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Assessment of cold chain implementation and quality product in frozen cooked tuna loin processing: A case study from PT XYZ, East Java, Indonesia

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Abstract
An adequate cold chain system is essential to maintain the quality of final product in fishery industries. Raw material, water and room temperatures were measured periodically during the preparation process of frozen cooked tuna loin. Additionally, sensory evaluation, histamine levels and total plate count (TPC) were assessed to determine the product quality. The results indicated that the temperature fluctuations occurred during the tuna preparation process; however, the tuna temperatures remained below 4°C. The water used during the thawing process and the room temperatures during preparation and production were approximately 27°C. This study suggests that the temperature should be maintained under the standard set by the company. Furthermore, the sensory evaluation of raw materials was consistent with Codex Standards, scoring around 8. The appearance, odor, and texture evaluations of cooked tuna loin scored 8.40, 8.80, and 7.88, respectively. Histamine levels in raw materials and end products did not increase significantly, measuring 3.01 and 4.68 ppm, respectively. The TPC of the end product was 1.2 x 10^4 CFU/g. Overall, the cold chain system was well-implemented, and the quality of the tuna product met FAO/WHO regulations.

INTRODUCTION

Tuna (*Thunnus* spp.) is considered an exclusive seafood product traded across the globe. Various species of tuna, such as bigeye (*Thunnus obesus*), skipjack (*Katsuwonus pelamis*), yellowfin tuna (*T. albacares*), albacore (*T. alalunga*), Atlantic bluefin tuna (*T. thynnus*), Pacific bluefin tuna (*T. orientalis*) and southern bluefin tuna (*T. maccoyii*), are among the most sought-after commodities in the international fisheries market. Tuna is traded in many forms to suit specific processing chains, including raw material for canning (in forms such as frozen round or headed and gutted (H&G), fresh or chilled round or H&G), pre-cooked loins for canning (frozen), tuna for direct consumption (fresh, chilled, and frozen), canned (solid pack, chunks, flakes, or grated), smoked and dried, as well as tuna-derived products like oil and meal for use in pet food or animal feed (Bayliff et al., 2004). Many studies show a strong correlation between fish quality characteristics and their market price. Sun et al. (2019) reported that the basic quality attributes of bluefin tuna include freshness, fat content, color, and shape of individual fish, with their price depending heavily on these attributes. Therefore, ensuring the quality of tuna is crucial to maintaining its high price.

Fish, widely recognized as a highly perishable commodity, must be controlled using the cold chain system to maintain the quality and prolong its shelf-life. Temperature is the most important factor affecting the fish quality during this process. Duarte et al. (2020) stated that temperature monitoring, temperature management and quality evaluation are interdependent, working together to ensure effective quality control in cold chain management. Therefore, the temperature must be monitored at every stage of fish processing to ensure proper implementation of the cold chain system. In many developing countries, particularly in Asia, the implementation of the cold chain system is still not fully sufficient. Low awareness of cold chains and a lack of adequate infrastructure, such as properly equipped landing centers, potable water, roads, ice plants, cold rooms and refrigerated transport, are key factors hindering progress (Panjaitan, Samanta, et al., 2024; Ryder et al., 2012). In addition, the prevalence of tropical temperatures contributes to high post-harvest losses and fish quality deterioration.

Indonesia is one of the leading countries exporting tuna globally, accounting for approximately 19.1% of worldwide total production and producing 1.5 million tons in 2023 (Kementerian Kelautan dan Perikanan Republik Indonesia, 2024). In addition, Indonesia is categorized as a developing Asian country with an average tropical temperatures of 27.1°C (BPS, 2021) . Therefore, the implementation of a cold chain system in tuna processing must be investigated. In this research, the cold chain implementation in the frozen cooked tuna loin production process was thoroughly examined. The freshness of tuna was found to significantly influence the quality of the final cooked product. Miao et al. (2017) revealed that a decrease in fish freshness contributes to a lower cooking grade for tuna steak. In line with this finding, the cold chain system must be implemented effectively prior to the cooking process to ensure a high-quality cooked tuna end product. Thus, the objective of this study was to observe the implementation of the cold chain system in a tuna company producing frozen cooked tuna loins, focusing on temperature monitoring at each stage of processing prior to cooking.

METHOD

The tuna company (PT XYZ) observed during this study is located in Banyuwangi, East Java. This company is officially registered as a producer and exporter of frozen precooked tuna loins for canning products, processing approximately 80 tons of raw material per day. The study period spanned from October 2023 to April 2024. The raw materials used were whole frozen tuna, with an average size ranging from approximately 1 to 9 kg, caught from the Indian Ocean. The tools utilized for observation included a thermocouple, digital indoor thermometer, thermo-gun, electric drill, and stopwatch.

Temperature measurement

Temperature data was collected throughout the processing stages, starting from the receipt of raw materials to the cold storage process. Measurements included the temperatures of the fish, water, and processing rooms. Temperature readings were taken three times daily, at 08:00 AM, 12:00 PM, and 03:00 PM, over the course of 32 days.

Fish temperature measurements were conducted at multiple stages, including receiving, size grading, cold storing, thawing, butchering, and freezing. To measure the tuna's core temperature, the fish was drilled using an electric drill, and the thermocouple was inserted 5-10 cm into the tuna's back until it reached the backbone. Water temperature was monitored during the thawing step (at the beginning and end), as well as during the butchering and cooling steps. The thermometer was dipped 5-10 cm deep to record the temperature. Room temperatures were observed in the preparation room, production room, chilling room, cold storage, and air blast freezer. Room temperature readings were taken using a thermometer affixed to the wall of each processing area, starting from the receiving step through to the cold storage step.

Quality analysis

The quality of the raw materials and final products was evaluated through sensory tests, histamine analysis, and Total Plate Count (TPC) analysis. The sensory test was performed by six trained panelists using a sensory evaluation form based on SNI 7968:2014 (Indonesian National Standard) to assess the appearance, odor, and texture of the samples (Badan Standarisasi Nasional, 2014). The samples included both raw materials and final products. The histamine analysis followed the method outlined in SNI 2354.10:2016 (Badan Standarisasi Nasional, 2016). For this analysis, a 10-gram fish sample was weighed and homogenized with 90 ml of distilled water. The supernatant was then extracted and analyzed using a Bio Fish 3000 machine to measure histamine levels. TPC analysis was conducted in accordance with the method described in SNI 2332.3:2015 (Indonesian National Standard) for microbiological testing (Badan Standarisasi Nasional, 2015). 25-gram sample of the final product was homogenized with 225 ml of sterile saline solution, followed by the preparation of a series of 10-fold dilutions. The TPC results were reported as log CFU/g.

RESULTS AND DISCUSSION

Frozen cooked tuna loin processing

The cold chain plays a critical role in preserving the quality of perishable foods, as time and temperature are key variables in controlling food quality during processing. Additionally, the cold chain helps reduce food loss by approximately 76% and lowers CO_2 emissions by about 16% (FAO, 2022). Correspondingly, cold chain management is gaining increased attention across various food categories, such as meat, dairy, seafood, fruit, and vegetable products (Han et al., 2021; Panjaitan, Samanta, et al., 2024; Ren et al., 2022). In line with this, this study highlights the implementation of a cold chain system in the cooked tuna loin processing, from the receiving of raw materials to the cold storage process.

Frozen cooked tuna loin processing, as depicted in Figure 1, begins with receiving raw materials to end with the cold storing process. The implementation of the cold chain system was monitored prior to cooking process. This included steps such as receiving raw materials, size grading, cold storing, thawing and butchering, followed by freezing and a final cold storage step.

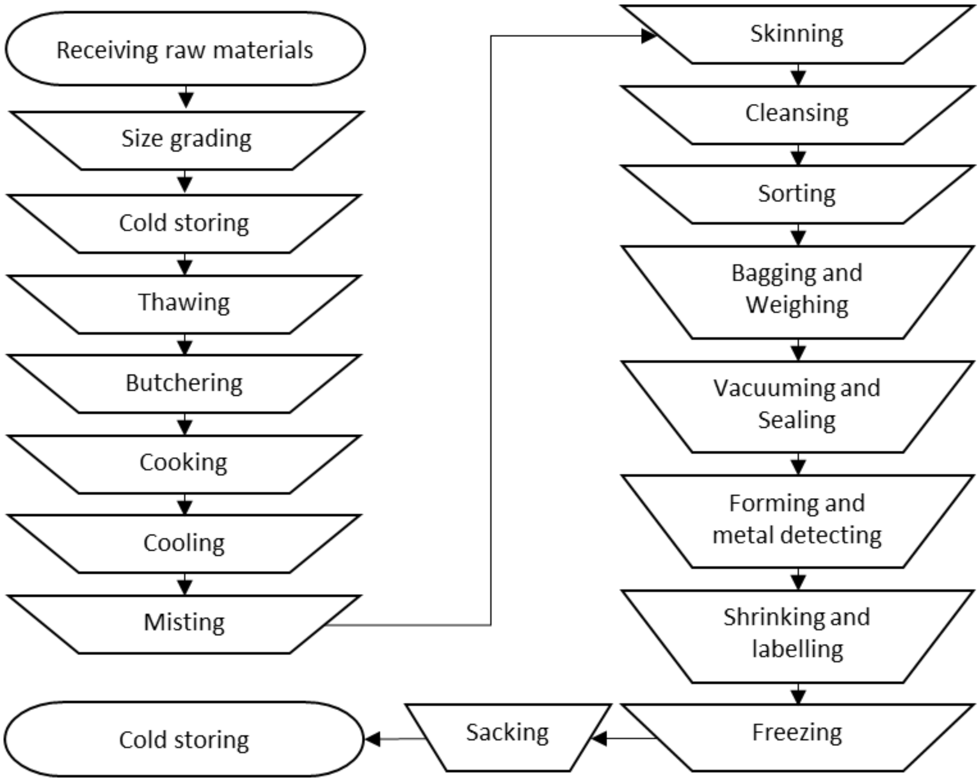

Figure 1. The flowchart of frozen cooked tuna loin processing

Description of tuna raw materials

Tuna raw materials were supplied in frozen form from several areas of Indonesia, including Banyuwangi, Jakarta, Surabaya, Trenggalek, Cilacap and Denpasar. The company received a total of 20 to 100 tons of raw materials per processing cycle, with individual tuna weighing approximately 1-9 kg and measuring around 20-90 cm in length, as shown in Figure 2.

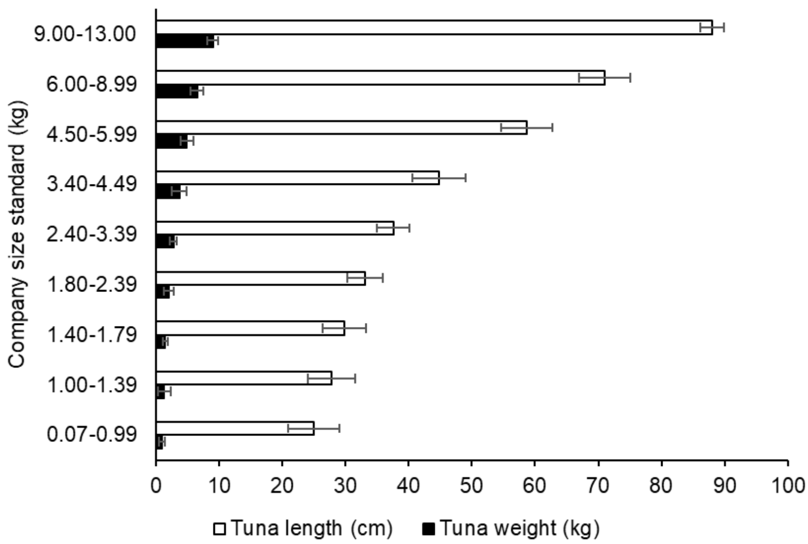

Figure 2. Weight and length of tuna raw materials collected in the receiving step

After being classified according to the company's size standards, the raw materials were transferred to the grading step. Frozen tuna was graded according to the company's standard. This process aimed to standardized fish sizes and align fish quality with the international requirements. Miao et al. (2017) reported that the freshness of tuna raw materials contributed significantly to cooking quality. Thus, monitoring the quality of raw materials before further processing is essential. The varying grades of tuna received by the company may result from handling practices prior to distribution. The quality grade of fish determines the market scope of final products (Panjaitan et al., 2023).

In this process, tuna was categorized into three grades: grade A, grade B, and grade AC, as shown in Table 1. This step is crucial for determining the quality of the final product. Miao et al. (2017) reported that the freshness of raw tuna is closely linked to the quality of cooked tuna steak

Table 1. Tuna's grades (A, B and AC) and the characteristics

Grade	Characteristics	Appearance
A	• The fish body remains intact, from head to tail • The gill covers are not red • Fish smell is fresh • Fish skin is naturally bright and vibrant	
B	• The fish body remains intact, from head to tail • The gill covers turn pinkish and red • Fish smell is fresh • Fish skin has minor scratches	
AC	• The fish body is not intact, with a ruptured belly, dents, a bend shape and burnt color • The gill covers turn into dark or bright yellow • Fish smell is earthy or frowsty • Fish is not completely frozen (soft texture)	

Typically, international markets demand high-quality raw materials. High-quality tuna (Grades A and B) can be obtained through proper handling of raw materials, whereas improper handling can lead to quality deterioration. Grade AC includes tuna with lower-quality characteristics. Raw tuna flesh in this category appears paler and softer than normal, while high-quality tuna is expected to be translucent, red and firm. Low-quality tuna is unsuitable for producing frozen cooked tuna loins and is instead directed to feed processing. Poor-quality tuna can result from inadequate temperature control, leading to microbial growth and chemical oxidations, which cause ruptured bellies, discolouration, and frowsty odors (Sampels, 2015). To address this, the optimal temperature range in an efficient cold chain must be maintained during processing to maximize the shelf-life and commercial potential. Storage temperatures are categorized as follows: ambient (15°C to 20°C), exotic -chilled (10°C to 15°C), medium-chilled (5°C), cold-chilled (0°C to 1°C), cold (-9°C to 2°C) and frozen (≤ -10°C).

Cold chain monitoring

The implementation of the cold chain on fish temperature was monitored during the receiving of raw materials, size grading, cold storing, thawing, butchering, and freezing steps, as shown in Table 2. The recorded temperatures were compared with the standards set by the Indonesian National Standard (SNI), the Food and Agriculture Organization of the United Nations (FAO), and the Southeast Asian Fisheries Development Center (SEAFDEC). Result showed that tuna temperature recorded in cold storage failed to meet the minimum temperature standard set by the company, SNI, FAO and SEAFDEC. The fish temperature was recorded at -11.70 ± 0.20°C, while the standard requires temperatures below -18°C. This finding showed that the fish temperature during the cold storage process deviated significantly from the standards. This condition may compromise tuna quality during cold preservation due to melting and recrystallization of ice inside the tuna meat. Several actions should be undertaken to prevent temperature abuse during storage, such as calibrating thermometers regularly, minimizing the frequency of opening the cold storage door, and organizing storage based on capacity and product density.

Table 2. Tuna temperature monitoring of frozen cooked tuna loin processing

Process	Temperature (°C)	Company's standard (°C)	SNI[a] (°C)	FAO[b] (°C)	SEAFDEC[c] (°C)
Receiving raw materials	-6.80 ± 1.60	≤ -4	0 – 4.40	≤ 4	0 – 5
Size grading	-5 ± 0.90	≤ -4	0 – 4.40	≤ 4	0 – 5
Cold storing	-11.70 ± 0.20	Min. -18	Min. -18	Min. -18	Min. -18
Thawing	-2.20 ± 0.06	≤ 3	≤ 4.40	≤ 4	0 – 5
Butchering	-1.80 ± 0.08	≤ 4	≤ 4.40	≤ 4	0 – 5
Freezing	-25.70 ± 0.90	Min. -18	Min. -18	Min. -18	Min. -18

[a]Indonesia National Standard
[b]Food and Agriculture Organization of the United Nations
[c]Southeast Asian Fisheries Development Center

Furthermore, the water temperature was monitored during the thawing process (at the start and end), as well as during butchering and cooling process. The temperature recorded during the butchering (27 ± 0.05 °C) and cooling (27.40 ± 0.05 °C) steps exceeded the temperature threshold set by the company's standard (25-27 °C) and FAO (5-15 °C). In other words, the water temperatures used during the butchering and cooling processes did not meet the company's standards. High water temperature can increase fish temperature, leading to quality deterioration if it keeps occurring. Therefore, strategic actions should be taken to control temperature within an allowable range, for example, providing training for personnel on cold chain management, using compatible processing equipment, implementing real-time temperature monitoring, and periodically adding ice slurry to the water during processing (Ndraha et al., 2019; Panjaitan, Samanta, et al., 2024). In addition, water quality should be considered as one of the most important factors in producing high-quality seafood products (Boziaris, 2014; Sampels, 2015).

Table 3. Water temperature monitoring of frozen cooked tuna loin processing

No	Process	Temperature (°C)	Company's standard (°C)	FAO (°C)
1	Thawing (starting)	27.30 ± 0.20	25 – 28	-
2	Thawing (ending)	9.70 ± 0.40	9 – 12	5 – 15
3	Butchering	27.00 ± 0.05	25 – 27	5 – 15
4	Cooling	27.40 ± 0.05	25 – 27	5 – 15

Room temperature was monitored in various areas, including the preparation room (receiving, size grading, thawing, butchering, racking, cooking, cooling, and misting), the production room (skinning, cleansing, sorting, bagging and weighing, vacuuming and sealing, forming and metal detecting, shrinking and labeling), the chilling room, cold storage, and the air blast freezer (ABF). Table 4 reveals that inadequate room temperatures were observed in the preparation and production room, 26.90 ± 0.90 °C and 22.00 ± 0.40 °C, respectively. In the preparation room, multiple activities were conducted simultaneously, including receiving, size grading, thawing, butchering, racking, cooking, cooling, and misting. Running the cooking process, which involves steaming tuna at high temperatures (100°C), in the same room as other activities likely contributed to the elevated room temperature. The hot steam generated by the fish cooker, combined with the heat released during cooling and misting processes, increased the overall room temperature. Separating cooking, cooling, and misting processes into dedicated rooms could effectively reduce the room temperature to within recommended limits. Before the cooking process, it is crucial to maintain the cold chain system. Environmental factors, particularly temperature, play a significant role in the shelf life and quality of tuna raw materials. An increase in temperature promotes microbial growth, resulting in quality degradation, food spoilage and an increase the risk of food poisoning. Similarly, unsuitable room temperatures in the production area should be avoided to ensure quality during processing. Maintaining ideal holding temperatures is critical for preventing quality loss and waste within the cold chain system (Badia-Melis et al., 2018).

Moreover, the temperatures observed in the cold storage used to keep raw materials and end products (-13.00 ± 0.50 °C and -21.90 ± 0.40 °C, respectively) were also not in compliance with the standard (min. -25 °C). Inadequate cold storage temperatures also impacted the stored fish temperature. A failure to control temperatures during preservation can adversely affect the final quality of cooked tuna loins. Through monitoring of precise temperature and storage times is essential in cold storage to prevent seafood quality degradation. Moreover, appropriate freezing conditions can eliminate parasitic worms in seafood products. Hall (2010) reviewed freezing condition, including freezing and frozen storage at -20°C or below for seven days, as well as freezing at -35°C or below until solid followed by storage at -35°C for 15 or storage at -20°C for 24 hours, respectively.

Table 4. Room temperature monitoring of frozen cooked tuna loin processing

No	Area/room	Temperature (°C)	DJPDSPKP standard (°C)*
1	Preparation room	26.90 ± 0.90	20
2	Production room	22.00 ± 0.40	20
3	Chilling room	2.40 ± 0.50	0 – (-5)
4	Cold storage (raw materials)	-13.00 ± 0.50	Min. -25
5	Cold storage (end products)	-21.90 ± 0.40	Min. -25
6	Air blast freezer (ABF)	-37.50 ± 0.90	-35 – (-40)

*Standard issued by The Director General of Marine and Fishery Product Competitive Power Development (DJPDSPKP) Number 15/PER-DJPDSPKP/2017 titled "The Technical Guidelines for Fish Processing Units with a Capacity of 200 Tons (UPI CS 200 Tons) (Kementerian Kelautan dan Perikanan Rapublik Indonesia, 2017).

Quality analysis of products

To evaluate the implementation of cold chain system, the quality of products was assessed through sensory evaluation, histamine analysis, and microbial analysis. This study demonstrated that the sensory evaluation scores for raw materials and final products were within acceptable ranges based on Indonesian standards and FAO guidelines. Sensory analysis is widely used to assess products quality based on specific attributes. The sensory scores of raw materials are largely influenced by the condition and characteristic of fish during the receiving process (Panjaitan, Utari, et al., 2024). Figure 3 illustrates the sensory evaluation results for raw materials (a) and end products (b). Overall, the sensory evaluation of frozen tuna raw materials ranged from 8.04 ≤ μ ≤ 8.56, which falls within the acceptable range according to the FAO (scoring around 8) and the Indonesian National Standard (SNI 4110:2014, minimum score of 7). Furthermore, the sensory parameters tested for final products, such as appearance, odor, and texture, were scored

8.40, 8.80, and 7.88, respectively. All sensory values met the required standard of a minimum score of 7 as per SNI 7968:2014.

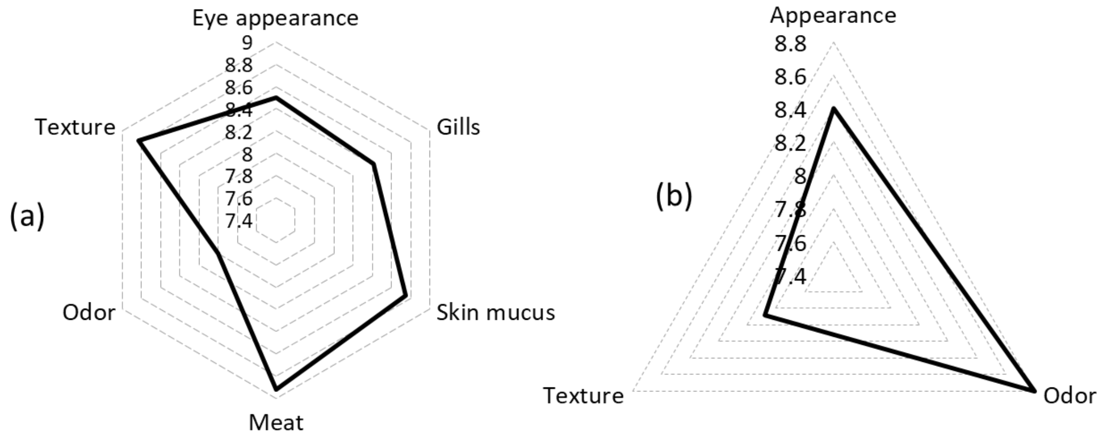

Figure 3. Sensory evaluation of raw materials (a) and end products (b)

Histamine and total plate count (TPC) values were analyzed to evaluate the quality of product during frozen cooked tuna loin processing, as listed in Table 5. The results showed that the histamine levels in both the raw material and final product were significantly below the thresholds set by the company, SNI and FAO standard. DeBeeR et al. (2021) reviewed variations in histamine level limits across countries, which range by a factor of 4, from 50 ppm to 200 ppm. Histamine levels detected in both raw tuna and final products were still in an acceptable ranges. Feng et al. (2016) categorized histamine levels as follows: up to 50 ppm is considered normal and safe for consumption; 50 to 200 ppm indicates mishandling and potential toxicity; 200 to 1000 ppm is unsatisfactory and likely toxic; and levels exceeding 1000 ppm are toxic and unsafe for human consumption.

Similarly, the TPC values of the raw materials were lower than the standards set by the company, SNI, and FAO. Microbiological assessment of frozen raw materials is essential to quantifying the quality of raw material. The storage conditions used in this study effectively prevented bacterial growth that could cause spoilage, such as slime formation, unpleasant odors, or yellow discoloration in tuna, typically observed when bacterial counts exceed ≥ 7 CFU/g (Silbande et al., 2016). Based on these results, the implementation of the cold chain system was effectively managed. The sensory evaluation, histamine levels, and microbial analysis all confirmed that the cold chain system maintained the quality and safety of both raw materials and final products.

Table 5. Histamine and total plate count (TPC) values of frozen tuna

Quality parameters	Sample	Present study	Company's standard	SNI*	FAO
Histamine (ppm)	Frozen tuna	3.01 ± 2.65	17	100	100
	Frozen cooked tuna loin	4.68 ± 2.89	50	100	100
Total plate count (CFU/g)	Frozen tuna	1.18 x 10^4	5.00 x 10^5	5.00 x 10^5	5.00 x 10^5

*Indonesia National Standard (SNI 7968:2014) titled Frozen cooked tuna loin

CONCLUSION

This study evaluated the cold chain system implementation in frozen cooked tuna loin processing, focusing on maintaining product quality from receiving raw materials to final cold storage. Temperature monitoring revealed deviations from established standards, with cold storage fish temperatures below the required standard, risking quality degradation. Similarly, room temperatures during processing were higher than recommended, likely due to overlapping activities like cooking and misting in shared spaces. Water temperatures in butchering and cooling also exceeded standards, highlighting the need for better regulation and ice addition. Despite these challenges, sensory evaluations indicated acceptable product quality. Histamine and Total Plate Count (TPC) levels were within safe limits, ensuring the products met safety standards. Low levels of histamine and TPC values suggested effective microbial control. However, temperature deviations in cold storage and processing rooms need improvement. Optimizing cold storage practices, calibrating thermometers, and enhancing water temperature control in butchering and cooling are essential for maintaining product quality and safety. Overall, the cold chain system was largely effective, but further refinements are needed to ensure full compliance with international standards and enhance seafood product quality.

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