Estimation of Shelf-life of Porang Glucomannan Analog Rice By Accelerated Shelf-life Testing (ASLT) Method

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ABSTRACT

Analog rice is rice made from some or all non-rice ingredients and was created as a food diversification product so that it can be an alternative staple food to replace rice produced from rice. The shelf-life of food products can be determined using the ASLT method, which in principle accelerates the rate of deteriorating quality of stored products measured by selected critical parameters, such as color, aroma or moisture content. The aim of this research was to establish critical parameters and determine the shelf-life of analog rice made from porang glucomannan flour without packaging and with vacuum packaging. In this study, the critical parameters for the shelf-life of analog rice were the moisture content and the degree of whiteness. Based on the results, the parameter with the lowest activation energy was the moisture content, and thus had the most influence on the deterioration of analog rice samples. The shelf-life of unpackaged analog rice at 35° was found to be 50.32 days while the shelf-life of vacuum-packed analog rice at the same temperature was 150.82 days. The results show that vacuum packaging could considerably improve the shelf-life of analog rice.

Keywords: *accelerated shelf-life test method, activation energy, analog rice, vacuum-packed, shelf-life*

1. INTRODUCTION

Analog rice is rice made from part or all of non-rice ingredients by extrusion technology [1]. Analog rice is a food diversification product as an alternative staple food to replace rice produced from rice. Flour derived from non-rice ingredients from local food products can be the raw material for the process of formulating analog rice, such as soy flour, corn flour, porang flour, cassava flour, and others [2]. Analog rice has a lower glycemic index value of 54 than that of rice, which is 73. Its fiber content is 13.3% on average [3]. Analog rice made from porang glucomannan flour has been found to have an even lower glycemic index. Thus, it is necessary to evaluate its shelf-life before this product can be commercialized.

Shelf-life of food products is important information for consumers. Each food product has a certain time limit for safe consumption. Shelf-life is always included on product packaging because shelf-life is related to food safety and product quality assurance until it reaches consumers. The use of packaging can slow down the rate of decline in product quality and the shelf-life of packaged products is usually longer. This study compared the shelf-life of porang glucomannan analog rice with vacuum packaging and without packaging. Vacuum packaging is considered to provide a better protective effect on food products because it dramatically limits the amount of gaseous air and water vapor inside the package that can cause the product to deteriorate.

The shelf-life of food products can be determined by Extended Storage Studies (ESS) and Accelerated Shelf-Life Testing (ASLT) methods. The ESS method consists of determining the shelf-life by observing products stored under normal conditions. This method is the conventional method with accurate results but takes a very long time. It is suitable for measuring the shelf-life of products that have a relatively short shelf-life. Meanwhile, the ASLT method can provide fairly accurate results in a shorter time. The ASLT method is carried out by accelerating the deterioration reaction of the stored product [4]. In general, acceleration of quality reduction can be achieved by storing the product under environmental

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conditions outside normal conditions, such as at higher temperatures or at increased humidity conditions during product storage. Selected quality deterioration data are then processed with the Arrhenius equation to determine the quality decline reaction constant which is then used to estimate the product shelf-life [5]. This study aims to determine the estimated shelf-life of porang glucomannan-based analog rice using the Accelerated Shelf-Life Test (ASLT) method with the Arrhenius approach.

2. METHODS

This study used porang glucomannan-based analog rice as the test sample. Two options of packaging were examined, namely samples without packaging (WP) and vacuum packaging (VP) samples. Vaccum packaging method was done by placing analog rice in a plastic film with a thickness of 0.12mm, removing air from inside and sealing the package. The research consisted of two stages, which included determining the initial and final critical quality characteristics of analog rice and estimating the shelf-life of analog rice using the Accelerated Shelf-Life Testing (ASLT) method of Arrhenius approach. The results of analog rice quality decline were processed using Microsoft Excel 2021. After obtaining a simple linear regression equation, the data were then processed with the Arrhenius equation for determination of the shelf-life. The statistical analysis was performed via ANOVA Two Ways with two factors, the first factor being the difference in storage temperature and the second factor the difference in packaging - without packaging and with vacuum packaging. Subsequently, the results of the data analysis were processed by a descriptive method. This research thus included the production of analog rice, assessing its water content and degree of whiteness, observing the initial and final quality characteristics of analog rice, and determining the shelf-life with the Arrhenius approach ASLT method.

2.1. Production of Analog Rice

The preparation of analog rice was carried out by combining the main ingredients such as glucomannan flour, tapioca flour and glycerol monostearate (GMS) based on the following formulation: tapioca flour (84.53%); glucomannan flour (14.11%), and GMS (1.36%). All ingredients were placed into a container, mixed with water and stirred to form a solid dough. The dough was then taken to taste and formed into a roll on a cutting board. The elongated oval-shaped dough was inserted into a clay metal extruder tube. The sides of the tube were covered with mold holes at the bottom and with a threader on the top. The extruded dough was cut with blades so that the shape resembled rice grains. The rice grains were dried in a cabinet dryer at 60° C for 2 h. After drying, the analog rice was stored in plastic bags.

2.2. Moisture Content Testing

Moisture content of the samples was determined by thermogravimetric method using an oven (Memmert). A porcelain crucible was used as the sample container that had been heated in an oven at 105° C for 1-2 h. The crucible was placed into a vacuum desiccator for 15 minutes, its weight recorded and reheated until a constant weight was obtained. A 2 g sample was placed in the crucible and heated in an oven at 105° C for 24 h, cooled in a desiccator for 15 min and weighed. The procedure was repeated until a constant weight was obtained.

2.3. Degree of Whiteness

Product whiteness was determined using a color reader (Konica Minolta). The color reader was first calibrated with a white plate before use. After calibration, measurements were taken by attaching the color reader lens to the sample that had been placed into a clear plastic clip. Measurements were repeated three times at 3 different points and the L* a* b* values recorded.

2.4. Observation of Initial and Final Quality Characteristics of Analog Rice

Observation of initial quality (A_0) characteristics was carried out by analyzing the initial values of moisture content and degree of whiteness of the sample followed by evaluation of the product acceptability by panelists. Ten trained panelists were given samples to observe and assess hedonically the combination of color, aroma, and appearance and to make recommendations on the products. Options were that the product is still acceptable or is being rejected. The acceptance test was stopped and the products discarded when a rejection rating of 50% was reached. After obtaining a rejection of 50% or more, the final quality (A_t) characteristics can now be directly observed by analyzing the final value of moisture content and degree of whiteness in Table 2.

2.5. Determination of Shelf-life ASLT Method

Analog rice samples with two packaging options, namely without packaging or vacuum packed, were each stored at three different temperatures, namely 35° C, 45° C, and 55° C.

Quality parameters, such as moisture content and degree of whiteness of the samples were determined every 5 days for 20 days. The results obtained were plotted against the storage time to obtain a linear regression with the equation y = bx + a where y is the characteristic value of analog rice, x is the storage time (days), a is the initial characteristic value of analog rice and b is the rate of change in characteristic value (slope = rate of quality deterioration = k).

Determination of the reaction order was done by comparing the coefficient of determination (R^2) in each regression equation. The largest R^2 value is the selected reaction order. The value of ln k was plotted against 1/T (K^{-1}) then the intercept and slope of the linear regression equation were obtained: ln k = ln k_0. (E_a/R)(1/T). ln k_0 is the intercept, Ea/R is the slope (R is the ideal gas constant = 1.986 cal/mol). The value of k_0 was obtained which is an exponential factor and the value of the activation energy (E_a) of the reaction of characteristic changes. In the next step, of the data were entered into the reaction rate equation (k) of characteristic changes with $k = k_0 .e^{-E/RT}$.

Determination of shelf-life is carried out by entering the value of each temperature into the equation ln k = ln k_0 . (E_a/R)(1/T). After obtaining the value of k, the shelf-life can be estimated based on the reaction order obtained from the parameter that has the lowest E_a value.

3. RESULTS AND DISCUSSION

3.1. Quality Characteristics of Analog Rice

In order to estimate its shelf-life, first the parameters affecting the initial quality of analog rice before storage must be determined (day 0, A_0). The selected parameters were moisture content and degree of whiteness. After the initial quality analysis, analog rice was stored at a temperature of 55° C which aims to accelerate the deterioration of analog rice during storage.

The evaluation of the final quality characteristics value (A_t) was obtained through storage of analog rice at 55°C and acceptance testing by 10 trained panelists. The evaluation was terminated when the panelists rejected 50% or more. The decline in quality of analog rice was solely based on exposure to one high temperature during storage (55°C).

Table 1. Initial Quality Characteristic Value (A_0) and Final Quality Characteristic Value (A_t) of Analog Rice

Parameter	Sample	(A_0)	(A_t)
Moisture content (%)	WP	9,66	6,16
	VP	9,66	7,12
Whiteness	WP	80,57	74,73
	VP	80,57	76,75

WP: Without Packaging; VP : Vacuum Packaging

3.2. Kinetics of Deterioration Reaction due to Moisture Content

Moisture content becomes one of the important product parameters because it can affect the quality and shelf-life of the product. Table 2 shows that the longer the rice was stored, the less moisture was found in analog rice. The decrease in moisture content is not surprising since moisture could evaporate due to relatively high temperatures during storage. Water vapor can move from the environment to the product or vice versa until equilibrium conditions are reached [6].

Table 2. Moisture Content of Analog Rice at 3 Accelerated Storage Temperatures

Day	Moisture content (%)					
	308 K		318 K		328 K	
	WP	VP	WP	VP	WP	VP
0	9,66± 0,96	9,66± 0,65	9,66± 0,43	9,66± 0,47	9,66± 0,91	9,66± 0,87
5	8,55± 0,98	9,01± 0,93	7,15± 0,16	8,36± 0,56	6,16± 0,16	7,12± 0,70
10	7,68± 0,90	8,10± 0,96	6,23± 0,31	7,28± 0,67	5,45± 0,96	6,12± 0,26
15	6,45± 0,91	7,47± 0,66	5,47± 0,38	5,94± 0,69	4,90± 0,16	5,62± 0,66
20	5,80± 0,93	6,63± 0,19	4,75± 0,96	5,38± 0,96	4,41± 0,76	4,91± 0,56

WP: Without Packaging; VP: Vacuum Packaging

Table 3. Regression Equation for Moisture Content of Product Without Packaging (WP)

Temp (K)	Regression Equation		Determination coefficient (R^2)	
	Zero Order	First Order	Zero Order	First Order
308	y = -0,1966x + 9,5916	y = -0,0261x + 2,2753	0,9931	0,994
318	y = -0,2299x + 8,9535	y = -0,0337x + 2,202	0,9128	0,9629
328	y = -0,2353x + 8,4696	y = -0,036x + 2,1306	0,7955	0,8724

Analog rice samples vacuum-packed with 0.12 mm thick polymeric material can still experience a decrease in moisture content. The reason is that the higher temperatures can increase the permeability of the packaging material. Thus, considerable amounts of moisture can pass through the polymeric packaging membrane [7].

Table 4. Regression Equation for Moisture Content of Vacuum Packaged Analog Rice at Different Temperatures (VP)

Temp (K)	Regression Equation		Determination Coefficient (R^2)	
	Zero Order	First Order	Zero Order	First Order
308	y = -0,1518x + 9,6926	y = -0,0188x + 2,28	0,9971	0,9931
318	y = -0,2194x + 9,5185	y = -0,0302x + 2,2704	0,9859	0,9921
328	y = -0,2199x + 8,8862	y = -0,0318x + 2,1899	0,8864	0,9402

According to [8], permeability to moisture can increase (Table 4) with higher storage temperatures (308 K, 318 K, and 328 K, respectively). According to the R^2 values, the decrease in water content at the three temperatures followed exponential kinetics at two storage temperatures of 318 K and 328 K (Table 5) while moisture evaporation at the storage temperature of 308 K followed zero order.

3.3. Kinetics of Deterioration Reaction on Whiteness of Analog Rice

The degree of whiteness (brightness) can demonstrate changes of a product as a consequence of deterioration. Table 6 shows that the longer the storage time, the less white the analog rice appeared to be. The higher the temperature was for storage, the lower the whiteness degree of the analog rice samples was observed.

Table 5. Whiteness Degree of Analog Rice at 3 Accelerated Storage Temperatures

Day	Whiteness Degree					
	308 K		318 K		328 K	
	WP	VP	WP	VP	WP	VP
0	80,57 ±0,96	80,57 ±0,96	80,57 ±0,98	80,57 ±0,13	80,57 ±0,94	80,57 ±0,95
5	78,90 ±0,15	79,15 ±0,96	77,38 ±0,96	78,47 ±0,53	74,73 ±0,43	76,75 ±0,96
10	76,38 ±0,20	77,59 ±0,34	75,61 ±0,74	76,91 ±0,91	72,00 ±0,61	73,91 ±0,97
15	74,48 ±0,15	74,99 ±0,73	72,73 ±0,73	73,75 ±0,90	68,46 ±0,96	70,43 ±0,91
20	72,65 ±0,67	73,19 ±0,69	70,30 ±0,12	71,77 ±0,96	66,80 ±0,96	68,88 ±0,92

The color of the analog rice which was originally white showed a change to yellow or brownish after the last day of storage. This can be explained by browning reactions that occur as a result of increased temperature [9]. A decrease in whiteness can also occur due to a decrease in moisture content during storage. High water content will make the product appear brighter because water has the property of reflecting and transmitting light [10]. In addition, non-enzymatic browning reaction or Maillard reaction is possible during storage at high temperatures as a consequence of high carbohydrate content originating from tapioca starch raw materials [11].

The change in degree of whiteness for the three storage temperatures of 308 K, 318 K, and 328 K followed first order. This indicates that it obeyed exponential kinetics at all three temperatures.

Table 6. Regression Equation Parameter of Degree of Whiteness after Vacuum Packaging (VP)

Temp (K)	Regression Equation		Determination Coefficient (R^2)	
	Zero Order	First Order	Zero Order	First Order
308	y = -0,3783x + 80,881	y = -0,0049x + 4,3937	0,9881	0,986
318	y = -0,4461x + 80,755	y = -0,0059x + 4,3924	0,9897	0,9878
328	y = -0,5942x + 80,049	y = -0,008x + 4,3838	0,9841	0,9878

Data in Tables 5 and 6 show that the two storage temperatures of 308 K and 318 K followed zero order while the storage temperature of 328 K followed first order. This indicates that the decrease in whiteness degree at 308 K and 318 K occurred constantly while at 328 K it obeyed exponential kinetics.

3.4. Estimation of Shelf-life of Analog Rice

The estimation of the shelf-life of analog rice was performed using the Accelerated Shelf-Life Test (ASLT) method with the Arrhenius approach. This method comprises the exposure of products to extreme environmental conditions such as high temperatures, thus accelerating quality decline [12]. The results for selected parameters are plotted against the storage time at each temperature and a linear regression equation is obtained. It reveals the type of order of quality decline. Further plots are made to obtain the Arrhenius equation which will be used for calculating the estimated shelf-life.

Table 7. Arrhenius Model for Critical Parameters

Critical parameters	Sample	Arrhenius equation
Moisture content	WP	Ln k = -1633,9 (1/T) + 1,6879
	VP	Ln k = -2676,4 (1/T) + 4,7813
Whiteness	WP	Ln k = -2780,4 (1/T) + 3,7712
	VP	Ln k = -2273,6 (1/T) + 6,3877

WP: Without Packaging; VP: Vacuum Packaging

Table 8. Activation Energy for Critical Parameters

Critical parameters	Sample	Activation energy (cal/mol)
Moisture content	WP	3244,92
	VP	5315,33
Whiteness	WP	5521,87
	VP	4515,37

WP: Without Packaging; VP: Vacuum Packaging

Tables 7 and 8 show the activation energy values calculated for each parameter and sample. The calculation of activation energy values aims at determining the estimated shelf-life of analog rice. The slope value of each Arrhenius equation was used to calculate the activation energy. The calculation is done by multiplying the slope value with R (ideal gas constant; R = 1.986 cal/mol K). It was selected because the lower the activation energy value of a reaction, the faster the quality deterioration will occur [12]. The calculation of shelf-life is based on the selected quality parameter that had the lowest activation energy value, in this case the water content of the sample without packaging. It is calculated based on the respective reaction order. The Arrhenius equation is selected from the parameter with the lowest activation energy and further calculations are carried out to obtain the value for the constant rate of quality decline in that parameter [13]

From Tables 9 and 10 it can be seen that the higher the storage temperature, the shorter the product life span will be. In this study, a comparison was made of analog rice without packaging (WP) and with vacuum-packaging (VP). The two types of storage options showed different effects on the product shelf-life. Vacuum-packed analog rice clearly had a longer shelf-life than analog rice that was left without packaging.

Although vacuum-packed products are safer, vacuum packaging can only provide a protective effect on the product when stored under normal conditions. Packaging can degrade as a result of extreme factors present during 55 °C where in this study, vacuum packaging was less resistant to high temperatures so that it affected the shelf-life in a hot environment [14].

Table 9. Estimation of shelf-life of samples without packaging (WP)

Temperature		k	Shelf-life	
°C	K		Days	Months
35	308	0,02686	50,32	1,68
45	318	0,03174	50,12	1,67
55	328	0,03712	44,68	1,49

Table 10. Estimation of shelf-life of samples with vacuum packaging (VP)

Temperature		k	Shelf-life	
°C	K		Days	Months
35	308	0,02007	150,82	5,03
45	318	0,02638	55,08	1,84
55	328	0,03410	45,67	1,52

4. CONCLUSIONS

The quality parameters analyzed in estimating the shelf-life of porang glucomannan-based analog rice are moisture content and degree of whiteness. The best results of the shelf-life estimation of porang glucomannan-based analog rice were achieved with vacuum packaging.

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