Asian Journal of Applied study for Community Development and Empowerment. Vol 8 (2024), No.3

AJARCDE
ASIAN JOURNAL OF APPLIED RESEARCH FOR COMMUNITY DEVELOPMENT AND EMPOWERMENT

Journal home page: http://ajarcde-safe-network.org ISSN 2581-0405

Shelf-Life Prediction of Shredded Duck "Cahyo" by *Accelerated Shelf-Life Testing* (ASLT) Technique Based on The *Arrhenius* Model

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ARTICLE INFO

Article History:
Received: 2 June 2024
Final Revision: 7 July 2024
Accepted: 10 July 2024
Online Publication: 11 July 2024

KEYWORDS

Shredded Duck "Cahyo", *Shelf Life*, *Accelerated Shelf Life Testing* (ASLT), *Arrhenius*

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A B S T R A C T

Shredded Duck "Cahyo" PT Deltasari Indah Restaurant is a shredded product made from duck meat. The shelf life of Shredded Duck "Cahyo" can be used as an indication in determining the time and expiration date. Expiration information is one of the important information that must be included in each food packaging. examinations made from the repository to changes in quality decline are carried out to decide the shelf life of Shredded Duck "Cahyo". Therefore, a study was conducted to forecast the shelf life of Shredded Duck "Cahyo" PT Deltasari Indah Restaurant. This study's objectives are to decide the critical criteria for determining the shelf life of Shredded Duck "Cahyo" and to forecast the shelf life of Shredded Duck "Cahyo" products stored at different thermal state conditions. In this study, Accelerated Shelf Life Testing utilizing the Arrhenius model was employed. Shredded Duck "Cahyo" packaged in PET jars underwent repository at thermal states of 30˚C, 40˚C, and 50˚C for 28 days, by examinations conducted every 7 days. Key criteria analyzed encompassed water content, Free Fatty Acid (FFA) levels, and total microbial presence. The critical criterion selected was the Free Fatty Acid (FFA) criterion, given its low activation energy (Ea) and high R2 value. outcomes indicated that utilizing the Arrhenius model ASLT approach, the shelf lives of Shredded Duck "Cahyo" at 30˚C, 40˚C, and 50˚C were 58 days, 51 days, and 44 days, respectively. Considering actual repository conditions (20˚C and 25˚C), the average shelf life of Shredded Duck "Cahyo" was decided to be 65.5 days.

1. INTRODUCTION

1.1. study Background

Shredded meat, a popular ready-to-eat dried food in Indonesia, is favored for its convenience, durability, and distinctive dry, light, crispy, and savory qualities [1]. PT Deltasari Indah Restaurant, an MSME, stands out for its innovation in transforming duck meat into shredded duck products. One of their trademark products is known as Shredded Duck "Cahyo". This choice was made due to the limited availability of shredded products made from duck meat in the market.

Upon initial production, shredded products are typically at their peak quality, marked at 100%, but this diminishes over time through the phases of repository, distribution, and marketing. Throughout these processes, food products experience reductions in weight, nutritional value, overall quality, market value, appeal, and reliability. Environmental exposure during repository and distribution further exacerbates these changes. Variables such as thermal state, humidity, oxygen levels, and light play critical roles in inducing alterations that may lead to the degradation of shredded products [2].

One common quality issue observed in shredded products is rancidity, particularly in fatty or oily foods. This deterioration can result from various factors such as fat absorption, enzymatic activity in fatty tissues, microbial processes, hydrolysis, and oxidation induced by oxygen, either individually or in combination [3]. thermal state plays a crucial role in altering food quality, facilitating chemical reactions that can accelerate rancidity. In shredded products, this susceptibility to rancidity is heightened by exposure to light, heat, and fluctuations in thermal state [4]. Therefore, in Shredded Duck "Cahyo", improved thermal states can expedite the onset of rancidity. The ASLT technique utilizing the Arrhenius approach is employed to assess this phenomenon, focusing on how thermal state changes affect chemical reactions that degrade food quality [5][6].

To forecast shelf life utilizing the Arrhenius model, the approach accelerates the degradation of products by subjecting them to higher-than-normal repository thermal states. This technique involves storing food items in at least three elevated thermal states to expedite deterioration, enabling extrapolation of shelf life based on these thermal state conditions [7]. Each ingredient may require different testing thermal states. For instance, for dried foods, it is advised to consider repository thermal states ranging from 25°C to 50°C [8]. thermal state treatments impact the metabolic activities of living tissues among food products. Optimal thermal states are necessary for the reproduction of living organisms. Moreover, varying repository thermal states can either inhibit or accelerate chemical reactions, enzymatic processes, or microbial growth [9]. These reactions ultimately lead to a decline in quality criteria such as free fatty acid levels, moisture content, and total microbial counts, all of which impact the product's shelf life.

When planning a shelf-life study, one of the initial considerations is determining the repository duration and sampling schedule. This can vary based on the product's expected shelf life: for short-term products, stored under cold conditions, testing may occur daily over a week; medium-term products, lasting three weeks, could be sampled each seven days; and long-term products, lasting up to a year, might be sampled monthly [8]. However, the specific testing schedule is tailored to the material's characteristics and repository conditions. In the case of shredded duck, which undergoes high-thermal state treatment, repository duration typically spans one month, with sampling scheduled every seven days to monitor changes effectively.

1.2. Literature Review

1.2.1. Shelf Life

Shelf life refers to the duration between production and consumption during which a product maintains its quality before it deteriorates and becomes unsuitable for consumption [8]. The duration of shelf life can be affected by alterations in product composition, environmental factors impacting the product, or modifications in the packaging system. Each factors impact the length of shelf life, including the composition of raw materials, the production techniques employed, the type of packaging used, and the repository conditions of the product [10].

Shelf-life determination involves monitoring a product throughout its repository period until changes render it unacceptable to consumers. This process includes observing the product over specific intervals to detect any alterations that may signify a decline in its quality. Consequently, conducting attribute tests on the product is crucial for assessing its shelf life. Chemical reactions among food products during repository can lead to cumulative and irreversible changes that ultimately compromise their quality, making it imperative to identify these reactions and their impacts over time [10].

1.2.2. Quality Deterioration of Shredded Meat during Repository

Throughout the repository, shredded products undergo a degradation in quality attributed to both physical and chemical transformations that occur over time. Products containing fats or oils commonly undergo a rancidity process characterized by the development of unpleasant odors and flavors as they age [3].

The development of rancidity in fatty or oily foods can arise from various sources, including fat absorption, enzymatic processes among fatty tissues, microbial activity, and oxidative reactions catalyzed by oxygen. These factors may act independently or synergistically to induce rancid flavors and aromas [3]. Furthermore, microbial growth, encompassing bacteria and molds, can contribute to food spoilage by generating undesirable odors (rancidity) and producing substances such as mucus, gases, acids, toxins, and discoloration [11].

1.2.3. correlation between thermal state, moisture content, total microbes, and FFA content by the shelf life of shredded meat

Thermal state plays a crucial role in influencing various processes that contribute to spoilage, including microbial growth rate, lipid or pigment oxidation, browning reactions, and vitamin degradation. These factors directly correlate by thermal state levels. Evaluating quality indicators specific to food, such as nutrient loss, changes in sensory attributes like taste or color, and the proliferation of target microorganisms or toxins, provides insights into product deterioration and enables the prediction of shelf life. The impact of the thermal state on these indicators is analyzed through kinetic studies that apply the principles of the Arrhenius equation [12].

In dry food items like jerky, crackers, shredded meat, and milk powder, managing water content is critical. Even a small rise in moisture levels among these dry materials can lead to detrimental effects, including chemical reactions and the proliferation of spoilage microorganisms [13].

Microbial growth, including bacteria and molds, can lead to food spoilage, characterized by undesirable odors (rancidity), along with the production of mucus, gases, acids, toxins, and color changes [11].

Rancidity in food products can also result from oxidation or hydrolysis of food components, contributing to product deterioration. The extent of this damage can be assessed utilizing Free Fatty Acid (FFA) analysis [14].

1.3. Objective

The objective of this study was to establish critical criterions defining the shelf life of shredded duck product "Cahyo" utilizing the Accelerated Shelf-Life Testing (ASLT) technique employing the Arrhenius model. This involved subjecting the product to three distinct thermal state conditions to simulate accelerated aging.

2. MATERIALS AND METHOS

2.1. Materials and Tools

The equipment and materials employed included shredded duck "Cahyo", physiological saline solution, Plate Count Agar (PCA), 1% phenolphthalein indicator, 0.1 N NaOH, filter paper, 70% alcohol, distilled water, denatured alcohol, matches or lighters, aluminum foil, PET plastic jars by lids, plastic wrap, and labels.

The equipment used in this study includes digital scales, spatulas, porcelain cups, weighing bottles, desiccators, microwaves, burettes, test tubes, measuring cups, volumetric flasks, Erlenmeyer flasks, droppers, stirrers, mortars, beakers, stands by clamps, Petri dishes, watch glasses, vortex mixer, sterile spoons, Erlenmeyer flasks, test tubes, incubator, autoclave, micropipettes, room thermometer, label paper, plastic wrap, markers, aluminum foil, blue and yellow tips, Eppendorf tubes, Bunsen burner, and microwave.

2.2. Design of Experiment and Analysis

This study intended to decide the shelf life of Shredded Duck "Cahyo" in PET jars manufactured by PT Deltasari Indah Restaurant. The experiment involved storing the product at thermal states of 30°C, 40°C, and 50°C for 28 days, by examinations conducted each 7 days.

The analysis employed the *Accelerated Shelf-Life Testing* (ASLT) technique utilizing the Arrhenius model, adapted from the Labuza equation. It focused on chemical criteria such as moisture content and *Free Fatty Acid* (FFA) levels, as well as microbiological criteria including total microbial count assessed via the Total Plate Count (TPC) technique [15].

2.3. Procedure

2.3.1. Chemical Analysis

The primary chemical analysis conducted in the study of shredded duck utilizing the Arrhenius technique focused on determining water content and Free Fatty Acid (FFA) levels. The FFA measurement involved placing 14 grams of oil sample in a 250 ml Erlenmeyer flask, adding 25 ml of 95% ethanol, and heating it to 40°C. Subsequently, 2 ml of phenolphthalein indicator was added, and titration was performed with 0.05 M NaOH solution until a persistent pink color appeared for at least 30 seconds [16]. The calculation of FFA (%) was decided utilizing the following formula:

$$\text{FFA}\ (\%) = \frac{\text{ml NaOH x berat molekul x N NaOH x }100\%}{\text{gram contoh x }1000}$$

Description:
FFA (%) = Free fatty acid content
ml NaOH = Volume of NaOH titrant
N NaOH = Molarity of NaOH solution (mol/L)
Gram sample = Weight of Oil Sample
Molecular weight = Oil Weight (Palmitic Acid) 256 g/mol

To determine the moisture content, a ceramic vessel is subjected to a heat treatment in a microwave at a thermal state range of 102-105°C for 12 hours, followed by a period of cooling in a desiccator lasting 30 minutes. The cooled vessel is carefully weighed, and a quantity of 1-2 grams of the specimen is introduced into the vessel. The specimen is subsequently subjected to drying in a microwave set at a thermal state range of 100-105°C for 3 hours, followed by cooling in a desiccator before reweighing. This procedure is reiterated: the specimen is subjected to heat in the microwave for 30 minutes, subsequently cooled in a desiccator, and weighed repeatedly until consecutive weighings exhibit a variance of no more than 0.2 mg, signifying equilibrium [17]. The determination of water content in fragmented items is subsequently determined in the following manner.

$$\text{Water Content }(\%) = 100\%\text{ x }\frac{\text{B} - \text{C}}{\text{B} - \text{A}}$$

Description:
A : Weight of cup + sample before drying (g)
B : Weight of cup + sample after drying (g)
C : Sample weight (g)

2.3.2. Microbiological Analysis

One gram of the specimen was meticulously weighed and blended in 9 ml of a 0.85% Buffered Peptone Water (BPW) solution to create dilutions varying from 10^-1 to 10^-6. Following that, 500 microliters of each dilution were evenly distributed on the sterile Plate Count Agar (PCA) medium and subsequently placed in an incubator at 37°C for 18-24 hours. The resulting colonies were then enumerated and quantified as Colony Forming Units per gram (CFU/g) of the sample utilizing the prescribed formula [18].

$$\text{CFU} = \text{number of colonies x }\frac{1000}{500}\text{ x dilution factor}$$

2.4. study Analysis

The study's experimental framework involved manipulating the thermal state and repository duration based on the Arrhenius model. Table 1 displays an illustrative summary of the analytical outcomes of the investigation.

Table 1. Chemical and Microbiological Response Design of Shredded Duck "Cahyo" Products

Temp (˚C)	examination Time	Response		
		Water Content (%)	FFA (%)	TPC(cfu/g)
30	Day 1			
	Day 7			
	Day 14			
	Day 21			
	Day 28			
40	Day 1			
	Day 7			
	Day 14			
	Day 21			
	Day 28			
50	Day 1			
	Day 7			
	Day 14			
	Day 21			
	Day 28			

Following the analysis, each criterion's data is graphed over time (days), yielding a linear equation specific to each repository thermal state condition, formulated as follows:

$$y = bx + a$$

Description:
y = Examined parameters (humidity level, Free Fatty Acids, or Total Plate Count) in the analysis.
x = duration of repository (days).
a = Assessed the worth at the commencement of the repository period.
b = Rate of degradation constant.

https://doi.org/10.29165/ajarcde.v8i2.447

To decide the reaction order for each criterion, the regression values (R2) of the linear equations at identical thermal states are compared. The reaction order corresponding to the criterion is identified based on the higher R2 value obtained.

After formulating a linear equation for each repository thermal state, the slope value (referred to as "k") is determined to signify the alteration in product attributes. Subsequently, the \(k \) value is converted to the natural logarithm of \(k \) and graphed against the reciprocal of thermal state (K-1) in the Arrhenius equation. The slope and intercept values of the linear regression equation are determined from this equation as follows:

$$\ln k = \ln k_0 - \frac{(\frac{Ea}{R})}{(\frac{1}{T})}$$

Description:

- $\ln k_0$ = intercept
- Ea/R = slope
- Ea = activation energy
- R = gas constant (1.986 cal/mol)

The equation yields the constant k0, a factor reflecting the exponential decline in quality under typical repository conditions, and the activation energy (Ea), which governs changes in product characteristics. Additionally, the reaction rate equation model is established based on the thermal state, where k denotes the decline in product quality, calculated by the following formula:

$$k = k_0 . e^{-Ea/RT}$$

Description:

- k = deterioration constant
- k_0 = constant (independent of thermal state)
- e = base logarithm (2.718282)
- Ea = activation energy
- T = absolute thermal state (C+273)
- R = gas constant (1.986 cal/mol)

utilizing the Arrhenius equation provided earlier, the determination of the k value enables the calculation of the shelf life of Shredded Duck "Cahyo" utilizing the reaction order equation as outlined below:

$$t \text{ Zero order } = \frac{\Delta A\ (A_0 - A_t)}{k}$$

$$t \text{ First Order } = \frac{\ln A_0 - \ln A_t}{k}$$

Description:

- t = predicted shelf life (days)
- ΔA = change in product quality
- A0 = initial product quality value
- A = remaining product quality value at time t
- K = deterioration constant at normal thermal state

3. RESULT AND DISCUSSION

3.1. Quality Change in Shredded Duck "Cahyo" Based on TPC criterions

The proliferation of microorganisms, such as bacteria and molds, can lead to food spoilage, resulting in off-putting smells (rancidity), along with the production of slime, gases, acids, toxins, and discoloration [11]. To assess the overall microbial presence in the "Cahyo" shredded duck product throughout its repository duration, a Total Plate Count (TPC) test was conducted. The presence of these microbes can indicate spoilage and rancidity in the Shredded Duck "Cahyo".

Figure 1 displays the graph illustrating the linear regression equation derived from the results of the zero-order TPC test.

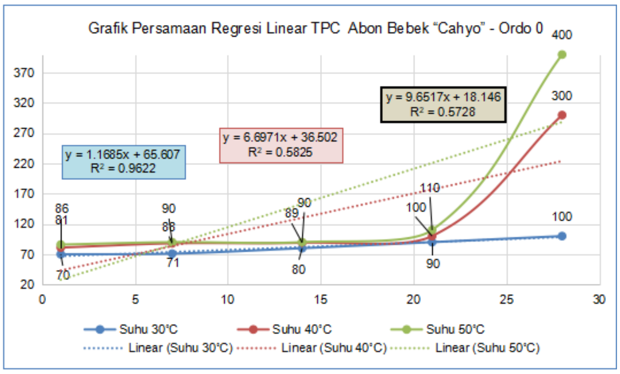

Figure 1. Zero Order TPC Linear Regression Equation Graph

In the case of the first-order graph, a plot depicting the ln k value against repository time was generated. Figure 2 displays the linear regression graph derived from the outcomes of the first-order TPC examination.

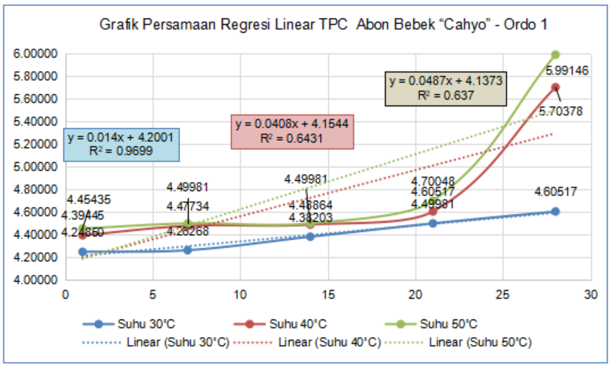

Figure 2. TPC Linear Regression Equation Graph of Order One

From Figure 1 and Figure 2, it is evident that repository thermal states of 40°C and 50°C exhibit higher bacterial counts compared to 30°C. This examination aligns with the concept that higher thermal states accelerate the rate of quality deterioration, particularly in microbial growth [19]. This phenomenon is attributed to the presence of mesophilic microbes, which thrive in room thermal state conditions ranging from 20-40°C, and thermophilic groups that flourish at higher thermal states, specifically between 40-60°C [20].

3.2. Quality Change in Shredded Duck "Cahyo" Based on *Water* Content criterions

In dry food items like jerky, crackers, shredded products, and milk powder, monitoring water content is crucial, as high moisture levels can lead to product spoilage. This is because harmful microorganisms thrive in moist environments, accelerating deterioration [13]. To assess the overall moisture level in "Cahyo" shredded duck during its repository period, water content testing is conducted. This moisture measurement helps decide the potential for bacteria, molds, and yeasts to grow and cause the Shredded Duck "Cahyo" to spoil more rapidly.

Figure 3 illustrates the graph representing the linear regression equation derived from the zero-order TPC test results.

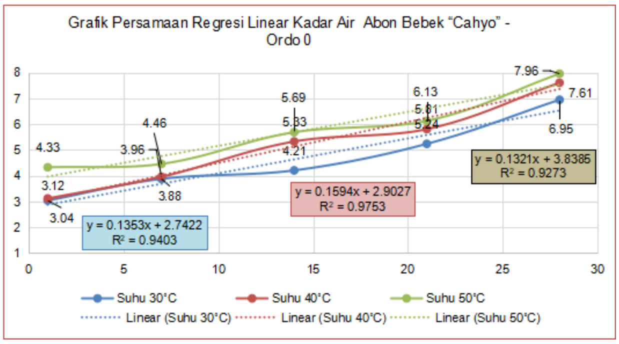

Figure 3. Linear Regression Equation Graph of Zero Order Water Content

A plot of ln k values against repository time was created for the first-order graph. Figure 4 showcases the linear regression equation derived from the first-order moisture content data.

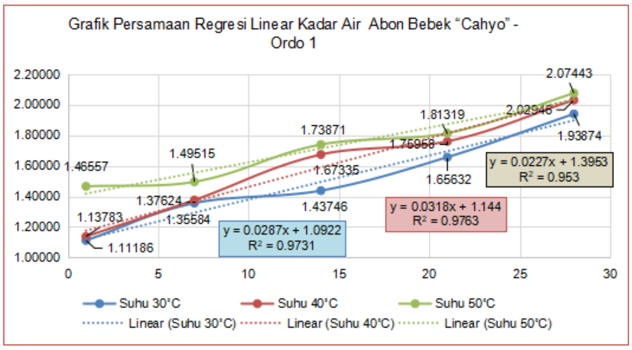

Figure 4: Linear Regression Equation Graph of First-Order Water Content

Figures 3 and 4 demonstrate that a repository thermal state of 50°C results in a higher water content compared to repository thermal states of 30°C and 40°C. This phenomenon is likely due to water evaporation at higher thermal states, where the moisture becomes trapped and subsequently reabsorbed by the food, leading to improved water content and humidity levels [21].

The reabsorption of moisture by Shredded Duck "Cahyo" leads to an improvement in the material's water content and activity (aw). This aligns with the examination that high humidity levels in repository areas can cause materials to absorb water vapor from the air, thereby raising their moisture content [21]. Additionally, elevated thermal states contribute to a rise in water content, which correlates with an improvement in total microbial presence in the Shredded Duck "Cahyo" This phenomenon supports the notion that higher water content can elevate water activity, promoting microbial growth that can cause spoilage [22]

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3.3. Quality Change in Shredded Duck "Cahyo" Based on FFA criterions

Food product deterioration is often due to rancidity, which results from the oxidation or hydrolysis of food components. The extent of this damage can be assessed through Free Fatty Acid (FFA) analysis [14]. FFA content testing measures the amount of free fatty acids present in the Shredded Duck "Cahyo" throughout its repository period. The detected FFA levels serve as an indicator of the rancidity process affecting the Shredded Duck "Cahyo"

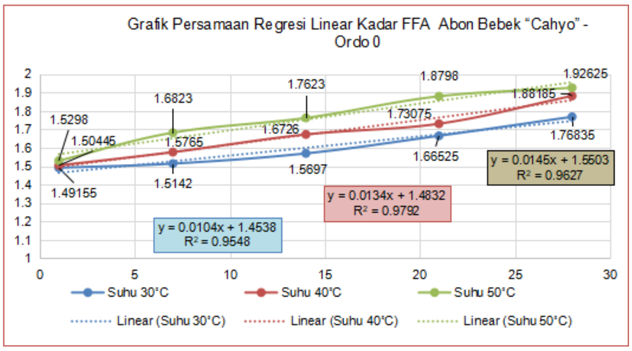

Figure 5. Linear Regression Equation Graph of Zero Order FFA Value

A plot was created for the first-order graph, showing the ln k values against repository time. The linear regression equation derived from the first-order FFA values is depicted in Figure 6.

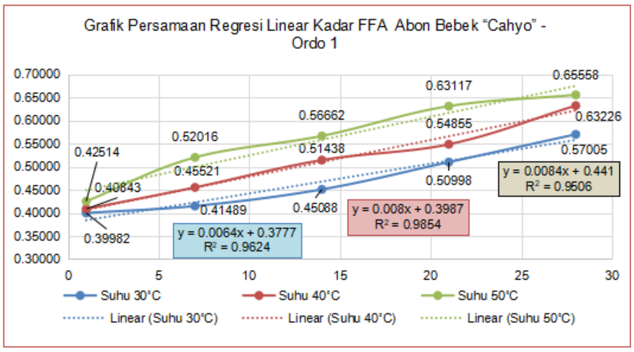

Figure 6. Linear Regression Equation Graph of First-Order FFA Value

Figures 5 and 6 demonstrate that the FFA content at a repository thermal state of 50°C is higher compared to repository thermal states of 30°C and 40°C. The improvement in FFA content is associated with higher repository thermal states. This rise is attributed to the hydrolysis of the oil present in the Shredded Duck "Cahyo" This phenomenon aligns with the understanding that prolonged improper repository can lead to the breakdown of glyceride bonds, resulting in the formation of fatty acids and glycerol, which subsequently cause hydrolysis reactions and degradation of fats or oils in food products [23]. The rise in FFA levels at elevated thermal states corresponds to the improvement in water content in Shredded Duck "Cahyo" High moisture levels can promote hydrolysis reactions, leading to higher FFA levels. This is consistent with the assertion that an abundance of water can cause the oil in food to hydrolyze, resulting in the formation of free fatty acids (FFA), triglycerides, fatty acids, and glycerol [24].

The data on quality changes in Shredded Duck "Cahyo" over the repository period can be represented utilizing both linear and exponential curves. Linear curves suggest a zero-order reaction, while exponential curves indicate a first-order reaction. These graphical representations can be found in Figures 1 through 6. The equations of these graphs and the R2 values for the quality criteria across different repository conditions are provided in Table 2.

3.4. Determination of Reaction Order

Table 2. Reaction Equation of the correlation between Quality Change and repository thermal state at Reaction Order Zero and Reaction Order One

Quality criterions	thermal state (˚C)	Reaction Order Zero		Reaction Order One		Selected Reaction Order	
		Reaction Equation	R^2	Reaction Equation	R^2		
ALT/TPC	30	Y= 1.1685x + 65.607	0.9622	Y= 0.014x + 4.2001	**0.9699**	1	1
	40	Y= 6.6971x + 36.502	0.5825	Y= 0.0408 + 4.1544	**0.6431**	1	
	50	Y= 9.6517x + 18.146	0.5728	Y= 0.0487 + 4.1373	**0.637**	1	
Water Content	30	Y= 0.1353x + 2.7422	0.9403	Y= 0.0287x + 1.0922	**0.9731**	1	1
	40	Y= 0.01594x + 2.9027	0.9753	Y= 0.0318x + 1.144	**0.9763**	1	
	50	Y= 0.1321x + 3.8385	**0.9273**	Y= 0.0227x + 1.3953	0.953	0	
FFA	30	Y= 0.0104x + 1.4538	0.9548	Y= 0.0064x + 1.3777	**0.9624**	1	1
	40	Y= 0.0134x + 1.4832	0.9792	Y= 0.008x + 0.3987	**0.9854**	1	
	50	Y= 0.0145x + 1.5503	**0.9672**	Y= 0.0104x + 1.4538	0.9506	0	

The determination of reaction order is crucial for understanding the rate of quality changes. For a zero-order reaction, the rate of deterioration remains constant, while a first-order reaction indicates that the rate of deterioration follows a logarithmic or exponential pattern.

To select the appropriate reaction order, quality reduction data is plotted for both zero and first-order reactions, followed by the creation of a linear regression equation. The reaction order by the highest R2 value is chosen, as a value closer to 1 signifies a stronger correlation between the data points.

3.5. Key criterion Criteria for Shelf Life Forecasting

Various criteria are employed in the choosing of quality standards to ascertain the shelf life of products, including [25]:.

1. The criteria that exhibited the most rapid deterioration during the repository were assigned the highest absolute k coefficient or coefficient of determination (R2) values.
2. The most discerning quality indicator for alterations was pinpointed by the gradient of the Arrhenius equation or the minimum activation energy (Ea).
3. If multiple quality criteria were found to meet the aforementioned standards, the one that indicated the shortest shelf life was selected.

Information regarding the coefficient of determination (R2), activation energy value (Ea), and shelf-life forecasting based on multiple criteria is presented in Table 3.

According to the data in Table 3, the FFA criterion is the most suitable reference for estimating shelf life. This choice is based on Each criterion: the FFA and TPC criteria have the highest R2 values, indicating strong correlations. For activation energy (Ea), the FFA and water content criteria are the lowest, signifying greater sensitivity to changes. Additionally, the FFA criterion indicates the shortest shelf life. Thus, the FFA criterion meets all three criteria: lowest activation energy, high R2 value, and shortest shelf life duration. Consequently, the FFA content is the key criterion for determining the shelf life of Shredded Duck "Cahyo" [25].

Table 3. Results of Analysis of FFA Content in Shredded Duck "Cahyo" Order Zero

criterions	R^2	Ea	Shelf-Life (Days)		
		(kcal/mol)	10˚C	30˚C	50˚C
TPC/ALT	**0.8668**	12203.3742	212	111	60
Water Content	0.4227	**1019.36**	1475	1539	1256
FFA	**0.8912**	**2659.85**	**58**	**51**	**44**

3.6. Prediction of Product Expiration Shelf Life on Key Criteria

3.6.1. Calculation of Shelf Life at Selected Criteria by Arrhenius technique

Shelf-life calculations are performed utilizing the selected criterion, the FFA value, to ensure the quality of the product. This criterion is chosen because it has the lowest activation energy (Ea) and a high coefficient of determination (R2), indicating its sensitivity to change and quick reaction to quality deviations during the repository of Shredded Duck "Cahyo" The k value derived from these calculations for the FFA criterion is correlated by thermal state utilizing the Arrhenius equation:

$$\mathrm{k = ko\,.\,exp^{-(\frac{Ea}{RT})}}$$

or in its logarithmic form:

$$\mathrm{\ln k = \ln A - \left(\frac{Ea}{RT}\right)}$$

Or

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

Plotting the natural logarithm of the rate constant (ln k) on the vertical axis against the reciprocal of the thermal state (1/T) on the horizontal axis will result in a linear correlation represented by the equation y = bx + a. In this context, the slope (b) represents the activation energy divided by the gas constant (Ea/R), and the y-intercept (a) represents the natural logarithm of the pre-exponential factor (ln k0). It is important to note that the thermal state in the Arrhenius equation is typically expressed in Kelvin (K). To convert from Celsius to Kelvin, simply add 273 to the Celsius thermal state, as exemplified in Table 4.

Table 4. Values of K, (1/T), Slope (k), and ln k of Shredded Duck at 3 repository thermal state Points criterion Value FFA Reaction Order One

Temp (˚C)	Temp (˚K)	(1/T)	Slope (k)	Ln K
30	303	0.00330033	0.0064	-5.05146
40	313	0.003194888	0.008	-4.82831
50	323	0.003095975	0.0084	-4.77952

By regressing the ln k values against (1/T), we obtain the line equation shown in Figure 18. From this Arrhenius plot, the correlation between ln k and (1/T) for Shredded Duck "Cahyo" is decided to be ln k = -1339.3 (1/T) - 0.6045. This equation is employed to calculate the k values at various repository thermal states, allowing for the determination of the shelf life under different repository conditions based on the repository thermal state of Shredded Duck "Cahyo" The changes in the Arrhenius plot illustrating the correlation between ln k and (1/T) for the FFA value, assuming a first-order reaction, are depicted in Figure 7.

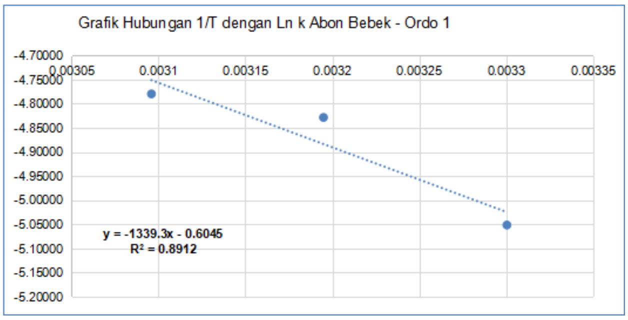

Figure 7.. Changes in the Arrhenius Plot Graph of the correlation between Ln k and (1/T) Shredded Duck "Cahyo" FFA Values Reaction Order One

3.6.2. Convert Shelf Life to Expiration Time

Transforming shelf life into expiration time can be achieved through accelerated repository techniques like ASLT or ASS. Among the various techniques to convert shelf life into expiration time, the numerical technique used in this study is the most effective for demonstrating the principle of this conversion. Shelf life under specific conditions equates to expiration time. However, expiration time is typically calculated for a single condition, such as 30˚C, 40˚C, or 50˚C, while expiration time is a generalized concept [26].

This is feasible because the conditions are considered cumulatively. Following the manufacturing process, Shredded Duck "Cahyo" is stored in warehouses, undergoes distribution, and is later placed in a retail repository before being available to consumers. Consequently, the conversion of shelf life to expiration time needs to consider the diverse repository conditions it goes through.

The following calculations decide the shelf life of shredded duck "Cahyo" stored at 20˚C (293 K) and 25˚C (298 K), which are the actual repository thermal states used by PT. Rumah Makan Deltasari Indah:

For repository at 20˚C or 293˚K:

ln k = -1339,3 (1/T) - 0,6045

ln k = -1339,3 (1/293) - 0,6045

ln k = -3.96648976109215

k = 0.0189397998077591

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 1{,}768 - \ln 1{,}491}{0.0189397998077591}$$

t = 68 days

For repository at 25˚C or 298˚K:

ln k = -1339,3 (1/T) - 0,6045

ln k = -1339,3 (1/298) - 0,6045

ln k = -3.88979530201342

k = 0.0189397998077591

$$t = \frac{\ln A_0 - \ln A}{k}$$

$$t = \frac{\ln 1{,}768 - \ln 1{,}491}{0.0204495315874787}$$

t = 63 days

Given that the two thermal states mentioned play a significant role in the repository conditions of shredded duck "Cahyo" in supermarkets, minimarkets, or retail stores, the expiry period can be determined by computing the mean of the two shelf lives based on the Free Fatty Acid (FFA) value criteria.

Expiration time of shredded duck "Cahyo" = (68 days + 63 days)/2= 65.5 days

The analysis reveals that the shelf life of shredded duck "Cahyo" in supermarkets or convenience stores, kept within a projected thermal state range of 20°C to 25°C, is determined to be 65.5 days. This calculation is predicated on the crucial criterion of the FFA value.

4. CONCLUSION

The study concludes that the FFA content is the critical criterion for determining the shelf life of Shredded Duck "Cahyo" This is determined by the unique blend of the minimum activation energy (Ea), a notably high R2 value, and the briefest shelf life. The shelf life estimated utilizing the FFA criterion at repository thermal states of 30°C, 40°C, and 50°C amounts to 58 days, 51 days, and 44 days, respectively. At PT Deltasari Indah Restaurant, the designated repository thermal states of 20°C and 25°C determine an average shelf life of 65.5 days.

ACKNOWLEDGMENT

The authors extend their heartfelt gratitude to the professors and staff at the Department of Food Technology, Universitas Pembangunan Nasional "Veteran" East Java, for their guidance, advice, and support in the creation of this manuscript.

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