Shelf-life prediction of sago flour (*Metroxylon sagu* Rottb) in polyethylene packaging

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**Abstract.** Sago is one of the local foods in Indonesia which is very rich in carbohydrates. This food product has been used as an alternative staple food in various regions. Sago can usually be found on the market in the form of packaged flour. Each type of packaging will of course have a different effect on the shelf life. This research was conducted to determine how long the shelf life of sago flour is packaged in polyethylene packaging with various thicknesses, namely 0.03, 0.05, and 0.08 mm. Estimation of shelf life was carried out using the Labuza approach by utilizing information from the sago starch isotherm sorption curve. Sago flour is packaged using polyethylene packaging and placed in a room with RH of 60, 70 and 80%, and at a temperature of 30 and 40 °C. The shelf-life prediction based on this Labuza approach showed that the product in polyethylene packaging with a thickness of 0.08 mm had the longest shelf-life. The thicker the packaging, the longer the shelf-life of sago flour, which was caused by the lower permeability value of packaging. This finding supports the fact that the permeability value of packaging is inversely proportional to the packaging thickness.

**1 Introduction**

Sago plants have long served as an alternative source of carbohydrates, providing a basis for a variety of traditional foods. Numerous studies have been conducted on sago plants, primarily focusing on their processing into flour and derived products. However, the significance of storage and packaging conditions for these food products has not received equal attention, despite their crucial role in ensuring stability.

A vital indicator of product stability is its shelf-life duration. In certain food items, particularly those prone to increased water content like flour products, heightened microorganism activity poses a potential risk. Thus, determining the shelf life of sago flour becomes paramount, considering various influential conditions.

Previous research on the shelf life of sago flour by Rachmat & Istanto [1] yielded results ranging from 1 to 3 weeks at varying moisture content levels. However, this study overlooked several environmental factors that could impact shelf life, including storage temperature,
humidity levels, and packaging conditions. For a more precise estimation, this study proposes predicting the shelf life of sago flour using the Accelerated Life Testing (ASLT) method, employing an isotherm sorption curve approach. The isotherm sorption curve delineates the relationship between water activity and the equilibrium moisture content of materials. To ascertain this curve, several equation models commonly used in relevant studies will be employed. The selection of the most suitable model will contribute to accurately describing isotherm sorption patterns.

Based on these considerations, this study aims to predict the storage duration of sago flour utilizing the Accelerated Life Testing (ASLT) method under various storage and packaging conditions. The storage temperature will range between 30 and 40 °C, and the packaging will be constructed from polyethylene plastic.

2 Research Method

The procedure in this study consisted of several sections, including preparing samples, constructing isothermal sorption curves, and determining the best mathematical model. The procedure comprised several stages, which involved:

2.1 Preparing dried samples

Dry sample preparation was conducted to obtain material characteristics in accordance with applicable quality standards. This dry sample preparation involved the wet sago flour drying process using the gravimetric drying method with the assistance of an oven until it reached the standard moisture content of sago flour, which was 13%, or until the weight of the material became constant.

After the material was in a dry condition with a specific moisture content level, the next step was sieving to refine the texture of the flour. Sieving was carried out using a 100-mesh sieve.

2.2 Determining isotherm sorption curve

Research on the characteristics of the isothermal sorption curve of sago flour has previously been conducted by Adil et al. [2]. This study contains information about the characteristics of the isothermal sorption curve of sago flour as well as the best predictive model for isothermal sorption that can be utilized. The observations were carried out under various environmental conditions, namely at relative humidity (RH) values of 10-80% and at temperatures of 30°C and 40°C.

The determination of the best predictive model for isothermal sorption was also carried out by testing several commonly used isothermal sorption models, namely Oswin, Chung-Pfost, and Halsey, using the testing of coefficient of determination ($R^2$) and Root Mean Squared Error (RMSE).

2.3 Estimating the shelf-life

The calculation of the shelf-life of sago flour was conducted using the Accelerated Life Testing (ALT) method, which involved environmental conditions with high humidity, specifically at RH 60%, 70%, and 80%. Several stages had to be undertaken in this procedure, including:
2.3.1 Sample preparation of shelf-life test

The sample preparation was carried out by preparing dry samples of about 5 g and placing them into polyethylene plastic packaging with sizes of 0.03, 0.05, and 0.08 mm. The samples in these packages were then placed in a desiccator containing saturated salt solutions of NaNO₂, NaCl, and KCl, each with relative humidity (RH) of 60%, 70%, and 80%, respectively. After that, each sample in the desiccator was stored in an incubator at temperatures of 30 and 40°C. The packaged samples were then periodically weighed every 3 days until the material showed a significant decrease in quality based on the critical parameters as a reference.

2.3.2 Determining the initial and equilibrium moisture content of materials

The initial moisture content and equilibrium moisture content of the dry sago flour product in this study were determined using the thermogravimetric method. The initial moisture content values of the samples were obtained based on the results of previous drying procedures, and the equilibrium moisture content values could also be obtained from the results of isothermal water absorption testing.

2.3.3 Determining the critical moisture content

The determination of the critical moisture content could be established when the material had reached its critical condition. To identify the critical condition in the sample, there were several parameters that could serve as references, namely changes in color and the moisture content of the material. The formula for calculating the degree of whiteness was as follows [3]:

\[ W = 100 \cdot \left( \frac{100 - L}{a^2 + b^2} \right)^{0.5} \tag{1} \]

2.3.4 Determining the packaging area and weight of solids per package

The area of the primary packaging used was calculated by multiplying the length by the width of the packaging and expressed in square meters. The initial weight of the product in one package was weighed and corrected for its initial moisture content, and then expressed as the solid weight per package.

2.3.5 Determining the packaging permeability

The determination of packaging permeability was carried out using desiccant in the form of silica gel. Silica gel was placed in a dish and then sealed with the packaging whose permeability to water vapor would be determined. Silica gel, along with the dish and the sealed packaging, was then weighed to determine the initial weight. Subsequently, each day, the silica gel and the dish, sealed with the packaging, were weighed to observe the changes in the weight of the silica gel, indicating the absorption of water vapor. Weight measurements were taken until a minimum of five data points was achieved. Next, the collected data was plotted on a graph, with the total weight of the silica gel and packaging on the Y-axis and the observation time on the X-axis. From the graph, the slope could be determined. The formula used to calculate the packaging permeability was as follows [4]:

\[ \frac{k}{x} = \frac{S}{AxPout} \tag{2} \]
Information:
\( k/x \) = packaging permeability (gram \( H_2O \)/day.m\(^2\).mmHg)
\( S \) = slope (gram\( H_2O \)/day)
\( A \) = cross-sectional area of packaging (m\(^2\))
\( P_{out} \) = water vapor pressure at storage temperature \( x \) RH (mmHg)

2.3.6 Determining the slope value of the isotherm sorption curve

The slope value of the isothermal sorption curve (b) could be obtained from the information of the isothermal sorption curve based on the selected best model. The value was used and incorporated into the shelf-life calculation based on the Labuza equation (equation 3).

2.3.7 Calculating of shelf life

The shelf life of a product in packaging could be predicted based on the theory of diffusion or gas absorption by or from the product. By utilizing several variables previously, the theory could be elaborated into the mathematical equation [4] below:

\[
\theta = \frac{ln\left(\frac{Me-Mi}{Me-Mc}\right)}{\left(\frac{A}{Ws}\right)\left(\frac{P_{out}}{b}\right)}
\]

Information:
\( \theta \) = time to reach critical moisture content or shelf life (days)
\( Me \) = product equilibrium moisture content (g\( H_2O \)/gsolid)
\( Mi \) = initial moisture content of the product (g\( H_2O \)/gsolid)
\( Mc \) = critical moisture content of the product (g\( H_2O \)/gsolid)
\( k/x \) = bottled water vapor permeability (g/m\(^2\).*day.mmHg)
\( A \) = packaging surface area (m\(^2\))
\( Ws \) = weight of solids per package (g)
\( P_{out} \) = water vapor pressure in storage space (mmHg)
\( b \) = slope of isotherm sorption curve

3 Result and Discussion

3.1 The Characteristic of Sorption Isotherm Curve

The research conducted by Adil et al. [2] concludes that the characteristic of the isotherm sorption curves of sago flour were found to be Type II based on the van der Waals isotherms sorption type approach described in Brunauer et al. [5]. This type of curve, which is showed by Fig. 1, was closely related to the material's properties which was generally obtained from materials with soluble properties. In most studies, this curve pattern was characteristic of dry and carbohydrate-rich foodstuffs.

The sorption isotherm value of sago flour was experimentally compared with three isotherm models, including Oswin, Chung-Pfost, and Hasley model. The Chung-Pfost model was identified as the most suitable model for describing the sorption isotherm of sago flour. Therefore, the Chung-Pfost model can be utilized to predict the sorption isotherm of sago flour within a temperature range of 30 ± 40 °C and a relative humidity range of 10 ± 80%.
The estimation of shelf-life

The shelf life of a food product is greatly influenced by several properties of the ingredients, packaging (permeability), and environmental conditions. Therefore, through the approach of the isothermic sorption curve, the shelf life of sago flour packaged with a specific type of packaging and under various environmental conditions could be mathematically predicted. In the study, the estimation of the shelf life of sago flour was conducted under different environmental conditions, specifically at RH 60%, 70%, and 80% each at temperatures of 30°C and 40°C. Meanwhile, the type of packaging used was polyethylene plastic packaging with thickness variations of 0.03 mm, 0.05 mm, and 0.08 mm.

3.2.1 Initial, equilibrium, and critical moisture content

Initial moisture content and equilibrium moisture content of the material are some variables needed in predicting the shelf life of sago flour using the critical moisture content approach. The critical moisture content of sago flour could be determined based on several test criteria related to its quality deterioration. However, in this study, the test criteria most likely used were changes in color or degree of whiteness and moisture content. Nevertheless, the current Indonesian National Standard documents do not explicitly mention the degree of whiteness values for sago flour standards. Therefore, the determination of the critical moisture content of sago flour in this research referred to its moisture content quality requirement [6], which is 13%.

3.2.2 Packing area and weight of solids per package

The type of packaging used in this study was polyethylene plastic with various thickness levels, namely 0.03 mm, 0.05 mm, and 0.08 mm. Each of these plastic packages had dimensions of 8 x 12 cm, making the total packaging area 9.6 x 10^-3 m^2. Meanwhile, the solid weight per package was calculated by subtracting the initial product weight in the packaging from its initial moisture content value. The initial moisture content of the material was 7.43%, and the weight of the material in the packaging was 30 grams, resulting in a solid weight per package of 27.77 grams.
3.2.3 Packaging permeability

Packaging processed food products is one way to slow down the rate of quality deterioration in those products. One crucial parameter affecting the quality conditions of a product is the permeability of the packaging or the packaging's ability to allow water vapor to pass from the environment into the material.

The determination of plastic permeability was conducted at room temperature (28°C) with a room relative humidity (RH) of 65%. The calculation of the outside air pressure (P_{out}) was performed by multiplying the vapor pressure value at the existing room temperature by the RH value. According to the Labuza table, the vapor pressure value at 28°C was 28.349 mmHg. Therefore, the P_{out} value for measuring the permeability of this plastic packaging was 18.427 mmHg. Further details on the permeability values of each type of plastic packaging used in this study can be found in Table 1 below.

<table>
<thead>
<tr>
<th>Types of plastics</th>
<th>Thickness (mm)</th>
<th>Area (m²)</th>
<th>Slope (gramH₂O/day)</th>
<th>P_{out} (mmHg)</th>
<th>Permeability (gramH₂O/day.m².mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE 03</td>
<td>0.03</td>
<td>9.6 × 10⁻³</td>
<td>0.018</td>
<td>18.427</td>
<td>0.102</td>
</tr>
<tr>
<td>PE 05</td>
<td>0.05</td>
<td>9.6 × 10⁻³</td>
<td>0.017</td>
<td>18.427</td>
<td>0.096</td>
</tr>
<tr>
<td>PE 08</td>
<td>0.08</td>
<td>9.6 × 10⁻³</td>
<td>0.007</td>
<td>18.427</td>
<td>0.040</td>
</tr>
</tbody>
</table>

This research utilized Polyethylene (PE) plastic with varying packaging thicknesses, namely 0.03 mm, 0.05 mm, and 0.08 mm. In Table 1 above, it can be observed that the permeability values of the plastic packaging are inversely proportional to the thickness. The thicker the plastic, the lower the permeability value of the packaging. This indicates that the moisture vapor protection of PE plastic packaging with a thickness of 0.08 mm is the highest compared to other thicknesses. Septianingrum [7] also mentioned that for the same type of plastic packaging, the greater the thickness, the lower the permeability value of the packaging to moisture vapor.

Information regarding the permeability values of plastic packaging is crucial when considering packaging materials for specific food products. This is because the permeability value itself can influence the rate of product quality degradation. Packaging with low permeability has a greater potential to maintain the quality and durability of the product because of its lower ability to allow moisture vapor to penetrate the material. The greater the amount of moisture vapor that can pass through the packaging into the material within a specific period, the quicker the material will become moist, stimulating the growth of microorganisms.

3.2.4 The slope value of the isotherm sorption curve

The determination of the slope values of the isothermal sorption curve (b) referred to the curve generated by the selected isothermal model based on Adil et al. [2]. The chosen best isothermal sorption model was Chung-Pfost. The slope of this isothermal sorption curve was determined using a linear approach. Based on Fig. 1, referring to the isothermal sorption curve by the Chung-Pfost prediction model, the respective slope values for temperatures 30°C and 40°C were obtained as 19.85 and 15.82, respectively. The determination of the slope values of the isothermal sorption curve can be observed in Fig. 2, where the slope value (b) is obtained from the linear regression results with the equation pattern y = bx + a.
### 3.2.5 Calculation of shelf-life

The estimation of the shelf life of sago flour in this study used two temperature conditions, namely 30 and 40°C, as well as three levels of packaging thickness, namely PE 03, PE 05, and PE 08. In summary, the parameters for estimating the shelf life of sago flour in this study can be seen in **Table 2**.

**Table 2.** Parameters of estimating the shelf life of sago flour with an isotherm sorption curve approach.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial moisture content (Mi)</td>
<td>gram H₂O/gsolid</td>
</tr>
<tr>
<td>Critical moisture content (Mc)</td>
<td>gram H₂O/gsolid</td>
</tr>
<tr>
<td>The slope of the isotherm sorption curve (b)</td>
<td></td>
</tr>
<tr>
<td>Temperature 30°C</td>
<td>-</td>
</tr>
<tr>
<td>Temperature 40°C</td>
<td>-</td>
</tr>
<tr>
<td>Weight of solids (Wₖ)</td>
<td>gram</td>
</tr>
<tr>
<td>Packaging area (A)</td>
<td>m²</td>
</tr>
<tr>
<td>Pure water vapor pressure</td>
<td></td>
</tr>
<tr>
<td>Temperature 30°C</td>
<td>M mhg</td>
</tr>
<tr>
<td>Temperature 40°C</td>
<td>M mhg</td>
</tr>
<tr>
<td>Packaging permeability</td>
<td></td>
</tr>
</tbody>
</table>
The determination of the shelf-life of sago flour was then completed using the aforementioned parameters through equations. The results of the calculation of the shelf life of sago flour can be seen in Table 3 below.

Based on the shelf-life calculation, it was found that the type of packaging had a significant impact on its shelf life. The lower the permeability value of the packaging, the higher the potential shelf life of sago flour. This is closely related to the influence of the plastic thickness. Packaging plastic with a larger thickness tends to hinder the water vapor transfer process from the environment into the material. As a result, the moisture condition of the material inside the packaging will be better preserved, and the growth of microorganisms will be slower. Budijanto et al. [8] stated in their research that the shelf-life difference of a product can be influenced by various environmental characteristics, such as temperature, relative humidity, and packaging permeability.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>PE 03</th>
<th>PE 05</th>
<th>PE 08</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°C</td>
<td>43.4 days</td>
<td>46.1 days</td>
<td>110.7 days</td>
</tr>
<tr>
<td>40°C</td>
<td>55.4 days</td>
<td>58.9 days</td>
<td>141.4 days</td>
</tr>
</tbody>
</table>

**Table 3.** Shelf-life of sago flour at various packaging thicknesses.

### 4 Conclusion

Shelf-life predictions in this study indicated that sago flour packaged in 0.08 mm-thick polyethylene had the longest shelf life, specifically 110.7 days at 30°C and 141.4 days at 40°C. The packaging thickness is directly correlated with a longer shelf life for sago flour, attributed to the lower permeability value of the packaging. This finding is consistent with the principle that packaging thickness and permeability value have an inverse relationship.

### 5 References
