Shelf-life Evaluation of Packaged Fermented Cassava Flour

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Abstract. Cassava is a carbohydrate source with high productivity per hectare of plantation. Cassava is made into flour to extend its shelf life. However, traditional flour still has low quality due to its yellowish color and distinct odor. Fermented cassava flour (FERCAF) is produced by fermentation of cassava chips in a circulated retting fermenter by using a combination of *Lactobacillus plantarum*, *Bacillus subtilis*, and *Aspergillus oryzae*, followed by drying and milling. This process has been used successfully to produce flour with a white color and a neutral aroma. To enable industrial scale production and market introduction, the quality deterioration and shelf life of packaged FERCAF should be determined. The objective of this research was to investigate the effect of storage time and packaging type on the physicochemical properties and to determine shelf life of packaged FERCAF. FERCAF was stored in a controlled-incubator over 94 days using two packaging types: LDPE plastic and kraft paper. Based on the result, the number of microorganisms over 94 days of storage was within safe limits. The average estimated shelf life of packaged FERCAF was in the range of 3-4 months at ambient temperature. The shelf life of FERCAF packaged in LDPE plastic was approximately 15 days longer than that packaged in kraft paper.

Keywords: *FERCAF; fermented cassava flour; packaging; physical properties; shelf-life determination.*

1 Introduction

Cassava is a local Indonesian food commodity and has the second highest carbohydrate content after rice. Based on the Central Bureau of Statistics 2017, cassava productivity in Indonesia reached 23 tonnes/ha, while rice productivity only reached 5,4 tonnes/ha [1]. Although cassava productivity is higher than that of rice, the use of cassava is still limited to direct consumption and therefore limited by the shelf life of fresh cassava roots. To improve cassava utilization, cassava processing technologies, especially to produce cassava food ingredients such as cassava flour, need to be further developed. Cassava

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contains about 60% starch on a dry basis [2]. To improve its shelf life, cassava can be dried and processed to produce flour, such as modified cassava flour (MOCAF) and isolated/purified cassava starch (tapioca). In Indonesia, cassava is traditionally dried and milled to produce flour, called *gaplek*. Although the production rate is quite high, the yellowish color and distinct aroma of *gaplek* limits its utilization. On the other hand, tapioca has a higher value than *gaplek* due to its functional properties and can be used as a thickening agent and stabilizer. However, the potential availability of cassava is higher than the current consumption rate of tapioca. Therefore, to enhance the utilization of cassava it is necessary to produce cassava flour as a food ingredient that fulfills industrial standards, such as having a white color, neutral aroma, higher availability, hygienic and consistent quality.

Cassava processing can be further developed by using microorganism (fermentation) to break down the fibers and reduce the organic cyanide content of the cassava. This process increases the protein levels, lowers the cyanide level, and softens the structure of the cassava [3-6]. After further drying and milling, flour from fermented cassava is called modified cassava flour (MOCAF). Further improvement of the cassava chip fermentation process can be conducted using a circulated retting fermentation reactor, which is more hygienic and efficient in producing fermented cassava flour or FERCAF.

FERCAF is a second-generation MOCAF with a more hygienic production system and can be implemented on an industrial scale. FERCAF has been produced using circulated fermentation reactors with a capacity of 3 kg of cassava/batch [4,5]. As a staple food, FERCAF may be stored for a certain time before consumption. Storage of FERCAF may lead to quality degradation or a change in its characteristics, affecting its sensory, functional and biological quality. Sensory changes include changes in taste, texture and aroma, while functional changes include water binding ability and solubility. Concerning food safety, the growth of microorganisms is the most important aspect.

These combined parameters determine the shelf life of FERCAF. Among the parameters that can affect shelf life are storage temperature and type of packaging. The packaging used may limit the transfer of moisture, oxygen or hazardous nanoparticles through the product and reduce the deterioration rate of the quality attributes during storage, distribution and transportation [7,8]. Being a relatively new cassava-based product, FERCAF’s shelf life has not yet been determined. Therefore, this research aimed to determine the effect of storage time and type of packaging on the quality of FERCAF at ambient storage conditions and give recommendations regarding the shelf life of FERCAF.

2 Methods

2.1 Materials and Reagents

Fresh cassava roots (with peel) were bought from a regular supplier at a local market in Bandung, Indonesia. The cassava roots were then washed, peeled and sliced into chips. The starter culture applied for cassava chip fermentation was composed of a mixture of *Aspergillus oryzae* ITB L24, *Bacillus subtilis* ITB B128, and *Lactobacillus plantarum* ITB B188, obtained from the culture collection of the Microbiology and Bioprocess Technology Lab, Chemical Engineering Department, Institut Teknologi Bandung, Indonesia. Two types of packaging materials, low density polyethylene (LDPE) and kraft paper (cellulose fiber), were used to pack the FERCAF.

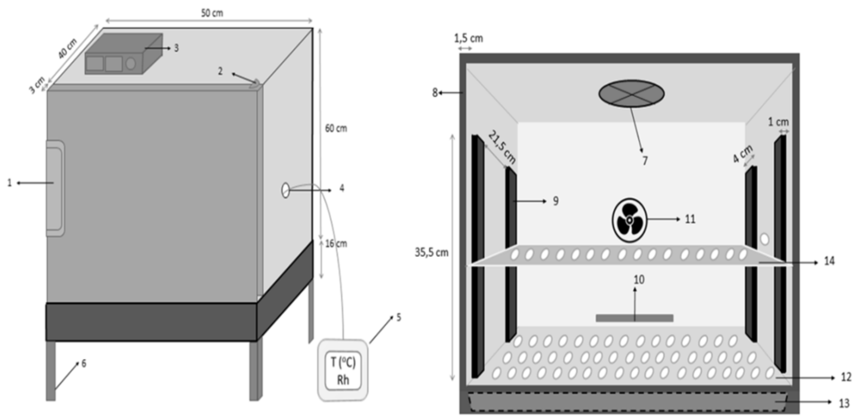
2.2 Production of Fermented Cassava Flour (FERCAF)

Production of FERCAF consists of 3 stages: microbial starter culture preparation, cassava chip preparation and fermentation, following the method from Kresnowati [9]. Briefly, the starter culture of microorganisms was made by growing *B. subtilis* and *A. oryzae* in 20 mL of potato dextrose broth and growing *L. plantarum* in 20 mL MRS broth. The culture was incubated at ambient temperature (30 °C) for 48 h until the exponential phase was reached. Then, the culture was grown on a mixture of 100 g of cassava and 1 L of demineralized water that had been sterilized previously.

The mixture was stirred and incubated at ambient temperature for 24 h. For the fermentation process, the fresh cassava roots were processed within 24 h, consisting of peeling, washing and chipping to approximately 0.1 cm thickness. Fermentation was conducted by soaking 3 kg of cassava chips with 2 L of inoculum solution in a circulation fermentation reactor at a controlled temperature of 34 °C for 24 h, followed by addition of demineralized water, giving a final volume of 20 L, following the method from [4,6]. Subsequently, the fermented cassava chips were dried at room temperature using a fan before milling into FERCAF flour.

2.3 Effect of Packaging and Storage on Shelf Life of FERCAF

FERCAF was stored packaged in 16 kraft paper and 16 LDPE plastic, respectively, each sample consisting of 100 g of the fermented flour. The packages were stored at 30 °C in an incubator (Figure 1). Relative humidity (RH) was measured but not regulated to simulate actual household storage conditions. The storage time was observed over 94 days with data collection of FERCAF quality attributes on days 0, 10, 24, 31, 38, 64, 75, and 94. All experiments were conducted in duplicate.



Note:

1. Door opening
2. Door hinges
3. Temperature display
4. Ventilation hole
5. Hygrometer & Thermometer
6. Incubator support
7. Incandescent lamp
8. Rubber seal
9. Tray holder
10. Thermocouple
11. Fan
12. Incubator base
13. Water tray
14. Storage tray

Figure 1 Scheme of FERCAF storage incubator.

2.4 Permeability Measurement of Packaging Materials

Water vapor permeability was determined following the method from Jaya & Das [10]. Briefly, about 5 g of silica gel was packaged in LDPE plastic or kraft paper packaging. Then, each package was placed in an incubator for six days under the actual storage conditions, i.e. 30 °C. The mass of silica gel was weighed every 24 hours for six days. Packaging permeability, K (kg $H_2O/(m^2$. Pa. day), was calculated using Eq. (1) as follows:

$$K = \frac{dw/_{d\theta}}{A_p\, P^*} \tag{1}$$

where $dw/_{d\theta}$ is the gradient obtained from cumulative mass water vapor over time, w is the mass of silica gel in the package, and θ represents time, A_p is the surface area of the package, and P^* is the saturated water vapor pressure at the measuring temperature.

2.5 Measurement of FERCAF Quality

The measured FERCAF quality attributes were moisture content, water activity, swelling power, and microorganism concentration. These quality measurements were evaluated for different storage times to observe the changes in characteristics during storage.

2.5.1 Moisture Content Analysis

Moisture content of FERCAF samples was measured using the method from the Indonesian National Standardization Agency [11]. Briefly, about 2 g of FERCAF was dried using a convection oven at a temperature of 130 ± 3 °C for 1 hour. After drying, the FERCAF samples were put in a desiccator to cool until ambient temperature was reached, followed by weighing using an analytical balance. The measurement was conducted in duplicate. Eq. (2) was used to calculate the water content of the FERCAF:

$$Moisture\ content\ (\%) = \frac{Initial\ mass\ of flour - Mass\ of\ dried\ flour}{Initial\ mass\ of\ flour} \times 100\% \quad (2)$$

2.5.2 Water Activity Measurement

Water activity (a_w) is a common indicator to estimate changes in food quality during storage and is often used as an important target parameter in food preservation [12,13]. Water activity was measured using a water activity meter (Novasina LabSwift-aw, Novatron Scientific Ltd, UK).

2.5.3 Whiteness Index

The whiteness index (WI) represents the degree of whiteness of the product, which is susceptible to change during storage [14]. WI was measured using a 3nh NH310 Portable Colorimeter from Shenzhen Threenh Technology Co. Ltd. Briefly, the colorimeter was calibrated using a white blank. Then, flour samples were put into a container for color measurement. The analysis results appeared on the display screen as color parameters L*, a*, and b*. L* (0 to 100) is the brightness parameter (0 is black and 100 is white), a* is the green-red color parameter, and b* is the blue-yellow color parameter [3,15]. WI was calculated using Eq. (3), while total color difference (ΔE) was calculated using Eq. (4):

$$WI = 100 - \sqrt{(100 - L^{*2}) + a^{*2} + b^{*2}} \quad (3)$$

$$\Delta E = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (4)$$

2.5.4 Swelling Power Analysis

Swelling power indicates the ability of starch to hold water molecules in its granules. Swelling power was measured by dissolving 0.1 g of flour in 10 ml aqua dm followed by heating at 65 °C for 30 minutes and centrifugation at 2500 rpm and 25 °C for 15 minutes [16]. The supernatant and precipitate formed were separated by decantation. The swelling power was calculated using Eq. (5):

$$Swelling\ power = \frac{Mass\ of\ wet\ paste}{Mass\ of\ initial\ flour} \tag{5}$$

2.5.5 Quantification of Microorganisms

Quantification of microorganisms was conducted using the total plate count method (TPC). Briefly, about 1 g of FERCAF was dissolved in 9 mL water, followed by filtration and dilution. About 1 mL of diluted solution was analyzed on agar medium. The agar medium consisted of mannitol egg yolk polymyxin agar (MYP), which was prepared by pour plating, and *Aspergillus flavus/Parasiticus agar* (AFPA), which was prepared by spread plating. MYP was used to quantify *B. substilis*, while AFPA was used to quantify *A. oryzae*.

2.6 Determination of Moisture Sorption Isotherm of FERCAF

The moisture sorption isotherm describes the relationship between moisture content and water activity, following the Guggenheim, Anderson, and De Boer (GAB) model. The GAB model is the most widely used model for food systems, such as packaged cassava flour [17-20], and is shown in Eq. (6):

$$\frac{a_w}{X} = \frac{1}{CZX_m} + \frac{(C-2)}{CX_m} a_w + \frac{Z(1-C)}{CX_m} {a_w}^2 \tag{6}$$

where a_w is water activity, X is moisture content in dry basis, X_m is a parameter that is interpreted as the value of X in a saturated water monolayer on the adsorbing surface, while C and Z are constants in the GAB model related to heat of adsorption.

2.7 Shelf Life Estimation of Packaged FERCAF

Based on a previous study on food shelf life [21], changes in food characteristics follow the reaction kinetics expressed in Eq. (7):

$$\pm \frac{d[Q]}{dt} = k[Q]^n \tag{7}$$

where Q is the quality of the attribute, t is the storage time, k is the reaction rate constant, and n is the order of reaction. The ± sign indicates that the attribute quality may increase or decrease during storage. Reactions in a food system generally follow zero-order or first-order reaction kinetics. In a zero-order reaction, the change in quality during storage is linear, while in a first-order reaction, the degradation of the quality attribute occurs exponentially. Each quality attribute has its own limit value. The time span until the degradation reaches its limit is called the shelf life.

3 Results and Discussion

3.1 Permeability of Packaging

Water vapor permeability of the packaging was determined by measuring the mass of moisture absorbed by silica gel. Figures 2A and 2B show the cumulative mass of moisture absorbed by silica gel packaged in LDPE plastic or kraft paper for 6 days. Figure 2A shows that the mass of moisture in the silica gel packaged in LDPE plastic increased linearly over 6 days of storage. On the other hand, we observed that the permeability of moisture in the silica gel packaged in kraft paper showed a different trend (Figure 2B). At first, the cumulative mass of moisture in the silica gel was followed every 24 h for 6 days (1^{st} data set) and it was observed that the permeability value was constant from day 1 to day 6. This may indicate that the silica gel was already saturated within the first day of observation. Therefore, we repeated the observation using a shorter sampling time during the first day (0, 1, 2, 3, 5, 8, 18, and 24 h), followed by cumulative mass measurements of moisture every 24 hours from day 1 to day 6 (2^{nd} data set). From the 2^{nd} data set, it was observed that there were two permeability zones of kraft paper packaging during the time of observation. In the first zone, the mass of moisture absorbed by silica gel increased linearly from hour 0 (day 0) to hour 24 (day 1) (Figure 2B), while in the second zone, the mass of moisture in the silica gel was saturated.

Moisture permeability for the LDPE plastic packaging was calculated from day 0 to day 6, while moisture permeability for the kraft paper packaging was only calculated from the first zone of the second data set. The parameter values required to determine the packaging permeability are shown in Table 1. The permeability of the kraft paper was approximately 240-times larger than that of LDPE plastic (Table 2), which indicates that the moisture diffusion through kraft paper was higher than through LDPE plastic. Therefore, FERCAF packaged using kraft paper material may tend to absorb more moisture from the surroundings than FERCAF packaged in LDPE plastic.

Table 1 Permeability measurement for two types of FERCAF packaging: LDPE plastic and Kraft paper.

Parameter	LDPE Plastic	Kraft Paper
$\frac{dW}{d\theta}$ (kg/days)	$0{,}02 \times 10^{-3}$	$6{,}50 \times 10^{-3}$
Area of packaging, A_p (m^2)	0,0164	0,0222
Saturated vapor pressure at 30 °C, P* (Pa)	4245,5	
Permeability, K (kg/(m^2· Pa. days))	$2{,}89 \times 10^{-7}$	689×10^{-7}

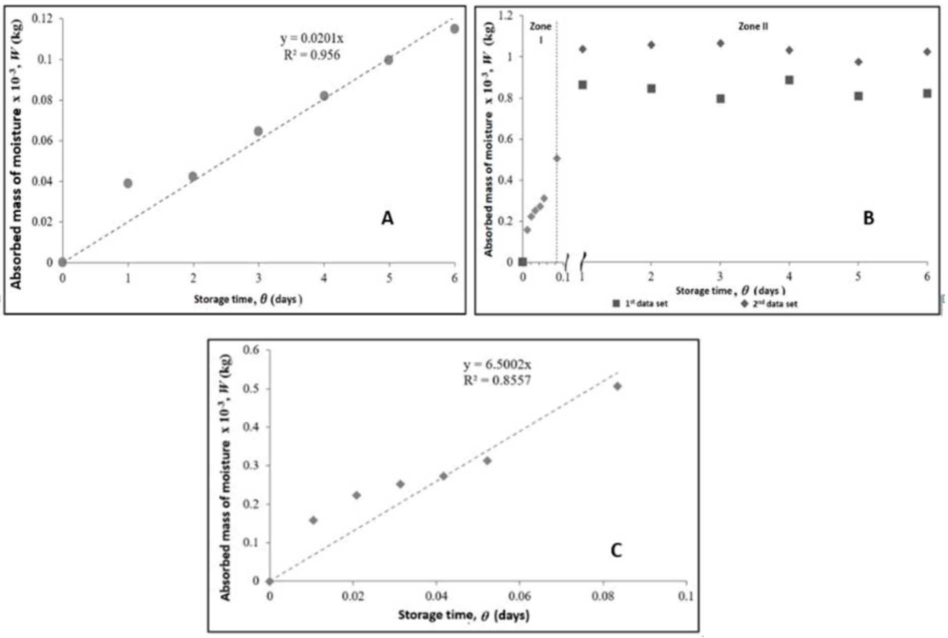


Figure 2 The absorbed moisture mass in silica gel through LDPE plastic (A) and kraft paper (B) over 6 days of storage time, and the first zone of absorbed moisture over kraft paper (C) at 30 ± 0.8 °C and RH range 63-75%.

3.2 Effect of Storage Time and Packaging Type on Moisture Content and Water Activity of Packaged FERCAF

Moisture content and water activity (a_w) are important parameters in evaluating food products. A certain level of water activity is required to support the growth of microorganisms, for example most fungi cannot grow at $a_w < 0.7$, while most bacteria cannot grow at $a_w < 0.9$ [22]. The shelf life of a food product can thus be determined as the time before which the critical water activity of the product is reached. The moisture content of the packaged FERCAF increased over 94 days of storage (Figure 3A). Statistically, the increase of the moisture content was significantly affected by the storage time ($p < 0.05$) but not significantly affected by the type of packaging used ($p > 0.05$). Based on the experimental data, it was observed that the increased rate of FERCAF moisture content followed first-order reaction kinetics (Figure 3A).

Kraft paper is a cellulose-based material that is hygroscopic and porous, which tends to absorb moisture, both from external (the environment) and from internal (the packaged product) sources [23]. As a result, although moisture permeability through kraft paper is higher than through LDPE plastic, kraft paper may release moisture back into the environment. As a result, the moisture content of the FERCAF packaged in kraft paper was similar to the FERCAF packaged in LDPE plastic within the time of observation.

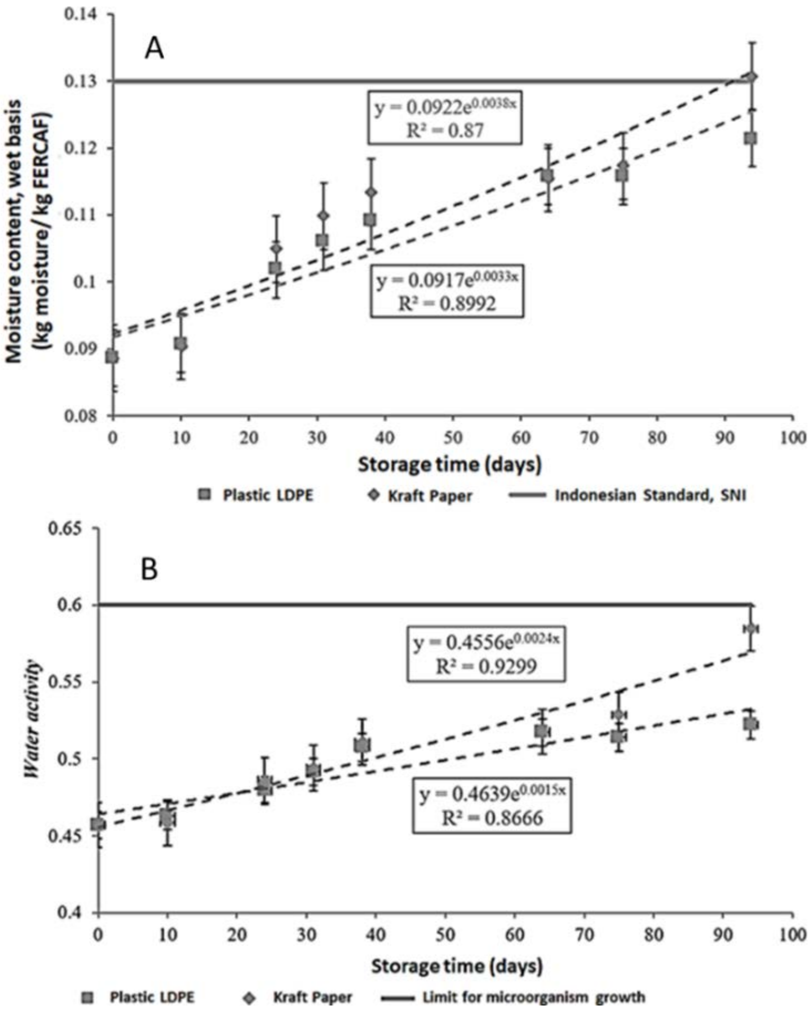


Figure 3 Changes in moisture content (A) and water activity (B) of FERCAF in packaged LDPE plastic and kraft paper over 94 days of storage time at 30 ± 0.8 °C and RH range of 54-77%.

Figure 3B shows the increased water activity of the FERCAF over 94 days of storage in LDPE plastic and kraft paper packaging respectively. Chiste, *et al*. [24,25] state that there is no significant growth of harmful microorganisms at water activity lower than 0.6. Water activity of FERCAF packaged in either

LDPE plastic or kraft paper had a value below 0.6 over 94 days of storage and therefore was still under the water activity limit for microorganism growth.

Statistically, storage time significantly increased the water activity ($p < 0.05$) of the packaged FERCAF, while the packaging type showed no significant effect on the increase of water activity ($p > 0.05$). The increased rate of water activity of the packaged FERCAF followed first-order reaction kinetics.

The relationship between dry basis moisture content (X) and water activity (aw) can be explained by the GAB model shown in Eq. (6). Moisture sorption isotherm (MSI) constants for the packaged FERCAF using GAB model are shown in Table 2. MSI curve of the LDPE-packaged FERCAF is shown in Eq. (8), while MSI curve of the kraft paper-packaged FERCAF is shown in Eq. (9):

$$a_w = \frac{2+\left(\frac{5{,}47}{X_S}-1\right)0{,}0043-\left[\left(2+\left(\frac{5{,}47}{X_S}-1\right)0{,}0043\right)^2-4(1-0{,}0043)\right]^{0{,}5}}{2(0{,}87)(1-0{,}0043)} \quad (8)$$

$$a_w = \frac{2+\left(\frac{4{,}49}{X_S}-1\right)0{,}0041-\left[\left(2+\left(\frac{4{,}49}{X_S}-1\right)0{,}0041\right)^2-4(1-0{,}0041)\right]^{0{,}5}}{2(0{,}89)(1-0{,}0041)} \quad (9)$$

Based on Table 2, estimate saturated water in the monolayer (X_m) was about 5.47 for FERCAF packaged in LDPE plastic and 4.49 for FERCAF packaged in kraft paper. Sanni, *et al.* [26] found that the X_m value of fermented cassava from Nigeria (fufu) was approximately 4.46, which is close to that of FERCAF.

Table 1 Moisture Sorption Isotherm Constants for FERCAF in LDPE Plastic and Kraft Paper Packaging over 94 Days of Storage at 30 ± 0.8 °C and RH range 54-77%.

GAB Constants	Packaged FERCAF	
	LDPE Plastic	**Kraft Paper**
C	0.0043	0.0041
Z	0.87	0.89
X_m	5.47	4.49

The moisture sorption isotherm of the packaged FERCAF followed a sigmoidal isotherm form (Figure 4). This curve type corresponds well to those of dry food products containing either low or high protein/fat content [27].

The water activity of the FERCAF packaged in LDPE plastic and kraft paper over 94 days of storage was within the range of 0.46 to 0.59. Thus, the range of water activity of packaged FERCAF was within zone II of the sigmoidal curve, where chemical reactions and microbial growth are limited or do not occur [28].

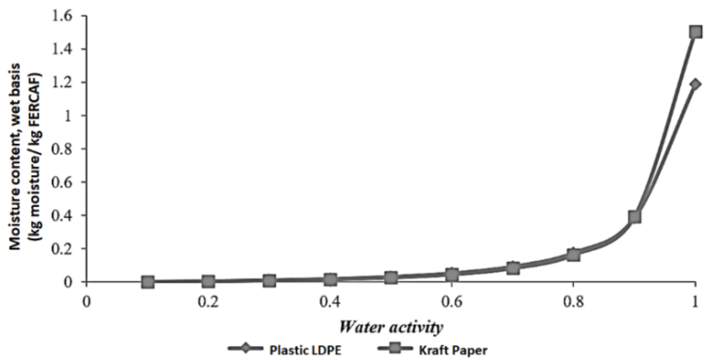


Figure 4 Moisture sorption isotherm FERCAF curve at temperature 30 ± 0.8 °C and RH range 54-77% for LDPE plastic and kraft paper packaging using the GAB model.

3.3 Effect of Storage Time and Package Type on FERCAF Whiteness Index (WI)

The color of food products may affect consumer perception. Commonly, flour products should have a white color. The changes in WI of the packaged FERCAF over 94 days storage for LDPE plastic and kraft paper packaging is shown in Figure 5. Statistically, the reduction of WI was not significantly affected by the type of packaging ($p > 0.05$), but it was significantly affected by storage time ($p < 0.05$). Based on the experimental data, the rate of WI changes for the packaged FERCAF followed first-order reaction kinetics (Figure 5). Uchechukwu-Agua [29] observed that the WI index of dried cassava flour (without treatment by microorganism) from two Nigerian cultivars after 12 weeks of storage was in the range of 84.6-91.2, i.e. higher than for FERCAF (WI of 82-83). Color changes in dried cassava flour may occur due to degradation of the yellow pigment in cassava, cultivar differences, significant variations in CHO composition (proximate analysis), or oxidation reactions during storage [29]. In this case, the difference in WI value may be due to fermentation or to the difference in cassava cultivars that were used as raw material. Kaur [30] observed that color degradation may indicate nutritional loss due to the auto-oxidation between anthocyanin and β-carotene.

Kresnowati [6] showed that fermented cassava flour generally has a whiter color, softer texture, and neutral aroma. In addition, fermentation with *L. plantarum* increases the protein content of cassava flour by about 8.6% compared to the protein content of native cassava flour at 0.3-3.5%. A higher protein content and low moisture content may contribute to the yellowish color of FERCAF by increasing the possibility of an enzymatic browning reaction at room temperature, followed by protein-polyphenol complexing during storage.

The total color difference (ΔE) between the packaged FERCAF at day 0 and day 94 was about 0.22 for LDPE plastic and 0.36 for kraft paper. A value of ΔE within 0 to 1 indicates that the color difference of the packaged FERCAF over the observed storage time could not be distinguished at a glance [31]. On the other hand, the overall ΔE value of the FERCAF over 94 days of storage was much lower than that of cassava flour over 12 weeks of storage from the study of Uchechukwu-Agua [29], which ranged from 2.3 to 6.4 (the color change could be clearly distinguished). Based on this result, fermentation of cassava chips prior to drying and milling successfully improves FERCAF's stability related to color degradation during storage.

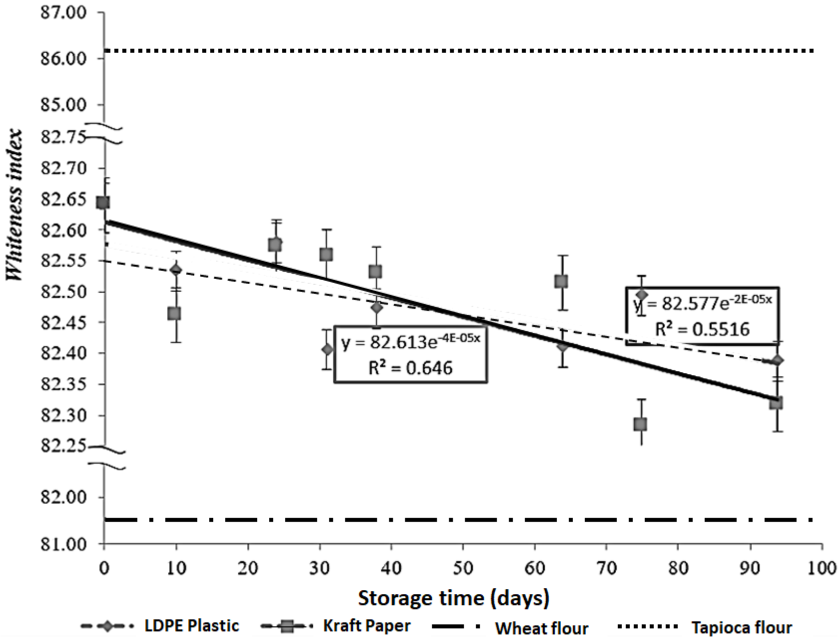


Figure 5 The changes of the whiteness index of FERCAF over 94 days of storage at 30 ± 0.8 °C and RH range 54-77% compared to reference wheat flour and tapioca flour (one-time measurement at t = 0).

The total color differences between the packaged FERCAF and two references of commercially available flour, wheat flour and tapioca flour, were also evaluated. However, the whiteness index of the two reference flours (wheat flour and tapioca) was only measured once, at t = 0. Therefore, the effect of storage duration and packaging type on color changes between the two reference flours and FERCAF could not be compared in this study. The whiteness indexes of the packaged FERCAF were within the range of 82-83. These values were lower on average than the WI of tapioca flour (86.2) but higher than that of wheat flour (81.5). The ΔE values for the packaged FERCAF for both packages compared to the reference flour were similar, with average ΔE of packaged FERCAF to tapioca starch at about 3.9 and average ΔE of packaged FERCAF to wheat flour at about 4.6. This ΔE value is within the range of 3.5-5, indicating that the color difference between the two flours could be clearly distinguished [32].

3.4 Effect of Storage Time and Packaging Type on Swelling Power

The swelling power reflects the composition of amylose and amylopectin of the carbohydrate flour and further indicates its ability to bind with water molecules, or the capability of the starch granules to swell during the cooking process. In general, the swelling power relates to product texture and elasticity [33]. Based on the experimental data, the swelling power of the packaged FERCAF was in the range of 12.4-13.9, indicating that storage time and packaging type had no significant effect on the swelling power of the tested packaged FERCAF ($p > 0.05$) (Figure 6). Swelling power is influenced by the amylose and amylopectin composition in flour [4,6]. In this research, there was no significant change in the swelling power of the packaged FERCAF over 94 days of storage, which may indicate that there were only small or no changes in the amylose and amylopectin content.

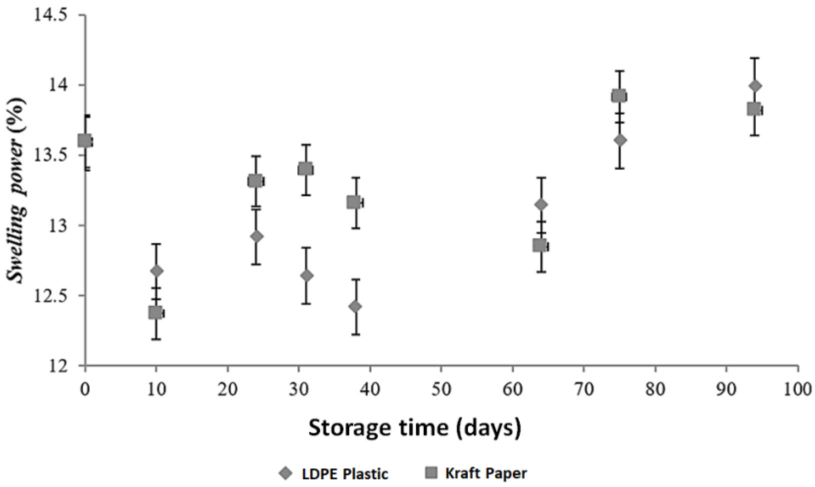


Figure 6 Swelling power of FERCAF packaged in LDPE plastic and kraft paper over 94 days storage at 30 ± 0.8 °C and RH range 54-77%.

3.5 Effect of Storage Time and Packaging Type on Microorganism Content

The microorganism content of food products is normally checked in relation to possible microbial contamination, which leads to food deterioration. In case of fermented food products it may be necessary to check the viability of fermenting microorganisms during the storage of final products and whether it may also contribute to some changes in the properties of the product. The microorganisms used in the fermentation for FERCAF production are *B. subtilis*, *A. oryzae*, and *L. plantarum*. While *L. plantarum* is a non-spore forming microorganism and will not survive after the drying process in the production of FERCAF, *B. subtilis* and *A. oryzae* are spore forming microorganisms which spores will remain in the FERCAF after the drying and milling of fermented cassava chips. Therefore, viability of these two microorganisms during storage needs to be further investigated.

Quantification of microorganisms was performed on *B. substilis* and *A. oryzae*. Figure 7 shows that the amount of *B. substilis* colonies formed in the FERCAF packaged in LDPE plastic was approximately 2.12 log CFU/gr, while for kraft paper it was approximately 2.06 log CFU/gr. These values are far below the safe limit of approximately 4 log CFU/gr. In addition, this study also showed that no *A. oryzae* was formed over 94 days of storage in both the FERCAF packaged using LDPE plastic and kraft paper. The obtained results are consistent with the moisture content and water activity measurement results discussed in Section 3.2.

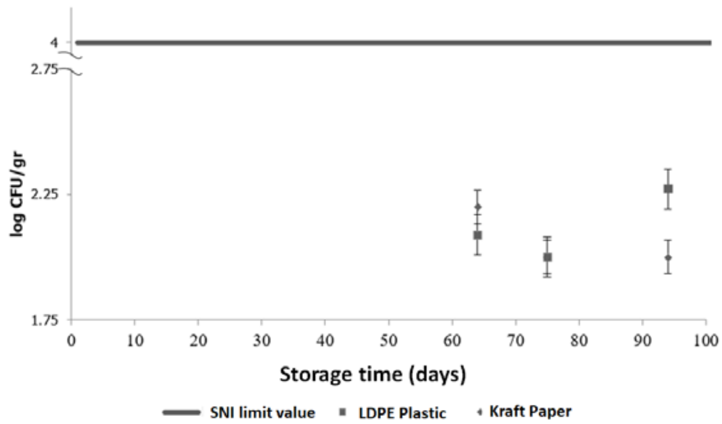


Figure 7 Number of *B. substilis* colonies in FERCAF packaged in LDPE plastic and kraft paper for 94 days storage at 30 ± 0.8 °C and RH range 54-77%.

3.6 Shelf life Evaluation of Packaged FERCAF

Parameters that were used to estimate FERCAF shelf life were moisture content, water activity, and color changes over the observed storage time. Indonesian National Standardization Agency has set a maximum limit of flour moisture content for safe consumption of 13% (kg water/kg flour) [11]. Commercially available wheat flour has an average shelf life of 4-6 months and its storage stability could be improved and its shelf life increased if its moisture content were approximately 9 to 10% [34]. The minimum limit of microorganism growth is indicated by a water activity value of 0.6, while the minimum whiteness index of FERCAF is indicated by the wheat flour whiteness index (81.5).

Fermentation seem to increase FERCAF's stability towards color degradation. Swelling power and the number of microorganisms were relatively constant over the observed storage time, so only the changes in whiteness index, moisture content, and water activity were used to evaluate the shelf life of the packaged FERCAF (Figure 8). The shelf life of the FERCAF was estimated as the shortest time to reach the limit value of one quality attribute, i.e. moisture content. Thus, the estimate shelf life of the FERCAF was 105 days when packaged in LDPE plastic and 90 days when packaged in kraft paper.

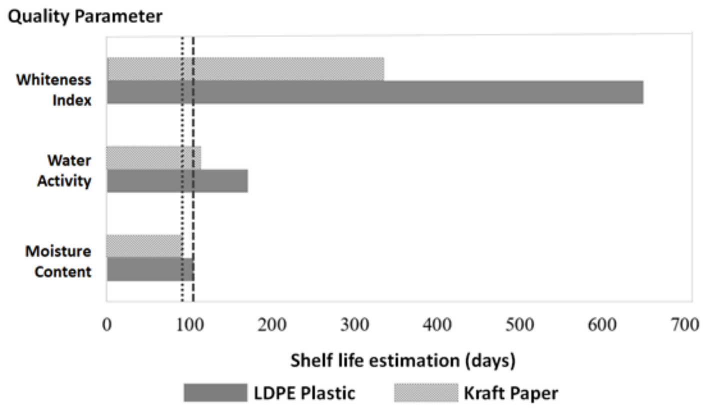


Figure 8 Shelf-life estimation of packaged FERCAF stored in LDPE plastic and kraft paper based on water content, water activity, and whiteness index of FERCAF.

4 Conclusion

Based on the results of this study, it can be concluded that storage time and packaging type have no significant effect on the swelling power of the packaged

FERCAF ($p > 0.05$), which may indicate that there are only small or no changes in the amylose and amylopectin content. On the other hand, the moisture content, water activity, and whiteness index of the packaged FERCAF were significantly affected by storage time ($p < 0.05$), but not significantly affected ($p > 0.05$) by packaging type. The color change in the packaged FERCAF during storage was considerably low, which indicates that fermentation of cassava chips prior to drying and milling successfully improved FERCAF's stability toward color degradation during storage.

Quantification of microorganisms showed that packaged FERCAF over 94 days of storage was still within safe limits, which is consistent with the moisture content and water activity measurements. However, *B. subtilis* and *A. oryzae* are spore forming microorganisms, thus their spores will remain in FERCAF after the drying and milling of fermented cassava into FERCAF. The rate of moisture change, water activity, and whiteness index follow first-order reaction kinetics. The average estimated shelf life of the packaged FERCAF was in the range of 3-4 months at ambient temperature. The shelf life for FERCAF packaged in LDPE plastic was approximately 15 days longer than for kraft paper.

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