IMPLEMENTASI SISTEM RANTAI DINGIN PENGOLAHAN TUNA (*Thunnus albacares*) SAKU BEKU

IMPLEMENTATION OF COLD CHAIN SYSTEM IN FROZEN YELLOWFIN TUNA (*Thunnus albacares*) SAKU

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ABSTRAK. Sistem rantai dingin merupakan komponen penting dalam menjaga mutu dan keamanan produk perikanan beku, khususnya tuna sirip kuning yang memiliki nilai ekonomi tinggi. Penelitian ini mengevaluasi penerapan sistem rantai dingin pada proses produksi tuna saku beku berbahan baku tuna sirip kuning di sebuah perusahaan pengolahan. Penelitian dilakukan dengan metode deskriptif melalui observasi langsung dan pemantauan suhu pada seluruh tahapan rantai dingin, meliputi penerimaan bahan baku, pengolahan, dan penyimpanan beku. Pengukuran suhu dilakukan pada produk tuna, air proses, dan ruang produksi, menggunakan tiga sampel tuna pada setiap periode pengamatan dengan tiga kali pengulangan untuk setiap sampel. Hasil penelitian menunjukkan bahwa suhu tuna berada di bawah batas regulasi Indonesia yaitu 4,4°C selama proses berlangsung, dengan suhu bahan baku rata-rata 2,4 ± 0,76°C. Suhu air selama penyimpanan sementara rata-rata 3,5°C, sedangkan suhu air pencucian berada pada kisaran 25–27°C. Suhu ruang produksi dipertahankan antara 22–23°C, sesuai dengan batas maksimum perusahaan yaitu 25°C. *Air Blast Freezer* (ABF) beroperasi pada kisaran –35 hingga –38,9°C, dengan rerata –37,76 ± 1,12°C selama sepuluh minggu, melebihi standar perusahaan maupun standar nasional (≤ –18°C). Suhu penyimpanan beku berada pada kisaran –20°C hingga –30°C, mempertahankan suhu inti produk pada –18°C. Meskipun pengendalian suhu secara umum telah sesuai standar, temuan penelitian mengidentifikasi perlunya pengawasan suhu yang lebih ketat untuk meminimalkan fluktuasi pada beberapa titik kritis. Penelitian ini menyimpulkan bahwa sistem rantai dingin telah diterapkan dengan baik, namun peningkatan stabilitas suhu secara konsisten diperlukan untuk mencegah potensi penurunan mutu produk.

KATA KUNCI: Rantai dingin, distribusi, produk beku, tuna, mutu.

ABSTRACT. Cold chain systems are essential in maintaining the quality and safety of frozen fishery products, particularly yellowfin tuna, which has high economic value. This study evaluates the implementation of the cold chain system in the production of frozen yellowfin tuna saku at a processing company. The research was conducted using a descriptive method through direct observation and temperature monitoring across all stages of the cold chain, including receiving of raw material, processing, and cold storing. Temperature measurements were conducted on tuna, water, and processing rooms, using three tuna samples per observation, with triplicate measurements for each sample. The results demonstrated that tuna temperatures remained below the Indonesian regulatory limit of 4.4°C throughout processing, with raw material temperatures averaging 2.4 ± 0.76°C. Water temperatures during temporary storage averaged 3.5°C, while washing water ranged from 25–27°C. Room temperatures across processing areas were maintained between 22–23°C, complying with the company's standard maximum of 25°C. The Air Blast Freezer (ABF) operated at –35 to –38.9°C, with an average of –37.76 ± 1.12°C across ten weeks, surpassing both company and national standards (≤ –18°C). Cold storage temperatures ranged from –20°C to –30°C, maintaining the product core temperature at –18°C. Although overall temperature control complied with required standards, the findings indicate the need for more stringent temperature monitoring to minimize fluctuations at several critical stages. The study concludes

that the cold chain system is effectively implemented, but improvements in consistent temperature stability are necessary to further prevent quality degradation.

KEYWORDS: *Cold chain, distribution, frozen product, tuna, quality.*

1. Introduction

Fish as an aquatic products, are highly perishable (Hu *et al.,* 2021), and their deterioration rate increases within temperature rising due to factors such as microbial metabolism, oxidative reactions and enzymatic activity (Xiao *et al.,* 2016). Tuna is one of the most widely consumed seafood worldwide, with the most common species including skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), and albacore tuna (*Thunnus alalunga*) (Fan *et al.,* 2021).Tuna has high economic value and is a key commodity in the fishing industry. It was processed into various fresh and frozen tuna loin products, as well as derivatives such as steak, saku, cube, slice, and more (Palyama & Dharmayanti, 2021).Tunas is stored under refrigerated conditions to preserve its freshness and extend its shelf life. However, its high protein and moisture content make it highly susceptible to deterioration caused by abundant endogeneous proteases and spoilage bacteria in its muscle tissue (Xiong *et al.,* 2024). The tuna export market demands high quality and strict food safety standards, making effective preservation techniques essential to maintaining both. Indonesia accounts for 15% of the world's tuna production (Massie *et al.,* 2022).

Specific catching and handling procedures were implemented to enhance quality, allowing a larger portion of the catch to be used for human consumption, primarily by freezing it whole or after heading and gutting (Sveinsdóttir *et al.,* 2020). Freezing is an effective method for preserving fish quality and extending its shelf life by inhibiting microbial growth and biochemical processes like lipid oxidation and hydrolysis, which contribute to seafood deterioration (Romotowska *et al.,* 2016). The quality and shelf life of frozen fish are affected by various factors, such as the chemical composition of the raw material (Romotowska *et al.,* 2016), the temperature and processing process before (Erikson *et al.,* 2021) and the conditions during frozen storage and transportation (Dang *et al.,* 2018). Accurate control of time and temperature during tuna processing is essential to preserving product quality (Romotowska *et al.,* 2016). While numerous studies have explored cold-chain systems, research on their implementation in tuna processing companies remains limited. Therefore, this study aims to examine application of cold chain in processing frozen pocket tuna, from receiving to storage in tuna industry.

2. Materials and Methods

2.1 Tools and Materials

Tool used in this research were stainless steel knive, pocket mold tools, CO injection machines and Air Blast Freezer (ABF) machines. The materials used is Yellowfin tuna (*Thunnus albacares*) that meets the SNI organoleptic standard with a minimum score of 7. The study was conducted from October to December 2024 at PT. Indotama Bahari, Denpasar – Bali.

2.2 Research Design

The processing steps of frozen pocket Yellowfin tuna (*Thunnus albacares*) were monitored to evaluate implementation of cold chain system from receiving step to cold storage. At the receiving step, yellowfin tuna was weighed and recorded. Product temperature was also observed at several critical stages, including deheading, loining, slicing, CO gas injection, final checking, and cold storing. During the CO gas injection, the tuna loins were placed in baskets and treated with carbon monoxide gas using a specialized injection system. The CO injection was performed at a pressure of 6 kg/cm² for 1–3 minutes at a controlled temperature of 1.2–3.9°C. After the treatment, the loins were stored under refrigeration for 48 hours prior to vacuum packaging.

Water temperature was measured during the temporary storage and washing process. Meawhile room temperature was monitored in several key process areas, such as the gross cutting room, clean cutting room, gas injection room, retouching room, chilling room, Air Blast Freezer (ABF) and cold storage facility. The temperatures of Yellowfin tuna, water, and the room were monitored at specific processing stages (**Figure 1**). Temperature measurements were taken throughout the frozen Yellowfin tuna saku processing, from receiving to cold storage.
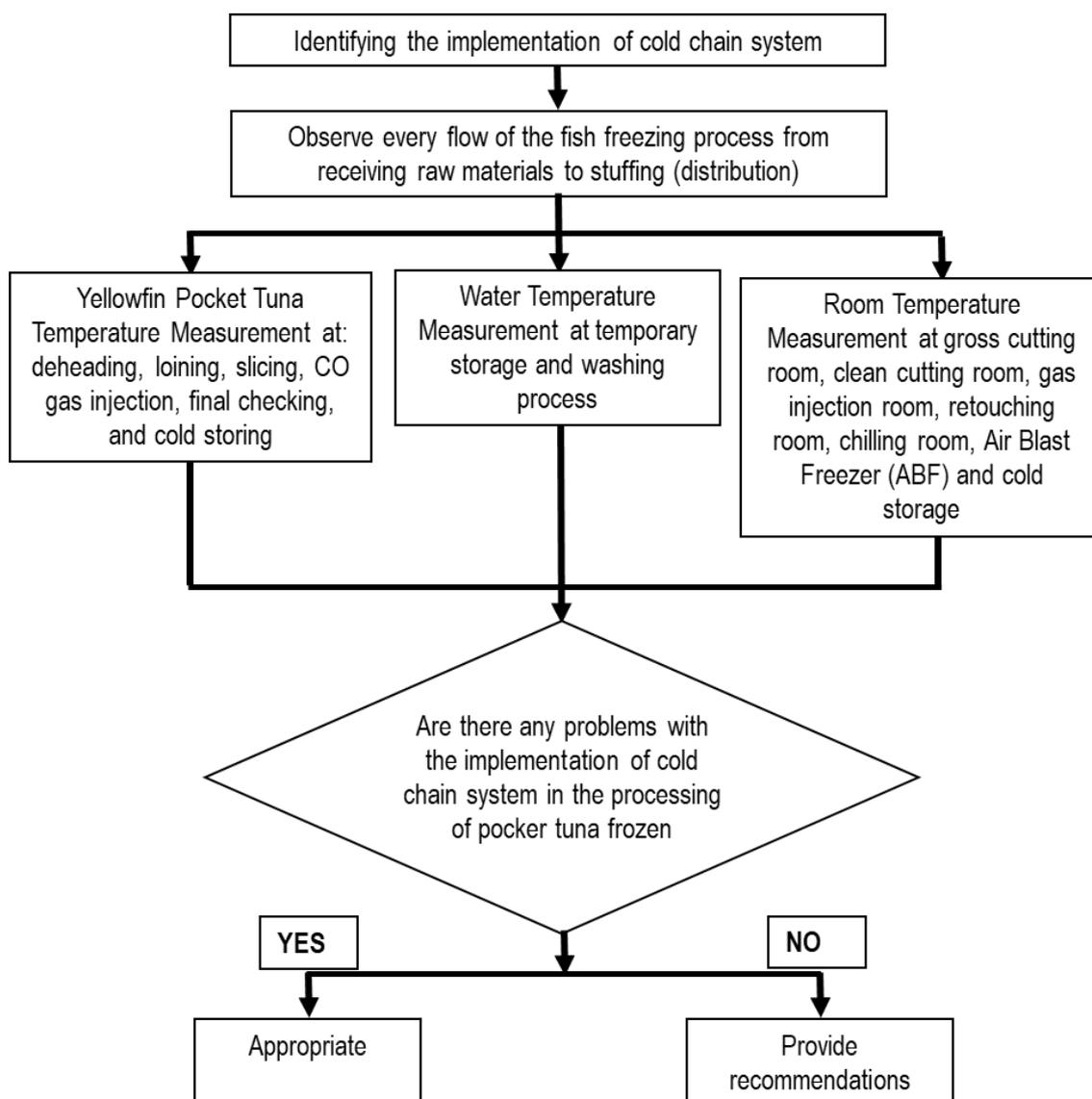
Figure 1. Cold Chain Monitoring in Frozen Pocket Tuna Processing Flow Diagram.

2.3 Methods

The receiving of raw material process begins with the arrival of gutted-fresh yellowfin tuna, withe each received fish was labeled with its weight and vessel code, which is attached to the tail. A total of 49 vessels serve as suppliers to PT. Indotama Bahari. The transportation of raw materials was carried out using closed pick-up vehicles to prevent contamination and physical damage. Upon arrival, the company's Quality Control (QC) team conducts an initial quality inspection of the raw fish, including temperature checks, histamine testing, and organoleptic evaluation. The company has established a maximum temperature standard of <4°C for the tuna raw material to maintain freshness and ensure product safety(Putri *et al.,* 2023).The temperature yellowfin tuna temperature was measured using a TP-300

thermometer stick. During each observation period, three tuna samples were selected, and the temperature of each sample was measured three times . This procedure was repeated across ten observation periods, allowing comprehensive temperature monitoring from the receiving stage through the final checking. The water temperature was measured by immersing a stick thermometer into the water contained in the fiber box. Each measurement was performed three times (Zalukhu *et al.,* 2023). The room temperature was monitored by a digital themometer placed in each room including gross cutting room, clean cutting room, gas injection room, retouching room, chilling room, ABF machines and cold storage. Additionally, the ABF and cold storage temperature were recorded from a digital thermometer attached to the machine. This procedure was repeated across ten weeks observation periods

2.4 Analysis Procedure

Temperature measurements were recorded and ensured compliance with the company's standards and Indonesian regulations, including the Indonesian Standard/SNI 2729:2021 (BSN, 2021)and the Ministry of Marine and Fisheries (MMAF) Regulation No. 15/PER-DJPDSPKP/2017 (MMAF, 2017). A triplicate of every observations was performed, and the results were presented as the mean ± standard deviation (SD).

3. Results And Discussion

3.1 Description of Frozen Yellowfin Tuna (Thunnus albacares) Pocket

The standard fish processing procedure starts immediately after the fish was caught. It includes receiving (capturing), stunning, bleeding and chilling, grading, deheading (beheading), scaling, filleting, skinning, trimming and portioning, mincing, byproduct recycling, and packaging. However, the quality of frozen fish products can be influenced by various factors, including seasonal variations in raw materials, handling techniques, freezing methods, packaging materials, temperature and duration of frozen storage (Romotowska *et al.,* 2016; Suryono *et al.,* 2023). The skin-on fresh tuna was loined, skinned and trimmed the brown meat. Then, tuna saku was weighed, treated with CO, wrapped with plastic packaging for tuna for 2 to 4 days, until the bright reddish color appeared. Hence, tuna saku trimmed again and packed in the plastic bag and frozen storage. Table 1 shows the information on tuna saku studied in this research which the final products were exported to United States. The demand for frozen fish mainly whole or headed and gutted in international markets has risen significantly and provide a high market demand. One of the potential problems of the tuna supply chain was the temperature management control. When tuna are have higher temperature above 4.4 °C, higher histamine levels were formed due to related to improper handling (Mercogliano & Santonicola, 2019).

Table 1. Information of Frozen Pocket Tuna.

No	Characteristic	Description
1	Product's name	Frozen Tuna Saku
2	Species	*Thunnus albacares*
3	Raw materials origin	WPP (Fisheries Management Area) 572 - located on East Coast of Sumatera (Hindia Ocean); WPP 573 – located on Indian Ocean (South of Java, South of Nusa Tenggara, Sawu Sea, and Northwest of Timor); WPP RI 713 – Makassar Strait, Bone Bay, Flores Sea, Balira Sea, Sawu Sea, and Northwest of Timor
4	Raw materials supplier	The raw materials obtained from fishing vessels and transportated using closed pickup trucks to prevent contamination and damage and maintained the temperature <4°C.
5	Auxiliary product	Water, chlorine, and ice
6	Final product	Frozen Tuna Saku
7	Types of packaging	*High Density Polyethylene* (HDPE) and master carton (MC)

No	Characteristic	Description
8	Storage	Stored in cold storage (-25ºC)
9	Expiration	18-24 months in frozen form
10	Directions of use	Edible for consumers but allergic people not suitable
11	Country of destination	The United States

3.2 Proccessing of Frozen Yellowfin Tuna (Thunnus albacares) Saku

The processing of frozen tuna saku ranging from receiving of raw material to cold storing as presented in Figure 1. The raw materials obtained from fishing vessels consisted of fresh tuna with the gills and internal organs already removed (Fauziyah & Syihab, 2024).The gutting process will remove the internal organs and clean the body cavity (Liu *et al.,* 2022). The transportation of raw materials to the processing company is carried out using closed pickup trucks and with temperature <4ºC to prevent contamination and damage. The company's Quality Control (QC) team then inspects the freshness of the raw materials, including checking the temperature, histamine testing, and organoleptic testing (Hwang *et al.,* 2003). The standard temperature set by the company for receiving tuna fish raw materials is maintained below 4ºC. Handling of the raw materials quickly and hygienically, is best to ensure the production of a high-quality final product. Then, the fresh tuna raw materials were stored in a special tank filled with water and ice to maintain the temperature within the range of 0ºC - 3ºC. During this process, lowering temperature leading to prevent increasing in histamine levels. The storage tank was also treated with chlorine at a concentration of 10 ppm as the desinfectant and lead to inactivation of bacterial growth (Chen & Hung, 2018). Afterward, the fresh tuna washed using running water and carefully scrubbed with a special fish brush to prevent any physical damage to the fish. Washing is carried out to reduce bacterial contamination from residual blood or foreign substances and removes blood and others impurities (Zhang *et al.,* 2022). The deheading process involves separating the tuna's head from its body by making a cut behind the pectoral fin, cutting from the top down to the lower jaw. The procedure is repeated on both sides of the fish until the head is completely detached.
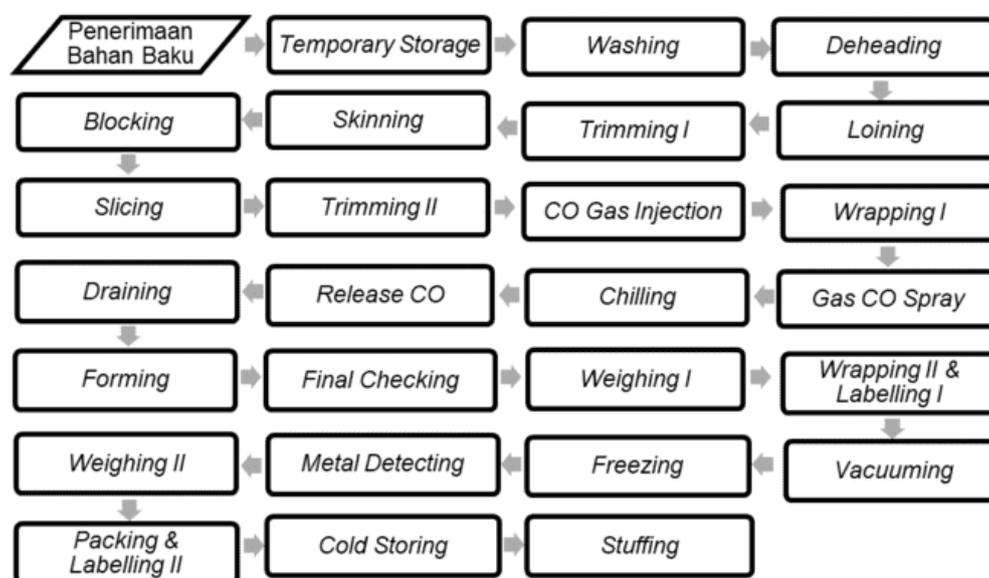

Figure 2. Flowchart of Frozen Tuna Saku.

Loining processing begins by cutting from the tail part of the fish to the belly and from the tail to the back until the fish meat separates from the bone structure. Then, the tuna is cut into two parts, dividing the body into four sections by slicing along the middle of the lateral line. The trimming process involves separating the red and dark meat because the dark meat in tuna contains very high lipid content that has been mainly associated with lipid oxidation and hydrolysis (Fauziyah & Syihab, 2024). Skinning involves

by removing the red meat, followed by a visual inspection ensures no scales remain, and it's essential to minimize the amount of meat left on the skin. This procedure also helps reduce the growth of microorganisms, thereby enhancing the shelf life and quality (Massie *et al.,* 2022). Each loin segment divided into two to three pieces, measuring between 18 cm and 20 cm in lenght, depending on the size of the fish. This process begins by removing the meat near the head and tail sections, as these parts do not meet the specific size standards required for tuna saku products. The slicing process involves cutting each fish block into slices with thick (4 cm) and long (18 to 20 cm), using a specialized cutting board designed to shape pocket-sized portions uniformity. Then, the cleaned fish were injected with carbon monoxide (CO) gas. The tuna fish were stacked in a maximum of two layers on the conveyor, after which the machine automatically injects CO gas into the fish meat. The use of CO in meat packaging is known to extend the stability of the red color. CO interacts with myoglobin, producing carboxymyoglobin - a stable, bright red pigment that lasts longer than oxymyoglobin. The main advantages of CO intended to color stability, to prevent the oxidative process, and reduce the growth of the spoilage organisms (Ariyani *et al.,* 2020; Djenane & Roncalés, 2018). Chilling is carried out to maintain the product's temperature during the CO gas absorption process, which lasts for 2 to 4 days. The redness color of CO-treated tuna, it is transferred to a designated room for CO gas release (Marrone *et al.,* 2015). At the end of the storage period, the gas is removed by unwrapping the product's plastic packaging in a designated room. Following this, the tuna saku is drained, shaped, and undergoes a final inspection before being weighed, wrapped, labeled, vacuum-sealed in a plastic bag, and frozen. Tuna saku was frozen using an Air Blast Freezer (ABF) at -30°C for 8 hours. The frozen tuna saku was then screened using a metal detector before being packed into a master carton. The final product was stored in cold storage at -25°C before being shipped overseas.

3.3 Cold Chain Implementation

Temperature is the primary factor affecting quality from final product tuna saku. Histamine content in tuna can develop during the stages of production, processing, and distribution. The formation of histamine is an decarboxylation involving bacterial enzymes of exogenous histidine-decarboxylase (Hwang *et al.,* 2003) (Mercogliano & Santonicola, 2019); therefore, histamine accumulation is highly influenced by temperature and time. Temperature measurement aims to determine the cold chain and the freshness level of the raw material to be processed, as depicted in **Figure 2**. The results indicated that the temperature of tuna saku measured at each processing stage remained below 4.4°C, demonstrating effective cold chain implementation. The lowest recorded temperature was observed during the raw material reception stage, averaging 2.4 ± 0.76°C, influenced by the addition of ice during the process. Monitoring the temperature of raw materials and final products is crucial to preventing quality degradation caused by excessive heat. The core temperature of fresh fish must remain below 4.4°C throughout the entire process, from raw material reception to final inspection. Observations conducted ten times revealed an average raw material reception temperature of 2.4°C. This meets the company's quality standards and complies with the requirements outlined in SNI 2729:2021 on Fresh Fish (BSN, 2021). Proper temperature control of raw materials helps reduce the risk of histamine level increases in fish (Zalukhu *et al.,* 2023).
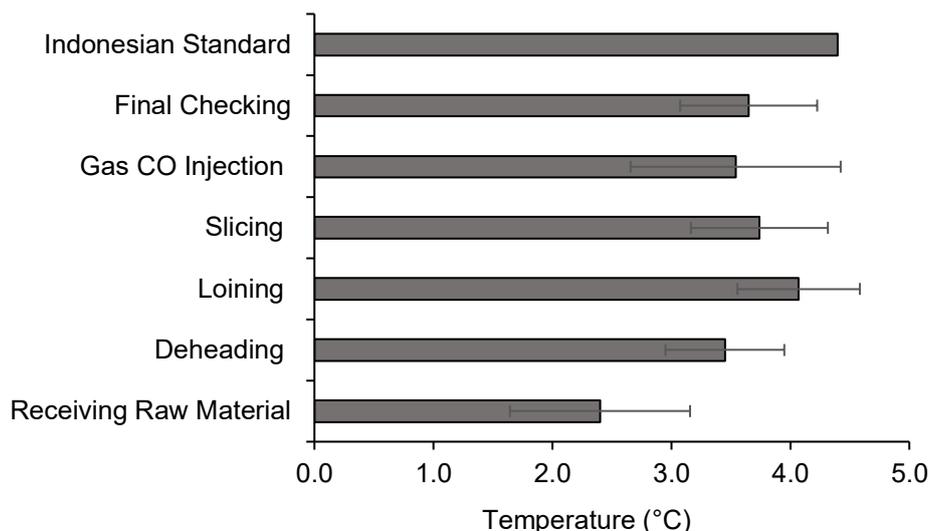
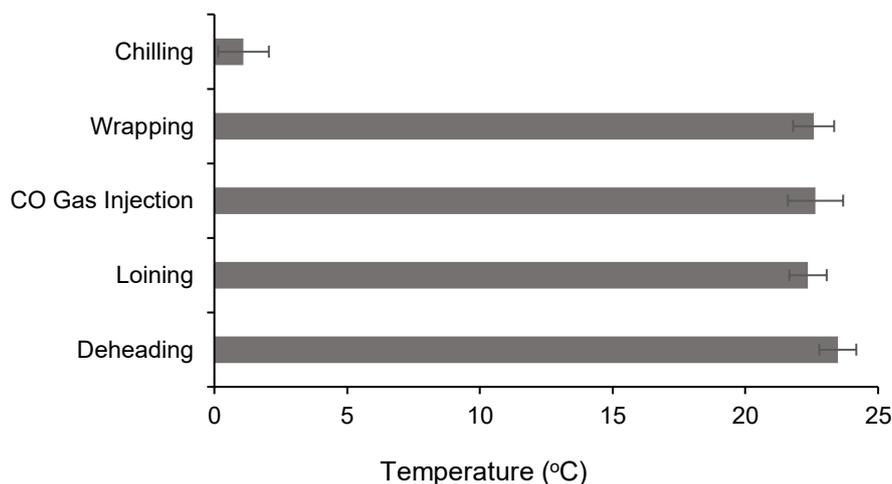**Figure 3. Product Temperature Monitoring of Tuna Saku Processing.**

The temperature monitoring of process water in frozen tuna saku processing was conducted at two stages: temporary storage and washing (**Figure 3**). During temporary storage, the average water temperature was 3.5°C, which meets both the company's standards and the requirements set by 2729:2021 (BSN, 2021). The washing process utilizes running water with a temperature of 25°C-27°C, as this facilitates the work of operators and speeds up handling and processing. Water temperature is a crucial factor to monitor, as water directly interacts with the product, making temperature control essential in inhibiting microbial growth. During the temporary storage process, the core temperature of tuna loin increased to 4.1-4.2°C, creating favorable conditions for the growth of psychrophilic bacteria. After being stored overnight in ice under aerobic conditions, *Pseudomonas* sp. and *Shewanella putrefaciens* become the dominant bacterial species (Suryaningrum & Ikasari, 2019). Cold temperatures suppress bacterial growth and inhibit pre-existing histidine decarboxylase from producing histamine. Bacteria responsible for converting histidine into histamine become more active in controlled temperature conditions, resulting in higher histamine production as the temperature increases. However, this process halts when fish are frozen at -18°C or below (Sarah *et al.,* 2024).
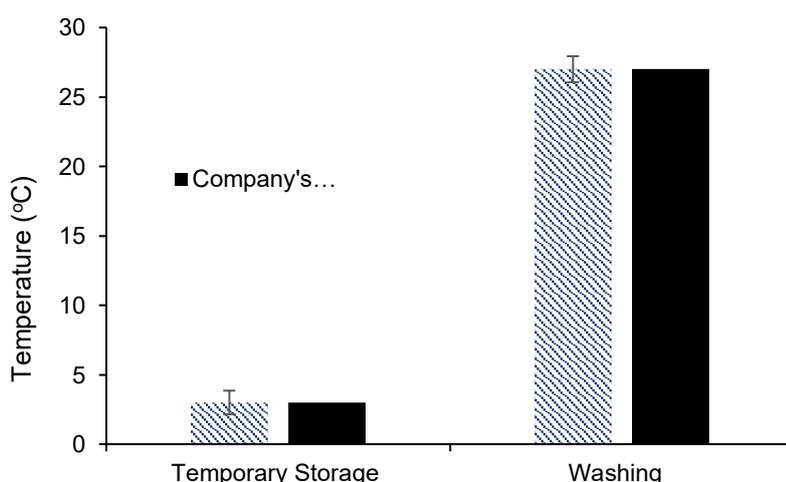
Figure 4. Water Temperature Monitoring of Tuna Saku Processing.

The temperature monitoring of processing rooms is conducted using thermostats installed in each room to regulate the temperature. The core temperature of the product is highly influenced by the room temperature, with the industrial standard set between 18-25°C. The temperatures recorded in the

deheading, loining, CO gas injection, wrapping, and chilling rooms averaged between 22-23°C, with a maximum allowable limit of 25°C, indicating compliance with company standards. Within this temperature range, the core temperature of the fish can be effectively maintained. During fish handling in the production area, processing speed significantly affects the fish's temperature. The slower the handling process, the faster the core temperature of the fish will rise in subsequent stages, leading to a more rapid formation of histamine (Denden *et al.,* 2024).

Figure 5. Room Temperature Monitoring of Tuna Saku Processing.

Pocket tuna products are categorized based on weight into three grades: SAA (less than 340 grams), AAA (340 to 490 grams), and WAAA (over 490 grams). Before freezing, the tuna is packed in HDPE plastic bags, with each grade using packaging of the same dimensions—21 cm in length and 19.5 cm in width. The packaging is then vacuum-sealed for 35 seconds. Air-blast freezing was conducted at temperatures ranging from -35°C to -38.9°C in an air-blast freezer (ABF) to rapidly freeze tuna pocket products within 6-9 hours. The ABF functions by circulating cold air (as low as -30°C) over the products, reducing freezing times to between 10 and 24 hours (L. Liu et al., 2023). Figure 5 (A) illustrates that the ABF temperature recorded over ten weeks reached -35°C, aligning with the company's standard (-35°C). Additionally, the temperature surpassed the Indonesian standard (-18°C), averaging -37.76 ± 1.12°C. Rapid freezing facilitates the formation of small ice crystals, which effectively minimizes tissue damage, thereby preserving the product's quality and value (Anderssen et al., 2021).This freezing method not only prevents quality deterioration caused by microbial activity, chemical reactions, and enzymatic processes but also helps reduce liquid loss after freezing (Erikson *et al.,* 2021).

Once frozen, the pocket tuna is stored in an inner carton, then it was placed inside a master carton. Each master carton contains two inner cartons, with a total weight of 10 kg. During storage, the product's core temperature is maintained at -18°C. The cold storage room temperature, monitored automatically, ranges between -20°C and -30°C. Additionally, the QC team performs manual product inspections once a week. To maintain proper storage conditions, the products must not touch the walls or ceiling, should be arranged with adequate spacing, and must not be positioned directly under the blower. The layout of the cold storage is carefully organized to ensure uniform air circulation and facilitate easy handling. The storage system used in cold storage (CS) follows the First In First Out (FIFO) method to prevent product accumulation, ensuring that the earliest stored products are the first to be distributed to consumers or buyers. Over extended storage periods, quality gradually declines. Additionally, temperature fluctuations can accelerate the rate of deterioration during storage (Erikson *et al.,* 2021). During the freezing process, the pH fluctuated but showed an overall decline. This decrease is attributed to ongoing biochemical processes during processing, which generate lactic acid and contribute to the pH reduction. A lower pH can impact the organoleptic properties of the product, particularly its taste, color, and appearance (Mercogliano & Santonicola, 2019). Cold chain management plays a crucial role in

preserving the quality, safety, and economic value of seafood, including fish and fishery products. Due to their high perishability and sensitivity to temperature, deterioration begins immediately after capture or harvest. Therefore, implementing an effective cold chain management system is essential to maintaining the safety, quality, and marketability of these products (Tingman et al., 2010) (Wang *et al.,* 2021).
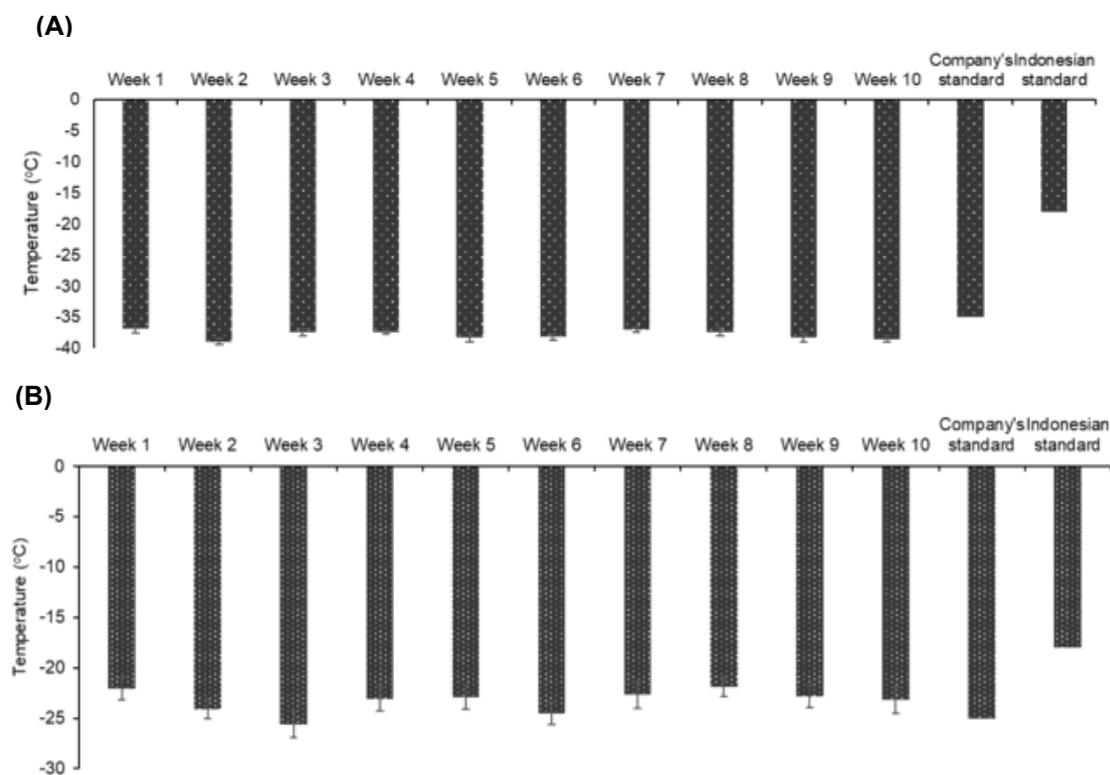

Figure 6. Temperature Monitoring of Air Blast Freezer (ABF) (A) and Cold Storage (B).

4. Conclusion

Findings of this experiment indicate that the temperatures of tuna, water, and the processing room met the company's standards. Tuna temperatures remained below 4.4°C, complying with Indonesia's regulations. Moreover, the Air Blast Freezer (ABF) and cold storage (CS) generally maintained appropriate temperatures in accordance with company guidelines. To enhance efficiency, the ABF and cold chain system should be optimized to consistently meet the company's maximum temperature standards. These findings highlight the need for tuna processing companies with similar operations to closely monitor these steps, minimizing temperature fluctuations and ensuring product quality.

References

Anderssen, K. E., Syed, S., & Stormo, S. K. (2021). Quantification and mapping of tissue damage from freezing in cod by magnetic resonance imaging. *Food Control, 123,* 1–20. https://doi.org/10.1016/j.foodcont.2020.107734

Ariyani, F., Kristiningrum, E., Barokah, G. R., & Januar, H. I. (2020). The effects of carbon monoxide treatment on the physical and chemical qualities of tuna steak during iced storage. *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology, 15*(2), 73–79. https://doi.org/10.15578/squalen.v15i2.456

BSN. (2021). *SNI 2729:2021 Tentang Ikan Segar.* Badan Standardisasi Nasional. www.bsn.go.id

Chen, X., & Hung, Y. C. (2018). Development of a Chlorine Dosing Strategy for Fresh Produce Washing Process to Maintain Microbial Food Safety and Minimize Residual Chlorine. *Journal of Food Science, 83*(6), 1701–1706. https://doi.org/10.1111/1750-3841.14189

Dang, H. T. T., Gudjonsdóttir, M., Karlsdóttir, M. G., Van Nguyen, M., Tómasson, T., & Arason, S. (2018). Stability of Golden redfish (Sebastes marinus) during frozen storage as affected by raw material freshness and season of capture. *Food Science and Nutrition*, *6*(4), 1065–1076. https://doi.org/10.1002/fsn3.648

Djenane, D., & Roncalés, P. (2018). Carbon monoxide in meat and fish packaging: Advantages and limits. *Foods*, *12*(7), 1–34. https://doi.org/10.3390/foods7020012

Erikson, U., Uglem, S., & Greiff, K. (2021). Freeze-chilling of whitefish: Effects of capture, on-board processing, freezing, frozen storage, thawing, and subsequent chilled storage—a review. *Foods*, *10*(11), 1–26. https://doi.org/10.3390/foods10112661

Fan, L., Liu, X., Dong, X., Dong, S., Xiang, Q., & Bai, Y. (2021). Effects of UVC light-emitting diodes on microbial safety and quality attributes of raw tuna fillets. *LWT*, *139*, 1–30. https://doi.org/10.1016/j.lwt.2020.110553

Fauziyah, A. F., & Syihab, A. (2024). Studi Proses Pengolahan Precooked Tuna Loin Frozen Jenis Skipjack Tuna. *Jurnal Perikanan*, *14*(1), 285–297. https://doi.org/10.29303/jp.v14i1.770

Hu, Y. M., Zhang, N. H., Wang, H., Yang, Y. F., & Tu, Z. C. (2021). Effects of pre-freezing methods and storage temperatures on the qualities of crucian carp (Carassius auratus var. pengze) during frozen storage. *Journal of Food Processing and Preservation*, *45*(2), 1. https://doi.org/10.1111/jfpp.15139

Hwang, B. S., Wang, J. T., & Choong, Y. M. (2003). A rapid gas chromatographic method for the determination of histamine in fish and fish products. *Food Chemistry*, *82*(2), 329–334. https://doi.org/10.1016/S0308-8146(03)00005-0

Denden, I., Njehi, M., & Krifi, B. (2024). Implementation of HACCP System in a tuna fish Industry. *World Journal of Advanced Research and Reviews*, *21*(3), 1899–1909. https://doi.org/10.30574/wjarr.2024.21.3.0158

Liu, L., Jiao, W., Xu, H., Zheng, J., Zhang, Y., Nan, H., & Huang, W. (2023). Effect of rapid freezing technology on quality changes of freshwater fish during frozen storage. *LWT*, *189*, 1–10. https://doi.org/10.1016/j.lwt.2023.115520

Liu, W., Lyu, J., Wu, D., Cao, Y., Ma, Q., Lu, Y., & Zhang, X. (2022). Cutting Techniques in the Fish Industry: A Critical Review. *Foods*, *11*(20), 1–24. https://doi.org/10.3390/foods11203206

Maharani Putri, N. N. F., Salampessy, R. B., & Sayuti, M. (2023). Karakteristik Mutu, Rantai Dingin, Rendemen dan Produktivitas Pengolahan Tuna (Thunnus sp.) Cube Beku di CV. Satu Tuna Nusantara, Denpasar-Bali. *Buletin Jalanidhitah Sarva Jivitam*, *5*(1), 11–21. https://doi.org/10.15578/bjsj.v5i1.12142

Marrone, R., Mascolo, C., Palma, G., Smaldone, G., Girasole, M., & Anastasio, A. (2015). Carbon monoxide residues in vacuum-packed yellowfin tuna loins (Thunnus Albacares). *Italian Journal of Food Safety*, *4*(3), 142–144. https://doi.org/10.4081/ijfs.2015.4528

Massie, G. K., Reo, A. R., Makapedua, D. M., Sanger, G., Montolalu, R. I., & Feny, M. (2022). Kajian Mutu Ikan Tuna Kaleng Selama Proses Sterilisasi Di PT. Sinar Pure Foods International. *Media Teknologi Hasil Perikanan*, *10*(2), 117–121. https://doi.org/10.35800/mthp.10.2.2022.40277

Mercogliano, R., & Santonicola, S. (2019). Scombroid fish poisoning: Factors influencing the production of histamine in tuna supply chain. A review. *LWT*, *114*, 1–7. https://doi.org/10.1016/j.lwt.2019.108374

MMAF. (2017). *Peraturan Direktur Jenderal Penguatan Daya Saing Produk Kelautan dan Perikanan Nomor 15/PER-DJPDSPKP/2017 Tentang Petunjuk Teknis Pengelolaan Bantuan Pemerintah Pembangunan Gudang Beku Terintegrasi Tahun 2017*. DJPDSPKP.

Palyama, A. F., & Dharmayanti, N. (2021). Indentifikasi Produktivitas Pengolahan Tuna Beku Pada PT. Maluku Prima Makmur di Kota Ambon. *Jurnal Penyuluhan Perikanan Dan Kelautan*, *15*(1), 1–17. https://doi.org/10.33378/jppik.v15i1.233

Romotowska, P. E., Karlsdóttir, M. G., Gudjónsdóttir, M., Kristinsson, H. G., & Arason, S. (2016). Influence of feeding state and frozen storage temperature on the lipid stability of Atlantic mackerel (Scomber scombrus). *International Journal of Food Science and Technology*, *51*(7), 1711–1720. https://doi.org/10.1111/ijfs.13146

Sarah, M., Marwati, Misran, E., & Madinah, I. (2024). Analysis of drip loss and thermal destruction rate of tuna fillets during the low-temperature preservation period. *Applied Food Research*, *4*(2), 1–15. https://doi.org/10.1016/j.afres.2024.100648

Suryaningrum, T. D., & Ikasari, D. (2019). Physicochemical and microbiological evaluation on Frozen Tuna Loin handling in Ambon, Indonesia. *Squalen Bulletin of Marine and Fisheries Postharvest and Biotechnology*, *14*(1), 9–19. https://doi.org/10.15578/squalen.v14i1.381

Suryono, M., Azka, A., Sada Harahap, K., & Fadilah, R. (2023). Identification Of Critical Points Of Traceability In Frozen Cube Tuna Using FMECA Method In Tuna Freezing Company. *Aurelia Journal*, *5*(1), 177–184.

Sveinsdóttir, H. I., Karlsdóttir, M. G., Arason, S., Stefánsson, G., Sone, I., Skåra, T., Rustad, T., Larsson, K., Undeland, I., & Gudjónsdóttir, M. (2020). Effect of antioxidants on the sensory quality and physicochemical stability of Atlantic mackerel (Scomber scombrus) fillets during frozen storage. *Food Chemistry*, *321*. https://doi.org/10.1016/j.foodchem.2020.126744

Tingman, W., Jian, Z., & Xiaoshuan, Z. (2010). Fish product quality evaluation based on temperature monitoring in cold chain. *African Journal of Biotechnology*, *9*(37), 6146–6151. https://doi.org/10.1111/ijfs.13146

Wang, D., Deng, J., Li, X., Yang, X., Chen, S., Zhao, Y., Li, C., & Wu, Y. (2021). Changes in microbial composition and quality characteristics of yellowfin tuna under different storage temperature. *Quality Assurance and Safety of Crops and Foods*, *13*(4), 54–61. https://doi.org/10.15586/qas.v13i4.988

Xiao, X., He, Q., Fu, Z., Xu, M., & Zhang, X. (2016). Applying CS and WSN methods for improving efficiency of frozen and chilled aquatic products monitoring system in cold chain logistics. *Food Control*, *60*, 656–666. https://doi.org/10.1016/j.foodcont.2015.09.012

Xiong, Z., Zhou, M., Xiao, S., Zhang, Z., & Li, D. (2024). Refrigerated Storage-Induced Quality Deterioration of Mandarin Fish (Siniperca chuatsi): Analyzing the Role of Endogenous Enzymes through TMT-Based Quantitative Proteomics. *LWT*, 116721. https://doi.org/10.1016/j.lwt.2024.116721

Zalukhu, R. M. S., Sayuti, M., & Salampessy, R. B. (2023). Quality Testing Of Frozen Cooked Tuna (Thunnus albacares) Loins. *Aurelia Journal*, *1*, 79–88.

Zhang, X., Zhang, Y., Ding, H., Zhang, W., & Dai, Z. (2022). Effect of Washing Times on the Quality Characteristics and Protein Oxidation of Silver Carp Surimi. *Foods*, *11*(16), 1–4. https://doi.org/10.3390/foods11162397