Characterization of temperature and quality changes in african catfish (*clarias gariepinus*) during domestic refrigeration

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Abstract. Fish is now one of the most popular and nutritious foods. In Indonesia, fish consumption has risen by 7.4% annually, from 38.14 to 54.5 kg per capita between 2014 and 2019. African catfish (*Clarias gariepinus*) is one of the most commonly consumed fish, often stored in household refrigerators. However, detailed studies on the temperature and quality changes of fish during refrigeration are limited. This study aims to explore the characterization of the temperature and quality changes of African catfish during storage in household refrigerators. In this experiment, the fish were stored in three compartments of the refrigerator: freezing (*R1*), chilling 1 (*R2*), and chilling 2 (*R3*), for a duration of three days. The temperature of both the fish and the refrigerator compartments was measured every 15 seconds. Additionally, electrical current was monitored to assess energy consumption. The quality of the fish, including total volatile basic nitrogen (TVB-N), moisture content, protein content, and mass (weight loss) was analyzed before and after the storage period. The refrigerator was also subjected to door-opening treatments to observe any impact. The study provides detailed insights into the temperature dynamics of African catfish, the room temperature inside the refrigerator, cooling times, fish quality changes (TVB-N, moisture, protein, mass), energy consumption, and the effect of refrigerator door openings.

1 Introduction

Fisheries play a vital role in Indonesia's economy, and fish has become one of the most popular and nutritious foods. Catfish, in particular, is a staple in Southeast Asia, including Indonesia [1]. From 2014 to 2019, fish consumption in Indonesia rose significantly by 7.4% per year, increasing from 38.14 to 54.5 kg per capita [2]. Catfish has grown in popularity due to its taste, affordability, and high nutritional value, leading to a 9.8% annual increase in

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production, from 679 .379 to 1 .013 .574 tons. African catfish (*Clarias gariepinus*) is one of the most widely consumed catfish species. Ideally, fish should be stored alive, but due to space constraints and the challenges of live storage, many are stored post-mortem. As a perishable seafood item, typically consumed domestically, fish are usually refrigerated to extend their shelf life for household use. To preserve freshness, fish should be stored at chilling temperatures between 0-5°C or frozen at temperatures below -18°C. While refrigeration can slow spoilage, detailed studies on how temperature and quality of fish change during storage in refrigerators are lacking. Refrigerator temperatures often fluctuate, particularly when the door is frequently opened for daily use [3], impacting the quality of stored fish. These fluctuations make it difficult to maintain consistent humidity and temperature, which can degrade fish quality over time.

While numerous studies have examined fish storage in refrigerators, few have comprehensively explored key parameters such as fish and refrigerator temperatures, fish quality, energy consumption, and the effects of refrigerator door openings. For instance, research on domestic refrigerator performance in real kitchens revealed temperatures ranging from -2.8°C to 7.5°C [4], influenced by factors such as room temperature, heat sources, and door-opening frequency. However, this study did not detail the relationship between refrigerator temperatures and fish quality. Other research has focused on reducing tuna drip loss in freezers with phase-change materials [5]. An investigation of coloration characteristics of mechanically processed channel catfish (*Ictalurus punctatus*) fillets was done after seven days of refrigerated (4–5 °C) storage [6] which found a big enhancement in yellowness. The benefits of the chitosan-gelatin coating had been studied combined with pomegranate peel extract (PPE) on the microbiological and chemical properties of Belanger's croaker (*Johnius belangerii*) fillets during refrigerated storage (4 ± 1°C) [7]. Chitosan- gelatin coating added with PPE has delaying effects on the spoilage of fish samples, thus lengthening the shelf life during refrigerated storage. An investigation of chemical and biochemical transformations of aquacultured hybrid catfish fillet (*Clarias macrocephalus* × *Clarias gariepinus*) was done during storage at 4 °C for 0, 3, 6, 9, 12, and 15 days [8]. The study recommended that the processing of hybrid catfish fillets was proper within 6 days.

Additionally, a study of household refrigerators in Belgrade (Republic of Serbia) showed that the majority of 120 household refrigerators (82.5%) operated above 5°C, with poor internal hygiene impacting food safety. TVC screening was up to 8.4 log10 CFU/ cm^2 indicating the unsatisfactory hygienic status of internal refrigerator surfaces which was needed for improving hygienic practices during food storage at home [9]. While some studies also explored the quality properties of fish under refrigeration. Raw and smoked channel catfish (*I. punctatus*) fillets textural properties were studied, and a novel sampling technique was developed [10]. Evaluation of soluble spray-dried protein powder (CRP) from catfish roe showed that CRP contained 67% protein, 4.5% moisture, 10% ash, and 18.3% fat [11]. Analysis of the physical and physicochemical composition and microbiological properties of mechanically separated meat (MSM) from Brazilian catfish (*Brachyplatystoma vaillantii*) stored at -22 °C identified that the fish residue had 78.36 g/100 g moisture, 9.52 g/100 g proteins, 10.80 g/100 g lipids and 18.41 mg TVB-N/100 g [12]. African catfish skin gelatin was studied to observe the gelatin properties and its physicochemical characteristics [13]. Another issue is about wasting food from home refrigerators. A better storage method of perishable foods was suggested as a method to minimize food waste where only a little research was studied about the management of home refrigerators [14].

The studies above have observed both temperatures and the quality of fish storage in refrigerators. However, detailed characterizations of temperatures and quality change during refrigeration specifically for African catfish remain underexplored, highlighting the need for further investigation into these parameters. Thus, this study aims to address that gap by exploring the characterization of temperature and quality change of African catfish under household refrigerator storage.

2 Materials and methods of research

2.1 Materials and equipments

A series of tests were conducted to observe the temperature and quality of African catfish during storage in the refrigerator. African catfish were stored in the refrigerator for 3 days. The refrigerator was attached by a temperature data logger and an electrical current data logger. In this study, raw African catfish (size 7 per kg) were stored in 3 compartments/shelves of the refrigerator: freezing (*R1*), chilling 1 (*R2*), and chilling 2 (*R3*) for 3 days with each compartment holding about 1 kg of fish. Two doors type household refrigerator was used and attached by the temperature data logger and electrical current data logger. Refrigerator specification was 310 liters (236 liters for the chiller and 74 liters for the freezer), an auto-defrost feature, and operated at 128 watts, 220 V, and 0.66 A. The measuring tools were a temperature data logger, an electrical current data logger, an ampere meter (to measure electrical current and voltage), a timer, and a scale. A schematic of the experimental setup is shown in Figure 1.

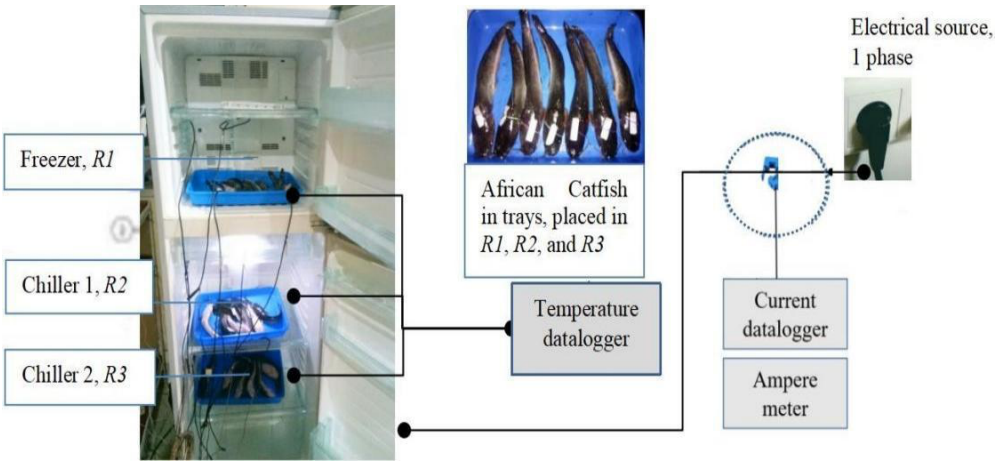

Fig. 1. Schematic illustration for experimental testing condition.

2.2 Methods

African catfish were placed in 3 trays and stored in racks *R1, R2*, and *R3*. Parameters observed were refrigerator room temperatures, fish temperatures, electrical current, and voltage to observe the consumption of power. The study measured the temperatures of both the fish and the refrigerator compartments every 15 seconds. Additionally, electrical current was monitored at the same intervals, while voltage was recorded daily. The quality of the fish, including total volatile basic nitrogen (TVB-N), moisture content, protein content, and mass (weight loss), was assessed before and after 3 days of storage. The equation used to calculate electrical power consumption was:

$$P_E = V.\, I \tag{1}$$

Where PE is electrical power in watts, V is voltage in volts, and I is current in amperes.

To simulate real household conditions, the refrigerator was also subjected to a door-opening test, where the doors remained open for 30 minutes to observe its impact on fish and compartment temperatures. Electrical current was continuously monitored during

this test. The electrical current was measured every 15 seconds by the current data logger. Temperatures were measured by a temperature data logger every 15 seconds.

The quality properties of African catfish studied were total volatile basic-nitrogen (TVB-N), moisture content, protein content, and mass (weight loss). The properties were determined by TVB-N procedure [15], protein content (Kjeldahl method) and moisture content (gravimetric method) procedures [16], and weight loss procedure [17]. TVB-N was tested by taking 5 grams of the ground sample, grinded with 25 ml of 5% TCA using a porcelain mortar and then filtered. 5 ml of extract was distilled in the protein distillation apparatus with 20 ml of NaOH-Tio (NaOH 40% + $Na_2S_2O_3$ 5%), and the distillation was run with a distillate container using 5% H_3BO_3 given the MR-BCG indicator. Then, a 60-ml volume of distillate was titrated using 0.02 N HCl and the titration volume was obtained (V_1, ml). TVB-N was calculated using the following equation:

$$\text{TVB-N (mg/100 g)} = [V_1 \text{ x N.HCl x } 14.008 \text{ x fp x } 100] / [\text{sample weight (g)}] \quad (2)$$

Protein content test was conducted by taking a sample weight of 0.2 grams put in a Kjeldahl flask and added with 0.7 grams of N catalyst (250 grams of Na_2SO_4 + 5 grams of $CuSO_4$ + 0.7 grams of Selenium/TiO_2), then 4 ml of concentrated H_2SO_4. After destruction in the acid cabinet until the green color, the sample was cooled and added with 10 ml of distilled water and then distilled by adding 20 ml of NaOH-Tio and the distillate was collected using 4% H_3BO_3 given MR-BCG indicator. After the volume reached 60 ml, the sample then was titrated using a 0.02 N HCl solution until pink color resulted V_1 titration volume in ml. The protein content was calculated using the formula:

$$\text{Protein content (\%)} = \text{Nitrogen content x conversion factor (6.25)} \quad (3)$$

$$\text{Nitrogen content (\%)} = [V_1 \text{ x N HCl x } 14.008 / (\text{sample weight in mg})] \text{ x100 \%} \quad (4)$$

Moisture/water content was analyzed by gravimetric methods. The constant crucible weight (A gram) was inserted into the sample (B gram). After putting it in the oven temperature of 105 °C for 6 hours, the constant weight (C gram) was obtained.

$$\text{Water Content (\%)} = [(A+B)-C)/B] \text{ x } 100\% \quad (5)$$

The weight loss of fish samples for each treatment was subjected to weighing at the commencement of the storage period (day 0) and the conclusion of the storage period (day 3). The concept of weight reduction may be quantified using an equation:

$$W\_loss\ (\%) = [(W_0 - W_1)/W_0] \text{ x } 100\% \quad (6)$$

W_loss indicates the weight loss in percentage, W_0 is initial weight, and W_1 is the weight after storage. Weight loss shows the total loss of fish after storage in refrigerator, including freeze loss and thawing loss. The parameter values were determined and graphed using Microsoft Excel, presenting the average ± standard deviation graphic visualization.

3 Results

In this study, African catfish were stored for 3 days in a refrigerator on three different racks: freezer (*R1*), chiller (*R2*), and chiller (*R3*). The effect of door opening on temperatures was also examined. The key measurements included refrigerator air temperatures, fish temperatures, electrical current, and voltage, which were used to analyze the current profile

and power consumption. Additionally, the fish properties—TVB-N, water content, protein content, and mass (weight loss)—were assessed both before and after the 3-day storage period.

3.1 Refrigerator room (air) temperatures

Refrigerator room temperatures during freezing in *R1* and chilling in *R2* and *R3* were graphed in Figure 2, describing the temperature profile every 15 seconds, cooling time, the effect of defrosting, and the effect of refrigerator opening. The ambient temperature was stable at 27.0-28.1 °C, only increased slightly by about 1 °C. Air temperature first decreased to a minimum at about -22 °C in *R1* and 4 °C in *R2* and *R3* in the first 19 hours with auto defrost. In the first 19 hours of cooling, *R1* air temperatures decreased to -15 °C for 7 hours, increased to 21°C along defrost process for 4 hours (until the 11th hour), and then decreased to -22 °C for 8 hours (until the 19th hour). While *R2* and *R3* temperatures were almost in the same temperature patterns. In the first 19 hours of cooling, *R2* and *R3* air temperatures decreased until 8 °C for 7 hours, increased to 23°C along defrost process for 4 hours (until the 11th hour), and then decreased to 4 °C for 8 hours (until the 19th hour). In this auto defrost refrigerator, defrost automatically occurred when a certain ice thickness in the freezer room was formed and covered the evaporator area. After reaching minimum temperature, the room temperature was stable unless auto defrosts occurred again. Defrost occurred 3 times in the 7th hour, 23rd hour, and 31st hour.

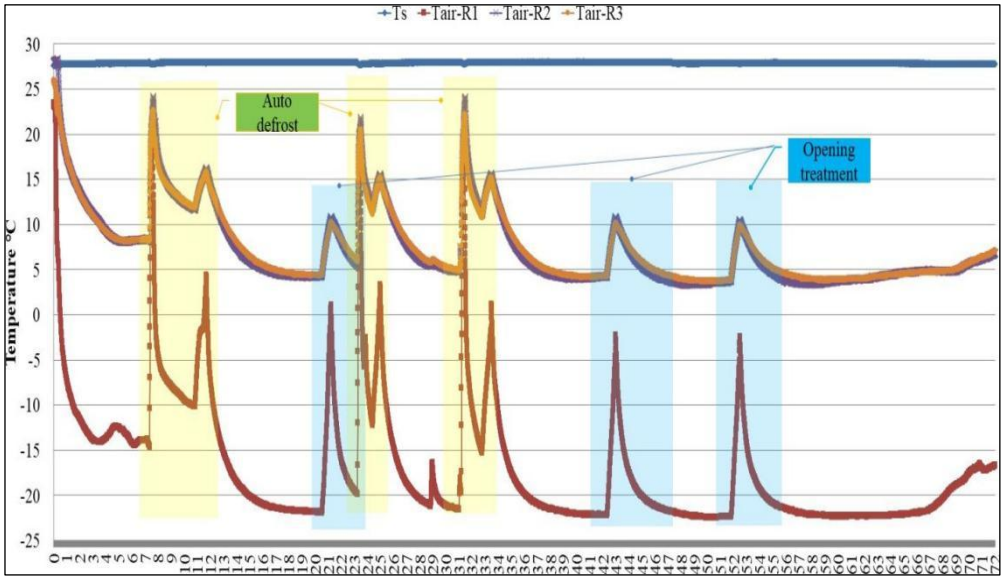

Fig. 2. Air temperature profiles every 15 seconds in freezer *R1* and chiller *R2* and *R3* during 3 days (72 hours) storage, the effect of defrosting (yellow blocks), and the effect of opening treatment (blue blocks). Ts: surrounding/ambient temperature, Tair-*R1*: air temperature in *R1*, Tair-*R2*: air temperature in *R2*, and Tair-*R3*: air temperature in *R3*.

The frosting phenomenon is destructive to the efficiency of the refrigerator. The frost accumulation clogs the airflow and decreases the cooling capacity and the coefficient of performance. Defrosting was used to remove excessive ice in the freezer by heating, melting, and draining [18]. Commercial refrigerators apply a blind and periodic defrosting cycle which leads to worse efficiencies [19]. Defrost formation has become a basic in refrigerators application and many studies have been done to observe and optimize/improve defrost systems. Domestic refrigerators made simpler food storage, but frost formation become a

basic problem mainly in tropical countries with high temperature and humid ambient conditions, including Indonesia. Adaptive defrost compared to the fixed defrost cycles could reduce energy consumption and Total Equivalent Warming Impact (TEWI) [20]. Also, the temperature variation of the compartments was reduced which prevents quality loss of the stored food during defrosting. Another study was the real-time thickness of the frost-based demand defrost technique for a domestic refrigerator [21] which yields 10% of the maximum energy conservation. The high maximum surface temperature was studied by the optimum heater power which reduced the temperature and made uniform temperature distribution and defrosting efficiency up to 6.7% [22]. Freezer compartment temperature and overall energy consumption can increase because of warm air intrusion. Defrost duration also can be longer caused by mismatched heat transfer coverage [18]. All of those studies conclude the essential effects of defrosting highly need to be improved.

In this study, defrosting cycles occurred 3 times during 3 days of storage in the 7th hour, 23rd hour, and 31st hour. This refrigerator with an auto-defrost feature performed similar patterns but different time cycles. The effect of defrosting formations on air temperatures was explained in Figures 3-4. All defrost formations had patterns that started with first heating with maximum increased air temperature, first recovery cooling, second heating, and second cooling. These patterns were mainly heating, melting, and draining [18].

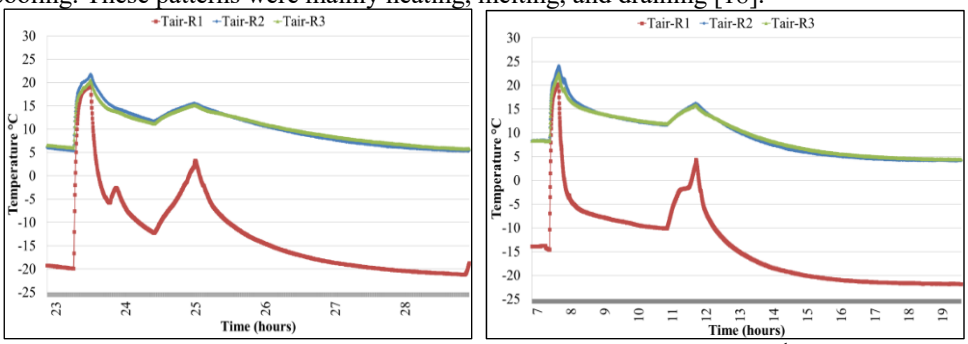

Fig. 3. The defrost effect on the air temperature pattern, the first defrost in the 7th hour (left) and the second defrost in the 23rd hour (right).

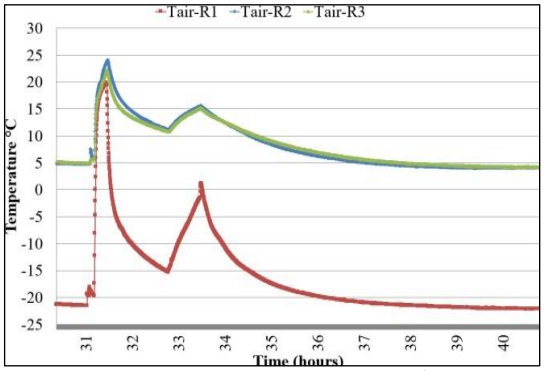

Fig. 4. The third defrost effect on air temperature pattern in the 31st hour.

First, defrost started at the 7th hour when the temperature increased to 21°C in *R1* and until 23°C in *R2* and *R3*) for about 15 minutes and then recovered the first cooling (until -10 °C in *R1* and 12°C in *R2* and *R3*) for about 3 hours. Second heating occurred for about 1 hour until 5°C in *R1* and 16°C in *R2-R3*) and finally recovered second cooling (until -22 °C in *R1* and 4°C in *R2- R3*) for about 7 hours. Second, defrost in the 23rd hour and third defrost in the 31st hour had the same patterns with different heating and cooling times as shown in Figures 4-5. The second defrost started at the 23rd hour when the temperature increased (until 20 °C

in *R1*, 22°C in *R2* and 21°C in *R3*) for about 15 minutes and then recovered first cooling (until -12 °C in *R1* and 12°C in *R2* and *R3*) for about 1 hour. The second heating occurred for about 1 hour (until 3°C in *R1* and 16°C in *R2-R3*) and finally recovered second cooling (until -22 °C in *R1* and 5°C in *R2-R3*) for about 4 hours. The third defrost started at the 31st hour when the temperature increased (until 20 °C in *R1*, 24°C in *R2*, and 23°C in *R3*) for about 15 minutes and then recovered first cooling (until -12 °C in *R1* and 12°C in *R2* and *R3*) for about 1,5 hours. Second heating occurred for about 1 hour (until 2°C in *R1* and 16°C in *R2-R3*) and finally recovered second cooling (until -22 °C in *R1* and 4°C in *R2-R3*) for about 6 hours. The result showed that defrosting formation made significant temperature increases/variations in freezer and chiller rooms [20]. Defrosting formation had its heating and recovery cooling patterns.

3.2 Fish temperatures

Fish temperatures during freezing in *R1* and chilling in *R2* and *R3* were shown in Figure 5, explaining the temperature profile every 15 seconds, cooling time, the effect of defrosting, and the effect of refrigerator opening. Fish temperature profiles were similar to air temperatures. Fish temperatures from ambient temperature started to decrease to a minimum at about -21 °C in *R1* and 2 °C in *R2* and *R3* in the first 19 hours with auto defrost. In the first 19 hours of cooling, *R1* fish temperatures decreased to -14 °C for 7 hours, increased to -3 °C along defrost process for 4 hours (until the 11th hour), and then decreased to -21 °C for 8 hours (until the 19th hour). While *R2* and *R3* temperatures were almost in the same temperature patterns. In the first 19 hours of cooling, *R2* and *R3* fish temperatures decreased to 5 °C for 7 hours, increased to 12°C along defrost process for 4 hours (until the 11th hour), and then decreased to 2 °C for 8 hours (until 19th hour). After achieving minimum temperature, the fish temperature was stable except auto defrost occurred again. Defrost occurred 3 times in the 7th hour, 23rd hour, and 31st hour.

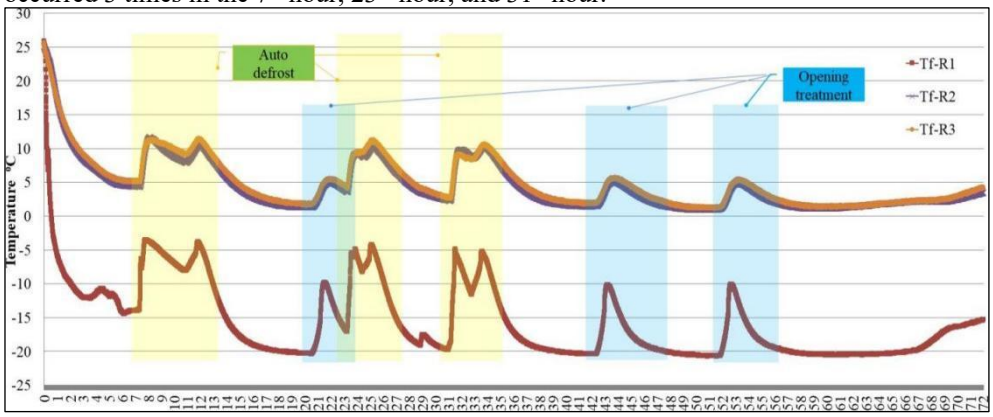

Fig. 5. Fish temperature profiles every 15 seconds in freezer *R1* and chiller *R2* and *R3* during 3 days (72 hours) storage, effect of defrosting (yellow blocks), and effect of opening treatment (blue blocks). Tf-*R1*: fish temperature in *R1*, Tf-*R2*: fish temperature in *R2*, and Tf-*R3*: fish temperature in *R3*.

Defrosting cycles occurred three times during the 3-day storage period: at the 7th, 23rd, and 31st hours. These automatic defrost cycles followed similar patterns but varied in timing. The effect of defrosting on fish temperatures is shown in Figures 6-7. Each cycle followed a sequence of initial heating (with a peak in air temperature), recovery cooling, second heating, and final cooling. During the first defrost at the 7th hour, fish temperatures rose to around -3°C in *R1* and 12°C in *R2* and *R3* over 15 minutes, followed by recovery cooling (to -8°C in *R1* and 8-10°C in *R2* and *R*3) over 3 hours. A second heating phase lasted about 1 hour

(raising fish temperatures to -3°C in *R1* and 11°C in *R2* and *R3*), followed by a second cooling phase (to -21°C in R1 and 2°C in *R2* and *R3*) lasting 7 hours. The second defrost at the 23rd hour saw fish temperatures rise to -5°C in *R1* and 8°C in *R2* and *R3* over 15 minutes, then cool down (to -8°C in *R1* and 7°C in *R2* and *R3*) within an hour. After second heating (1 hour), fish temperatures reached -4°C in *R1* and 12°C in *R2* and *R3*, before cooling again to -20°C in *R1* and 4°C in *R2* and *R3* over 4 hours. The third defrost at the 31st hour caused fish temperatures to rise to -5°C in *R1*, 10°C in *R2*, and 9°C in *R3* over 15 minutes, followed by recovery cooling (to -12°C in *R1* and 8°C in *R2* and *R3*) for 1.5 hours. Second heating lasted for an hour, raising temperatures to -5°C in R1 and 11°C in *R2* and *R3*, with final cooling bringing them down to -21°C in *R1* and 2°C in *R2* and *R3* over 6 hours.

These results demonstrate that defrosting caused significant variations in fish temperatures in both the freezer and chiller rooms. However, the defrost effect on fish temperatures was smaller than on air temperatures, as the fish acts as thermal storage, slowing the rate of temperature increase.

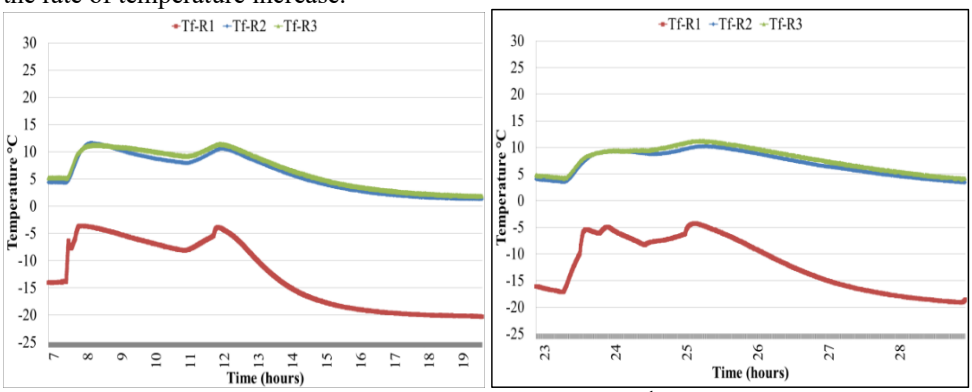

Fig. 6. The first defrost effect on fish temperature pattern in the 7th hour (left) and the second defrost in the 23rd hour (right).

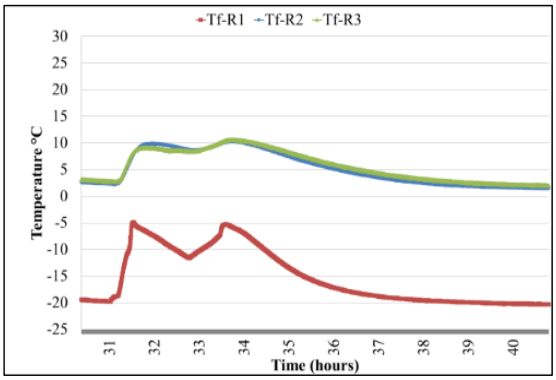

Fig. 7. The third defrost effect on fish temperature pattern in the 31st hour.

3.3 Effect of the refrigerator opening

A refrigerator door opening test was conducted to evaluate its effects on both air and fish temperatures. Over the 3-day storage period, the refrigerator door was opened three times for 30 minutes each. Air and fish temperatures were recorded every 15 seconds using a data logger, as shown in Figure 8. During the 30-minute door openings, air temperatures increased from -22 °C to around -2 °C in *R1* and from 4-5 °C up to 11°C in *R2* and *R3*. Meanwhile, fish temperatures rose from -22 °C to approximately -10 °C in *R1* and from 1-2 °C to 6 °C in

R2 and *R3*. The rise in fish temperatures was less pronounced than that of the air, which can be explained by the fish's higher thermal storage capacity compared to the air inside the refrigerator. These results contrast with chest freezer storage, where a temperature increase of only 3°C was observed under similar conditions [5]. Unlike refrigerators, chest freezers do not turn off the compressor when the door is opened, helping to maintain more stable temperatures.

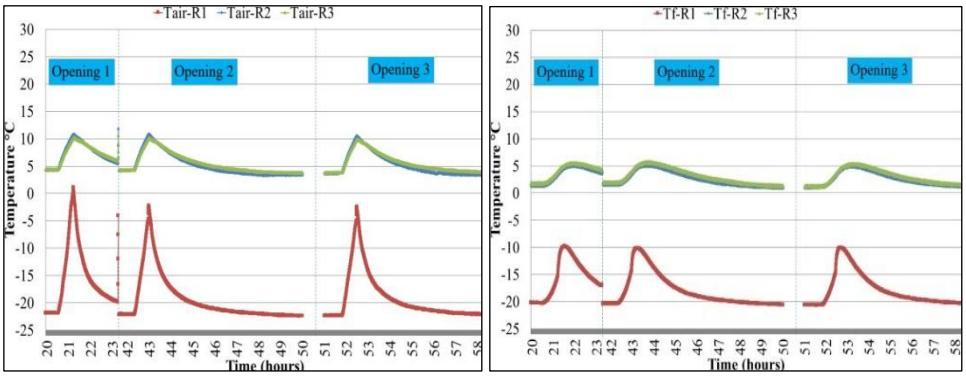

Fig. 8. Effect of the opening refrigerator on air temperatures (left) and fish temperatures (right).

3.4 Electrical current profile and energy consumption

Electrical current was measured every 15 seconds using a data logger, while voltage was monitored daily during the 3-day storage period. The electrical current profile (and power consumption) are illustrated in Figure 9. Throughout the 3 days of refrigerator operation, the electrical current ranged from 0.05 to 0.6 A. The refrigerator's compressor remained operational, except during defrosting cycles and when the refrigerator was opened. During defrosting and refrigerator openings, the electrical current dropped, as the compressor was switched off. During defrosting, the current was used solely for the heater and control systems, while during refrigerator openings, the current was used for control functions only. Meanwhile, energy consumption for the refrigerator can vary greatly depending on consumer behavior and external conditions [23]. Frequent refrigerator openings significantly impact energy consumption, making it a key factor. Energy usage is calculated using the formula (1), multiplying voltage and current and then multiplied by time (72 hours). The measured voltage ranged between 221.4 V and 229.9 V, with an average of 224 V. Based on the current profile recorded every 15 seconds, energy consumption over the 3 days was calculated to be 7.55 kWh. In comparison, previous studies have reported an average daily energy consumption of approximately 1.62 kWh/day (or 4.86 kWh over 3 days) [18]. Another reference indicated energy consumption of 1755 Wh, or about 5.27 kWh over 3 days [24]. The higher energy consumption in this study was primarily due to the compressor remaining operational for most of the time and frequent refrigerator openings.

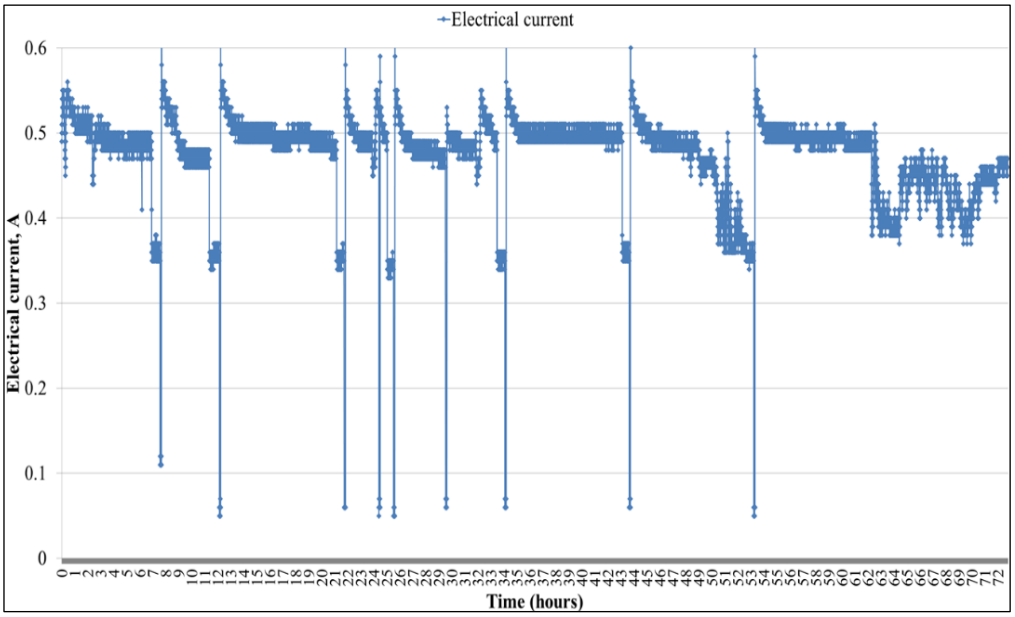

Fig. 9. Electrical current profile during 3 days of fish storage.

3.5 Quality properties/characterization

Table 1 presents the quality properties analyzed, including TVB-N, water/moisture content, protein, and mass (weight loss), both before and after three days of storage on the *R1*, *R2*, and *R3* shelves/racks. The TVB-N values ranged from 2.3183 to 2.70535 mg/100g, with R1 showing the lowest value, while R2 and R3 exhibited nearly identical levels. TVB-N content in the muscle of chilled African catfish was slightly higher than in frozen fish, suggesting that the increase in TVB-N is linked to bacterial spoilage. These findings indicate that biochemical and microbial changes progress more rapidly in chilled fish [17]. The water content increased slightly, ranging from 0.05165% to 2.2853%, though it did not show significant variation between chilling (5°C) and freezing (-20°C). The trend, however, suggested an increase after prolonged storage [17- 25]. The protein content decreased marginally, from 0.0388% to 0.54145%, indicating that proteins remained relatively stable during the storage period [26]. Fish mass decreased significantly, with reductions of 4.12% in the freezer (R1), 6.34% in the chiller (R2), and 6.4% in the chiller (R3). These results exceed the tuna drip loss observed after 60 hours of chest freezer storage, which was between 2.84% and 3.53% [5]. Temperature variations and low relative humidity (RH) in the refrigerator were key contributors to the mass reduction. In this study, RH ranged from 26% to 38% in freezer rooms and 33% to 50% in chiller rooms, influencing mass changes. Additionally, super-chilling and freezing led to mass loss due to drip loss, which was attributed to the reduced capacity of the fish to reabsorb water caused by fiber shrinkage, cell damage, and protein denaturation and aggregation during freezing and thawing [26 -27].

Table 1. Quality properties of African catfish before and after 3 days storage.

Racks/ Shelves	Days of storage		Increase/decrease	
	H-0	H-3		
	TVB-N (mg/100g)		TVB-N increase	
			mg/100g	%
R1	7.3059±0.2706	9.62415±0.15874	2.3183	31.73
R2	7.3059±0.2706	10.01125±0.15620	2.7054	37.03
R3	7.3059±0.2706	9.8500±0.15369	2.5441	34.82
	Water/moisture content (%)		Water content increase	
			%value	%
R1	76.3823±0.2709	78.66755±0.0464	2.2853	2.99
R2	77.6772±0.0613	77.72885±0.0467	0.0517	0.07
R3	75.9804±0.0213	78.1670±0.0275	2.1866	2.88
	Protein content (%)		Protein content decrease	
			%value	%
R1	13.33905±0.0549	13.30025±0.0091	-0.0388	-0.29
R2	13.6002±0.0018	13.05875±0.0303	-0.5415	-3.98
R3	13.1473±0.0438	12.7184±0.0210	-0.4289	-3.26
	Mass (gram)		Weight loss	
			(g)	%
R1	990.0	949.2	40.8	4.12%
R2	1.028.5	963.3	65.2	6.34%
R3	1.037.0	970.6	66.4	6.40%

4 Conclusions

This study characterized the temperature dynamics and cooling times of African catfish during three days of storage in a household refrigerator. The auto-defrost cycle significantly influenced temperature variations. The temperatures decreased to a minimum in about 19 hours with auto defrost and were stable unless defrost occurred. Frequent door openings led to notable increases in both refrigerator and fish temperatures across all compartments: the freezer (*R1*), and the chiller sections (*R2* and *R3*). During these door-opening events, fish temperatures were consistently lower than the surrounding air temperatures, indicating that the fish acted as thermal storage. Over the three-day period, the refrigerator's electrical current ranged from 0.05 to 0.6 A, resulting in an energy consumption of approximately 7.55 kWh. Quality assessments showed that while the fish's TVB-N, moisture content, and protein content remained relatively stable, there was a significant decrease in the fish's mass.

References

1. F. H. Jang, C. Wong, J. Choo, E. S. A. Sia, A. Mujahid, M. Müller, Increased transfer

of trace metals and Vibrio sp. from biodegradable microplastics to catfish *Clarias gariepinus*. Env. Pollut. **298**, (2022). https://doi.org/10.1016/j.envpol.2022.118850
2. Ministry of Marine Affairs and Fisheries Republic of Indonesia, Marine and fisheries in figures 2020 (The Center for Data, Statistics, and Information , Jakarta, 2021). https://statistik.kkp.go.id/home.php?m=publikasi&i=214
3. L. Harrington, L. Ayea, B. Fuller, G. Hepwoth, Peering into the cabinet: Quantifying the energy impact of door openings and food loads in household refrigerators during normal use. J. of Refrigeration. **104**, 437–454 (2019). https://doi.org/10.1016/j.ijrefrig.2019.05.040
4. S. Rahman, M. N. Sidik, M. H. Hassan, T. M. Rom, I. Jauhari, Temperature performance and usage conditions of domestic refrigerator-freezers in Malaysia. HKIE Transactions. **12** , 230-235 (2018). https://doi.org/10.1080/1023697X.2005.10668000
5. A. R. Hakim, A. Fauzi, I. Pranoto, Phase change material-assisted freezing of tuna: Impact on freezing process and thawing loss. J. of Food Process Eng. **45**, 4 (2022). https://doi.org/10.1111/jfpe.14011
6. M. A. Peterman, D. J. Cline, T. R. Hanson, J. A. Chappell, Coloration characteristics of mechanically processed Channel catfish (*ictalurus punctatus*) fillets held in refrigerated storage for seven days. J. of Appl. Aquaculture. **25**, 239–247 (2013). https://doi.org/10.1080/10454438.2013.814556
7. J. Saki, A. Khodanazary, S. M. Hosseini, Effect of chitosan-gelatin composite and bi-layer coating combined with pomegranate peel extract on quality properties of belanger's croaker (*johnius belangerii*) stored in refrigerator. J. of Aquatic Food Product Technol. **27**, 5, 557-567 (2018). https://doi.org/10.1080/10498850.2018.1461161
8. C. Chomnawang, K. Nantacha, J. Yongsawatdigul, S. Thawornchinsombu, S. Tungkawachara, Chemical and biochemical changes of hybrid catfish fillet stored at 4 °C and its gel properties. Food Chemistry. **103**, 2, 420-427 (2007). https://doi.org/10.1016/j.foodchem.2006.07.039
9. J. Jovanovic, I. Djekic, N. Smigic, N. Tomic, A. Rajkovic, Temperature profile and hygiene in household refrigerators in Belgrade, Serbia and their relation to consumers food safety knowledge and characteristics of the refrigerators. Food Control. **136**, 108813 (2022). https://doi.org/10.1016/j.foodcont.2022.108813
10. M. Jiang, Y. Wang, E. Santen, Chappel, Evaluation of textural properties of channel catfish (*Ictalurus punctatus Rafinesque*) fillet with the natural contour method. LWT - Food Science and Technol. **41**, 1548-1554 (2008) . https://doi.org/10.1016/j.lwt.2007.11.022
11. S. Sathivel, H. Yin, P. J. Bechtel, J. M. King, Physical and nutritional properties of catfish roe spray dried protein powder and its application in an emulsion system. J. of Food Engineering. **95**, 76–81 (2009). https://doi.org/10.1016/j.jfoodeng.2009.04.011
12. I. S. Oliveira, L. F. H. Lourenço, C. L. Sousa, Composition of MSM from Brazilian catfish and technological properties of fish flour. Food Control. **50**, 38-44 (2015). https://doi.org/10.1016/j.foodcont.2014.08.018
13. A. T. Alfaro, F. C. Biluca, C. Marquetti, I. B. Tonial, N. E. Souza, African catfish (*Clarias gariepinus*) skin gelatin: Extraction optimization and physical–chemical properties. Food Research Int. **65**, 416–422 (2014). https://doi.org/10.1016/j.foodres.2014.05.070
14. M. L. Davenporta, D. Qi, B.E. Roe, Food-related routines, product characteristics, and household food waste in the United States: A refrigerator-based pilot study. Resources, Conserv. & Recycling. **150**, 104440 (2019).

https://doi.org/10.1016/j.resconrec.2019.104440
15. A. Apriyantono, D. Fardiaz, N.L. Puspitasari, S. Yasni, S. Budiyanto, Analisis pangan (Institut pertanian bogor Press, Bogor, 1989)
16. Association of Official Analytical Chemists (AOAC), Official methods of analysis of AOAC International, twenty first ed. (AOAC International, Washington, DC, USA, 2019)
17. C. Bilbao-Sainz, A.J.G. Sinrod, T. Williams, D. Wood, B.S. Chiou, D.F. Bridges, V.C.H. Wu, C. Lyu, B. Rubinsky, T. McHugh, Preservation of Tilapia (*Oreochromis aureus*) fillet by isochoric (constant volume) freezing. J. of Aquatic Food Product Tech . **29**, 7, 629-640 (2020). https://doi.org/10.1080/10498850.2020.1785602
18. R. Zhao, D. Huang, X. Peng, L. Qiao, Comprehensive measures to enhance electric heater defrosting (EHD) performance for household frost-free refrigerators. Int. J. of Refrigeration. **111**, 1–8 (2020). https://doi.org/10.1016/j.ijrefrig.2019.12.002
19. A.N. Malik, S.A. Khan, I. Lazoglu, A novel hybrid frost detection and defrosting system for domestic refrigerators. Int. J. of Refrigeration. **117**, 256–268 (2020). https://doi.org/10.1016/j.ijrefrig.2020.05.016
20. F.G. Modarres, M. Rasti, M.M. Joybari, M.R.F. Nasrabadi, O. Nematollahi, Experimental investigation of energy consumption and environmental impact of adaptive defrost in domestic refrigerators. Measurement. **92**, 391–399 (2016). https://doi.org/10.1016/j.measurement.2016.05.096
21. A.N. Malik, S.A. Khan, I. Lazoglu, A novel demand-actuated defrost approach based on the real-time thickness of frost for the energy conservation of a refrigerator. Int. J. of Refrigeration. **131**, 168–177 (2021). https://doi.org/10.1016/j.ijrefrig.2021.07.032
22. H. Jeong, S. Byun, D.R. Kim, K. Lee, Power optimization for defrosting heaters in household refrigerators to reduce energy consumption. Energy Convers. and Management. **237**, 114127 (2021). https://doi.org/10.1016/j.enconman.2021.114127
23. J. Geppert, R. Stamminger, Analysis of effecting factors on domestic refrigerators' energy consumption in use. Energy Convers. and Management. **76**, 794–800 (2013). https://doi.org/10.1016/j.enconman.2013.08.027
24. S.A. Borikar, M.M. Gupta, M.A. Alazwari, P.D. Malwe, E.B. Mustafa, H. Panchal, A. Elsheikh, A case study on experimental and statistical analysis of energy consumption of domestic refrigerator. Case Studies in Thermal Eng. **28**, 101636 (2021). https://doi.org/10.1016/j.csite.2021.101636
25. X. Xie, X. Zhai, M. Chen, Q. Li, Y. Huang, L. Zhao, Q. Wang, L. Lin, Effects of frozen storage on texture, chemical quality indices and sensory properties of crisp Nile tilapia fillets. Aquaculture and Fisheries. **8**, 626–633 (2023). https://doi.org/10.1016/j.aaf.2022.11.007
26. I.M. Mackie, The effect of freezing on flesh proteins . Food Rev. Int. **9,** 4, 575–610 (1993). https://doi.org/10.1080/87559129309540979
27. Z.E. Sikorski, E. Kolakowski, Endogenous enzyme activity and seafood quality: influence of chilling, freezing, and other environmental factors, In: Haard NF, Simpson BK, editors, Seafood enzymes: utilization and influence on postharvest seafood quality (Marcel Dekker, Inc., Boca Raton , 2000).