

## ACCELERATED SHELF-LIFE MODELING OF MILKFISH (*Chanos chanos*) FLOSS SHEET

**Agussalim Matti\*, Ikbal Syukroni, Nurlaeli Fattah, Arham Rusli, Muh Ali Arsyad**

Aquatic Product Processing and Storage, Department of Agricultural Technology  
Pangkajene Islands State Agricultural Polytechnic  
Poros Makassar-Pare Main Road Km.83 Pangkep, South Sulawesi Indonesia 90655

Submitted: 8 July 2025/Accepted: 17 November 2025

\*Correspondence: [agussalimmatti@polipangkep.ac.id](mailto:agussalimmatti@polipangkep.ac.id)

**How to cite (APA Style 7<sup>th</sup>):** Matti, A., Syukroni, I., Fattah, N., Rusli, A., & Arsyad, M. A. (2026). Accelerated shelf-life modeling of milkfish (*Chanos chanos*) floss sheet. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 29(2), 133-147. <http://dx.doi.org/10.17844/se4qgf46>

### Abstract

The milkfish floss sheet is an innovative, dry-processed, fish-based, ready-to-eat food. Determining the shelf life of a product is essential to ensure product quality and safety during distribution and storage. This study aimed to estimate the shelf life of milkfish floss sheets using Accelerated Shelf-Life Testing (ASLT) based on the Arrhenius model, with moisture content as the critical parameter. The product was packed in Alupaper packaging designed to provide an effective barrier against moisture and oxygen and stored at three different temperatures (30, 40, and 50°C) for 70 days. The moisture content was measured periodically and analyzed using zero-order reaction kinetics. The results showed a significant increase in the moisture content during storage, with a faster rate at higher temperatures. The Arrhenius model demonstrated a strong correlation ( $R^2 = 0.998$ ) in predicting the moisture-absorption rate. Shelf-life prediction, based on the critical moisture content according to SNI 7690-2019 (maximum 15%), revealed that the product could last for 219.33 days (7.31 months) at 30°C, 197.71 days (6.59 months) at 40°C, and 179.37 days (5.98 months) at 50°C. Arrhenius extrapolation predicted a shelf life of approximately 230 days at ambient temperature (28°C). Moisture is a critical determinant of product stability, as excessive water absorption can accelerate lipid oxidation, microbial growth, and texture softening, ultimately leading to product deterioration. The study concluded that higher storage temperatures significantly accelerated quality degradation, reinforcing the importance of temperature control during storage to maintain product quality and safety of the product. Keywords: Arrhenius, food safety, packaging, moisture content, temperature

### Pemodelan Umur Simpan Abon Ikan Bandeng (*Chanos chanos*) Lembaran dengan Metode *Accelerated Shelf-Life Testing*

#### Abstrak

Abon ikan bandeng bentuk lembaran merupakan inovasi produk olahan kering sebagai makanan siap saji berbasis ikan. Penentuan umur simpan menjadi aspek penting untuk menjamin kualitas dan keamanan produk selama distribusi dan penyimpanan. Penelitian ini bertujuan untuk menduga umur simpan produk abon ikan bandeng bentuk lembaran menggunakan metode *Accelerated Shelf-Life Testing* (ASLT) berbasis model Arrhenius dengan parameter kritis kadar air. Produk dikemas menggunakan kemasan Alupaper (lapisan foil aluminium, polietilena, dan kertas litho) yang berfungsi sebagai penghalang efektif terhadap uap air dan oksigen. Pengujian dilakukan dengan menyimpan produk pada tiga suhu berbeda, yaitu 30, 40, dan 50°C selama 70 hari. Pengamatan kadar air dilakukan secara berkala dan dianalisis menggunakan model kinetika reaksi orde nol. Hasil penelitian menunjukkan bahwa kadar air abon ikan meningkat seiring waktu penyimpanan dan makin cepat pada suhu tinggi. Model Arrhenius menunjukkan korelasi yang sangat baik ( $R^2 = 0,998$ ) dalam memprediksi laju peningkatan kadar air. Umur simpan produk berdasarkan kadar air kritis sesuai SNI 7690-2019 (maksimal 15%) diperkirakan mencapai 219,33 hari (7,31 bulan) pada suhu

30°C, 197,71 hari (6,59 bulan) pada suhu 40°C, dan 179,37 hari (5,98 bulan) pada suhu 50°C. Ekstrapolasi Arrhenius lebih lanjut memprediksi masa simpan sekitar 230 hari pada suhu ruangan (28°C). Kadar air ditetapkan sebagai parameter kritis karena peningkatan kadar air dapat mempercepat oksidasi lemak, pertumbuhan mikroba, serta penurunan tekstur yang menyebabkan degradasi mutu produk. Peningkatan suhu penyimpanan terbukti mempercepat laju kerusakan mutu produk. Hasil ini menunjukkan bahwa kadar air efektif digunakan sebagai parameter kritis dalam penentuan umur simpan produk abon ikan bandeng lembaran dan pentingnya pengendalian suhu selama penyimpanan untuk menjaga kualitas dan keamanan produk.

Kata kunci: Arrhenius, kadar air, keamanan pangan, kemasan, suhu

## INTRODUCTION

Processed foods, such as floss fish, are becoming increasingly popular as public demand for high-quality ready-to-eat products grows (Kusumawati *et al.*, 2024; Sormin *et al.*, 2024). Fish floss is a type of processed fish that is seasoned and boiled and fried (Kasmiati *et al.*, 2020; Kasmiati *et al.*, 2023). One of the main challenges in processed food development is determining the optimal shelf life to ensure that products are consumed at their best quality. Floss sheets are an innovative processed fish product that combines the characteristics of traditional fish floss with a flat, biscuit-like shape. This product is made from milkfish (*Chanos chanos*) mixed with tapioca flour and sugar and then dried through a baking process. The resulting product is a rectangular sheet with a brownish-red color, crispy texture, and rough surface (Matti *et al.*, 2023). Milkfish floss sheets are classified as ready-to-eat (RTE) foods, meaning they can be consumed directly without cooking or reheating.

Estimating the shelf life of milkfish floss sheets is essential to ensure product quality and safety, given the potential deterioration caused by microbial activity. Although the product undergoes cooking and drying processes, the residual moisture content may still support microbial growth, which can accelerate protein degradation, lipid oxidation, and overall quality deterioration during storage (Rudenko & Bazhenova, 2022). Therefore, understanding the extent and rate of quality deterioration during storage is critical for establishing a scientifically sound shelf life for milkfish floss sheets. A reliable shelf-life evaluation should account for the interactions among residual moisture, microbial growth, and physicochemical changes, which collectively determine the

stability of the product over time.

Accurate shelf-life determination enables manufacturers to identify the optimal consumption period, reduce food waste, and enhance consumer satisfaction (Shi *et al.*, 2024). With the growing awareness of food safety and the standardization of product quality, effective and efficient shelf-life assessment methods have become increasingly important (Lisboa *et al.*, 2024; Muniandy *et al.*, 2023; Tarlak, 2023). Several methods are commonly used to estimate shelf life, including accelerated shelf-life testing (ASLT). This technique simulates long-term storage conditions within a shorter time frame (Ntzimani *et al.*, 2025; Nurhasanah *et al.*, 2022) and expedites product quality evaluation by replicating extreme but realistic environmental conditions (Chanadang & Chambers, 2019; Hidayati *et al.*, 2022; Muniandy *et al.*, 2023).

Shelf-life estimation using ASLT based on the Arrhenius model generally involves testing at various temperatures to determine the degradation reaction of the product (Prmono *et al.*, 2024; Yuwono, 2023). Traditional shelf-life tests are often time-consuming and inefficient, whereas ASLT provides a more rapid approach by simulating extreme storage conditions to accelerate the degradation of products (Ntzimani *et al.*, 2025). Consequently, the selection of appropriate quality parameters and the application of a suitable kinetic model are crucial for ensuring the accuracy of shelf-life predictions obtained through ASLT. By integrating temperature-dependent degradation kinetics with the Arrhenius model, the ASLT enables researchers to quantify the effect of storage conditions on product stability and generate reliable shelf-life estimates within a shorter period.



Several previous studies have estimated the shelf life of processed fishery products using accelerated shelf-life testing (ASLT) as a practical approach to expedite the estimation process. Sulaiman and Khairi (2024) applied ASLT to dried fish products using moisture content and microbial count as quality parameters and found that storage temperature significantly affected the spoilage rate. A similar study by Nopiani *et al.* (2024) on ready-to-eat (RTE) sardines used the Arrhenius model to predict shelf life based on changes in protein, fat, and sensory properties during storage at high temperatures. Nugraha *et al.* (2022) also applied ASLT to estimate the shelf life of *Nori Sargassum sp.* and *Eucheuma spinosum*, achieving faster shelf-life determination by monitoring changes in water content and sensory parameters. Pangawikan *et al.* (2022) examined fish crackers using ASLT and confirmed that higher storage temperatures accelerate degradation, with peroxide values serving as key indicators. Collectively, these studies demonstrate that the ASLT method effectively estimates the shelf life of processed fishery products by evaluating changes in their chemical and physical quality during storage.

Moisture content is a critical quality parameter for food products because it directly influences water activity ( $a_w$ ), which determines the microbiological, chemical, and physical stability of dry products, such as milkfish floss sheets. An increase in moisture content during storage can cause the loss of a crisp texture, heightened enzymatic activity, and proliferation of microorganisms (Bell, 2020). Compared to other parameters, such as free fatty acids or organoleptic attributes, moisture content is more responsive, exhibits a linear relationship with temperature, and is easy to measure at regular intervals, making it highly compatible with the principles of ASLT (Hassan *et al.*, 2022; Latief *et al.*, 2020; Tanaka *et al.*, 2016). Although previous studies have applied ASLT using moisture as a quality indicator, no study has specifically estimated the shelf life of milkfish floss sheets using the Arrhenius model with moisture content as the sole critical parameter while explicitly referring to the 15% maximum limit stated in SNI 7690-2019. This highlights a notable

research gap, as milkfish floss sheets are a newly developed innovative fishery product that combines the characteristics of traditional fish floss with dried sheet products. Owing to their unique formulation, thin structure, and high hygroscopicity, their moisture adsorption behavior and stability mechanisms are expected to differ from those of conventional dried fish products.

Therefore, this study aimed to quantitatively estimate the shelf life of packaged milkfish floss sheets using the ASLT method based on the Arrhenius model, with moisture content designated as the critical parameter. This study tested the hypothesis that the rate of moisture increase follows an Arrhenius-type temperature dependence, thereby enabling the accurate prediction of product stability and expiry under various storage conditions. The results are expected to provide empirical data and a predictive model that can serve as a scientific basis for determining expiration labels, storage temperatures, and supporting the commercialization of this new milkfish-based product within Indonesia's fishery industry.

## MATERIAL AND METHOD

### Preparation of Milkfish Floss Sheets

The preparation of milkfish floss sheets followed the procedure described by Matti *et al.* (2023). First, the milkfish meat was separated from the bones and skin and then steamed for 30 min using a stainless-steel steamer (Sekai, Indonesia). The cooked meat was finely shredded using a food processor (Mitochiba CH-200, Indonesia) and mixed with sautéed spices until fully cooked. The mixture was subsequently fried in cooking oil using a stainless steel frying pan (Maxim, Indonesia) over medium heat until dry.

Subsequently, the floss was blended with a 1% tapioca solution and 10% sugar, calculated based on the total weight of the milkfish floss dough. The dough was then molded into sheets measuring 4×9 cm with a thickness of 3 mm using a custom-made acrylic mold (custom-made, local). The sheets were dried at 60°C for 3 h in a drying oven (Wiratech, Indonesia).

## Moisture

The moisture content was evaluated using the gravimetric method specified in SNI 01-2354.2-2006. Approximately  $\pm 5$  g of milkfish floss sheet samples were weighed precisely using an analytical scale and placed in a dry porcelain cup of known weight. The samples were then dried in an oven (Wiratech, Indonesia) at  $105 \pm 2^\circ\text{C}$  for 5 h or until a constant weight was reached. After drying, the cups were removed from the oven, cooled in a desiccator for approximately 30 min, and weighed. This procedure was repeated thrice to obtain a representative average moisture content value. The moisture content (%) was calculated using the following equation:

$$\text{Moisture (\%)} = \frac{W_1 - W_2}{W_1 - W_0} \times 100$$

where:

$W_0$  = weight of the empty cups (g)

$W_1$  = weight of the cup + sample before drying (g)

$W_2$  = weight of the cup + sample after drying (g)

## Estimated Shelf Life

The stability of the milkfish floss sheets was tested through moisture content analysis to determine their shelf life (Fu & Labuza, 1993; Hasanah *et al.*, 2021). In this study, storage temperature was defined as the experimental treatment, whereas packaging type and environmental humidity were maintained as controlled variables. The samples were stored at three different temperatures (30, 40, and  $50^\circ\text{C}$ ) to simulate normal and accelerated storage conditions using the accelerated shelf-life testing (ASLT) method. The selected temperature range spans normal to accelerated storage conditions while maintaining the degradation mechanisms observed under actual storage conditions. This ensures that the quality deterioration follows consistent kinetics, allowing reliable shelf-life prediction based on the Arrhenius model. The samples were packed using Alupaper packaging, which consists of laminated layers of aluminum foil, polyethylene (PE), and litho paper, providing an effective barrier to oxygen and water vapor. The water vapor transmission rate (WVTR)

of Alupaper ranges from  $0.1506 \text{ g/m}^2/24 \text{ h}$  to  $0.3517 \text{ g/m}^2/24 \text{ h}$  (Syafira *et al.*, 2020), depending on the layer thickness, indicating excellent moisture resistance. Storage was conducted under controlled environmental conditions with an average relative humidity (RH) of  $75 \pm 2\%$ . Moisture content was observed at fixed intervals (0, 10, 20, 30, 40, 50, 60, and 70 days), and all measurements were conducted in triplicates to ensure accuracy and reproducibility. The moisture content data were analyzed using the Arrhenius equation.

The reaction kinetics were determined by plotting the average quality parameter values against the storage time at the three temperatures, and the best-fit kinetic model was selected based on the coefficient of determination ( $R^2$ ). The parameter values were plotted directly against the storage time for the zero-order model. The correlation coefficient ( $R^2$ ) was calculated using linear regression in Microsoft Excel to determine the slope of the curve as the reaction constant ( $k$ ). The obtained  $k$  value was then used to construct an Arrhenius curve by plotting  $\ln k$  against  $1/T$  ( $\text{K}^{-1}$ ), resulting in a line equation that generated a  $k_0$  value, intercept, and correlation coefficient. The constant  $k$  represents the gradient of the linear regression based on the three storage temperatures.

$$k = k_0 \cdot e^{-E_a/RT}$$

where:

$k$  = deterioration constant

$k_0$  = constant (temperature independent)

$E_a$  = activation energy

$T$  = absolute temperature (K)

$R$  = gas constant ( $1.986 \text{ cal/mol K}$ )

The line equation obtained follows the Arrhenius equation:

$$\ln k = \ln k_0 - \left( \frac{E_a}{R} \right) \times \left( \frac{1}{T} \right)$$

The value of  $k_0$  was obtained from this equation. The following formula was used to determine the shelf life:

$$t = \frac{A_0 - A_t}{k}$$



## RESULTS AND DISCUSSION

### Initial Quality of Milkfish Floss Sheet

Chemical characterization is crucial for evaluating nutritional quality, storage stability, and potential degradation during storage. Milkfish-based floss sheets demonstrated competitive nutritional value (Table 1), with the main chemical composition consisting of moisture  $3.49\pm 0.12\%$ , protein  $22.6\pm 0.45\%$ , fat  $13.48\pm 0.39\%$ , ash  $6.12\pm 0.21\%$ , and carbohydrate  $54.68\pm 1.12\%$ . The high protein content highlights the substantial nutritional contribution of this product, consistent with milkfish being a source of high-quality animal protein. Proteins function as both structural and metabolic components; however, they are sensitive to degradation, particularly in low-moisture systems with a high susceptibility to oxidation (Hematyar *et al.*, 2024; Nemova *et al.*, 2021).

The fat content of  $13.48\pm 0.39\%$  in milkfish floss sheets indicates a potential risk of oxidative reactions during storage. Fish lipids are particularly susceptible to degradation when exposed to oxygen, light, and elevated temperatures, leading to the formation of secondary compounds, such as free fatty acids (FFA) and peroxides (Suárez-Medina *et al.*, 2024). The initial FFA level of  $0.90\pm 0.05\%$  (expressed as oleic acid) and the peroxide value of  $4.00\pm 0.18$  meq/kg were still within the acceptable limits for dry-processed foods. The FFA value suggests that significant lipid hydrolysis has not yet occurred; however,

it remains a crucial early indicator of fat quality deterioration. The peroxide value, which reflects the degree of primary lipid oxidation, confirmed that the product was still in the initial oxidation phase but required controlled storage conditions to prevent rapid increases during shelf life (Winkler–Moser *et al.*, 2020).

The ash content of  $6.12\pm 0.21\%$  reflects the presence of minerals originating from the raw fish material and supplementary ingredients such as tapioca flour. In addition, the carbohydrate content of  $54.68\pm 1.12\%$  indicates the dominance of the energy fraction contributed primarily by the added starch, which influences the texture and physical stability of the product. Starch-based carbohydrates tend to remain stable against microbiological and chemical damage under dry conditions. However, their involvement in non-enzymatic browning (Maillard reactions) cannot be disregarded, particularly when reactive carbonyl compounds accumulate from protein degradation and sugar reduction (Ghizdareanu *et al.*, 2023).

The selection of moisture content as a critical parameter for estimating the shelf life of milkfish floss sheets is based on its high sensitivity to environmental changes and its influence on chemical, enzymatic, and microbiological degradation reactions. The initial moisture content of  $3.49\pm 0.12\%$  was within the ideal range for dry product. However, in shelf-life prediction, even slight increases in moisture can elevate water activity ( $a_w$ ), which may trigger microbial growth or

Table 1 Chemical composition, oxidation parameters, and microbiological characteristics of milkfish floss sheet

Parameter	Milkfish floss sheet	Catfish floss (Fahmi & Purnamayati, 2020)	SNI 7690:2019
Moisture (%)	$3.49\pm 0.12$	$9.94\pm 0.14$	Max. 15
Protein (%)	$22.60\pm 0.45$	$32.93\pm 0.07$	Min. 30
Fat (%)	$13.48\pm 0.39$	$24.86\pm 0.27$	Not specified
Ash (%)	$6.12\pm 0.21$	$6.67\pm 0.02$	Not specified
Carbohydrate(%)	$54.68\pm 1.12$	-	Not specified
Free Fatty Acid (FFA) (%)	$0.90\pm 0.05$	$2.09\pm 0.13$	Not specified
Peroxide Value (PV) (meq/kg)	$4.00\pm 0.18$	-	Not specified
Total Plate Count (TPC) (log CFU/g)	$1.80\pm 0.07$	-	Max. 3.7

chemical reactions, such as hydrolysis and lipid oxidation. Unlike other components, such as carbohydrates, which remain relatively inert under dry conditions, the moisture content is highly dynamic and directly affects product stability. Therefore, this parameter serves not only as an early quality indicator but also as the most sensitive measure for detecting deterioration, which ultimately determines the product's shelf-life endpoint.

Within the Accelerated Shelf-Life Testing (ASLT) approach, the moisture content functions as the primary trigger for reaction kinetics modeling, enabling an accurate and scientifically measurable estimation of the product expiration time. This relationship is supported by microbiological test results obtained using the Total Plate Count (TPC) method, which showed a very low initial value of  $1.80 \pm 0.07$  log CFU/g, indicating that the low moisture content effectively inhibited microbial growth during the early stages of storage. Thus, moisture content not only indicates physicochemical changes but also serves as a key controller of microbiological stability, making it a critical parameter for estimating the shelf life of milkfish floss sheets.

### Moisture Content of Milkfish Floss Sheet During Storage

Moisture content is a critical parameter for estimating the shelf life of milkfish floss sheets, as it directly affects the water activity ( $a_w$ ), which determines the rate of chemical, physical, and microbiological reactions during storage. High moisture content

accelerates product deterioration owing to microbial growth and fat oxidation, whereas low moisture levels can prolong shelf life by slowing these reactions (Olaimat *et al.*, 2020; Shaltout, 2024).

The correlation between moisture content and water activity ( $a_w$ ) is fundamental in determining the stability of products during storage. While the moisture content represents the total amount of water present,  $a_w$  reflects the fraction of free water available to support biochemical and microbiological processes. Even a minor increase in moisture can exponentially increase  $a_w$ , accelerating lipid oxidation, Maillard reactions, and microbial proliferation (Luo *et al.*, 2022). In low-moisture foods, this relationship is highly sensitive, as slight fluctuations in environmental humidity can significantly alter  $a_w$  and lead to quality degradation.

Therefore, monitoring the moisture content provides a practical and sensitive indicator for predicting the stability of the milkfish floss sheet. It directly influences chemical kinetic behavior and microbial growth dynamics, making it a primary determinant in shelf-life modeling under the Accelerated Shelf-Life Testing (ASLT) approach. The results showed that the moisture content of the milkfish floss sheet increased significantly during storage at the three tested temperatures of 30, 40, and 50°C (Table 2). This upward trend was consistently observed at all temperatures, with the rate of increase becoming more pronounced at higher storage temperatures than at lower ones. These

Table 2 Changes in the moisture content of milkfish floss sheet during storage

Days	Moisture content (%)		
	30°C	40°C	50°C
1	5.68±0.07	5.68±0.05	5.68±0.06
10	5.79±0.09	5.89±0.12	6.39±0.15
20	6.32±0.14	6.57±0.18	6.79±0.21
30	6.54±0.11	6.73±0.16	7.17±0.19
40	7.07±0.17	7.13±0.14	8.16±0.23
50	7.39±0.21	7.79±0.25	8.56±0.28
60	8.26±0.24	8.55±0.27	8.92±0.32
70	8.45±0.19	8.78±0.22	9.18±0.29



findings confirm that temperature plays a critical role in accelerating quality changes, particularly those associated with moisture uptake, which is an essential indicator of stability in low-moisture food products.

Milkfish floss sheets are dry, crispy processed fishery products that exhibit relatively high hygroscopicity. This characteristic allows the product to easily absorb moisture from the surrounding environment, especially when stored at ambient temperatures, where humidity control is limited. Foods with low initial moisture content tend to reach equilibrium with their storage environment, making moisture absorption unavoidable over time. In this study, samples were packaged in Alupaper (a laminated structure of aluminum foil, polyethylene, and litho paper) and stored under controlled conditions at 30, 40, and 50°C with a relative humidity of  $75 \pm 2\%$ , simulating typical tropical storage environments. These settings enabled precise monitoring of the moisture absorption pattern and its role in influencing product stability throughout the accelerated shelf-life testing period.

Dry foods are hygroscopic and have a high moisture affinity (Vego, Benders, *et al.*, 2023; Zou *et al.*, 2023). At higher storage temperatures, the relative humidity of the surrounding air tends to increase, resulting in faster moisture uptake by the product (Afolabi *et al.*, 2023; Romruen *et al.*, 2024). This condition explains the continuous increase in the moisture content of the milkfish floss sheets during storage, particularly at 40°C and 50°C relative to 30°C.

Increased storage temperature also accelerates physical and chemical changes in dry food products, including moisture absorption from the environment (Karwacka *et al.*, 2024; Silva-Espinoza *et al.*, 2021). The increase in moisture content observed in the milkfish floss sheet confirmed that water vapor was adsorbed into the hygroscopic product matrix. The regression analysis of the moisture content data (Figure 1) showed that the zero-order model produced high coefficients of determination ( $R^2$ ) at all storage temperatures:  $R^2 = 0.9759$  (30°C),  $R^2 = 0.9794$  (40°C), and  $R^2 = 0.979$  (50°C). These results were higher and more consistent than those of the first-order models, which showed  $R^2 = 0.9845$  (30°C),  $R^2 = 0.9853$  (40°C), and  $R^2 = 0.9669$  (50°C).

The zero-order kinetic model indicates that the rate of moisture increase remains constant over time and does not depend on the current moisture concentration of the product. This behavior corresponds to passive moisture diffusion from the external environment through the packaging layer to the product surface.

Pakpahan *et al.* (2017) explained that higher storage temperatures cause greater increases in moisture content. This increase can be attributed to several factors, including the moisture permeability of the packaging material, fluctuations in the relative humidity of the environment, and the porous structure of the product, which readily absorbs water vapor (Eze *et al.*, 2024). The immediate impact of rising moisture levels is the loss of crisp texture and the appearance of undesirable

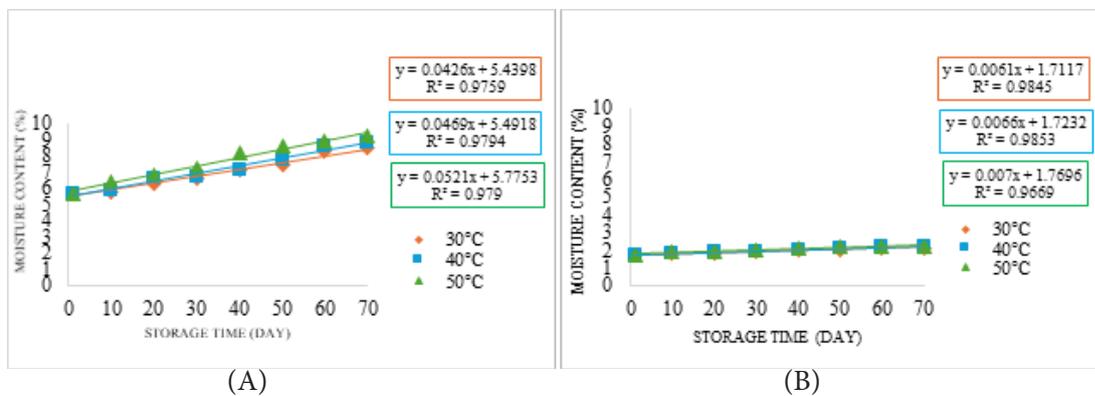


Figure 1 The relationship between storage time and the increase in the moisture content of milkfish floss sheet; (A) Ordo 0, (B) Ordo 1; (◆) 30°C, (■) 40°C, (▲) 50°C

sensory changes due to hydrolytic and oxidative reactions triggered by water absorption (Panda *et al.*, 2022). In milkfish floss sheet products, increased moisture content not only reduces crispness but also elevates the risk of chemical and microbiological deterioration, thereby accelerating the overall quality degradation.

### Kinetics of Product Quality Change During Storage

The results of this study (Table 3) were further supported by reaction kinetic analysis using the Arrhenius model, which demonstrated a linear relationship between  $\ln k$  and  $1/T$  (Figure 2), with a very high determination coefficient ( $R^2 = 0.998$ ), indicating excellent model accuracy in predicting the rate of change in the moisture content at different storage temperatures. The Arrhenius model assumes that the same degradation mechanism occurs at all tested temperatures and that the rate constant ( $k$ ) increases exponentially with increasing temperature. These assumptions were met in this study, as the increase in moisture content followed a consistent pattern with no changes in the reaction order or degradation mechanism at 30, 40, or 50 °C.

The Arrhenius model describes the effect of temperature on the rate of physical

and chemical reactions in food systems, which in this case represents moisture uptake caused by the adsorption of water vapor from the surrounding environment (Roos, 2024; Vego, Tengattini, *et al.*, 2023). Therefore, the Arrhenius model can be effectively used to predict the shelf life of food products based on changes in the moisture content.

The relationship between  $\ln k$  and  $1/T$  values in this study mathematically describes how the storage temperature affects the rate of change in the moisture content of the milkfish floss sheets. Based on the Arrhenius model, increasing the temperature accelerates the reaction rate of moisture uptake, as reflected in the higher reaction rate constant ( $k$ ) at elevated temperatures. When the value of  $1/T$  (in  $\text{Kelvin}^{-1}$ ) decreased with increasing temperature,  $\ln k$  increased, indicating a faster rate of moisture gain. The determination coefficient ( $R^2 = 0.998$ ) demonstrated excellent model accuracy for predicting changes in moisture content at different storage temperatures (Figure 2), confirming that the reaction rate constant was highly temperature-dependent.

From the slope ( $-Ea/R = -984.3$ ) and intercept ( $\ln k_0 = 0.0901$ ), the activation energy ( $Ea$ ) and pre-exponential factor ( $k_0$ ) were calculated as  $8.18 \text{ kJmol}^{-1}$  and  $1.09 \text{ d}^{-1}$ ,

Table 3 Linear regression equation of moisture content parameters

Temperature (°C)	Zero-order kinetic equation	$R^2$	T (K)	$1/T$	$k$	$\ln k$
30	$0.0426x+5.4398$	0.9759	303	0.0033	0.0426	-3.15590
40	$0.0469x+5.4918$	0.9794	313	0.0032	0.0469	-3.05974
50	$0.0521x+5.7753$	0.9790	323	0.0031	0.0521	-2.95459

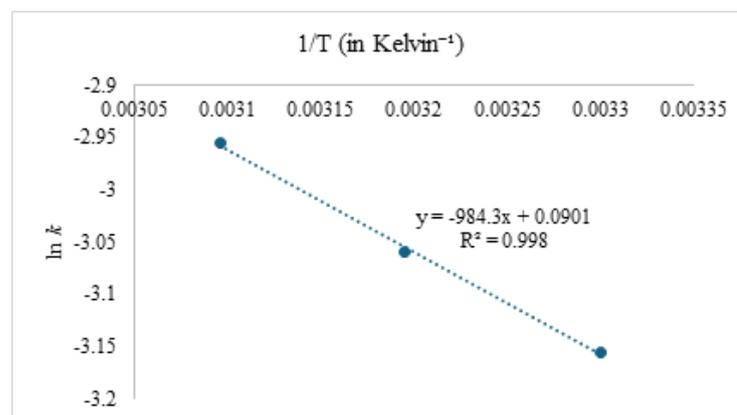


Figure 2 The relationship between  $\ln k$  and  $1/T$  based on the moisture content



respectively. The Arrhenius model explains how temperature influences chemical or physical reactions in food systems, which, in this case, is the increase in moisture content driven by the adsorption of water vapor from the surrounding environment (Roos, 2024; Vego, Tengattini, *et al.*, 2023).

The strong relationship between the Arrhenius model and the physical characteristics of the milkfish floss sheets lies in the product's dry and crispy structure, which relies on maintaining a low moisture level. As a flour- and fat-based product with a highly porous matrix, milkfish floss sheets easily absorb moisture from humid environments. With increasing storage temperature, the kinetic energy of water vapor molecules increases (Ajide & English, 2023), thereby accelerating their diffusion into the product. Consequently, the moisture content increases more rapidly at higher temperatures, which can lead to decreased crispness, texture softening, and other quality deterioration issues, such as rancidity triggered by enhanced fat oxidation in the presence of water (Kim *et al.*, 2021; Liu *et al.*, 2024).

The relationship between  $\ln k$  and  $1/T$  examined in this study confirmed that increasing the storage temperature significantly accelerated moisture absorption by the milkfish floss sheets, resulting in a continuous increase in moisture content during storage. This increase directly affects the potential for microbial growth, even though dry fishery products, such as milkfish floss sheets, are initially formulated to retain low moisture content (<10%) to suppress water activity ( $a_w$ ) and prevent microbial growth. However, elevated temperature and humidity during storage increase moisture uptake, which subsequently elevates  $a_w$  and allows the growth of certain microorganisms.

Milkfish floss sheets are commonly associated with microbial risks from molds and yeasts, as these organisms can survive and develop under low  $a_w$  conditions (approximately 0.60–0.80) (Deng *et al.*, 2020; Heredia *et al.*, 2024). Molds frequently detected in dry fishery products include *Aspergillus*, *Penicillium*, and *Eurotium* spp. (Baher *et al.*, 2024). Among them, *Aspergillus*

*flavus* is particularly concerning because of its ability to thrive in low- $a_w$  environments (Jia *et al.*, 2022; Romero Donato *et al.*, 2022) and produce aflatoxins that pose serious food safety risks. Yeasts such as *Candida* spp. and *Saccharomyces* spp. may also proliferate when the moisture content exceeds the safe threshold (Peleg *et al.*, 2015; Romero Donato *et al.*, 2022).

Thus, the rise in moisture content during storage, especially under high temperatures and humidity, not only leads to quality degradation, such as loss of crispness, but also increases the risk of microbial contamination of the product. Therefore, strict control of temperature and humidity during storage is essential to maintain a low moisture content and ensure the safety and stability of milkfish floss sheet products.

### Estimated Shelf Life

The results of this study (Table 4) show that the shelf life of the milkfish floss sheets decreased as the storage temperature increased. At 30°C, the estimated shelf life is 219.33 d (7.31 months), which decreases to 197.71 d (6.59 months) at 40°C and further to 179.37 d (5.98 months) at 50°C. This pattern aligns with the fundamental theory of chemical reaction kinetics in food deterioration, which states that the rate of quality degradation accelerates with increasing temperature owing to enhanced molecular activity (Zhang *et al.*, 2021).

Shelf-life estimation in this study used moisture content as the critical quality parameter, based on SNI 7690-2019, which sets a maximum permissible moisture level of 15% for milkfish floss. The selection of moisture content as a deterioration indicator is consistent with previous research on dry fish-based products, where increasing moisture content has been shown to accelerate both microbial growth and undesirable chemical reactions (Bilbie, 2022; Ramanda *et al.*, 2023; Sefrienda *et al.*, 2022). Therefore, this parameter is scientifically appropriate and regulatory compliant for determining product expiration.

The rate of increase in moisture content in this study increased with temperature,

Table 4 Estimated shelf life of milkfish floss sheet at different storage temperatures

Temperature (°C)	Critical moisture value of fish floss (SNI 7690-2019)	Initial moisture content	Rate of increase in moisture content	Shelf life (days)	Shelf life (month)
30	15	5.68	0.042493046	219.33	7.31
40	15	5.68	0.047140233	197.71	6.60
50	15	5.68	0.051960658	179.37	5.98

from 0.04249 at 30°C to 0.05196 at 50°C. This indicates that higher temperatures accelerate the absorption of moisture from the surrounding environment, thereby shortening the shelf life of the product. This finding extends previous research by Y. Q. Zhang *et al.* (2020). reported that temperature and relative humidity significantly affect the quality of dry products, particularly in relation to water absorption and texture changes.

The results of this study indicate that the optimal storage temperature for maintaining the quality of the milkfish floss sheet is below 30°C, ensuring that the product remains safe and complies with quality standards. In practical terms, this implies that for industrial-scale distribution, especially in tropical regions with high ambient temperature and humidity, packaging materials with high water vapor barrier properties, such as multilayer laminates or metallized films, are recommended to minimize moisture ingress and extend the shelf life. When storage occurs at temperatures above 40°C, the risk of excessive moisture gains beyond the standard increases more rapidly, causing accelerated product deterioration. This aligns with the shelf-life concept proposed by Fu and Labuza (1993), which states that the shelf life of food products is influenced by storage conditions, particularly temperature and humidity.

The shelf life of the milkfish floss sheets in this study was long, exceeding 5 months at an extreme temperature of 50°C. This indicates that the formulation and production processes can produce products with relatively high stability. Fat content and processing techniques, such as heating and drying, also influence the durability of shredded products (Cui *et al.*, 2023). However, it should be noted that the estimated shelf life of 7.31 months at 30°C is based on kinetic model extrapolation.

Therefore, validation through real-time storage studies under room-temperature conditions is recommended to confirm the accuracy and reliability of model predictions. In addition to accelerated temperature predictions, Arrhenius extrapolation indicated that the estimated shelf life of the milkfish floss sheet at a realistic ambient storage temperature of approximately 28°C was approximately 230 days. This prediction aligns with the Arrhenius kinetic principle, which states that lower temperatures reduce the rates of moisture absorption and quality deterioration.

## CONCLUSION

This study confirmed that the Accelerated Shelf-Life Testing (ASLT) method using the Arrhenius model provides a reliable approach for predicting the shelf life of milkfish floss sheets, with moisture content identified as the critical determinant of product stability. The estimated shelf life was 219.33 d at 30°C, 197.71 d at 40°C, and 179.37 d at 50°C, demonstrating that higher storage temperatures significantly accelerated quality degradation. Based on Arrhenius extrapolation, the predicted shelf life at a typical ambient temperature (28°C) was slightly longer than that at 30°C, indicating a stability of approximately 230 days under normal room-temperature storage conditions. These findings validate the use of a critical moisture content limit of 15% (SNI 7690-2019) as a scientific basis for expiration labeling, while offering practical implications for improving storage management, ensuring food safety, and supporting the competitiveness of fish-based ready-to-eat products.

## ACKNOWLEDGEMENT

The authors acknowledge the Directorate General of Vocational Education,



Ministry of Education, Culture, Research, and Technology, for providing funding through the 2022 Matching Fund Program for the Downstream of Superior Products (Contract No. 572/PKS/D.D4/PPK.01.APTV/XI/2022), with Dr. Agussalim M., S.T.P., M.Si. serving as the project leader. The authors also express their sincere gratitude to PT. Dunia Marine Products, Makassar, for their valuable collaboration and support as an industrial partner in this study.

## REFERENCE

- Afolabi, A. S., Choi, I.-L., Lee, J. H., Kwon, Y. B., & Kang, H.-M. (2023). High-relative-humidity storage reduces the chilling injury symptoms of red sweet peppers in the breaker stage. *Horticulturae*, 9(1), 116. <https://doi.org/10.3390/horticulturae9010116>
- Ajide, M. T., & English, N. J. (2023). Effect of temperature on the dipole response, structural and dynamical properties of water under external electric fields. *Journal of Molecular Liquids*, 389, 122675. <https://doi.org/10.1016/j.molliq.2023.122675>
- Baher, W. M., Mansour, M. E. E., Wormely, M. R., Elmehra, E. M. A., Nassar, A. H. M., & Darwish, W. S. (2024). Analysis of mold and aflatoxins in processed fish and their control with electrolyzed water. *Egyptian Journal of Animal Health*, 4(3), 37–49. <https://doi.org/10.21608/ejah.2024.358432>
- Bell, L. N. (2020). Moisture Effects on Food's Chemical Stability. In *Water Activity in Foods* (pp. 227–253). Wiley. <https://doi.org/10.1002/9781118765982.ch9>
- Bilbie, C. (2022). Setup of ASLT Parameters for Evaluation of the Shelf-Life for the New Dry Snack Food Product. *The 17th International Symposium; Priorities of Chemistry for a Sustainable Development; PRIOCHEM*, 75. <https://doi.org/10.3390/chemproc2022007075>
- Chanadang, S., & Chambers, E. (2019). Sensory shelf life estimation of novel fortified blended foods under accelerated and real-time storage conditions. *Journal of Food Science*, 84(9), 2638–2645. <https://doi.org/10.1111/1750-3841.14758>
- Cui, K., Liu, N., Sun, Y., Sun, G., Wang, S., Yang, M., Wang, X., Zhou, D., Ge, Y., Wang, D., & Wang, M. (2023). Effect of drying processes on the occurrence of lipid oxidation-derived 4-hydroxy-2-hexenal and 4-hydroxy-2-nonenal in Spanish mackerel (*Scomberomorus niphonius*). *Food Science & Nutrition*, 11(2), 1013–1023. <https://doi.org/10.1002/fsn3.3138>
- Deng, L.-Z., Tao, Y., Mujumdar, A. S., Pan, Z., Chen, C., Yang, X.-H., Liu, Z.-L., Wang, H., & Xiao, H.-W. (2020). Recent advances in non-thermal decontamination technologies for microorganisms and mycotoxins in low-moisture foods. *Trends in Food Science & Technology*, 106, 104–112. <https://doi.org/10.1016/j.tifs.2020.10.012>
- Eze, J., Duan, Y., Eze, E., Ramanathan, R., & Ajmal, T. (2024). Machine learning-based optimal temperature management model for safety and quality control of perishable food supply chain. *Scientific Reports*, 14(1), 27228. <https://doi.org/10.1038/s41598-024-70638-6>
- Fahmi, A. S., & Purnamayati, L. (2020). Cholesterol content, fatty acid composition and sensory analysis of deep fried and roasted *abon ikan* (fish floss/shredded fish flesh). *E3S Web of Conferences*, 147, 03009. <https://doi.org/10.1051/e3sconf/202014703009>
- Fu, B., & Labuza, T. P. (1993). Shelf-life prediction: theory and application. *Food Control*, 4(3), 125–133. [https://doi.org/10.1016/0956-7135\(93\)90298-3](https://doi.org/10.1016/0956-7135(93)90298-3)
- Ghizdareanu, A.-I., Pasarin, D., Banu, A., Ionita (Afilipoaei), A., Enascuta, C. E., & Vlaicu, A. (2023). Accelerated shelf-life and stability testing of hydrolyzed corn starch films. *Polymers*, 15(4), 889. <https://doi.org/10.3390/polym15040889>
- Hasanah, F., Siregar, N. C., Meutia, Y. R., Rahimah, S., & Jeanette, G. (2021). Pendugaan umur simpan kerupuk tulang ikan tenggiri (*Scomberomorus commerson*) dengan proses penirisan dan tanpa penirisan dengan metode akselerasi kadar air kritis. *Warta Industri Hasil Pertanian*, 38(2), 132. <https://doi.org/10.1111/1750-3841.14758>

- org/10.32765/wartaihp.v38i2.7412
- Hassan, A., Mustafa, F. E., Ahmed, H., & Abd El-Malek, A. (2022). Nutritional value and organoleptic characteristics of some imported canned tuna sold in assiut governorate. *Assiut Veterinary Medical Journal*, 68(172), 68–77. <https://doi.org/10.21608/avmj.2022.113633.1047>
- Hematyar, N., Policar, T., & Rustad, T. (2024). Importance of proteins and mitochondrial changes as freshness indicators in fish muscle post-mortem. *Journal of the Science of Food and Agriculture*. <https://doi.org/10.1002/jsfa.14044>
- Heredia, S. M. S., Le Marc, Y., Martín, J. S., Possas, A., Jiménez, E. C., & Díaz, A. V. (2024). Inter-strain variability on the cardinal parameters (pH and Aw) of clinical and food isolates of *Listeria monocytogenes* using turbidimetric measurements. *International Journal of Food Microbiology*, 411, 110521. <https://doi.org/10.1016/j.ijfoodmicro.2023.110521>
- Hidayati, S., Sartika, D., Sutoyo, S., & Fudholi, A. (2022). Predict the shelf life of instant chocolate in vacuum packing by using accelerated shelf life test (ASLT). *Mathematical Modelling of Engineering Problems*, 9(2), 443–450. <https://doi.org/10.18280/mmep.090220>
- Jia, S., Li, C., Wu, K., Qi, D., & Wang, S. (2022). Effect of water activity on conidia germination in *Aspergillus flavus*. *Microorganisms*, 10(9), 1744. <https://doi.org/10.3390/microorganisms10091744>
- Karwacka, M., Ciurzyńska, A., Galus, S., & Janowicz, M. (2024). The effect of storage time and temperature on quality changes in freeze-dried snacks obtained with fruit pomace and pectin powders as a sustainable approach for new product development. *Sustainability*, 16(11), 4736. <https://doi.org/10.3390/su16114736>
- Kasmiasi, Ekantari, N., Asnani, Suadi, & Husni, A. (2020). Mutu dan tingkat kesukaan konsumen terhadap abon ikan layang (*Decapterus* sp.). *Jurnal Pengolahan Hasil Perikanan Indonesia*, 23(3), 470–478.
- Kasmiasi, Putri, A. A., Sumule, O., Latuconsina, N., Khasanah, R., Khotimah, H., Nurfaidah, Laga, S., Handarini, K., Rahmatang, & Metusalach. (2023). Karakteristik mutu abon ikan sapu-sapu (*Pterygoplichthys pardalis*) dari Perairan Danau Tempe, Sulawesi Selatan. *Jurnal Pengolahan Hasil Perikanan Indonesia*, 26(2), 291–302. <http://dx.doi.org/10.17844/jphpi.v26i2.43873>
- Kim, S.-M., Kim, T.-K., Kim, H.-W., Jung, S., Yong, H. I., & Choi, Y.-S. (2021). Quality characteristics of semi-dried restructured jerky processed using super-heated steam. *Foods*, 10(4), 762. <https://doi.org/10.3390/foods10040762>
- Kusumawati, E., Candriasih, P., & Astaty, A. (2024). The effect of deep-frying and pan-frying methods on the organoleptic properties, protein, and calcium content of presto milkfish floss (*Chanos chanos*). *Italian Journal of Food Safety*, 14(1), 13085 <https://doi.org/10.4081/ijfs.2024.13085>
- Latief, R., Farahdiba, A. N., & A N Amalia, A. (2020). Shelf life study of bolu cukke using the accelerated shelf life testing (ASLT) method. *IOP Conference Series: Earth and Environmental Science*, 486(1), 012052. <https://doi.org/10.1088/1755-1315/486/1/012052>
- Lisboa, H. M., Pasquali, M. B., dos Anjos, A. I., Sarinho, A. M., de Melo, E. D., Andrade, R., Batista, L., Lima, J., Diniz, Y., & Barros, A. (2024). Innovative and sustainable food preservation techniques: enhancing food quality, safety, and environmental sustainability. *Sustainability*, 16(18), 8223. <https://doi.org/10.3390/su16188223>
- Liu, X., Zhou, K., Chen, B., Xie, Y., Ma, Y., Zhou, H., & Xu, B. (2024). Insight into the evolution of textural properties and juiciness of ready-to-eat chicken breasts upon different thermal sterilization: From the perspective of protein degradation. *Journal of Texture Studies*, 55(3). <https://doi.org/10.1111/jtxs.12835>
- Luo, K. K., Huang, G., & Mitchell, A. E. (2022). Acceleration of lipid oxidation in



- raw stored almond kernels in response to postharvest moisture exposure. *Journal of the Science of Food and Agriculture*, 102(3), 1155–1164. <https://doi.org/10.1002/jsfa.11452>
- Matti, A., Syukroni, I., Fattah, N., Rusli, A., Adilham, A., Arsyad, M. A., & Riska, R. (2023). Karakteristik abon lembaran dari ikan bandeng (*Chanos chanos*) dengan penambahan tepung tapioka. *Jurnal Fishtech*, 12(1), 1–8. <https://doi.org/10.36706/fishtech.v1i1.19750>
- Muniandy, A., Benyathiar, P., Ozadali, F., & Mishra, D. K. (2023). Multi-accelerant approach for rapid shelf-life determination of beverages in polymeric packaging. *Food Research International*, 173, 113318. <https://doi.org/10.1016/j.foodres.2023.113318>
- Nemova, N. N., Kantserova, N. P., & Lysenko, L. A. (2021). The traits of protein metabolism in the skeletal muscle of teleost fish. *Journal of Evolutionary Biochemistry and Physiology*, 57(3), 626–645. <https://doi.org/10.1134/S0022093021030121>
- Nopiani, Y., Hasnah, N., Dameswary, A. H., & Yunita, I. (2024). Estimation of shelf life for ready-to-eat sardines (RTE) using the accelerated shelf-life testing (ASLT) method. *BIO Web of Conferences*, 99, 02017. <https://doi.org/10.1051/bioconf/20249902017>
- Ntzimani, A., Tsevdou, M., Andrianos, E., Gounaris, D., Spiliotopoulos, T., Taoukis, P., & Giannakourou, M. C. (2025). Validating accelerated shelf life testing methodology for predicting shelf life in high-pressure-processed meat products. *Applied Sciences*, 15(3), 1264. <https://doi.org/10.3390/app15031264>
- Nugraha, M. I. S., Afrianto, E., Liviawaty, E., Pratama, R. I., & Rochima, E. (2022). Shelf life of combination nori *Sargassum* sp. and *Eucheuma spinosum* with aluminium foil packaging based on the accelerated shelf life test method. *Asian Journal of Fisheries and Aquatic Research*, 12–23. <https://doi.org/10.9734/ajfar/2022/v16i430377>
- Nurhasanah, S., Setyadi, A., Munarso, S. J., Subroto, E., & Filianty, F. (2022). Shelf-life prediction of peanut oil (*Arachis hypogaea* L.) using an accelerated shelf-life testing (ASLT) method in the polypropylene packaging. *IOP Conference Series: Earth and Environmental Science*, 1024(1), 012056. <https://doi.org/10.1088/1755-1315/1024/1/012056>
- Olaimat, A. N., Osaili, T. M., Al-Holy, M. A., Al-Nabulsi, A. A., Obaid, R. S., Alaboudi, A. R., Ayyash, M., & Holley, R. (2020). Microbial safety of oily, low water activity food products: A review. *Food Microbiology*, 92, 103571. <https://doi.org/10.1016/j.fm.2020.103571>
- Pakpahan, N., Kusnandar, F., & Syamsir, E. (2017). Perilaku isotherm sorpsi air dan perubahan fisik kerupuk tapioka pada suhu penyimpanan yang berbeda. *Jurnal Teknologi dan Industri Pangan*, 28(2), 91–101. <https://doi.org/10.6066/jtip.2017.28.2.91>
- Panda, B. K., Mishra, G., Ramirez, W. A., Jung, H., Singh, C. B., Lee, S.-H., & Lee, I. (2022). Rancidity and moisture estimation in shelled almond kernels using NIR hyperspectral imaging and chemometric analysis. *Journal of Food Engineering*, 318, 110889. <https://doi.org/10.1016/j.jfoodeng.2021.110889>
- Pangawikan, A. D., Mukti, R. C., Sari, D. I., & Ridhowati, S. (2022). Prediksi masa simpan kerupuk ikan Palembang melalui pendekatan angka total oksidasi (totox) dengan metode *accelerated self-life test* (ASLT). *Jurnal Teknologi & Industri Hasil Pertanian*, 27(2), 81. <https://doi.org/10.23960/jtihp.v27i2.81-89>
- Peleg, M., Corradini, M. G., & Normand, M. D. (2015). On modeling the effect of water activity on microbial growth and mortality kinetics (pp. 263–278). [https://doi.org/10.1007/978-1-4939-2578-0\\_19](https://doi.org/10.1007/978-1-4939-2578-0_19)
- Pramono, Y. B., Mulyani, S., Abduh, S. B. M., Kamil, R. Z., Legowo, A. M., Lestari, T. Y., Astuti, A. T., Putri, D. R. B., Puspita, D. A., & Bramantyo, F. R. (2024). Shelf-life determination of “hiwan tahu” using accelerated shelf-life testing (ASLT) with arrhenius model. *International Journal on Advanced Science, Engineering*

- and Information Technology*, 14(2), 717–722. <https://doi.org/10.18517/ijaseit.14.2.19193>
- Ramanda, M. R., Nasution, S., Rahmadi, I., & Munawaroh, N. L. (2023). Penentuan umur simpan keripik buah dengan metode *accelerated shelf life test* model kadar air kritis. *Teknologi Pangan : Media Informasi dan Komunikasi Ilmiah Teknologi Pertanian*, 14(2), 246–259. <https://doi.org/10.35891/tp.v14i2.3788>
- Romero Donato, C. J., Cendoya, E., Demonte, L. D., Repetti, M. R., Chulze, S. N., & Ramirez, M. L. (2022). Influence of abiotic factors (water activity and temperature) on growth and aflatoxin production by *Aspergillus flavus* in a chickpea-based medium. *International Journal of Food Microbiology*, 379, 109841. <https://doi.org/10.1016/j.ijfoodmicro.2022.109841>
- Romruen, O., Kaewprachu, P., Sai-Ut, S., Kingwascharapong, P., Karbowski, T., Zhang, W., & Rawdkuen, S. (2024). Impact of environmental storage conditions on properties and stability of a smart bilayer film. *Scientific Reports*, 14(1), 23038. <https://doi.org/10.1038/s41598-024-74004-4>
- Roos, Y. H. (2024). Water sorption modeling and monolayer of biological and food materials. *LWT*, 201, 116271. <https://doi.org/10.1016/j.lwt.2024.116271>
- Rudenko, O. S., & Bazhenova, A. E. (2022). Forecasting the safety of confectionery products by microbiological indicators. *Tovaroved Prodovolstvennykh Tovarov (Commodity Specialist of Food Products)*, 5, 355–357. <https://doi.org/10.33920/igt-01-2205-18>
- Sefrienda, A. R., Febriani, F. L., Anandito, R. B. K., Ariani, D., & Fathoni, A. (2022). Shelf-life estimation of mocaf dry noodles using critical moisture content approach in various packaging. *IOP Conference Series: Earth and Environmental Science*, 1024(1), 012012. <https://doi.org/10.1088/1755-1315/1024/1/012012>
- Shaltout, F. (2024). Impact of extending the shelf life of the meat on public health. *Open Access Journal of Veterinary Science & Research*, 9(2). <https://doi.org/10.23880/oajvsr-16000274>
- Shi, C., Zhao, Z., Jia, Z., Hou, M., Yang, X., Ying, X., & Ji, Z. (2024). Artificial neural network-based shelf life prediction approach in the food storage process: A review. *Critical Reviews in Food Science and Nutrition*, 64(32), 12009–12024. <https://doi.org/10.1080/10408398.2023.2245899>
- Silva-Espinoza, M. A., Camacho, M. del M., & Martínez-Navarrete, N. (2021). Effect of storage temperature on the crispness, colour and bioactive compounds of an orange snack obtained by freeze-drying. *British Food Journal*, 123(6), 2095–2106. <https://doi.org/10.1108/BFJ-11-2020-1061>
- Sormin, R. B. D., Naralyawan, P. F., & Tapotubun, A. M. (2024). Mutu abon ikan layang (*Decapterus* sp.) asal Banda. *INASUA: Jurnal Teknologi Hasil Perikanan*, 4(1), 255–261. <https://doi.org/10.30598/jinasua.2024.4.1.256>
- 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), 1097. <https://doi.org/10.3390/foods13071097>
- Sulaiman, I., & Khairi, I. (2024). Shelf-life measurement of dried fish (Keumamah) using The accelerated shelf-life testing (ASLT) with the arrhenius model using microwave. *Agroindustrial Technology Journal*, 8(1), 118–127. <https://doi.org/10.21111/atj.v8i1.11955>
- Syafira, S., Supardianningsih, S., & Nugraha, M. (2020). Identification of water vapour transmission rate (wvtr) of aluminum foil packaging barrier using the gravimetric testing method. *Jurnal Ilmiah Publipreneur*, 6(1), 49–54. <https://doi.org/10.46961/jip.v6i1.80>
- Tanaka, R., Ishimaru, M., Hatate, H., Sugiura, Y., & Matsushita, T. (2016). Relationship between 4-hydroxy-2-hexenal contents and commercial grade by organoleptic judgement in Japanese dried laver *Porphyra* spp. *Food Chemistry*, 212,



- 104–109. <https://doi.org/10.1016/j.foodchem.2016.05.166>
- Tarлак, F. (2023). The use of predictive microbiology for the prediction of the shelf life of food products. *Foods*, 12(24), 4461. <https://doi.org/10.3390/foods12244461>
- Vego, I., Benders, R. T., Tengattini, A., Vergeldt, F. J., Dijkman, J. A., & van Duynhoven, J. P. M. (2023). Heterogeneous swelling of couscous particles exposed to a high relative humidity air, as revealed by TD-NMR and X-ray tomography. *Food Structure*, 37, 100330. <https://doi.org/10.1016/j.foostr.2023.100330>
- Vego, I., Tengattini, A., Lenoir, N., & Viggiani, G. (2023). The influence of water sorption on the microstructure of a hydro-sensitive granular material (couscous) deduced from simultaneous neutron and X-ray tomography. *Granular Matter*, 25(4), 65. <https://doi.org/10.1007/s10035-023-01356-5>
- Winkler–Moser, J. K., Hwang, H., & Kerr, B. J. (2020). Changes in markers of lipid oxidation and thermal treatment in feed-grade fats and oils. *Journal of the Science of Food and Agriculture*, 100(8), 3328–3340. <https://doi.org/10.1002/jsfa.10364>
- Yuwono, S. S. (2023). The shelf-life prediction of sweet soy sauce using ASLT method with arrhenius model. *Jurnal Pangan Dan Agroindustri*, 11(4), 196–206. <https://doi.org/10.21776/ub.jpa.2023.011.04.4>
- Zhang, W., Luo, Z., Wang, A., Gu, X., & Lv, Z. (2021). Kinetic models applied to quality change and shelf life prediction of kiwifruits. *LWT*, 138, 110610. <https://doi.org/10.1016/j.lwt.2020.110610>
- Zhang, Y.-Q., Hui, Y., Wang, Y., Zhang, B., Guo, B.-L., Zhang, G.-Q., & Wei, Y.-M. (2020). Effects of drying temperature and relative humidity on quality properties of chinese dried noodles. *Journal of Food Quality*, 2020, 1–9. <https://doi.org/10.1155/2020/8843974>
- Zou, Y., Yan, L., Maillet, B., Sidi-Boulenouar, R., Brochard, L., & Coussot, P. (2023). Critical role of boundary conditions in sorption kinetics measurements. *Langmuir*, 39(51), 18866–18879. <https://doi.org/10.1021/acs.langmuir.3c02729>