four testing indicators with an average score of 81.35. Here are the details of the scores for each indicator:

1. The indicator "QR code functions when scanned with different devices" scored 100. Tests were conducted on mobile devices with Android and iOS operating systems, which are currently the most widely used. The results showed good performance as the QR code was successfully scanned on both devices, thus earning the maximum score of 100.
2. The indicator "QR Code is easily scanned from the desired distance" received a score of 75. Testing was conducted at four scanning distance conditions: 0-0.25 cm, > 0.25-0.5 cm, up to 1 m and 2 m. The results indicated that at distances of 2 meters and beyond, the performance was not optimal because 1 out of the 3 distance conditions failed to be scanned.
3. The indicator "QR Code is easily scanned in different lighting conditions" scored 100. Testing was performed in morning, noon, evening, and night lighting conditions. The results showed good performance as scanning was successful under all lighting conditions, thus earning the maximum score of 100.
4. The indicator "QR Code is easily scanned in conditions of dirt, tear, fade, or scratches/abrasions" received a score of 50. Testing was conducted under four physical conditions of the QR Code: dirty, torn, faded, and scratched/abraded. The results showed less than optimal performance because 2 out of the 4 physical conditions failed to be scanned

3.2.2.2 Validity Aspect of Communication Quality and Display (V_{a2})

The validity aspect of Communication Quality and Display (V_{a2}) includes two testing indicators:

1. The indicator "QR Code directs to the correct information when scanned" achieved a maximum test scoring of 100, as the information displayed during the QR Code scanning process was correct and accurate.
2. The indicator "QR Code directs to information with a clear display" also received a maximum test scoring of 100, because the information displayed during the QR Code scanning process was very clear.

3.3.2.3 Validity Aspect of Overall Media Function (V_{a3})

The validity aspect of Overall Media Function (V_{a3}) consists of one testing indicator with a score of 75, according to the validator's justification. The empirical score (TSE) achieved was 85.42, derived from the average of the three aspects with more than one assessment indicator, namely V_{a1} = 81.35, V_{a2} = 100, and V_{a3} = 75. The TSE score of 85.42 was then divided by the maximum score of 100 and presented, resulting in a final score of 85.42%. Based on the expert validity assessment criteria (see Table 4), this result falls within the VALID criteria (range 70% - 90%).

4. CONCLUSION

Based on the research outcomes aligned with the objectives, it was found that the traceability of tuna loin quality at FPU XYZ is as follows:

1. FPU XYZ has three supply chain stations: fishermen, collectors, and the Fish Processing Unit (FPU). Fishermen at FPU XYZ catch tuna in areas WPP715 and WPP714 using environmentally friendly fishing gear, specifically Hand Line, and have implemented good fish handling practices post-capture. Collectors also apply good handling practices, and at the FPU station, handling is conducted by HACCP standards.
2. Quality testing of tuna loin at each supply chain stage indicates that the product still meets the SNI standards for Histamine, Total Plate Count (TPC), and Salmonella parameters.
3. Information from laboratory tests and the supply chain designed in QR Code format has been validated across three aspects: Accessibility and Navigation, Communication Quality and Display, and Overall Media Function, with results declared valid.
4. The QR Code-based Traceability System for Fresh Tuna Loin Quality at FPU XYZ can be accessed anytime and anywhere.

Further research is recommended to test for heavy metal content such as Cd, Pb, Hg, and Mercury in tuna from the Tomini Bay Waters (WPP715) to determine the potential for heavy metal contamination in the raw materials to be consumed, as well as to assess the water quality in that area. To maintain product quality and achieve higher profits, FPU XYZ and stakeholders must facilitate collectors and fishermen in more effectively controlling temperatures throughout the supply chain to maintain fish quality.

Disclaimer (Artificial intelligence)

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Details of the AI usage are given below:

1.

2.

3.

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