Estimation of Shelf Life of Pegagan Tea (*Centella asiatica* (L) Urban) using Accelerated Shelf Life Testing (ASLT) Method with Arrhenius Model

Pendugaan Umur Simpan Teh Pegagan (Centella asiatica (L) Urban) menggunakan Metode Accelerated Shelf Life Testing (ASLT) Model Arrhenius

Kavadya Syska[1], Ropiudin[2], Etik Rudiyanti[1], Asti Dewi Nurhayati[1], Fatimah Wahdah[1]

[1] Teknologi Pangan, Fakultas Sains dan Teknologi, Universitas Nahdlatul Ulama Purwokerto
Jl. Sultan Agung No.42, Kabupaten Banyumas, Jawa Tengah 53145, Indonesia
[2] Teknik Pertanian, Fakultas Pertanian, Universitas Jenderal Soedirman
Jl. Profesor DR. HR Boenyamin No.708, Kabupaten Banyumas, Jawa Tengah 53122, Indonesia

email: syska.kavadya@gmail.com

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ABSTRACT

This research aimed to evaluate the shelf life of pegagan (*Centella asiatica* (L) Urban) tea using the Accelerated Shelf Life Testing (ASLT) method by applying the Arrhenius Model since its widely known for its various health benefits, including its ability to enhance cognitive function and exhibit antioxidant effects. The ASLT method was employed to accelerate the chemical and physical changes in the product, thereby enabling a shorter estimation of shelf life compared to conventional methods. In this research, samples of pegagan tea were packaged in paper sacks, aluminum foil, and vacuum-sealed plastic and stored at temperatures of 15, 30, and 45 °C for 28 days, with observations conducted every 7 days. The Arrhenius Model was utilized to predict the rate of chemical reactions in the product, taking into account the temperature's influence on these changes. The data were analyzed using Analysis of Variance (ANOVA) at a 5% confidence level. If the ANOVA results showed significant differences, Duncan Multiple Range Test (DMRT) was further conducted. The results of the observations indicated that storage temperature and packaging type significantly influenced the yield value and pH value, but had no significant effect on the moisture content of pegagan tea. The estimated shelf life of pegagan tea for 28 days using paper sack packaging at temperatures of 15, 30, and 45 °C was 173, 616, and 195 days, respectively. For aluminum foil packaging, the estimated shelf life was 189, 661, and 205 days at the same temperatures. As for vacuum-sealed plastic packaging, the estimated shelf life was 551, 192, and 597 days at the respective temperatures. The findings of this research are expected to provide valuable information for manufacturers and consumers regarding the shelf life of pegagan Tea. Additionally, the research

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aims to offer a scientific basis for appropriate packaging and storage practices to better maintain the product's quality.

ABSTRAK
Penelitian ini bertujuan untuk mengevaluasi umur simpan teh pegagan (Centella asiatica (L) Urban) menggunakan metode Accelerated Shelf Life Testing (ASLT) dengan menerapkan Model Arrhenius. Teh pegagan telah dikenal luas karena manfaat kesehatan yang beragam, termasuk kemampuannya dalam meningkatkan fungsi kognitif dan efek antioksidan. Metode ASLT digunakan untuk mempercepat proses perubahan kimia dan fisik dalam produk, sehingga memungkinkan pendugaan umur simpan dalam waktu lebih singkat dibandingkan dengan metode konvensional. Pada penelitian ini, sampel teh pegagan dikemas menggunakan kemasan paper sack, aluminium foil dan plastik vakum dan disimpan pada suhu 15, 30, dan 45 °C selama 28 hari dan pengamatan dilakukan setiap 7 hari. Model Arrhenius digunakan untuk memprediksi laju reaksi kimia dalam produk dengan mempertimbangkan efek suhu terhadap perubahan ini. Data dianalisis menggunakan Analysis of Varians (ANOVA) dengan tingkat kepercayaan 5% jika hasil ANOVA menunjukkan perbedaan yang signifikan, dilanjutkan dengan Duncan Multiple Range Test (DMRT). Hasil pengamatan didapatkan bahwa suhu penyimpanan dan jenis kemasan berpengaruh nyata terhadap nilai rendemen dan nilai pH, namun tidak berpengaruh nyata terhadap kadar air teh pegagan. Nilai umur simpan teh pegagan selama 28 hari menggunakan kemasan paper sack pada suhu 15, 30, dan 45 °C berturut-turut adalah 173, 616, 195 hari, kemasan aluminium foil 189, 661, 205 hari, dan kemasan plastik vakum 551, 192, 597 hari. Hasil penelitian ini diharapkan dapat memberikan informasi berharga kepada produsen dan konsumen mengenai umur simpan teh pegagan, serta memberikan dasar ilmiah untuk pengemasan dan penyimpanan yang tepat guna mempertahankan kualitas produk dengan lebih baik.

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1. Introduction

Centella asiatica (L.) Urban, commonly known as "pegagan," is an herbal beverage extensively used in traditional medicine across various cultures [1]. The pegagan plant has a long history of use for diverse purposes, including its traditional application to enhance cognitive function, alleviate stress, and aid specific skin conditions [2]. Furthermore, this plant is renowned for its bioactive compounds, such as triterpenoids, asiaticoside, and madecassoside, which have the potential to promote overall health [3]. In the herbal product industry, ensuring the quality and stability of products during storage is crucial [4]. Physical, chemical, and microbiological changes that occur during storage can influence the expected health benefits of pegagan tea [4], [5]. Therefore, scientific research is necessary to accurately and efficiently evaluate the shelf life of pegagan tea.

Estimating the shelf life is a critical aspect of herbal product development, including pegagan tea [6]. Conventional methods for determining shelf life can be time-consuming and require observing the product under natural storage conditions, which may not represent products with an extended shelf life [7]. Therefore, there is a need for an approach that can accelerate the shelf-life determination process while considering the changes that occur in the product over a shorter period of time.

Shelf life is the time during which a food product remains suitable for consumption, starting from the date of production until it experiences a decline in quality or becomes unfit for consumption [8], [9]. Shelf life is an essential parameter that should be included in the packaging of food products [10]. Information about shelf life is intended to ensure that the product maintains its quality when consumed and does not pose any health hazards to consumers [11], [12]. By estimating the shelf life, it can be determined how long a product can be stored before it is consumed [13].

The estimation of shelf life can be carried out using the Accelerated Shelf-life Testing (ASLT) method, which involves subjecting food products to storage conditions that accelerate their deterioration, such as higher temperatures or humidity [14], [15]. Accelerated testing allows for a shorter duration of experimentation while maintaining good accuracy [16]. This method utilizes the Arrhenius equation as a linear model, which demonstrates the relationship between temperature and storage time [17]. It is considered the most valid and suitable approach, especially for high-temperature storage during the storage period [18]. By employing this model, researchers can extrapolate and predict the product quality changes at lower storage temperatures and over longer periods, thereby enabling a faster and more efficient estimation of shelf life.

This research aims to evaluate the shelf life of pegagan tea using the Accelerated Shelf Life Testing (ASLT) method with the application of the Arrhenius Model [19]. The ASLT method allows for the simulation and acceleration of chemical and physical changes in the product by creating tightly controlled storage conditions [20]. By applying the Arrhenius Model, the activation energy of chemical reactions in pegagan tea at various storage temperatures will be estimated, enabling the prediction of its shelf life under different temperature conditions [21].

2. Materials and Methods

2.1 Materials and Equipment

The material used to make the pegagan tea is fresh pegagan leaves. The materials used for the analysis are distilled water, paper sacks, aluminum foil, and vacuum plastic. The instruments employed in this research include an oven, digital scale, baking pan, heat sealer, pH meter, and refrigerator. Additionally, various auxiliary tools consist of porcelain cups, beakers, and tongs. This research utilizes the Completely Randomized Design (CRD) Factorial method with 2 factors. The first factor is the type of packaging, consisting of 3 experimental levels: paper sack, aluminum foil, and vacuum plastic (@2g). Meanwhile, the second factor is the storage temperature, comprising 3 experimental levels: 15, 30, and 45 °C, resulting in a total of 9 treatment combinations. Each treatment combination is replicated 3 times, leading to a total of 27 experimental units.

1. Sample Preparation: Prepare samples of pegagan tea in a way that reflects the actual conditions of the product as closely as possible.
2. ASLT Procedure: Expose the samples to elevated temperatures for a specific period. This is usually done in a controlled environment, such as an oven or environmental chamber.
3. Temperature and Humidity:
   - The temperature and humidity conditions during ASLT are crucial. Typically, higher temperatures are chosen to accelerate the degradation process. The specific temperature would depend on the characteristics of the tea and the intended storage conditions. Common temperatures for ASLT range from 30 to 50 °C.
   - The relative humidity (RH) during ASLT should be considered, especially if the product is sensitive to moisture. However, in some cases, ASLT is conducted at constant humidity.
4. Drying Process:
   - If a drying process is involved, it would depend on the characteristics of the tea and the desired final product. Drying is often done to reduce moisture content and inhibit microbial growth.
   - The type of dryer can vary, such as conventional ovens, vacuum dryers, or freeze dryers, depending on the specific requirements of the product.
5. Arrhenius Model:
   - After exposure to elevated temperatures, measure the relevant quality parameters (e.g., chemical composition, sensory attributes) at different time points.

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- Use the Arrhenius equation to model the relationship between temperature and the rate of degradation. The equation is often expressed as $k = Ae^{(-Ea/RT)}$, where k is the rate constant, A is the pre-exponential factor, Ea is the activation energy, R is the gas constant, and T is the absolute temperature.

6. Extrapolation to Normal Storage Conditions: Use the Arrhenius model to extrapolate the data to the normal storage conditions and estimate the shelf life.

This research employs the Accelerated Shelf Life Testing (ASLT) method with the Arrhenius model. Observations were conducted on days 7, 14, 21, and 28 for each storage temperature. The parameter tested for estimating the shelf life using the ASLT Arrhenius model is the water content test data. The experimental design model in this research can be seen in **Table 1.**

Table 1. Experimental Design Model

Type of packaging (K)	Storage temperature (T)	Replication Group		
		I	II	III
Paper sack (K1)	15 °C (T1)	K1T1	K1T1	K1T1
	30 °C (T2)	K1T2	K1T2	K1T2
	45 °C (T3)	K1T3	K1T3	K1T3
Aluminium foil (K2)	15 °C (T1)	K2T1	K2T1	K2T1
	30 °C (T2)	K2T2	K2T2	K2T2
	45 °C (T3)	K2T3	K2T3	K2T3
Vacuum plastic (K3)	15 °C (T1)	K3T1	K3T1	K3T1
	30 °C (T2)	K3T2	K3T2	K3T2
	45 °C (T3)	K3T3	K3T3	K3T3

2.3 Variable and Measurement

The variables measured in this research are weight loss determination, pH value, water content, and estimation of shelf life using the ASLT Arrhenius model. The following is an explanation of the details of the research variables:

2.3.1 Yield

The yield calculation according to [22] is performed by comparing the mass of dried pegagan with the mass of fresh pegagan before the drying process (**Equation 1**).

$$\text{Yield} = \frac{Final\ mass}{Initial\ mass} \times 100\% \qquad (1)$$

2.3.2 Analysis of Acidity Level (pH)

The pH value measurement was carried out using a calibrated pH meter with pH 4 and 7 buffers. The electrode was rinsed with distilled water and dried with a tissue. Subsequently, the electrode was immersed in the sample until a stable scale reading was obtained.

2.3.3 Moisture Contents

The analysis of moisture content begins by drying an empty crucible in an oven for 1 hour and weighing it. Next, 2 grams of pegagan tea are weighed and placed into the pre-weighed crucible. The pegagan tea is then dried in the oven at 105 °C for 24 hours, cooled in a desiccator for 15 minutes, and weighed. Subsequently, the pegagan tea is returned to the oven for 30 minutes, cooled again in the desiccator, and weighed. This procedure is repeated until the sample reaches a constant weight, which is calculated using the **Equation 2**.

$$\%\ \text{Moisture contents (b/k)} = \frac{Initial\ Weight\ (g) - Final\ Weight\ (g)}{Final\ Weight\ (g)}\ x\ 100\% \qquad (2)$$

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2.3.4 Estimation of Shelf Life
The data from the analysis of each parameter is plotted against time (days) and a linear equation is obtained (**Equation 3**).

$$y = ax + b \quad (3)$$

Description:
y : the value of the product characteristic
x : storage time (days)
a : rate of change of the characteristic
b : initial value of the product characteristic

The selection of the reaction order for a specific parameter is performed by comparing the regression values (R^2) for each linear equation at the same temperature. The reaction order with a higher R^2 value is considered to be the reaction order used by that particular parameter. Once the linear equations are obtained for each storage temperature, the slope value (**Equation 3**), which indicates the change in the product characteristic, is calculated as ln a for plotting in the Arrhenius equation (Equation 4). In the Arrhenius equation, ln a represents the natural logarithm of the rate constant (ln k), plotted against 1/T (K-1). From the Arrhenius equation, the slope and intercept values of the linear regression equation are determined (**Equation 4**).

$$\ln k = \ln k_0 - \frac{(Ea/R)}{(1/T)} \quad (4)$$

Description:
k_0 : refers to the intercept
Ea/R : represents the slope
Ea : denotes the activation energy
R : Ideal gas constant (1.986 cal/mol).

From the equation, the value of constant k_0 represents the exponential factor indicating the quality reduction when stored at normal temperature, and the value of activation energy (Ea) represents the reaction's energy barrier for the change in the product characteristic. Furthermore, the model for the reaction rate equation concerning temperature is determined, and the value of k, indicating the product's quality reduction, can be calculated using **Equation 5**.

$$k = k0 . e^{-Ea/RT} \quad (5)$$

Based on the Arrhenius equation (**Equation 4**) and the calculation of the value of k (**Equation 5**), the shelf life of pegagan tea can be determined using the reaction order **Equation 6** and **Equation 7**.

$$t_{\text{zero order}} = \frac{\Delta A}{k} \quad (6)$$

$$t_{\text{first order}} = \frac{\ln(A0/A)}{k} \quad (7)$$

Description:
t : represents the predicted shelf life (days)
ΔA : denotes the change in product quality
A0 : initial quality value
A : remaining product quality value at time t
k : constant for quality reduction at normal temperature

2.4 Data Analysis
The data processing for this research was conducted using Analysis of Variance (ANOVA) with Microsoft Excel 2019 data analysis tool. If a significant difference in treatments is found, it will be followed by Duncan Multiple Range Test (DMRT) analysis.

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3. Results and Discussion

3.1 Yield

In this research, the yield is used to indicate the overall loss during the process of manufacturing pegagan tea. The yield is determined by comparing the mass of dried pegagan leaves with the mass of fresh pegagan leaves. The yield test results for pegagan tea are presented in **Figure 1**, showing the average yield values obtained from the analysis calculations.

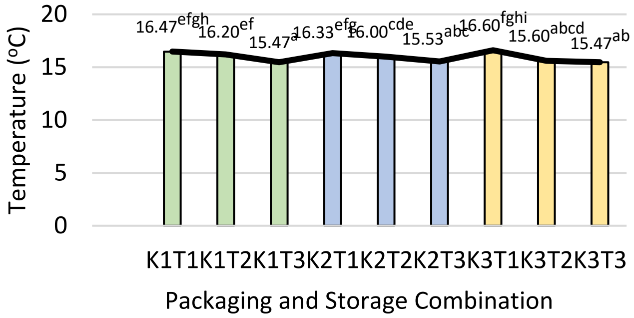

Figure 1. Analysis of pegagan tea yield

By **Figure 1**, the results indicate that the highest yield value is achieved in treatment K3T1, where vacuum plastic packaging is used with a storage temperature of 15 °C, resulting in a yield of 16.60%. Conversely, the lowest yield value is observed in treatment K1T3, which involves paper sack packaging with a storage temperature of 45 °C, yielding 15.47%.

Investigations have shown that storage temperature and packaging type have a statistically significant impact on the yield of pegagan tea at a 5% significance level. As mentioned in [23], the reduction in yield persists with increasing temperature and longer drying durations during the drying process. This phenomenon is attributed to the reduction in moisture content due to heating. Additionally, [24] confirms that an extended drying time leads to a decrease in the yield of herbal tea made from sungkai leaves, as the yield decreases with the prolonged drying duration.

3.2 Analysis of Acidity Level (pH)

The pH value is utilized to indicate the acidity or alkalinity level of a solution. In the case of a food product, the pH value plays a crucial role in determining its resistance to the growth of spoilage microorganisms during processing, distribution, and storage. The pH test conducted on the infusion of pegagan tea resulted in data for average pH values, which are shown in **Figure 2**.

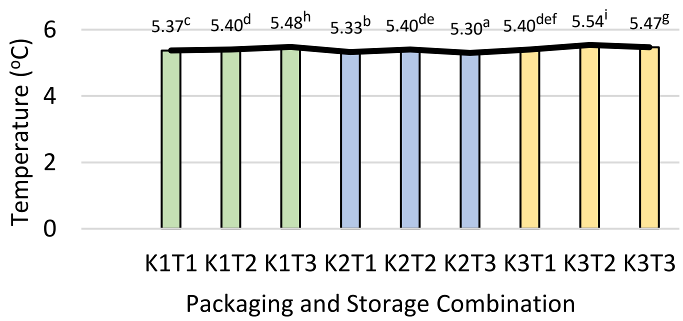

Figure 2. Analysis of pegagan tea pH

Based on the data presented in **Figure 2**, it is evident that the highest pH value is achieved in treatment K3T2, where vacuum plastic packaging is used with a storage temperature of 30 °C, resulting in a pH of 5.54. Conversely, the lowest pH value is observed in treatment K2T3, which involves aluminum foil packaging with a storage temperature of 45 °C,

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yielding a pH of 5.30. The pH of pegagan tea increases at a storage temperature of 30 °C but relatively decreases at a storage temperature of 45 °C. The most favorable pH value for pegagan tea is obtained in treatment K2T3, characterized by aluminum foil packaging and a storage temperature of 45 °C, yielding a pH of 5.30. A lower pH value indicates that pegagan tea will have a longer shelf life, primarily due to the inhibitory effect of low pH on microbial growth, resulting in increased durability of pegagan tea.

The storage temperature and type of packaging exhibit statistically significant differences at a 5% significance level in relation to the acidity level (pH) of pegagan tea. The pH test results presented in Figure 2 vary from 5.30 to 5.54. These outcomes are in line with the findings of research conducted by Muzaki and Ratna (2015), which reported average pH values ranging from 4.837 to 5.730 for the infusion of South African herbal tea leaves (*Vernonia amygdalina*) during pH tests.

3.3 Moisture Content

Moisture content represents the quantity of water contained within a food substance, expressed as a percentage (%). The determination of moisture content is based on the weight difference between the samples before and after drying. The results of the moisture content test conducted on pegagan tea are presented in **Figure 3** based on the observation in 28 day, displaying the average moisture content values obtained from the analysis calculations.

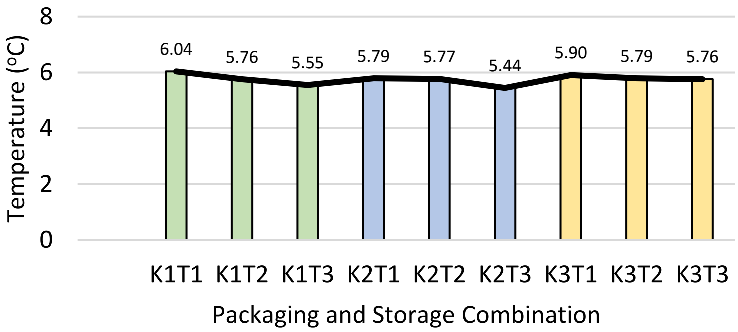

Figure 3. Analysis of pegagan tea moisture content

Following the data presented in **Figure 3**, the highest moisture content value is obtained in treatment K1T1, involving paper sack packaging with a storage temperature of 15 °C, resulting in a moisture content value of 6.04% on a wet basis. Conversely, the lowest moisture content value is observed in treatment K2T3, which includes aluminum foil packaging storage temperature of 45 °C, yielding a moisture content value of 5.44% wb.

The storage temperature and type of packaging do not show a statistically significant difference at a 5% significance level with the moisture content of pegagan tea. This lack of significant difference is attributed to the consistent temperature and drying duration across all treatments, resulting in minimal impact on the moisture content of pegagan tea. This observation aligns with the findings of research [25], which suggests that adding stevia leaf powder to mulberry leaf tea does not lead to a significant change in its moisture content. The moisture content of mulberry leaf tea remains unaffected due to the consistent drying temperature and duration across all treatments, resulting in no notable influence on the moisture content.

The results of the moisture content test shown in **Figure 3** range from 5.44% to 6.04%. These values are in line with the standard for desirable tea moisture content. According to SNI (2013) No. 01-3836-2013 on packaged dried tea, the maximum allowable moisture content for tea products is 8%. As explained in [23], the reduction in moisture content of a material is influenced by convective mass transfer on the material's surface. The decrease in moisture content with increasing temperature is due to the increased evaporation of water molecules from the material.

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3.4 The Weight Changes of Pegagan Tea During Storage

In vacuum plastic packaging, at a storage temperature of 15 °C, the weight of pegagan tea changed on day 7 (0.10), day 14 (0.08), day 21 (0.06), and day 28 (0.09). At a storage temperature of 30 °C, the weight changed on day 7 (0.10), day 14 (0.16), day 21 (0.15), and day 28 (0.21). At a storage temperature of 45 °C, the weight changed on day 7 (0.9), day 14 (0.6), day 21 (0.8), and day 28 (0.12). The data of pegagan tea weight changes during storage can be seen in **Table 2**, **3**, and **4**.

Table 2. Average weight analysis results of pegagan tea during storage in paper sack packaging

Day	Temperature (°C)		
	15	30	45
7	2.26	2.43	2.12
14	2.26	2.43	2.17
21	2.27	2.43	2.21
28	2.27	2.48	2.21

Table 3. Average weight analysis results of pegagan tea during storage in aluminum foil packaging

Day	Temperature (°C)		
	15	30	45
7	2.07	2.14	2.06
14	2.17	2.21	2.17
21	2.08	2.20	2.09
28	2.11	2.20	2.46

Table 4. Average weight analysis results of pegagan tea during storage in vacuum plastic packaging

Day	Temperature (°C)		
	15	30	45
7	2.10	2.10	2.09
14	2.08	2.16	2.06
21	2.06	2.15	2.08
28	2.09	2.21	2.12

Throughout the storage period, pegagan tea undergoes an increase in weight, which is affected by the storage temperature and duration. As mentioned in [26], the rise in moisture content during storage is a result of the high humidity in the surrounding environment.

3.5 Estimating Shelf Life of Pegagan tea

Estimation of shelf life begins with constructing a regression model to establish the relationship between observed sample weight parameters and storage duration. The values of the linear regression equation for the sample weight of pegagan tea during storage under different temperatures and packaging can be seen in **Tables 5**, **6**, and **7**.

Table 5. The linear regression equation for the weight of pegagan tea in paper sack packaging

Temperature (°C)	Linear regression equation		R^2	
	Ordo 0	Ordo 1	Ordo 0	Ordo 1
15	-0.7775x + 6,7206	-1.103x + 6.9011	0.0709	0.1237
30	-5.5017x + 29,967	-5.817x + 29.987	0.4985	0.4994
45	-8.5482x + 44,937	-8.837x + 44.971	0.4982	0.4992

Table 6. The linear regression equation for the weight of pegagan tea in aluminum foil packaging

Temperature (°C)	Linear regression equation		R^2	
	Ordo 0	Ordo 1	Ordo 0	Ordo 0
15	-0.8025x + 6.7169	-1.115x + 6.700	0.0745	0.1255
30	-5.5528x + 29.965	-5.839x + 29.984	0.4984	0.4993
45	-8.5029x + 44.773	-8.818x + 44.900	0.4934	0.4969

Table 7. The linear regression equation for the weight of pegagan tea in vacuum plastic packaging

Temperature (°C)	Linear regression equation		R^2	
	Ordo 0	Ordo 1	Ordo 0	Ordo 1
15	-0.810x + 6.7259	-1.118x + 6.904	0.076	0.126
30	-5.552x + 29.937	-5.839x + 29.971	0.497	0.499
45	-8.576x + 44.978	-8.850x + 44.989	0.499	0.500

The selection of the reaction order for a certain parameter is performed by comparing the regression values (R^2) of each linear equation at the same temperature. The reaction order with a higher R^2 value is considered the reaction order used for that parameter. Based on **Tables 5**, **6**, and **7**, it can be observed that the coefficient of determination for first-order reaction is greater than the coefficient of determination for zero-order reaction, indicating that the first-order reaction is the one governing the shelf-life determination of pegagan tea. The determination of the Arrhenius equation is accomplished by plotting the values of ln k against 1/T for the reaction involving the change in the weight of pegagan tea [3]. The results of these ln k and 1/T plots are presented in **Figure 4**, **5**, and **6**.

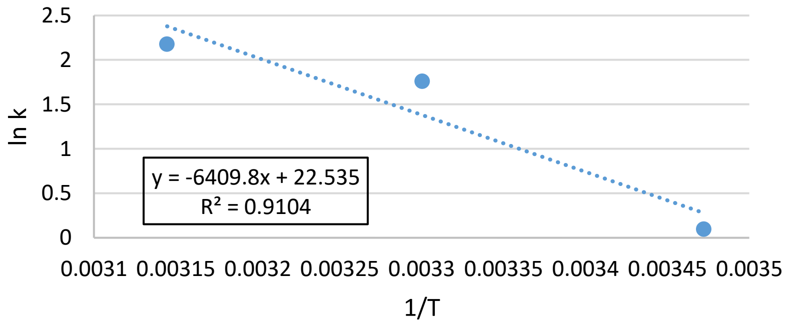

Figure 4. Relationship between ln k and 1/T weight test results for pegagan tea at 15, 30, and 45° C on paper sack packaging

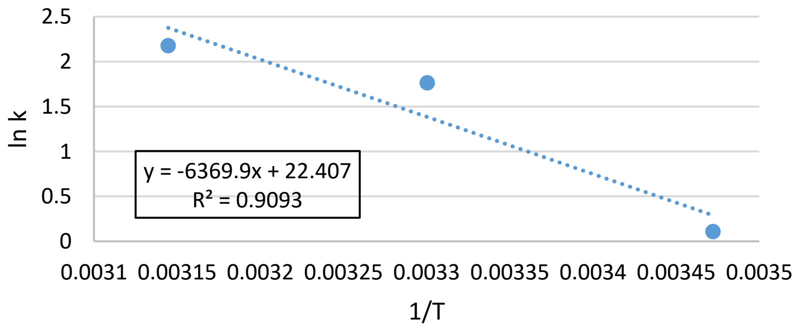

Figure 5. Relationship between ln k and 1/T weight test results for pegagan tea at 15, 30, and 45 °C on aluminum foil packaging

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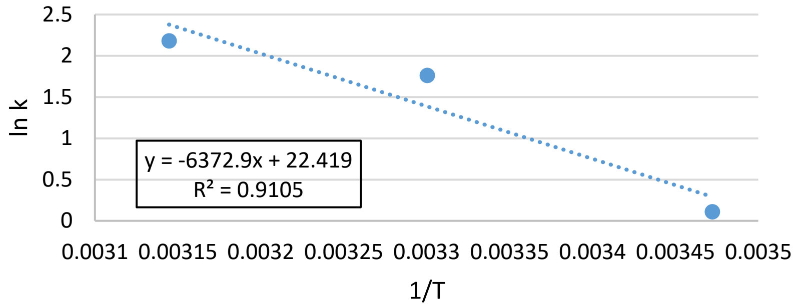

Figure 6. Relationship between ln k and 1/T weight test results for pegagan tea at 15, 30, and 45 °C in vacuum plastic packaging

The result of plotting the ln k values against 1/T in **Figure 4**, **5**, and **6** yields regression equations, where the slope represents the value of -Ea/R (activation energy divided by the gas constant), and the intercept gives the ln k0 value. The linear regression equations from the ln k and 1/T plots for the change in the weight (mass) parameter of pegagan tea at temperatures in paper sack packaging at 15, 30, and 45 °C are as follows: y = -6409.8x + 22.535 with R^2 = 0.910; in aluminum foil packaging at 15, 30, and 45 °C: y = -6369.9x + 22.407 with R^2 = 0.909; and in vacuum plastic packaging at 15, 30, and 45 °C: y = -6372.9 + 22.419 with R^2 = 0.911. After obtaining the values of k, the shelf life of pegagan tea at temperatures of 15 °C (288K), 30 °C (303K), and 45 °C (318K) is calculated using the Arrhenius equation.

The shelf life (t) is calculated using the kinetic reaction equation based on the reaction order. The parameter of water content follows first-order reaction kinetics and is calculated using **Equation 7**, where Ao represents the initial quality value of pegagan tea before storage, A represents the final quality value of pegagan tea after storage, and t represents the predicted shelf life (days). The determination of the shelf life involves first determining the value of k, which is then used to obtain the shelf life as shown in **Table 8**.

Table 8. Relationship between storage temperature and different packaging

Packaging	Shelf Life		
	15 °C	30 °C	45 °C
Papersack	173	616	195
Aluminum foil	189	661	205
Vacuum Plastic	551	192	597

Based on the table, the obtained shelf life values for pegagan tea during storage for 28 days are as follows: for paper sack packaging at 15 °C, the shelf life is 173 days; at 30 °C, the shelf life is 616 days, and at 45 °C, the shelf life is 195 days. Using the same calculation formula, the shelf-life values for aluminum foil packaging at 15 °C are 189 days, at 30 °C are 661 days, and at 45 °C are 205 days. Furthermore, for vacuum plastic packaging, the shelf-life values at 15, 30, and 45 °C are 551, 192, and 597 days, respectively. The effects of storage conditions on the shelf life of pegagan tea (*Centella asiatica*) or any other product can be influenced by various factors such as temperature, humidity, packaging materials, and the presence of oxygen. In a hypothetical scenario:

1. Vacuum Plastic at 45 °C: High temperatures can accelerate chemical reactions and potentially lead to degradation of the tea. However, if the tea is stored in a vacuum-sealed plastic, it might be protected from factors like oxidation, which can contribute to the preservation of quality. The Arrhenius model is often used to estimate the impact of temperature on the rate of chemical reactions, but the success of this approach depends on various factors, including the specific characteristics of the product.

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2. Vacuum Plastic at 30 °C: If the temperature is lower, the rate of chemical reactions may slow down, potentially extending the shelf life. However, the vacuum-sealed plastic may not provide as much protection against oxidation at this lower temperature compared to the higher temperature scenario.
3. Paper Sack and Aluminum Foil at 30 °C: The combination of paper sack and aluminum foil could provide effective protection against light and oxygen, which are factors that can contribute to the degradation of tea. Additionally, the lower temperature might slow down the rate of chemical reactions, contributing to a longer shelf life.

It's essential to note that the specific effects of storage conditions can vary based on the unique characteristics of the tea, packaging materials, and the specific conditions used in the research. Storage temperature is one of the most critical factors that will affect the moisture content of the product. According to [27], the higher the storage temperature used, the higher the temperature inside the packaging, leading to increased water vapor absorption in the tea. As the storage temperature increases, the rate of quality degradation also increases, resulting in a shorter shelf life. The increasing moisture content is influenced by changes in temperature and the duration of storage [28].

The estimation of the shelf life of pegagan tea using the Accelerated Shelf Life Testing (ASLT) method with the Arrhenius model indicates that the shelf life of pegagan tea in aluminum foil packaging at 30 °C tends to be longer compared to other packaging types. This finding is consistent with research [29], which states that higher storage temperatures result in a shorter shelf life.

Aluminum foil packaging is known for its ability to impede the rate of water and gas evaporation, thus slowing down the increase in moisture content. Aluminum foil packaging also exhibits flexible, hermetic, light-blocking properties, excellent heat conductivity, and low permeability [29]. These characteristics align with the findings of research [30], which state that bamboo leaves stored in aluminum foil packaging have the lowest moisture content after 42 days of storage. The same research [30] also indicates that coffee powder packaged in aluminum foil experiences a slower rate of quality degradation compared to plastic packaging.

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