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Shelf-Life Estimation of Dried Sago Noodles Using the Accelerated Shelf-Life Testing (ASLT) Method

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Abstract

Indonesia holds significant potential for sago (Metroxylon sagu Rottb.) development, especially in the eastern regions. Sago starch offers an alternative to wheat flour in noodle production, promoting local food diversification. This study aims to estimate the shelf-life of dried sago noodles using the Accelerated Shelf-Life Testing (ASLT) method based on selected quality parameters. Dried sago noodles were produced from sago starch originating from Merauke, South Papua. The packaging uses polyethylene film (thickness 0.10). Each package contains a 250 gram sample and stored at 35°C, 45°C, and 55°C. Quality attributes—moisture content, aroma, and taste—were analyzed during storage to model degradation kinetics and determine activation energy (Ea) using the Arrhenius approach. Among the tested parameters, aroma exhibited the lowest activation energy (636.04 cal/mol), indicating it as the critical parameter for predicting shelf-life. Based on the regression of ln k versus 1/T, the shelf-life at 27°C (room temperature) was estimated at 49 days. The study concludes that aroma degradation is the key factor in determining the shelf-life of dried sago noodles, and that accurate sensory evaluation using trained panelists is crucial for improving the reliability of shelf-life prediction.

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1. Introduction

Indonesia has significant potential in the development of sago cultivation, with an area covering approximately 51% of the total 2.3 million hectares of sago plantations worldwide. Around 90% of this potential is in the Papua and Maluku regions (Sidiq et al., 2021). Sago (Metroxylon sagu Rottb.) has long been known as a local food staple, particularly in eastern Indonesia, especially Papua (Widayanti et al., 2016). Along with the advancement of food innovation, sago is no longer limited to traditional forms such as papeda but has also been processed into a variety of food products including sago porridge, sago cendol, sago biscuits, and sago noodles (Putri et al., 2019).

Noodles are one of the most popular food products in Indonesia and are often consumed as an alternative to rice. In general, noodles are made from wheat flour, a commodity that is still largely

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imported (Engelen et al., 2015). To reduce dependency on wheat imports, efforts toward local food diversification are necessary. One promising strategy is the use of sago starch as a raw material for noodle production (Patty et al., 2023).

In the food industry, determining shelf-life is crucial to ensure product safety and comply with labelling requirements. Shelf-life provides consumers with information regarding the safe consumption period (Herawati, 2008), and it is also a mandatory requirement for food marketing as stated in Indonesian Law No. 8 of 1999, Article 8, point 1, letter (g) (Sari, 2023). Conventional shelf-life testing requires long durations and high costs due to the need for real-time storage. Therefore, the Accelerated Shelf-Life Testing (ASLT) method serves as an efficient alternative. ASLT accelerates product degradation by subjecting the product to elevated or extreme storage temperatures (Haouet et al., 2018).

Each food product has different quality parameters and durability characteristics, requiring tailored shelf-life assessment approaches. Several previous studies have applied the ASLT method for estimating the shelf-life of sago noodles, such as in instant noodles based on sago and patin fish (Yusmarini et al., 2013) and in sweet potato sago noodles (Nurlia, 2017). Based on these considerations, this study aims to estimate the shelf-life of dried sago noodles made from sago starch using the Accelerated Shelf-Life Testing (ASLT) method, considering relevant quality parameters.

2. Material and Methods

This study utilized both primary and supplementary materials. The primary material was sago starch, used in the production of sago noodles. The sago starch was sourced from Tambat Village, Tanah Miring District, Merauke Regency, South Papua Province. The supplementary materials included water and table salt. The equipment used to produce dried sago noodles included a stove, steamer, gloves, measuring cups, scales, a noodle roller, buckets, and polypropylene (PP) plastic packaging. Additionally, for shelf-life estimation, the following equipment was used: electric oven, desiccator, gloves, analytical balance, sample plastic bags, labeling paper, and spoons.

This study consists of two main stages: the production of dried sago noodles and the estimation of shelf-life using the Accelerated Shelf-Life Test (ASLT) method. The first stage involves the production process of dried sago noodles, which begins with the mixing of raw materials, followed by boiling, drying, and packaging. The packaged noodles are then used as samples for shelf-life testing. The second stage is the shelf-life estimation using the ASLT approach. Noodle samples are stored under three different temperature conditions—35 °C, 45 °C, and 55 °C—to accelerate the degradation reactions related to shelf-life. During the storage period, observations and analyses are conducted on several quality parameters used as indicators of quality deterioration, namely moisture content, aroma, taste, and color.

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The observational data are used to model the quality degradation over time and temperature. The results are analyzed to determine the degradation reaction rate and activation energy (E_a) using either zero-order or first-order kinetics, depending on the characteristics of the quality parameter. Subsequently, the shelf-life of dried sago noodles at ambient temperature is estimated using the Arrhenius equation. The overall research procedure is illustrated in Figure 1.

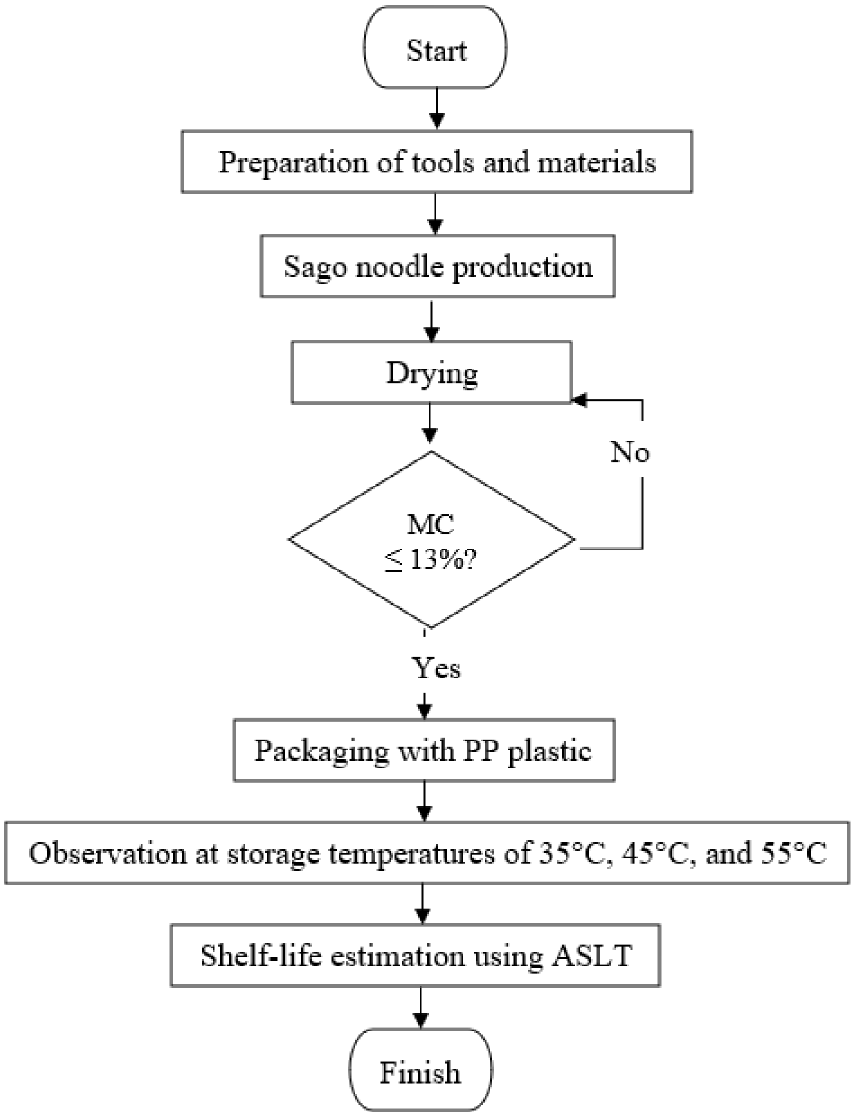

Figure 1. Research Flowchart.

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2.1 Dried Sago Noodle Production

The production of dried sago noodles followed the procedure and formulation previously established by Engelen et al. (2015). The process began with the preparation of raw materials, including sago starch, binder, water, and salt. The binder was made by cooking sago starch in boiling water until gelatinized, functioning as a dough adhesive. All ingredients were mixed and stirred until a homogeneous dough was formed, then shaped using a noodle extruder. The extruded noodles were steamed in boiling water and subsequently sun-dried until the moisture content reached ≤13%. Moisture content was measured using the gravimetric method. Products with a moisture content of ≤13% were packaged in polypropylene (PP) plastic, each weighing 250 g. Products with moisture content exceeding 13% were re-dried until they met the requirement. The packaged products were then used for shelf-life testing using the ASLT method.

2.2 Accelerated Shelf-Life Test (ASLT)

Sago noodle was stored in three separate storage chambers set at different temperatures: 35°C, 45°C, and 55°C. Samples at each temperature were observed every seven days, with quality parameters including moisture content, aroma, taste, and color. Observations were conducted until most panelists deemed the product unacceptable. The observation data were plotted against storage time for each temperature to determine the relationship between time and quality degradation. The slope of the graph indicates the rate of deterioration (k value). Activation energy was calculated using Equation 1(Nurhayati et al., 2017) :

$$\ln k = \ln k_0 - \frac{E_a}{R} \cdot \frac{1}{T} \qquad (1)$$

Where: k= reaction rate constant, k_0 = frequency factor, Ea = activation energy (kcal/mol), R = universal gas constant (1.986 kcal/mol·K), T = absolute temperature (K).

A plot of ln k versus 1/T was used to obtain E_a (activation energy) and k_0. The parameter with the lowest activation energy (E_a) is considered the most susceptible to deterioration and is therefore used as the determining factor for shelf-life estimation. The parameter used to determine the shelf-life of dried sago noodles was aroma; thus, the shelf-life equation is expressed as Equation 2 (Nurhayati et al., 2017).

$$t_s = \frac{N_0 - N_t}{k} \qquad (2)$$

Where: N_0 = initial quality attribute value, N_t = final (threshold) quality attribute value, k = reaction rate constant, t_s = shelf-life (days).

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3. Results and Discussion

3.1 Dried Sago Noodle Production

The mixing of raw materials for sago noodle production yielded 13.57 kg of noodle dough. After steaming in boiling water for 2 minutes, the noodle weight increased to 13.70 kg. The final product resulted in dried sago noodles weighing 8.75 kg with an average moisture content of 9.4%. The appearance of the noodles before drying is shown in Figure 2(a), while Figure 2(b) displays the dried sago noodles.

Figure 2. Sago Noodle Production Results: (a) After Steaming and (b) After Drying.

3.2 Shelf-Life Estimation

The first step in determining shelf-life is to establish a regression relationship between the quality parameter and the storage duration. The x-axis of the curve represents the storage time of the dried sago noodles, while the y-axis represents the observed parameter values. Linear regression graphs of zero-order and first-order kinetics were constructed based on the measurement results of each parameter, in order to identify the model with the highest coefficient of determination (R^2). This serves as the basis for justifying which reaction order will be used to estimate the product's shelf life.

3.3 Moisture Content

Moisture content refers to the amount of water present in a material or food product. The presence of water in food significantly affects its shelf-life. A lower moisture content is one of the key factors that contributes to longer shelf stability of food products (Kurnia et al., 2021). The results of moisture content measurements in dried sago noodles are presented in Figure 3.

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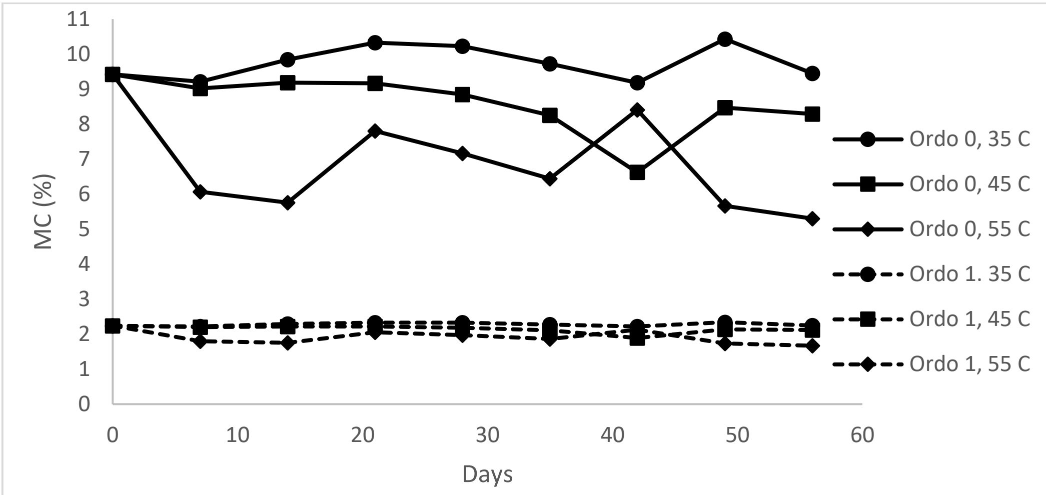

Figure 3. Moisture Content Measurement Results of Fried Sago Noodles.

Figure 3 shows that the moisture content at a storage temperature of 35°C tends to increase, which may be attributed to microbial activity. Exposure of the product to oxygen due to non-vacuum packaging (Nisa & Kusharto, 2022) accelerates microbial activity that may still be present in the product. At 45°C and 55°C, the moisture content tends to decrease due to elevated temperatures, as high storage temperatures lead to moisture loss (Heryani et al., 2020). Based on the moisture content measurements of dried sago noodles in Figure 3, the zero-order and first-order regression equations were obtained, as presented in Table 1.

Table 1. Zero-order and First-order Regression Equations of Moisture Content.

T (°C)	Regression Equation		R^2	
	Zero-order	First-order	Zero-order	First-order
35	y = 0.0109x + 9.5263	y = 0.0011x + 2.2537	0.1419	0.1376
45	y = -0.037x + 9.5295	y = -0.0045x + 2.2594	0.4988	0.4607
55	y = -0.0224x + 7.6378	y = -0.0029x + 2.0129	0.0795	0.0684

Based on Table 1, the coefficient of determination (R^2) for the zero-order regression is higher than that of the first-order regression. Therefore, the zero-order reaction model is used to determine the shelf-life of dried sago noodles.

The linear regression equation for moisture content changes in dried sago noodles, as shown in Figure 4, is y = -3728.4x + 7.8608 with R^2 = 0.361. The activation energy (Ea) for moisture content change is 7404.6024 cal/mol, indicating that this amount of energy is required to initiate the change in moisture content. The Arrhenius constant was calculated based on Figure 4, the correlation of ln k (y) with 1/T (x) yields the k values listed in Table 2.

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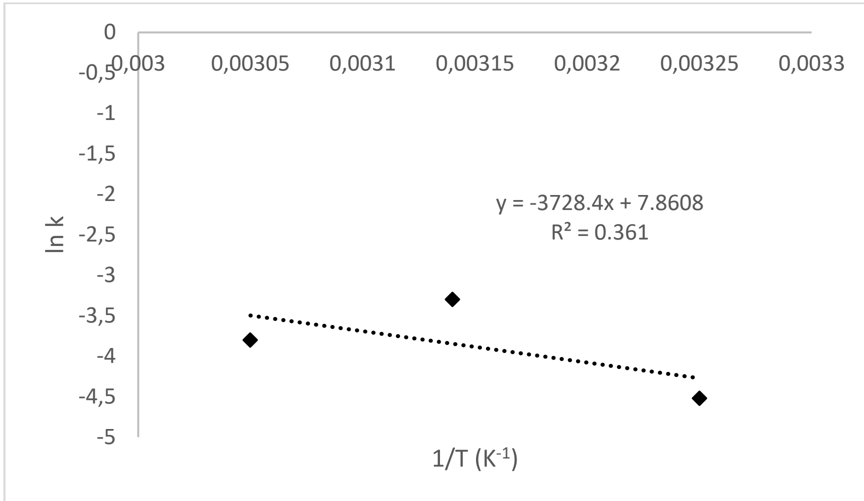

Figure 4. Comparison Between ln k vs 1/T of Moisture Content.

Table 2. Rate Constant Values of Moisture Content.

T (°C)	k
35	0.0143
45	0.0210
55	0.0300

3.4 Aroma

Aroma is a key factor in the success of food processing, as consumer preferences are generally strongly influenced by the product's aroma (Maligan et al., 2018). The results of aroma analysis through organoleptic testing at each storage temperature are presented in Figure 5.

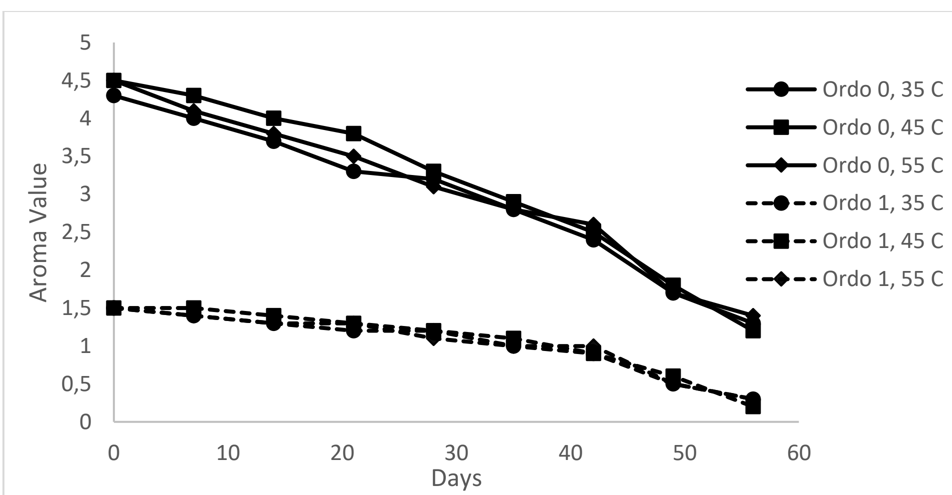

Figure 5. Aroma Value Results of Dried Sago Noodles.

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As shown in Figure 5, the aroma of dried sago noodles tends to decline or become less preferred by panelists as storage time increases. Based on the graph in Figure 5, zero-order, and first-order regression equations for aroma degradation at each storage temperature were obtained and are listed in Table 3.

Table 3. Zero-order and first-order Regression Equations of Aroma.

T (°C)	Regression Equation		R^2	
	Zero-order	First-order	Zero-order	First-order
35	y = -0.0487x + 4.3623	y = -0.0167x + 1.5259	0.9708	0.9065
45	y = -0.0545x + 4.7278	y = -0.0175x + 1.6108	0.9733	0.918
55	y = -0.0518x + 4.5417	y = -0.0172x + 1.5688	0.9646	0.8928

The linear regression equation derived from the plot of ln k versus 1/T for aroma degradation in dried sago noodles (Figure 6) is y = -320.26x + 1.9562 with R^2 = 0.3166. The activation energy (Ea) for aroma degradation is 636.03636 cal/mol, indicating the amount of energy required to initiate changes in aroma. The Arrhenius constant was calculated from the correlation plot of ln k (y) versus 1/T (x). The k (rate constant) values at each storage temperature as shown in Table 4.

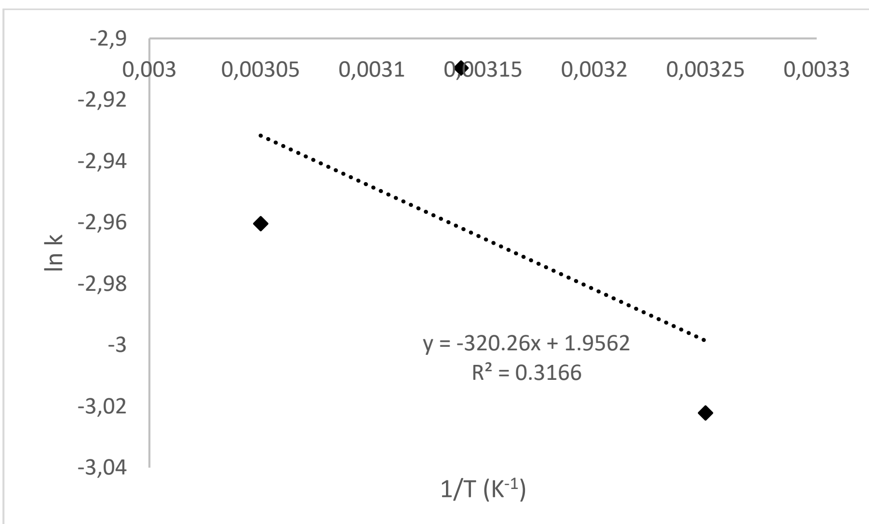

Figure 6. Comparison Between ln k vs 1/T of Aroma Value.

Table 4. Rate constant values of aroma reaction.

T (°C)	k
35	0.0500
45	0.0516
55	0.0533

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3.5 Taste

Taste is a sensation perceived by the tongue as a gustatory receptor in humans and is generally categorized into four types: salty, sweet, bitter, and sour (Lamusu, 2018). Taste is one of the crucial factors in consumer acceptance of a food product to be consumed (Ruhil Fida, 2022). The results of taste analysis through organoleptic testing at each storage temperature are presented in Figure 7.

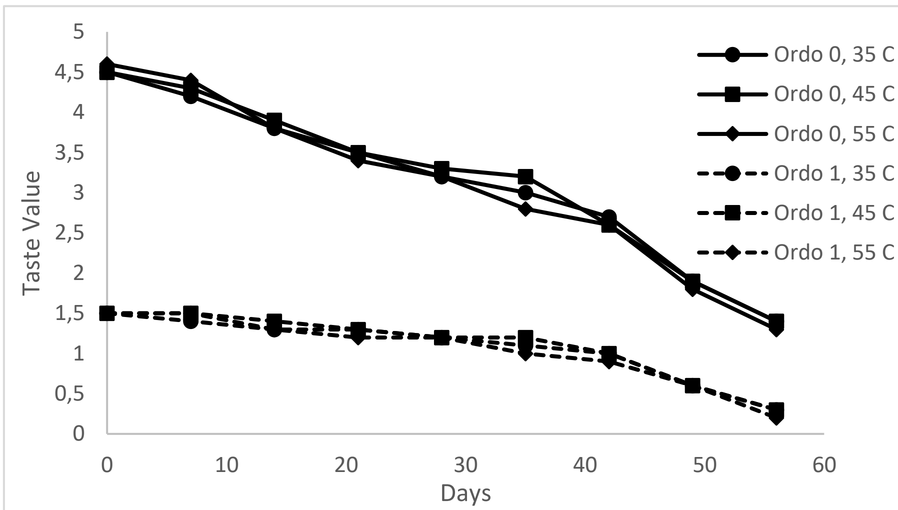

Figure 7. Taste Value Results of Dried Sago Noodles.

From Figure 7, it can be observed that the taste of dried sago noodles tends to decline or become less preferred by the panelists as the storage period increases. Based on Figure 7, the organoleptic taste evaluation of dried sago noodles resulted in zero-order and first-order regression equations as shown in Table 5. According to Table 5, the coefficient of determination (R^2) for the zero-order reaction is greater than that of the first-order reaction. Therefore, the zero-order reaction model is used to determine the shelf-life of dried sago noodles.

Table 5. Zero-order and First-order Regression Equations of Taste.

T (^{o}C)	Regression Equation		R^2	
	Zero-order	First-order	Zero-order	First-order
35	y = -0.0481x + 4.5174	y = -0.0155x + 1.5531	0.9701	0.9105
45	y = -0.0498x + 4.6215	y = -0.0158x + 1.5787	0.9601	0.8979
55	y = -0.0544x + 4.6467	y = -0.0176x + 1.5888	0.9787	0.93

The linear regression equation from the plot of ln k versus 1/T for the taste degradation of dried sago noodles is y = -618.67x – 1.0351 with R^2 = 0.9316. The activation energy (Ea) for the taste change is 1228.67862 cal/mol, which indicates the amount of energy required to initiate the change in taste. The Arrhenius constant was calculated from the correlation graph of ln k (y) against 1/T (x), the values of k were obtained as presented in Table 6.

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Table 6. Constant Values for Taste Quality Degradation.

T (°C)	k
35	0.0477
45	0.0508
55	0.0539

3.6 Shelf-Life

In determining the shelf-life of a food product, it is essential to first identify the parameters to be used, among other parameters that serve as the basis for estimating shelf-life (Nurhayati et al., 2017). The estimation of the shelf-life of dried sago noodles utilizes the degradation rate reaction with storage temperature as a factor to accelerate the deterioration of the product. The determination of the parameter used in estimating the shelf-life of dried sago noodles is based on the lowest activation energy (Ea). The shelf-life of dried sago noodles is obtained from the lowest activation energy among the tested parameters. The lower the activation energy, the faster the reaction occurs, thereby contributing more rapidly to the degradation of the dried sago noodles.

Table 7. Regression Equations and Activation Energy Values of Each Quality Parameter.

Parameter	Arrhenius Equation	Activation Energy (cal/mol)
Moisture	y = -3728.4x + 7.8608	7404.6024
Aroma	y = -320.26x - 1.9562	636.03636
Taste	y = -618.67x - 1.0351	1228.67862

The equation (Table 7) obtained to estimate the shelf-life of dried sago noodles based on aroma degradation was y = -320.26x-1.9562 with an activation energy of 636.04 cal/mol. Based on this, the shelf-life at different storage temperatures is presented in Table 8. The shelf life of dried sago noodles at each storage temperature was as follows: 52 days at 35°C, 52.9 days at 45°C, and 53 days at 55°C. Shelf-life estimation using the Arrhenius approach heavily relies on the temperature-dependent reaction rate constant. Assuming the storage temperature is room temperature (27 °C), the reaction rate constant was calculated as k = 0.049978.

Table 8. Shelf-Life of Dried Sago Noodles at Various Storage Temperatures.

T (°C)	N_0	N_t	t_s (days)
35	4	1.7	52
45	5	1.8	52.9
55	5	1.7	53

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The critical point for dried sago noodles is defined as the moment when the product becomes unacceptable to consumers in terms of aroma, set at a sensory score of 2 (dislike), with the initial value being 4.4 (N_0). Therefore, the shelf-life at 27 ℃ can be estimated using Equation 2. Based on these calculations, dried sago noodles are estimated to have a shelf-life of 49 days, or approximately 1 month and 19 days, at room temperature (27°C).

4. Conclusion

Based on the results of the organoleptic test of dried sago noodles, the critical parameter was identified as aroma. The activation energy values obtained for each quality parameter were as follows: 7404.60 cal/mol for moisture content, 636.04 cal/mol for aroma, and 1228.68 cal/mol for taste. Using the Arrhenius approach for shelf-life estimation, aroma was selected as the critical parameter due to having the lowest activation energy (636.04 cal/mol). At a storage temperature of 27 ℃ (room temperature), dried sago noodles were estimated to have a shelf-life of 49 days.

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