April – June, 2026
Original Article
DOI: http://dx.doi.org/10.30867/action.v11i2.3212

AcTion: Aceh Nutrition Journal
Pages: 643 – 651 | p-issn 2527-3310; e-issn 2548-5741

Influence of storage temperature on lipid oxidation kinetics and quality stability of snakehead fish (*Channa striata*) sausages

Pengaruh suhu penyimpanan terhadap kinetika oksidasi lipid dan stabilitas mutu sosis ikan gabus (Channa striata)

Sri Iriyanti[1*], Budi Kristanto[2], Nia Budhi Astuti[3]

[1] Department of Nutrition, Politeknik Kesehatan Jayapura, Jayapura, Indonesia. E-mail: iriyantisri26@gmail.com
[2] Department of Nutrition, Politeknik Kesehatan Jayapura, Jayapura, Indonesia. E-mail: bkbudikristanto@gmail.com
[3] Department of Nutrition, Politeknik Kesehatan Jayapura, Jayapura, Indonesia. E-mail: ninia8504@gmail.com

***Correspondence Author:**
Department of Nutrition, Politeknik Kesehatan Jayapura, Jayapura, Indonesia, 99225. E-mail: iriyantisri26@gmail.com

Article History:
Received: April 09, 2026; Revised: April 23, 2026; Accepted: May 01, 2026; Published: June 07, 2026.

Publisher:
Politeknik Kesehatan Aceh
Kementerian Kesehatan RI

Abstract

Lipid oxidation is the primary cause of quality deterioration in fish-based products, with malondialdehyde (MDA) accumulation posing implications for sensory quality and food safety. This study evaluated the effect of storage temperature on lipid oxidation kinetics in snakehead fish (*Channa striata*) sausage over 30 d. Room temperature (25 ± 3 °C) and cold storage (10 ± 2 °C) were applied to nine independent samples each. Lipid oxidation was quantified as thiobarbituric acid reactive substances (TBARS) on days 0, 5, 10, 15, 20, 25, and 30, and zero- and first-order kinetic models were evaluated. TBARS increased under both conditions, reaching 0.376 mg MDA/kg at 25 °C and 0.178 mg MDA/kg at 10 °C on day 30, both of which were below the sensory rancidity threshold. Storage temperature, time, and their interaction significantly affected TBARS ($p < 0.001$; $\eta^2 = 0.79, 0.85, 0.53$). The first-order model fit better at 25 °C ($R^2 = 0.996$; $k = 0.0598$ d $^{-1}$), and the zero-order model fit better at 10 °C ($R^2 = 0.981$; $k = 0.0350$ d $^{-1}$). The Arrhenius activation energy was measured to be 25.11 kJ/mol. Cold storage reduced the oxidation rate by approximately 41% compared to room temperature, making it a practical option for slowing lipid oxidation in snakehead fish sausage during short-term storage.

Keywords: Lipid oxidation, snakehead fish sausage, TBARS, Arrhenius kinetics, oxidative stability

Abstrak

Oksidasi lipid merupakan salah satu penyebab utama penurunan mutu produk olahan ikan, dengan akumulasi malondialdehida (MDA) yang berimplikasi pada mutu sensoris dan keamanan produk. Penelitian ini mengevaluasi pengaruh suhu penyimpanan terhadap kinetika oksidasi lipid pada sosis ikan gabus (*Channa striata*) selama 30 hari. Dua perlakuan suhu diterapkan: suhu ruang (25 ± 3 °C) dan penyimpanan dingin (10 ± 2 °C), dengan sembilan sampel independen per perlakuan. Oksidasi lipid diukur sebagai thiobarbituric acid reactive substances (TBARS) pada hari ke-0, 5, 10, 15, 20, 25, dan 30 menggunakan model kinetika orde nol dan orde satu. Nilai TBARS meningkat pada kedua kondisi, mencapai 0,376 mg MDA/kg pada suhu 25 °C dan 0,178 mg MDA/kg pada suhu 10 °C pada hari ke-30, keduanya di bawah ambang ketengikan sensoris. Suhu, lama penyimpanan, dan interaksinya berpengaruh signifikan terhadap nilai TBARS ($p < 0,001$; $\eta^2 = 0,79; 0,85; 0,53$). Model orde satu lebih sesuai pada suhu 25 °C ($R^2 = 0,996$; $k = 0,0598$ hari^{-1}) dan model orde nol pada suhu 10 °C ($R^2 = 0,981$; $k = 0,0350$ hari^{-1}). Energi aktivasi Arrhenius sebesar 25,11 kJ/mol. Penyimpanan dingin menurunkan laju oksidasi sekitar 41% dibandingkan suhu ruang, menjadikannya pilihan praktis untuk memperlambat oksidasi lipid pada sosis ikan gabus.

Kata Kunci: Oksidasi lipid, sosis ikan gabus, TBARS, kinetika Arrhenius, stabilitas oksidatif

Introduction

Snakehead fish (*Channa striata*) is an important freshwater fish in Indonesia, particularly in Papua, where it is widely consumed and used as a raw material for various processed products. This species is valued for its high protein content and the presence of unsaturated fatty acids, including EPA and DHA, which contribute to its nutritional value (Nguyen et al., 2024). Its high albumin content and amino acid profile have been associated with nutritional benefits in local communities, including support for protein adequacy and recovery from illness (Hapsari & Tjandrawinata, 2025; Pasaribu et al., 2020). In addition to household consumption, *Channa striata* has been developed into processed products, such as fish sausage, with potential for small-scale and household food industry applications (Zakaria & Sarbon, 2018).

Despite its potential, fish sausage is susceptible to quality deterioration during storage. One of the main causes of this deterioration is lipid oxidation. This process may reduce the nutritional quality, alter the sensory characteristics, and produce oxidation compounds associated with rancid odors and flavors (Iqbal et al., 2025). Among the secondary products of lipid oxidation, malondialdehyde (MDA) is of particular concern because it can interact with proteins and nucleic acids and is associated with cytotoxic and genotoxic effects. In tropical areas, such as Papua, where environmental temperatures are relatively high, this problem becomes more relevant for storage and distribution. For small-scale producers, deterioration during storage may reduce product value and shorten its marketability (Maheshwara et al., 2017).

Storage temperature is one of the main factors influencing lipid oxidation in fish-based products. Elevated temperatures accelerate oxidation reactions by promoting free radical chain reactions and the decomposition of lipid hydroperoxides into secondary carbonyl compounds, whereas reduced temperatures slow these processes (Farhoosh, 2022). Husain et al. (2016) reported activation energy values of 20–30 kJ/mol for lipid oxidation in snapper (*Lutjanus sp.*) fillets, indicating moderate temperature sensitivity. Zakaria & Sarbon (2018) reported increased TBARS values and reduced physicochemical stability in snakehead fish emulsion sausage at higher storage temperatures. However, these studies were conducted under different product formulations and experimental conditions, and their kinetic parameters cannot be directly applied to other snakehead fish products (Suárez-Medina et al., 2024).

Most studies on oxidation kinetics in fish products have focused on marine species such as tuna and rainbow trout (Zakaria & Sarbon, 2018). In contrast, studies on tropical freshwater fish products, including snakehead fish sausages, remain limited. Differences in lipid composition and product characteristics indicate that findings from marine species cannot be directly generalized to freshwater fish products (Husain et al., 2018; Matbo et al., 2025). In particular, kinetic data on lipid oxidation in *Channa striata* sausages stored under tropical conditions room temperature (approximately 25°C) and refrigeration (approximately 10°C) are not available in the published literature. This absence limits the ability to estimate the shelf life or develop storage recommendations based on product-specific kinetic data.

Therefore, this study evaluated the effects of two storage temperatures room temperature (25 ± 3°C) and cold storage (10 ± 2°C) on lipid oxidation in snakehead fish (*Channa striata*) sausage over a 30-day period. Lipid oxidation was quantified as thiobarbituric acid reactive substances (TBARS), and the temperature dependence of the oxidation rate was characterized using the Arrhenius equation, with the aim of generating kinetic parameters applicable to storage and handling conditions in tropical regions such as Papua.

Methods

Study Design

This laboratory-based experimental study examined the effect of storage temperature on lipid oxidation in snakehead fish (*Channa striata*) sausage. The experiments used a completely randomized design with two storage temperature treatments: room temperature (25 ± 3 °C) and cold (10 ± 2 °C). The two temperature levels were selected based on the storage conditions typically available to small-scale fish processors in Papua ambient room temperature and basic mechanical refrigeration and represent the temperature range within which snakehead fish sausage is ordinarily handled in this setting.

The samples were evaluated at predetermined intervals during the 30-day storage period (0, 5, 10, 15, 20, 25, and 30 days). Independent sausage samples were analyzed at each time point to avoid the effects of repeated handling during the storage period. Each temperature treatment included nine samples at each sampling interval. All measurements were performed in duplicate to ensure the analytical reliability.

Materials and Sausage Preparation

Fresh snakehead fish (*Channa striata*) were obtained from the Jayapura Fish Market in Papua, Indonesia. Fish were selected based on a weight range of 500–700 g and freshness scores of 8–9, according to the FAO organoleptic standards. The fish were filleted, skinned, and deboned before processing. The sausage batter was prepared by grinding fish fillets using a meat grinder with a 5 mm plate. The ground fish was mixed with tapioca flour at a ratio of 70:30 and supplemented with salt (2%), garlic (1%), white pepper (0.5%), and sugar (0.5). The mixture was mixed for 15 min at 8–10 °C, after which approximately 10% crushed ice was added to maintain the temperature stability.

The mixture was filled into collagen casings (22 mm diameter) and pasteurized at 80 °C for 20 min. After heating, the sausages were cooled in ice water for 5 min and dried before packaging. Moisture content (65 ± 2%) and pH (6.5 ± 0.2) were measured prior to storage to ensure product consistency. All processing procedures followed the Indonesian National Standard for processed fish products (SNI 7758:2013) and were conducted in accordance with Good Manufacturing Practice (GMP) guidelines.

Storage Conditions

Sausage samples were stored under two controlled temperature conditions. Room temperature storage (25 ± 3 °C) was maintained using a laboratory incubator (Memmert IN75, Germany), whereas cold storage (10 ± 2 °C) was maintained using a laboratory refrigerator (Panasonic PR-321, Osaka, Japan).

Temperature and relative humidity were monitored using digital data loggers that recorded the environmental conditions at regular intervals throughout the storage period. To minimize external influences, the samples were stored in a dark environment and protected from direct light exposure. The relative humidity of the storage environment was maintained at approximately 75 ± 5%. At each sampling interval (days 0, 5, 10, 15, 20, 25, and 30), the sausage samples were randomly selected from each temperature treatment and analyzed. Once removed for analysis, the samples were not returned to storage to avoid changes in packaging conditions or repeated exposure to the environment.

Determination of Lipid Oxidation

Lipid oxidation was determined using the thiobarbituric acid reactive substances (TBARS) method with slight modifications. Approximately 5 g of each sausage sample was homogenized with 25 mL of 7.5% (w/v) trichloroacetic acid (TCA) using a homogenizer under cold conditions. The homogenate was centrifuged at 4000 × g for 15 min at 4 °C, and 2 mL of the supernatant was mixed with 2 mL of 0.02 M thiobarbituric acid (TBA) solution. The mixture was heated in a water bath at 95 °C for 40 min and cooled on ice. The absorbance was measured at 532 nm using a UV–visible spectrophotometer (UV-1800; Shimadzu).

Malondialdehyde (MDA) concentrations were determined using a standard calibration curve and expressed as mg of MDA per kg of the sample. Each sample was analyzed in duplicate to ensure the precision of the results. TBARS, expressed as MDA equivalents, are widely used as indicators of secondary lipid oxidation in fish-based products and were considered appropriate for the 30-day storage duration examined in this study (Iqbal et al., 2025). The analysis did not include additional oxidation markers, such as the peroxide or anisidine values, which represents a limitation acknowledged in the interpretation of the results.

Statistical Analysis

Descriptive statistics were calculated to summarize the TBARS values across storage temperatures and observation days. Prior to the inferential analysis, the data distribution was evaluated using the Shapiro–Wilk test, and the homogeneity of variance was assessed using Levene's test. The results of both tests were used to confirm the appropriateness of the parametric analysis. Where departures from normality were observed at individual time points, two-way ANOVA was considered acceptable given the equal group sizes (n = 9 per

group) and consistent homogeneity of variance across all time points (Levene's test, $p > 0.05$ at all intervals). The effects of storage temperature and storage time on the TBARS values were evaluated using a two-way analysis of variance (ANOVA). When significant differences were observed, post hoc comparisons were performed using Tukey's test. Effect sizes were reported using partial eta squared (η^2) and interpreted using conventional benchmarks ($\eta^2 \geq 0.01$, small; ≥ 0.06, medium; ≥ 0.14, large).

To evaluate the lipid oxidation kinetics, both zero- and first-order kinetic models were fitted to the TBARS data for each temperature condition. Model selection was based on the coefficient of determination (R^2), with the better-fitting model used to estimate the reaction rate constant (k) for each treatment group. The temperature dependence of the oxidation rate was evaluated using the Arrhenius equation as follows:

$$k = A \exp(-Ea/RT)$$

Where k represents the reaction rate constant, A the pre-exponential factor, Ea the activation energy (J/mol), R the universal gas constant (8.314 J/mol·K), and T the absolute temperature (K). The activation energy was determined from the slope of the linear regression of ln(k) against 1/T at. As only two temperature conditions were evaluated, the Arrhenius parameters reported here are descriptive estimates for the tested range and should not be extrapolated beyond the experimental conditions of this study. All statistical analyses were conducted using SPSS version 20.0 (IBM Corp., USA), with a significance level set at $p < 0.05$.

Ethical Compliance

This study was conducted entirely in a laboratory setting and did not involve human participants, animals, human tissues, or personal data. Therefore, ethical approval was not required for this study.

Result and Discussion

Changes in the TBARS Values During Storage

Table 1 presents the mean TBARS values of the snakehead fish (*Channa striata*) sausages stored at room temperature (25 °C) and cold storage (10 °C) during the 30-day observation period. TBARS values increased with storage time under both conditions, although the rate and magnitude of the increase differed between the treatments. At room temperature (25 °C), the TBARS values increased from 0.075 ± 0.007 mg MDA/kg on day 0 to 0.376 ± 0.012 mg MDA/kg on day 30. Under cold storage conditions (10 °C), the increase occurred more slowly, reaching 0.178 ± 0.012 mg MDA/kg at the end of the storage period.

As illustrated in Figure 1, the divergence between the two temperature treatments was gradual during the early storage period but became more distinct from day 15 onward. Figure 2 shows that the 95% confidence intervals of the two treatments did not overlap from day 5 onward, indicating statistically distinguishable TBARS levels between the storage conditions throughout most of the observation period. All the TBARS values recorded in this study remained below 1 mg MDA/kg, which is generally regarded as the threshold associated with sensory rancidity in fish products.

Table 1. Mean TBARS values of snakehead fish sausage during storage at different temperatures

Storage Day	25 °C (Mean ± SD)	95% CI	10 °C (Mean ± SD)	95% CI
Day 0	0.075 ± 0.007	0.070 – 0.080	0.075 ± 0.007	0.070 – 0.080
Day 5	0.113 ± 0.007	0.108 – 0.118	0.090 ± 0.010	0.082 – 0.098
Day 10	0.130 ± 0.007	0.125 – 0.135	0.115 ± 0.014	0.104 – 0.126
Day 15	0.174 ± 0.007	0.169 – 0.179	0.138 ± 0.006	0.133 – 0.143
Day 20	0.230 ± 0.005	0.226 – 0.234	0.143 ± 0.007	0.138 – 0.148
Day 25	0.306 ± 0.013	0.296 – 0.316	0.155 ± 0.007	0.150 – 0.160
Day 30	0.376 ± 0.012	0.366 – 0.386	0.178 ± 0.012	0.168 – 0.188

The differences between the temperature treatments became more apparent after day 15. At this time point, the TBARS values reached 0.174 mg MDA/kg at 25 °C and 0.138 mg MDA/kg at 10 °C. The increase became more pronounced during the later stages of storage. Between days 20 and 30, the TBARS values at room temperature increased from 0.230 to

0.376 mg MDA/kg, whereas those of samples stored at 10 °C increased from 0.143 to 0.178 mg MDA/kg during the same period. By day 30, the TBARS values at 25 °C were approximately 2.1 times higher than those at 10 °C, reflecting a substantially faster rate of oxidative development at the higher storage temperature.

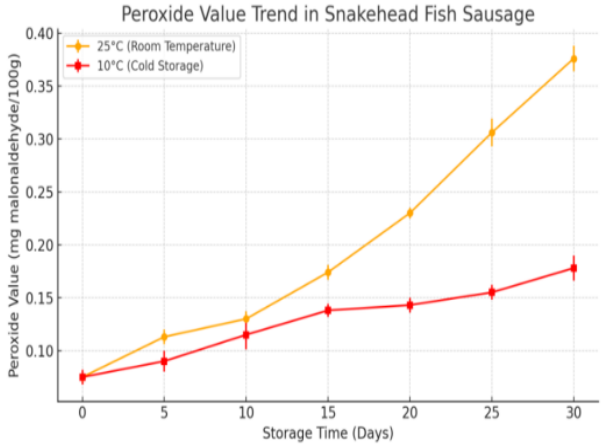

Figure 1. Trend of TBARS values in snakehead fish sausages during storage at 25 °C (room temperature) and 10 °C (cold storage)

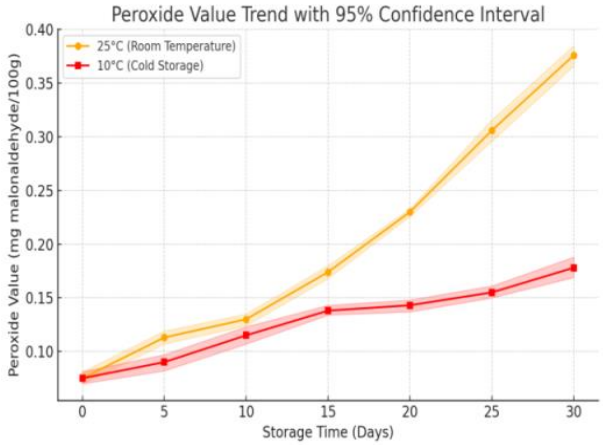

Figure 2. TBARS values with 95% CI for snakehead fish sausages stored at 25 °C and 10 °C during the 30-day storage period.

Effects of Storage Temperature and Storage Time

Prior to the two-way ANOVA, the Shapiro–Wilk test indicated that normality was satisfied on days 0, 5, and 10 for both temperature groups ($W = 0.862–0.940$, $p > 0.05$). Minor departures from normality were detected on days 15, 20, 25, and 30 in one or both groups ($W = 0.743–0.880$, $p < 0.05$ at selected time points). The homogeneity of variance assumption was met at all time points (Levene's test, $p > 0.05$), and two-way ANOVA was considered appropriate given the equal group sizes ($n = 9$ per group). Two-way ANOVA indicated that storage temperature ($F = 412.6$, $df = 1$, $p < 0.001$, $\eta^2 = 0.79$), storage time ($F = 538.4$, $df = 6$, $p < 0.001$, $\eta^2 = 0.85$), and their interaction ($F = 74.9$, $df = 6$, $p < 0.001$, $\eta^2 = 0.53$) significantly affected TBARS values.

The η^2 values indicated large effect sizes for all three sources of variation, with storage time accounting for the largest proportion of variance in the TBARS values. Samples stored at room temperature consistently exhibited higher TBARS values than those stored under cold storage conditions throughout the observation period.

Table 2. Two-way ANOVA results for the effects of storage temperature and storage time on the TBARS values

Source of variation	df	F value	p value	Effect size (η^2)
Storage temperature	1	412.6	<0.001	0.79
Storage time	6	538.4	<0.001	0.85
Temperature × Time	6	74.9	<0.001	0.53

Kinetic Analysis of Lipid Oxidation

The kinetics of lipid oxidation were evaluated by fitting both zero- and first-order models to the TBARS data for each temperature condition, as summarized in Table 3. At 25 °C, the first-order model provided a better fit ($R^2 = 0.996$) than the zero-order model ($R^2 = 0.958$), indicating that the oxidation rate at this temperature was proportional to the remaining oxidizable substrate concentration. At 10 °C, the zero-order model produced a higher R^2 (0.981) than the first-order model (0.955), suggesting that oxidation proceeded at a relatively constant rate during cold storage. The reaction rate constant at 25 °C was estimated to be 0.0598 day^{-1}, whereas the reaction rate constant at 10 °C was 0.0350 day^{-1}, indicating that lipid oxidation proceeded more rapidly at the higher storage temperature.

The relationship between the natural logarithm of k and the inverse of the absolute temperature produced a linear Arrhenius relationship, as shown in Figure 3. Based on the slope of this relationship, the activation energy for lipid oxidation in snakehead fish sausage was calculated to be 25.11 kJ/mol.

Table 3. Kinetic parameters of lipid oxidation in snakehead fish sausages based on the Arrhenius model

Parameter	25 °C (298.15 K)	10 °C (283.15 K)
Zero-order rate constant (k_0)	0.00985 mg MDA/kg/day	0.00334 mg MDA/kg/day
Zero-order R^2	0.958	0.981
First-order rate constant (k_1)	0.0598 day^{-1}	0.0350 day^{-1}
First-order R^2	0.996	0.955
Best-fit model	First-order	Zero-order
Activation energy (Ea)	25.11 kJ/mol	25.11 kJ/mol
Preexponential factor (A)	1500.43	1500.43

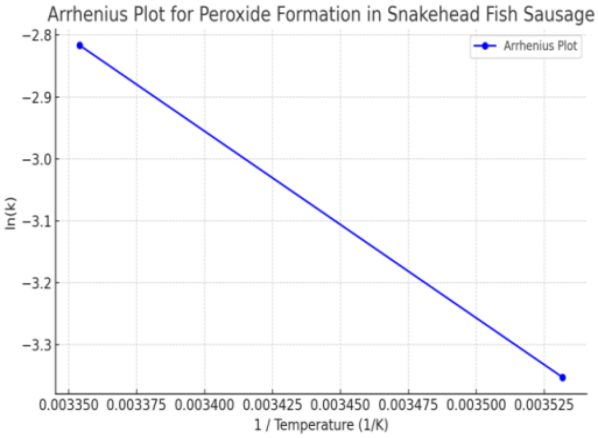

Figure 3. Arrhenius plot showing the relationship between ln(k) and the inverse of the absolute temperature (1/T) for lipid oxidation in snakehead fish sausage during storage.

Elevated temperatures increase the rate of free radical initiation and accelerate peroxyl radical chain reactions, leading to a faster accumulation of lipid hydroperoxides and their subsequent decomposition into secondary carbonyl compounds, including MDA (Wang et al., 2023). At lower temperatures, these reaction rates are suppressed, which accounts for the slower TBARS accumulation observed at 10 °C (Farhoosh, 2022).

The results of the kinetic analysis supported this observation. The best-fit model differed between the two temperature conditions: first-order at 25 °C (R^2 = 0.996) and zero-order at 10 °C (R^2 = 0.981), indicating that oxidative progression followed different patterns at each temperature. At 25 °C, first-order kinetics suggest that the oxidation rate is proportional to the concentration of the oxidizable substrate, consistent with an autocatalytic process driven by hydroperoxide accumulation (Bao & Pignitter, 2023). At 10 °C, zero-order kinetics suggest a more constant rate, which may reflect a slower initiation phase in which temperature is the primary limiting factor, rather than substrate availability. Differences in the best-fit reaction order across temperature conditions have been reported for other processed aquatic products (Li et al., 2025). The reaction rate constant at 25 °C (0.0598 d^{-1}) was higher than that at 10 °C (0.0350 d^{-1}), and the activation energy of 25.11 kJ/mol fell within the range of 20–30 kJ/mol reported by Husain et al. (2016) for lipid oxidation in tropical fish fillets, suggesting comparable temperature sensitivity between snakehead fish sausage and snapper fillets despite differences in product form and processing conditions.

The findings of the present study are consistent with those of Zakaria and Sarbon (2018), who reported increased TBARS formation in snakehead fish emulsion sausage at higher storage temperatures. However, direct comparison of oxidation rates is limited by differences in product formulation; their emulsion sausage contained protein hydrolysate, which may influence oxidative stability differently from the tapioca-based formulation used here. Husain et al. (2018) similarly reported accelerated peroxide formation and reduced EPA and DHA content in snapper fillets at elevated temperatures. Regarding health implications, MDA interacts with amino acid residues and can impair DNA by crosslinking with nucleotide bases (Wang et al., 2024). Although the TBARS values in this study remained below 1 mg MDA/kg, their gradual accumulation warrants consideration for products intended for extended distribution.

Temperature-dependent oxidation kinetics have been reported for various seafood matrices. Sullivan Ritter et al. (2015) reported pseudo–first-order kinetics for peroxide and anisidine value increases in fish oil, while Xie et al. (2020) found that esterified polyunsaturated fatty acid

degradation in dried scallops followed a first-order model. The kinetic patterns observed in the present study extend this literature to a processed freshwater fish product under tropical storage conditions, with the additional observation that the best-fit model differed between the two temperature conditions tested.

Previous studies have also shown that storage temperature may influence oxidation, even when oxygen exposure is limited. Iqbal et al. (2025) reported increased peroxide and anisidine values in fish products stored at 25 °C, despite sealed packaging, indicating that temperature alone can substantially influence oxidation. Similarly, Maheshwara et al. (2017) reported that the quality of fish sausages stored at ambient temperature deteriorated rapidly, whereas those stored under refrigeration deteriorated considerably. These findings correspond with the slower increase in TBARS values observed in the present study under the cold storage conditions.

Lower storage temperatures reduce the rate of hydroperoxide formation and slow the conversion of primary oxidation products into secondary compounds that are responsible for rancidity. Several studies have reported similar effects of reduced temperatures on fish products. Nguyen et al. (2024) reported lower peroxide and TBARS values in snakehead fish fillets stored at lower freezing temperatures. Reduced peroxide formation in dried snakehead fish stored under refrigerated conditions combined with vacuum packaging.

Although freezing temperatures can strongly inhibit lipid oxidation, such conditions are not consistently accessible to small-scale processors in tropical regions. Based on the rate constants obtained in this study, oxidation at 10 °C ($k = 0.0350\ d^{-1}$) proceeded at approximately 41% of the rate observed at 25 °C ($k = 0.0598\ d^{-1}$), indicating a significant reduction under refrigeration. The Arrhenius parameters derived in this study may serve as a reference for estimating TBARS accumulation during storage and distribution under similar conditions, consistent with the application of kinetic modeling for shelf-life estimation in processed fish products (Brilliantina et al., 2022).

This study has several limitations. The use of only two temperature conditions restricts the robustness of the Arrhenius parameters, as the activation energy derived from two data points is a descriptive estimate rather than a statistically validated kinetic constant. The reliance on TBARS as a single oxidation marker and the exclusion of microbiological evaluation limit the completeness of the quality assessment. The 30-day observation period and use of raw materials from a single location and season further constrain the generalizability of these findings. The kinetic model was developed under controlled laboratory conditions, and its applicability to commercial distribution environments with fluctuating temperatures requires further validation in real-world settings.

Conclusion

Storage temperature affects the rate and pattern of lipid oxidation in snakehead fish (*Channa striata*) sausage over a 30-day storage period. TBARS values were consistently higher at room temperature (25 °C) than under cold storage (10 °C), and the two conditions produced different best-fit kinetic models: first-order at 25 °C and zero-order at 10 °C. The activation energy of 25.11 kJ/mol fell within the range reported for lipid oxidation in tropical fish products.

Cold storage at 10 °C reduced the oxidation rate by approximately 41% relative to room temperature, with TBARS values remaining below the threshold associated with sensory rancidity for the entire observation period. For small-scale processors handling snakehead fish sausage under conditions similar to those tested, storage at approximately 10 °C is a practical option to slow oxidative deterioration during short-term storage. The kinetic parameters reported here are descriptive of the tested conditions and should not be extrapolated beyond the experimental temperature range or storage duration. Studies incorporating additional temperature points, longer observation periods, and complementary oxidation markers will strengthen the predictive utility of the kinetic model.

Acknowledgements

The authors gratefully acknowledge the support provided by Politeknik Kesehatan Jayapura in facilitating this research. We also appreciate the laboratory staff who assisted in sample preparation and analytical procedures throughout the study. Their technical support

significantly contributed to the completion of this study. This research was funded by the Daftar Isian Pelaksanaan Anggaran (DIPA) of Politeknik Kesehatan Jayapura, Indonesia.

References

Bao, Y., & Pignitter, M. (2023). Mechanisms of lipid oxidation in water-in-oil emulsions and oxidomics-guided discovery of targeted protective approaches. *Comprehensive Reviews in Food Science and Food Safety, 22*(4), 2678–2705.

Brilliantina, A., Wardani, D. K., Fadhila, P. T., Hariono, B., & Wijaya, R. (2022). Accelerated shelf life test method with arrhenius approach for shelf life estimation of tongkol 'euthynnus affinis' balado in cans. *IOP Conference Series: Earth and Environmental Science*, *980*(1), 12038. https://doi.org/10.1088/1755-1315/980/1/012038

Farhoosh, R. (2022). New insights into the kinetic and thermodynamic evaluations of lipid peroxidation. *Food Chemistry, 375*, Article 131659. https://doi.org/10.1016/j.foodchem.2021.131659

Hapsari, R., & Tjandrawinata, R. R. (2025). Nutritional composition and action mechanism of *Channa striata* meat in wound healing: A systematic review. *Narra Journal, 5*(3), e2903. https://doi.org/10.52225/narra.v5i3.2903

Husain, R., Suparmo, Harmayani, E., & Hidayat, C. (2016). Kinetic oxidation of protein and fat in snapper (Lutjanus sp) fillet during storage. *AIP Conference Proceedings*, *1755*(1), 50006. https://doi.org/10.1063/1.4958489

Husain, R., Suparmo, S., Harmayani, E., & Hidayat, C. (2018). Komposisi asam lemak, angka peroksida, dan angka TBA fillet ikan kakap (*Lutjanus* sp.) pada suhu dan lama penyimpanan berbeda. *Agritech, 37*(3), 319–326. https://doi.org/10.22146/agritech.10529

Iqbal, S., Akram, S., Zafar, S., Shah, S. H. B. U., Saeed, R. F., & Butt, M. S. (2025). Determination of physicochemical properties, oxidative and storage stability of fish and flaxseed oil. *Current Research in Nutrition and Food Science Journal, 13*(1), 162–171. https://doi.org/10.12944/CRNFSJ.13.1.13

Li, Q., Lei, J., Su, K., Chen, X., Cheng, L., Yang, C., & Ou, S. (2025). Processing and shelf-life prediction models for ready-to-eat crayfish. *Foods, 14*(8), Article 1296. https://doi.org/10.3390/foods14081296

Maheshwara, K., Naik, J., Balamatti, A., & Jagadish, T. (2017). Biochemical and shelf life study of quality of fish sausage in ambient and refrigerated storage. *Biochemical and Cellular Archives, 17*(1), 225–230. https://www.cabidigitallibrary.org/doi/full/10.5555/20173175593

Matbo, A., Ghanbari, M. M., Sekhavatizadeh, S. S., & Nikkhah, M. (2025). Stabilizing fish oil during storage with *Satureja bachtiarica* Bunge. *Foods and Raw Materials, 13*(2), 254–263. https://doi.org/10.21603/2308-4057-2025-2-254-263

Nguyen, M., Thai, D., & Nguyen, D. (2024). Effects of packaging method and temperature on the quality and lipid degradation of snakehead fish (*Channa striata*) fillets during frozen storage. *Food Research, 8*(3), 408–416. https://doi.org/10.26656/fr.2017.8(3).1097

Pasaribu, Y. P., Buyang, Y., Suryaningsih, N. L. S., Dirpan, A., & Djalal, M. (2020). Effect of steaming and pressurized boiling process on the nutrient profile of Papuan cork fish (*Channa striata*) as a potential protein-rich food to prevent stunting. *Medicina Clínica Práctica, 3*, 100120. https://doi.org/10.1016/j.mcpsp.2020.100120

Suárez-Medina, M. D., Sáez-Casado, M. I., Martínez-Moya, T., & Rincón-Cervera, M. Á. (2024). The effect of low-temperature storage on the lipid quality of fish, either alone or combined with alternative preservation technologies. *Foods, 13*(7), Article 1097. https://doi.org/10.3390/foods13071097

Sullivan Ritter, J. C., Budge, S. M., Jovica, F., & Reid, A. J. M. (2015). Oxidation rates of triacylglycerol and ethyl ester fish oils. *Journal of the American Oil Chemists' Society, 92*(4), 561–569. https://doi.org/10.1007/s11746-015-2626-9

Wang, D., Xiao, H., Lyu, X., Chen, H., & Wei, F. (2023). Lipid oxidation in food science and nutritional health: A comprehensive review. *Oil Crop Science, 8*(1), 35–44. https://doi.org/10.1016/j.ocsci.2022.11.002

Wang, X., Fan, J., Dong, X., Zhang, S., Yang, Q., Chi, S., ... Tan, B. (2024). Dietary malondialdehyde impairs intestinal health and fillet quality of hybrid grouper (*Epinephelus fuscoguttatus* ♀ × *E. lanceolatus* ♂). *Animals, 14*(22), 3208. https://doi.org/10.3390/ani14223208

Xie, H., Yin, F., Liu, Z., Hu, Y., Yu, M., Zhou, D., & Zhu, B. (2020). Oxidation kinetics of polyunsaturated fatty acids esterified into triacylglycerols and phospholipids in dried scallop (*Argopecten irradians*) adductor muscles during storage. *Food & Function, 11*(3), 2349–2357. https://doi.org/10.1039/C9FO02688D

Zakaria, N., & Sarbon, N. (2018). Physicochemical properties and oxidative stability of fish emulsion sausage as influenced by snakehead (*Channa striata*) protein hydrolysate. *LWT, 94*, 13–19. https://doi.org/10.1016/j.lwt.2018.04.034