Kinetics of Quality Changes in Porang (*Amorphophallus oncophyllus*) Flour during Storage at Various Temperatures

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ABSTRACT

Porang (*Amorphophallus oncophyllus*) flour is a raw material for producing glucomannan with low moisture content and hygroscopic properties. Proper storage of porang flour is an important strategy needed in production to maintain the quality. Therefore, this study aimed to assess shelf life of porang flour under various temperature conditions using a reaction kinetics model and to characterize the quality of porang flour during storage. Porang flour was packaged in polyethylene plastic bags and stored at a relative humidity (RH) of ± 70% at different temperatures of 15 °C, 20 °C, 25 °C, and 30 °C. Storage duration was 90 days, and the measurements of viscosity, density, and color were taken at 5-day intervals. Meanwhile, measurements of glucomannan and ash content were conducted at 15-day intervals. Kinetics model was used to determine shelf life of porang flour based on viscosity parameters according to commercial standards set by the Chinese government. The statistical results showed that storage temperature significantly affected density and color but had no significant effect on glucomannan and ash content parameters. Kinetics analysis of viscosity and density changes in porang flour followed a first-order reaction, where higher temperatures resulted in larger rate constants. The validation test with Arrhenius equation derived equations for density and viscosity parameters, namely Y= -4128.1x+6.7104 and Y= -4148.4x+8.1565, respectively. Furthermore, the results showed that shelf life of porang flour with an initial viscosity of 19,000 mPa.s under conditions of ±70% RH and storage temperatures of 15 °C, 20 °C, 25 °C, and 30 °C was 28, 21, 18, and 13 days, respectively, for first-grade quality. For second-grade quality at temperatures of 15 °C, 20 °C, 25 °C, and 30 °C, shelf life was 161, 117, 102, and 76 days, respectively.

Keywords: Porang flour; reaction kinetics; shelf life; storage; temperature

INTRODUCTION

Porang flour is derived from the tubers of porang plant (*Amorphophallus oncophyllus*) belonging to the Aranceae family, used for making glucomannan with hygroscopic properties. According to a previous study, the glucomannan content in porang flour is quite high at ± 40% (Sirotkin, 2021). This flour can be developed into a standard material for the food and health industries is also capable of thickening and forming gels (Alvarez-Manceñido et al., 2008; Wardani et al., 2021). In Indonesia, porang flour is processed into chips and low-oxalate flour (Wardani et al., 2021), and then exported to several countries, such as China, Vietnam, and Thailand (Dermoredjo et al., 2021). Porang flour has hygroscopic properties, showing its ability to seamlessly absorb water (Mustafidah & Widjanarko, 2015). Therefore, the transfer of water vapor to the product can cause a decrease in quality and shorten shelf life (Aprida et al., 2017).

Study on storage conditions of porang flour has not been widely carried out in Indonesia, even though this information is needed by exporters to fulfill the requirements of China, namely GACC (The General

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Administration of Customs of The People's Republic of China). Therefore, this study aimed to examine storage of porang flour at various temperatures to determine shelf life. The parameters in determining shelf life follow the commercial standards of porang flour. The results from this study can be used as information for exporters to determine the right storage room conditions.

Shelf life of products during the export process needs to be predicted for easy products according to the quality set by the destination country for export (Loebis & Junaidi, 2013; Yin et al., 2022). Sensory, chemical, and physical properties of porang flour, such as color, aroma, glucomannan content, particle size, and viscosity are quality parameters set as international standards for porang flour (Amyranti & Nurlatifah, 2022) with another name of clude porang flour (CPF) (Li et al., 2019). Packaging can help extend shelf life of products by preventing damage during storage and distribution processes to maintain quality (Othman et al., 2022; Yin et al., 2022). Therefore, this study aimed to determine shelf life and storage time of porang flour using the ASLT (accelerated self-life test) and Arrhenius method, respectively with polyethylene used as packaging. In the analysis of shelf life calculations, the ASLT method was based on kinetics change method, the correlation between temperature and storage time to the decrease in viscosity value, and the density of porang flour. The activation energy (Ea) was determined using the reaction kinetics equation and Arrhenius method.

METHOD

Materials

The main material in this study was porang flour produced by PT. Sanindo Porang West Java Indonesia and polyethylene packaging with a thickness of 0.075. The supporting materials for relative humidity (RH) conditioning were NaCl salt and distilled water. The equipment used was containers, thermohygrometers as a measuring tool for air humidity and temperature, ovens with specifications of the SANYO Drying Oven brand with model MOV-112 P, room heaters used to regulate room temperature, analytical scales with specifications of Shimadzu brand (Japan) with model AUW-22, frequency 50 Hz, accuracy 0.0001 grams, sealers used to seal the packaging, and magnetic stirrers with specifications of the Adventec brand (Japan) and model SRS710HA, power 11 kW, and frequency 50Hz. These materials also had a heating capability of 0-300 °C, a viscometer with specifications of AMETEK Brookfield (United States), and model RVT-105202, 3.5 W power, 230-volt voltage, and 50Hz frequency. Furthermore, the materials were equipped with a spindle to stir the sample and a variation of a rotation speed of 0.5, 1, 2.5, 5, 10, 20, 20, and 100 RPM, colormeter with specifications of Taiwan Taishi brand, model TES_135.

Study Stages

Conditioning container RH and storage room temperature

RH of storage room was conditioned to ± 70% by dissolving NaCl salt in distilled water until supersaturated. Storage room temperature was 15 °C, 20 °C, 25 °C, and 30 °C, then the room conditions were kept constant by placing a thermohygrometer in each container.

Preparation of porang flour samples

A total of 100 g porang flour was packed in polyethylene packaging with a size of 12 cm x 20 cm and a thickness of 0.075 mm. Porang flour samples were prepared in 21 packages for each temperature variation and placed in containers whose RH was determined using a supersaturated salt solution.

Changes in viscosity, density, and color were measured at 5-day intervals for 3 months using a Brookfield Viscometer with spindle no. 4 and RPM 0.5. Density measurement was carried out by weighing the mass of porang flour placed in a tube with a volume of 6.8 cm^3 and color was measured using colormeter. Measurements of glucomannan and ash content were carried out at 15-day intervals using an extraction method with 96% ethanol. Ash content was measured using the ashing method at 550 °C for 3 hours following the procedure of (Dipahayu & Kusumo, 2020). The measurement was carried out by weighing the remaining minerals from burning organic materials at a high temperature of 550 °C for 3 hours. In the combustion process, only the organic components were burned, while the inorganic remained unaffected.

Shelf life analysis

During storage process, physical, chemical, and biochemical changes occurred due to reactions, causing the quality [Q] of food products to decrease until the product was no longer suitable for consumption. Kinetics method could describe the quality reduction reaction (dQ/dt) as a function of various reaction variables. Reaction kinetics showed how the process occurred or the speed of the reaction. Meanwhile, chemical reaction kinetics were influenced by the reaction at a certain level or order, leading to the achievement of a rate constant (Dewati, 2010).

The parameters analyzed were viscosity and density, then each parameter was plotted against time (days), and linear regression equations were obtained. Consequently, 4 equations were acquired at each storage temperature variation with y = bx + a where y described the product characterization value, x represented storage time (days), b depicted the change rate (slope = quality change rate), and a is the initial characteristic value of the product. The reaction order of a parameter was selected by comparing the coefficient of determination (R^2). The first order reaction equation is displayed in the formula 1 (Sarungallo et al., 2018):

$$\frac{dA}{dt} = -k\,[A]^2$$

$$\ln A_t = \ln A_0 - kt \quad (1)$$

Shelf life was determined using Arrhenius method, where Ln k was plotted against the 1/T (K^{-1}) value to get the intercept and slope from the linear regression equation. Arrhenius equation was ln k = ln k_0 – (Ea/R) (1/T) where k_0 was the intercept, Ea/R was the slope, Ea was the activation energy, and R was the ideal gas constant (1.986 cal/mol). The equation then obtained the constant (k_0) and the activation energy value (Ea) which could be used to determine the reaction rate equation model (k), namely changes in product characteristics during storage. The equation was changed to formula 2:

$$\ln k = \ln k_0 - (E_a/RT) \quad (2)$$

Shelf life of porang flour was determined using the zero or first-order reaction kinetics equation. The reaction order kinetics equations are as follows:

$$t = (A_0 - A_t)/k \quad \text{(zero order)}$$

$$t = \ln\,(A_0 - A_t)/k \quad \text{(first order)}$$

Where t was the product shelf life (days), A_0 was the initial product quality value (day 0), A_t was the final product quality value (day t), and k was the product quality reduction constant.

Statistical analysis

The data obtained were then analyzed using SPSS software data with the Two-Way Analysis of Variance (ANOVA) method. For a statistically significant result, the analysis was then continued with the Duncan Multiple Range Test (DMRT) at a significance level of 5% (≤0.05).

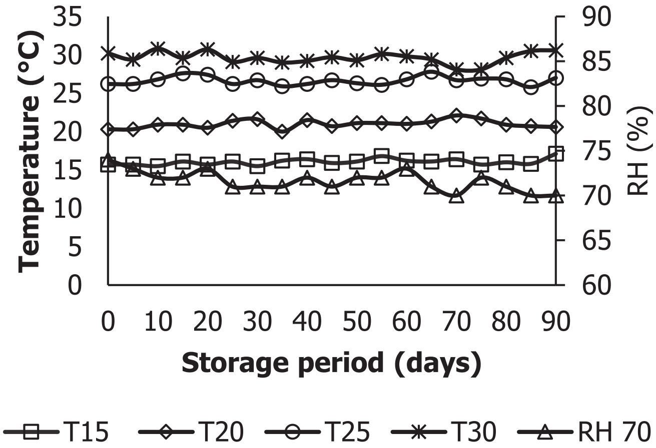

Figure 1. Changes in temperature and RH during storage

RESULTS AND DISCUSSION

Changes in Temperature and RH During Storage

The temperature and RH of the environment can change rapidly when not properly conditioned, thereby necessitating conditioning to ensure stability. To maintain temperature stability, the product was stored in a controlled storage room to maintain the conditions. RH conditions of storage room were carried out by making a supersaturated salt solution using NaCl salt with a humidity of ± 70%.

The temperature and RH of storage room can affect the decline in the quality of porang flour. Figure 1 shows changes in temperature and humidity values during storage, measured at 5-day intervals with the help of a thermohygrometer placed on the container. This setting facilitates easier measurement of temperature and RH in storage room.

Characterization

Viscosity

The decrease in viscosity value of porang flour can be influenced by storage room, where viscosity value was inversely proportional to the temperature of storage room (Bagus et al., 2020; Damayanti et al., 2018). The increase and decrease in viscosity were generally influenced by temperature and RH. Therefore, the product will bind free water in a solution (total concentration, sugar content, salt) and the hydrocolloid content forms porang flour gel.

The analysis results showed that temperature treatment had a significant effect on viscosity. Figure 2 shows that the temperature treatment of 15 °C has the highest viscosity value. Temperature is closely related to

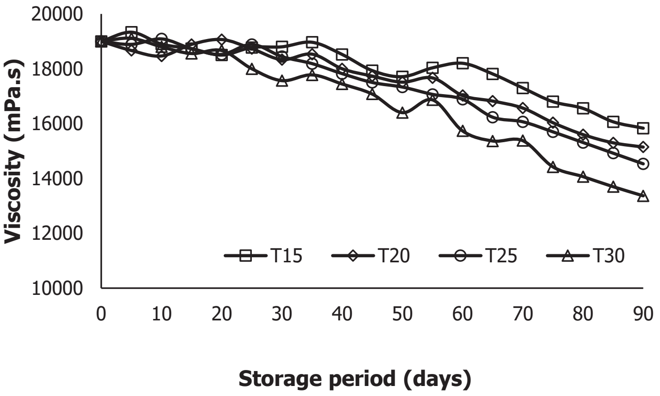

Figure 2. Changes in viscosity of porang flour

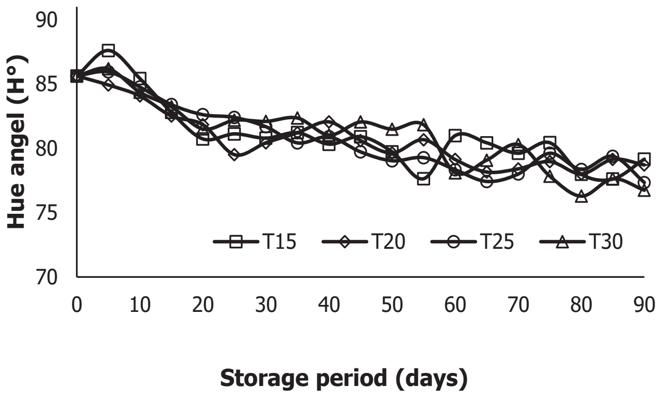

Figure 4. Changes in the color of porang flour

viscosity, where the higher storage room temperature, the lower viscosity value of a material (Lumbantoruan & Yulianti, 2016; Zhang et al., 2023). Additionally, a smaller particle size produces a larger surface area, which can cause greater water absorption and affect viscosity value. Based on previous study on the effect of storage temperature on kokum, korondo, and cashew apple syrup, as well as mango pulp, viscosity value decreases with increasing storage temperature (Swami et al., 2013).

Density

Density is a physical characteristic generally used to show the compactness of a product in occupying space, such as planning the volume of processing equipment and transportation facilities. Density is defined as the space between the particles of the material (Sasmitaloka et al., 2022). This study measures the density of porang flour to determine the effect of storage at various temperatures and air humidity in storage room.

Figure 3 shows that the process of storing porang flour using various temperatures in storage room has a decreasing density value. The decrease in the density value of porang flour during storage can be caused by

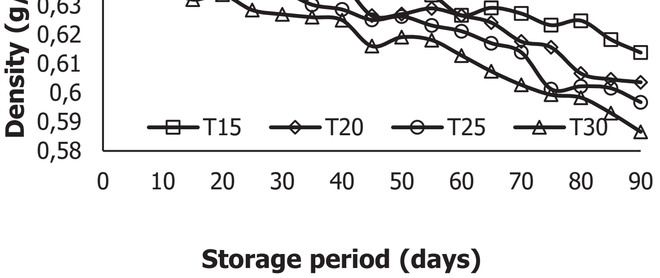

Figure 3. Changes in the density of porang flour

an increase in moisture content which affects the shape of the particles (Purwitasari et al., 2014; Sasmitaloka et al., 2022). The analysis of variance shows that temperature treatment has a significant effect on the density value of porang flour. Figure 3 shows that the density value decreases with increasing moisture content, resulting in a larger particle size during storage and affecting volume (Rahmawati et al., 2014).

Color

The color of porang flour was determined using a colormeter every 5 days, with the values of L (lightness), a* (redness), and b* (blueness) being defined by the CIE (Commission Internationale de I'Exlairage) system. Color is an important concern in measuring the quality of a food product because it is a physical parameter that can be visualised, thereby affecting consumers. Changes in the color of porang flour were analyzed using hue angle, which was then used as an indicator to determine the characteristics of a food product.

Figure 4 shows that storage room temperature affects the hue angle value of porang flour. The analysis of variance shows that the treatment of storage room temperature has a significant effect on the color of porang flour. Figure 4 also shows that a temperature of 15 °C has the smallest value on the change in hue angle. Measurement of porang flour was based on the hue angle value because changes in the color can be caused by the formation of metmyoglobin, which changed the color to brown. This occurs when the mineral content in the sample is oxidized and turns brown (Othman et al., 2022).

Glucomannan content

Glucomannan contained in porang flour can be used for gel formation, texture improvement, thickening agents, and other activities in the industrial sector (Afifah et al., 2014). Glucomannan test was carried out

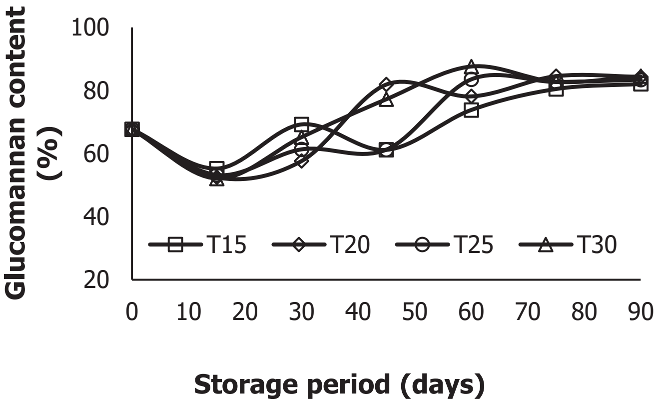

Figure 5. Changes in glucomannan content of porang flour

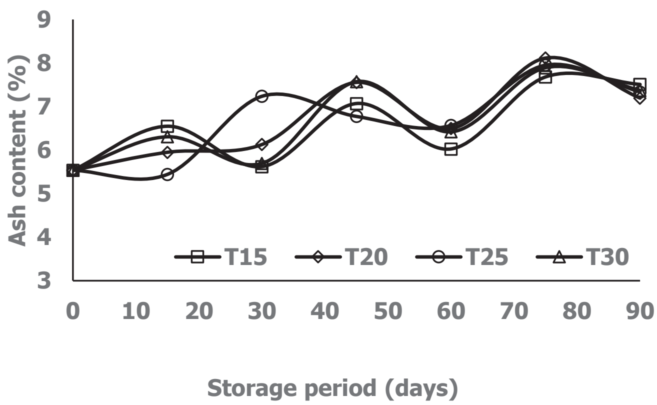

Figure 6. Changes in the ash content of porang flour

by extracting and separating porang flour using 96% ethanol. This extraction process can remove impurities, such as starch, fiber, protein, and other ingredients besides glucomannan (Salim et al., 2021). Porang flour purification process using the washing method with ethanol is very effective in reducing impurities in the material as well as preparation before alkali treatment.

Figure 5 shows that storage temperature treatment has no significant effect on glucomannan content. This result is supported by a uniformity test, which shows no significantly different results ($p \geq 0.05$) at room temperature storage on changes in glucomannan content. These changes are mostly influenced by plant age, type, and growth environment, consistent with previous studies that a shorter harvest age has a lower glucomannan content (Azizi & Kurniawan, 2021).

Ash content

Ash content serves as an indicator of the total mineral content present in food ingredients. This content is significantly influenced by the mineral composition of the soil in the area where the ingredients are grown.

In general, Figure 6 shows that the treatment of storage room temperature does not significantly affect ash content of porang flour. The high and low mineral content in tubers was influenced by plant genetic or growth environment factors (Hoover et al., 2010; Idrus et al., 2013; Lisa et al., 2015).

Kinetics Analysis

Changes in the density of porang flour based on kinetics model

Kinetics model of density changes can be determined by first-order linear regression where the increase or decrease rate is influenced by the initial concentration. Figure 7 shows the relationship between the reaction rate constant of changes in the density of porang flour with various storage temperatures of 15 °C, 20 °C, 25 °C, and 30 °C. The result shows that the density value increases with increasing temperature. The treatment of storage room temperature impacts the changes in the density of porang flour, with an increase in temperature leading to a decrease in the density value. The decrease in density of porang flour at temperatures of 288 K, 293 K, 296 K, and 303 K follows a first-order reaction with an R^2 close to 1. The magnitude of the k value at each temperature is presented in Table 1, showing that an increase in storage room temperature correlates with a higher k value.

Table 1. Linear regression equation on zero and first-order porang flour density parameters

Temperature (K)	Linear regression equation		R^2	
	Zero order	First order	Zero order	First order
288	y=-0.0003x + 0.0037	y=-0.0005x + 0.006	0.924	0.9219
293	y=-0.0005x + 0.0057	y=-0.0008x + 0.0092	0.9032	0.9007
296	y=-0.0006x + 0.003	y=-0.0009x + 0.0053	0.9521	0.9488
303	y=-0.0006x – 0.0013	y=-0.001x – 0.0014	0.9229	0.9707

Table 2. Arrhenius parameters of changes in porang flour density

T (°C)	T (K)	1/T	k	Ln k
15	288	0.0347	0.0005	-7.6009
20	293	0.00341	0.0006	-7.41858
25	296	0.00336	0.0009	-7.1309
30	303	0.0033	0.001	-6.90776

The determination of Arrhenius equation in

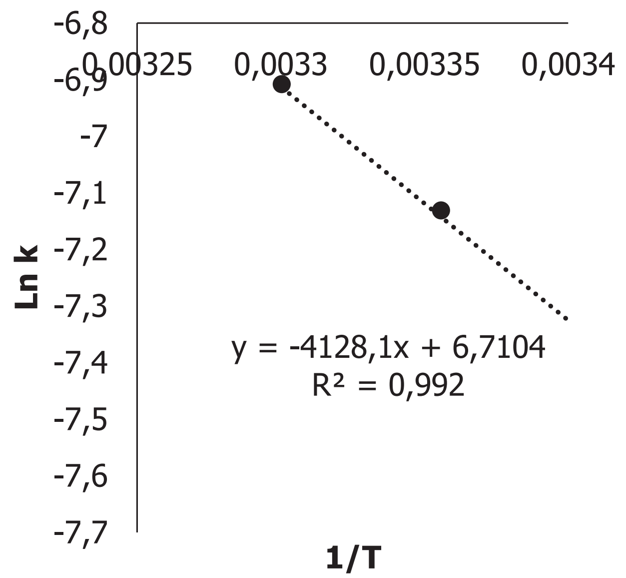

Figure 7. Relationship between ln k and 1/T

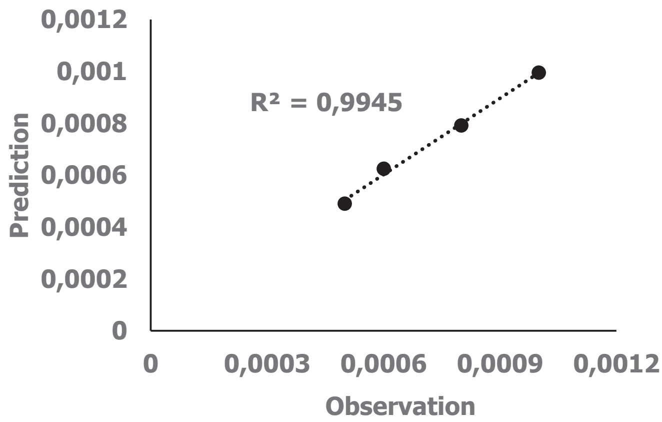

Figure 8. Relationship between prediction and observation

The linear regression equation in Figure 7 from plotting the ln k value against 1/T is y = -4128.1 + 6.7104 with R^2 0.992. The relationship between observation and prediction is depicted in Figure 8. The observation values are derived from observational data, while the prediction data are obtained using the order kinetics equation.

Changes in viscosity of porang flour based on kinetics model

Changes in viscosity of porang flour can be analyzed using zero and first-order kinetics. The analysis was carried out by comparing the correction values (R^2) of the zero and first orders, then the R^2 value closest

Table 3. Linear regression changes in porang flour viscosity parameters

Temperature (K)	Linear regression equation		R^2	
	Zero order	First order	Zero order	First order
288	y=-34.031x + 519.71	y=-0.0019x + 0.0304	0.849	0.8387
293	y=-43.906x + 506. 78	y=-0.0026x + 0.0317	0.9086	0.8991
296	y=-51.536x + 641.93	y=-0.003x + 0.0404	0.951	0.9398
303	y=-65.708x + 656.84	y=-0.004x + 0.0458	0.9623	0.9477

Table 4. Arrhenius parameters of porang flour viscosity changes

T (°C)	T (K)	1/T	k	Ln k
15	288	0.0347	0.0019	-6.2659
20	293	0.00341	0.0026	-5.9522
25	296	0.00336	0.003	-5.8091
30	303	0.0033	0.004	-5.5215

to 1. The rate of changes in the density of porang flour follows the first order. The results of kinetics test represent the changes in the quality of the test material under specific conditions and over certain periods.

The activation energy value (Ea) of porang flour viscosity during storage can be modeled using Arrhenius equation. This occurs due to the influence of storage room temperature on the rate of change in porang flour viscosity. The validation test based on Arrhenius equation was carried out by plotting ln K against 1/T (1/K) for each storage room temperature against changes in porang flour viscosity, as shown in Figure 10.

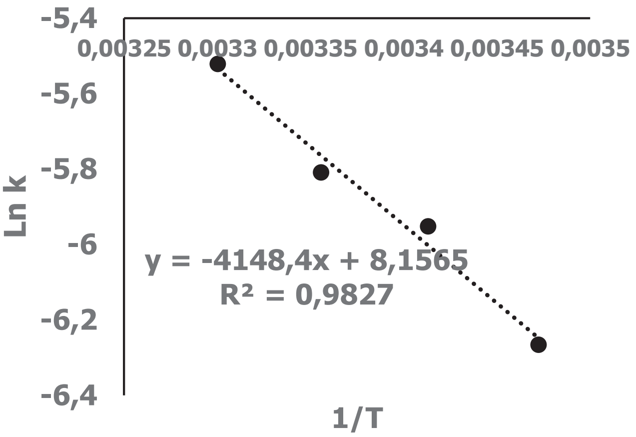

Figure 10. Relationship between ln k and 1/T

Figure 11 shows that the prediction and observation values follow a linear pattern, suggesting an accurate result. Linear regression analysis of the natural logarithm of the k value (ln k) against the reciprocal of the temperature (1/T) for determining viscosity of porang flour produced the equation y = -4148.4x + 8.1565 with R^2 value of 0.9827. This means that the value of Ea/R is -4148.4, where R, the gas constant, is 1.986 cal/mol. The calculated activation energy of 8238.72 cal/mol shows the energy required by the material to reduce

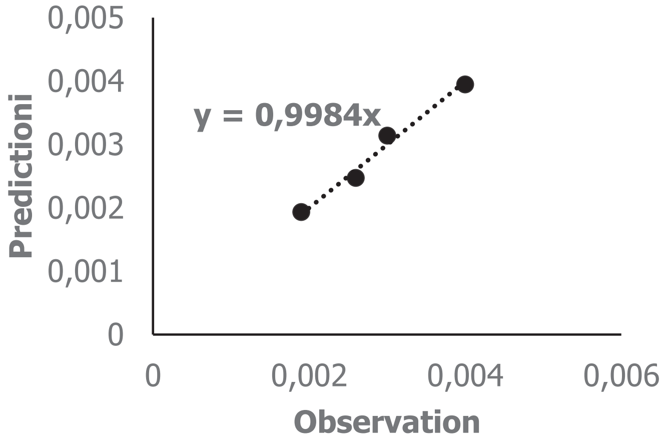

Figure 11. Relationship between prediction and observation

viscosity value. The determination of shelf life follows the first-order reaction kinetics equation, namely t= ln $(A_0 - A_t)/k$. The critical viscosity limit of porang flour to calculate At (viscosity value at the time of damage) refers to GACC standard for exports in China at first and second grades ≥18000 mPa.s and second grade ≥14000 mPa.s, respectively (Peiying et al., 2002). The results of calculating shelf life of porang flour at various storage room temperatures are shown in Table 5.

Application of shelf life in porang flour based on Arrhenius

The determination of shelf life of porang flour is crucial for assessing product quality. Porang flour possesses hygroscopic properties, which means flour absorbs moisture from the environment, leading to rapid degradation in quality. Understanding viscosity is essential for evaluating shelf life because this parameter correlates with increased moisture content. Shelf life of porang flour in a temperature range of 15 °C to 30 °C can be ascertained by determining the prediction constant. The calculation of the prediction constant was conducted using Arrhenius equation, with the A and Ea values. Subsequently, the calculation of shelf life uses the first-order kinetics

Table 5. Results of calculating shelf life of porang flour at various storage temperature conditions

Storage conditions		Shelf life (days) by China standard	
Temperature (°C)	RH (%)	≥18000 mPa.s	≥14000 mPa.s
15	70	28	161
20		21	117
25		18	102
30		13	76

Table 6. Application of storage temperature range in porang flour

Temperature (°C)	Temperature (K)	Shelf life (days) according to commercial standards for porang flour		Temperature (°C)	Temperature (K)	Shelf life (days) according to commercial standards for porang flour	
		≥18000 mPa.s	≥14000 mPa.s			≥18000 mPa.s	≥14000 mPa.s
15	288	28	158	23	296	19	107
16	289	26	150	24	297	18	102
17	290	25	143	25	298	17	97
18	291	24	136	26	299	16	93
19	292	23	129	27	300	16	89
20	293	22	123	28	301	15	85
21	294	21	118	29	302	14	81
22	295	20	112	30	303	13	77

equation at an air humidity of approximately 70%. The criteria for shelf life are based on Chinese commercial standards, which define first and second grades as having viscosity of at least 18000 and 14000 mPa.s, respectively. The calculated shelf life of porang flour at the chosen temperature is shown in Table 6.

Table 6 shows the results of applying kinetics model with Arrhenius equation to determine shelf life of porang flour at the desired temperature range. The result showed that a higher temperature is equivalent to a shorter shelf life. This is supported by the constant value which is getting bigger along with the increase in storage room temperature.

CONCLUSION

In conclusion, shelf life of porang flour was determined using the reaction kinetics equation at various storage room temperatures of 15 °C, 20 °C, 25 °C, and 30 °C with an air humidity of approximately 70%. The results showed shelf lives of 28, 21, 18, and 13 days for the first-grade standard, along with 161, 117, 102, and 76 days for the second-grade standard. Storage room temperature affected viscosity, density, and color properties of porang flour during storage process, but had no significant effect on glucomannan and ash content. The short shelf life of porang flour could be influenced by packaging factors. Furthermore, a higher storage room temperature affected viscosity, density, and color values of porang flour. The application of shelf life in porang flour showed an increase along with the rising constant values, which were influenced by the increasing temperatures in storage room.

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