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Effect of Starch, Lipid, and Protein Components in Flour on the Physical and Mechanical Properties of Indonesian Biji Ketapang Cookies

Asep Bayu Dani Nandiyanto[1*], Risti Ragadhita[1], A. Ana[2], Belkheir Hammouti[3]

[1]*Departemen Kimia, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229 Bandung, 40154, Indonesia*
[2]*Fakultas Pendidikan Teknik dan Kejuruan, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudhi No. 229 Bandung, 40154, Indonesia*
[3]*Laboratory LCAE, Faculty of Sciences, Mohammed Premier University, Oujda 60000, Morocco*

Abstract. The objective of this study was to evaluate the effects of starch, lipid, and protein components in flour on the mechanical properties of Indonesian Biji Ketapang (BK) cookies. Since the type of flour determines the amounts of nutrients, three types of flour (i.e., wheat, rice, and tapioca flour) were used as models. The results showed that the rheological properties of flour, which depend on starch, lipid, and protein components, influenced the spread ratio, making the components homogeneously distributed and controlling the dimensions and pores inside the cookies. Indeed, changes in the dimensions and pores affected the mechanical properties of the cookies (compressive strength and hardness parameters). Cookies made from rice, wheat, and tapioca flours have a pore size (μm)/shore scale of 42/52.57, 23/45.14, and 15/35.71, respectively. In general, the nutrients in the flour had a significant impact on the physical and mechanical properties of cookies. Starch is the main nutrient that influences the physical properties of cookies. Lipid and protein influence the amount of water absorbed, while water molecules can spread the material components in the cookies to make them more homogeneous, allowing cookies to swell with pores and influencing their mechanical properties. Flour with low-protein content led to the creation of cookies with better crispness and hardness. A proposed mechanism in the formation of pores in the cookies during the preparation of BK was presented. The analysis of nutrient components (i.e., starch, lipid, and protein) in the BK is also presented. The results are important in terms of the health benefits of these cookies related to the type of flour used, especially for producing "gluten-free foods." Thus, the results could offer benefits for product management.

Keywords: Cookies Quality; Crispness; Rice Flour; Tapioca Flour; Wheat Flour

1. Introduction

Biji ketapang (BK) cookies are a traditional Indonesian snack food made from flour, sugar, margarine, and egg yolk (Delima, 2013). BK cookies are popular because of their sweet and crunchy taste and hard texture. They are convenient, ready to eat, and have a long shelf life (Nagi et al., 2012). They offer a valuable opportunity for nutritional improvement because they are usually made with enriched additives, such as fat, sugar, and developer ingredients. In addition, cookies are the largest category of snacks worldwide. The rate of dried cookie consumption in Indonesia in 2011–2015 represented 24.22% of the total food consumption. This consumption rate is higher than that of wet

*Corresponding author's email: nandiyanto@upi.edu, Tel.: +62-22-2000579, Fax: +62-22-2000579
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cookies (17.78%) (Meilysa, 2018). The creation of highly delicious cookies has been well documented, either using single flours or a mixed composition of flours. Various flours have been reported, including wheat (Loza et al., 2017), legume, sorghum (Okpala and Okoli, 2011), cassava (Yenrina et al., 2020), wheat and plantain, sorghum, and legume (Okpala and Okoli, 2011), mocaf and ketapang seeds (Yenrina et al., 2020), and wheat and cassava (Bala et al., 2015). However, few studies have examined how to control the hardness of cookies.

To make BK with a specific level of crispness, good strategies (especially in the selection of raw materials) are required. Although some reports have presented strategies for controlling crispness (reducing water levels or dehydration processes as well as modification, fortification, the substitution of flour with suitable raw materials and the addition of crunchy ingredients (Cardoso et al., 2019), there is no information on applying these techniques to BK. Understanding BK is important since it has socioeconomic (to understand what people need) and culture and heritage impacts (Ashari et al., 2021; Qotrunnada and Nurani, 2022).

Based on our previous works on controlling the mechanical properties of the food material (i.e., cookies and crackers) (Anggraeni et al., 2020a; Anggraeni et al., 2020b; Anggraeni et al., 2020c; Nandiyanto et al., 2018; Nandiyanto et al., 2020; Triawan et al., 2020), the objective of this study was to evaluate the effects of starch, lipid, and protein components of flour on the mechanical properties of BK. Since the type of flour determines the amount of nutrients, three types of flours were used in this study (i.e., wheat, rice, and tapioca flours). The novelties of this research are (i) understanding phenomena happening during the baking process, including changes in nutrients and physicochemical properties; and (ii) understanding how to adjust the hardness of cookies by controlling the nutrient composition (e.g., protein, carbohydrates, fat, water). The analysis of nutrient components (i.e., starch, lipid, and protein) in BK is presented. The results are important in terms of the health benefits of these cookies relating to the flour used, especially to support people suffering from allergies caused by selected fractions of gluten proteins. In addition, there is a consumer trend for selecting so-called "gluten-free foods." We found that this type of food can be achieved when producing BK from a specific flour (i.e. tapioca flour). Thus, the results offer product management benefits. Indeed, it is the main duty of engineers to develop products (Kusrini and Kartohardjono, 2019; Suzianti et al., 2015).

2. Methods

Figure 1 provides a detailed illustration of the experimental method. In preparing the BK, butter (100 g), sugar (175 g), and eggs (2) were mixed using a mixer (600 rpm) to obtain a homogeneous mixture. A total of 750 g of flour was added into the mixture along with coconut milk. The dough was re-stirred until the dough became smooth. The dough was then molded using an oval cookie mold (2.5 x 0.5 x 1.3 cm). The molded cookies were placed into an electric oven and baked at 150°C for 30 min.

Proximate analyses were carried out: moisture and ash content using the gravimetric method, carbohydrates (starch) using the Luff Schoorl method, protein using the Kjeldahl method, lipid using the Soxhlet method, and total dietary fiber using The American Association of Cereal Chemists (AACC) method.

The particle shape and size of the flour as well as the surface of the BK were analyzed using a digital microscope (BXAW-AX-BC, China). The physical dimensions (i.e., length, thickness, and diameter) of the samples were measured using Vernier calipers. The spread factor of the sample was calculated by dividing the average diameter (D) by the thickness (T) of the cookies. The particle size distribution of the flour was determined using a sieving apparatus (Niaga Kusuma Lestari, Indonesia, in accordance with ASTM D1921) with hole sizes of 48, 58, 74, 100, 125, 250, and 530 µm. The pore size was measured using a Ferret analysis of the microscope images based on our previous report (Yolanda and Nandiyanto, 2022). Analysis of the presence of functional groups in flour and BK was carried out using a Fourier transform infrared spectrometer (FTIR, FTIR-4600, Jasco Corp, Japan) and compared with the literature (Nandiyanto et al., 2019a). The rheological properties of the flour were analyzed based on bulk density and viscosity parameters. The bulk density of the flour was calculated by dividing the mass and the volume of the specimen (Nandiyanto et al., 2021), whereas the Zahn cup tool (Zahn cup # 2) was used to determine the viscosity (Maryanti et al., 2020).

The compressive strength and hardness tests used the same procedure as in previous studies. For the compressive test, the Screw Mount test instrument (Model I ALX-J, China) equipped with a digital force-measuring instrument was used (Model HP-500, Serial, No H5001909262; applying a constant displacement rate of 2.6 mm/min). For the hardness test, the Shore durometer instrument (Shore A Hardness, in size, China) was used.

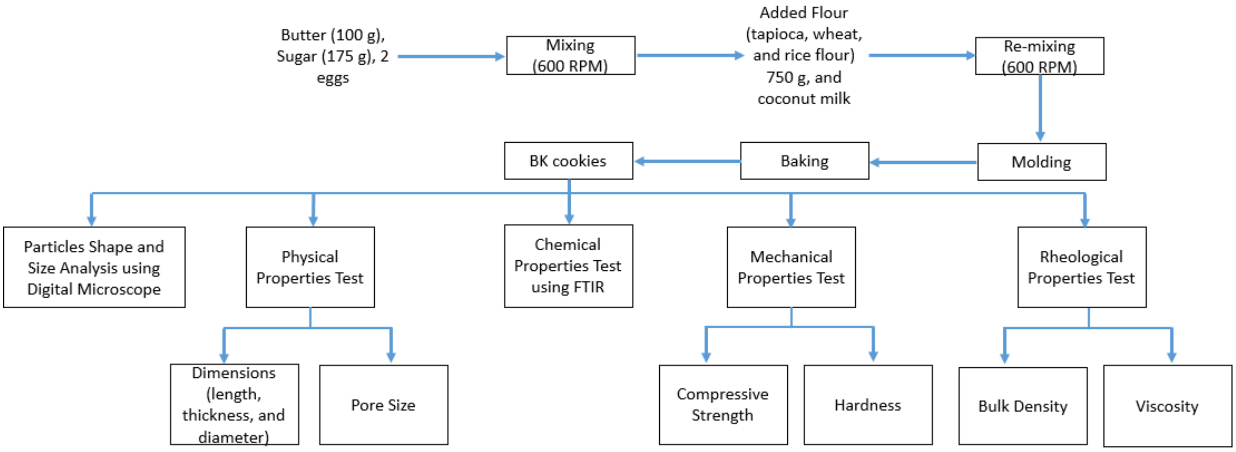

Figure 1 Detailed illustration of the experimental method

3. Results and Discussion

3.1. Physical Characteristics of the Flour and Biji Ketapang Cookies

Rice, wheat, and tapioca flour have particle sizes in the range of 50–160, 74–250, and 50–250 µm, respectively. Rice and tapioca flour have relatively similar particle sizes. Meanwhile, wheat flour has larger particle sizes compared to other types of flour. Table 1 shows the bulk density and viscosity of each type of flour. The amounts of the ingredients used in BK formulations and their interactions influence the viscosity of the dough, where the dough viscosity parameter relates to the spreading ratio of the dough. Viscosity is influenced by the protein content in flour. Lower viscosity of the dough is due to the existence of low-protein content (Miller et al., 1997), and it increases the spread ratio of the dough, influencing the gelatinization of the starch and the coagulation of proteins. Thus, the dough has higher dough flow rates, contributing to the production of larger cookies. Bulk density is used to determine the dough expansion and porosity of cookie products. The bulk density of flour depends on the particle size, individual particle density, humidity, and surface characteristics. Lower bulk density generally results in higher compactness and lower porosity of cookies, which are necessary for cookies with a smooth and dense texture (Chandra and Samsher, 2013).

Table 1 Bulk Density and Viscosity Parameters

Sample	Bulk Density (g/cm^3)	Viscosity (cSt)*
Rice Flour	0.732	26.01
Wheat Flour	0.686	1211.00
Tapioca Flour	0.610	9.77

Note: * % flour in water = 36%; room temperature

Figures 2 (a and b) present front and side views of oval cookies molds, respectively. Figures 2 (c, d, and e) show images of molded cookie dough before being baked. The molded doughs from different types of flour (i.e., wheat, rice, and tapioca) were identical in sizes and morphologies.

Figures 2 (f, g, and h) show the BK prepared using wheat, rice, and tapioca flours, respectively. Different characteristics of cookies after baking with each flour type cause the differences in the physical characteristics of the BK, resulting in different cookie sizes and dimensions. Each flour has different dough viscosity characteristics, as mentioned earlier. Cookies with the lowest viscosity (Table 1) made from tapioca flour have the largest size.

All cookies had a brown color, which is due to the caramelization of sugar, saccharification of starch (Chung et al., 2012), and the Maillard reaction during baking at high temperatures. The Maillard reaction involves a complex reduction reaction of saccharides and amino acids. The browning of cookies is also influenced by sugar type, temperature, pH, and overall processing conditions (Singh et al., 2007).

Figures 2 (i, k, and m) show microscope images of the inner surface of the BK samples prepared from wheat, rice, and tapioca flours, respectively. Figures 2 (j, l, and n) present microscope images of the outer surface of the BK samples prepared from wheat, rice, and tapioca flours, respectively. BK cookies made from rice flour (Figures 2 (k and l)) have porous structures. Meanwhile, cookies made from wheat (Figures 2 (i and j)) and tapioca flours (Figures 2 (m and n)) have a relatively dense texture (fewer pores). Wheat and tapioca cookies have a lower bulk density (Table 1) than those made from rice flour, producing smooth and dense cookies.

Table 2 shows the dimensions of BK before and after the baking process. Cookies before the baking process did not have different dimensions, but this changed after the baking process (Figures 2 (f, g, and h)), which is due to the viscosity and the spread ratio value. The spread ratio relates to the rate of spreading and expansion of the dough. The highest to the lowest spread ratio values were found for tapioca > rice > wheat flours, sequentially. Cookies with the highest spread ratio value have the lowest dough viscosity (Table 1). The viscosity allowed the spread of the dough to be faster, resulting in a larger cookie dimension. A high spread ratio value is considered to give positive characteristics to cookies. The highest spread ratio was obtained when no gluten was added to the cookie recipes (Panghal et al., 2018). This is confirmed by the fact that tapioca flour (which has no gluten) has the highest spread ratio and the lowest viscosity. Thus, tapioca flour resulted in the largest cookies (compared to other types of flour).

3.2. Chemical Characteristics of Flour and Biji Ketapang Cookies

Table 3 shows the results of the proximate analyses of flour and BK. The ash and fiber content were not significantly different. A change in the water content from flour to cookies was found, which is due to water evaporation during the baking process. Starch content was also reduced in the baking process, correlating to the increases in ash content. Protein and lipid content increased due to the additional ingredients used in the cookie production (i.e., protein from eggs and lipid from butter). The protein content was the lowest using tapioca flour. These results are important in terms of the health benefits of cookies related to the type of flour used, especially for people who suffer from allergies caused by selected fractions of gluten proteins.

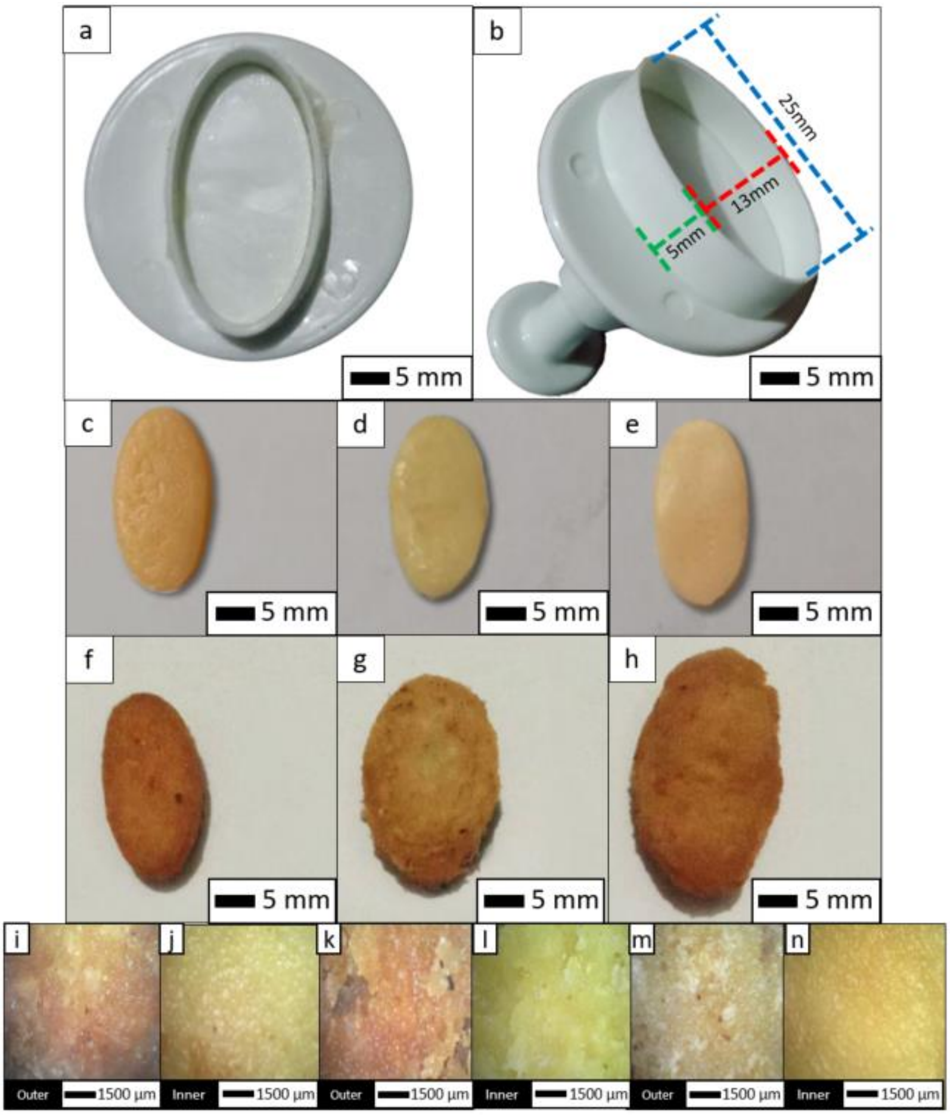

Figure 2 The mold and cookies before and after the baking process. (a) and (b) show the mold from the front and side views, respectively. (c–e) and (f–h) are the cookies before and after the baking process, respectively. (i,k,m) and (j,l,n) are the inner and outer surface of the cookies, respectively. (c,f,i,j), (d,g,k,l), and (e,h,m,n) are the cookies made from wheat, rice, and tapioca flour, respectively.

Table 2 Diameter and Thickness of Biji Ketapang Cookies.

Cookies made by the type of flour	Before Baking Process			After Baking Process			Spread Ratio of Cookies (D/T)
	Diameter (*D*) (mm)	Thickness (*T*) (mm)	Length (*L*) (mm)	Diameter (*D*) (mm)	Thickness (*T*) (mm)	Length (*L*) (mm)	
Wheat	13.0	5.0	25.0	13.0	5.6	26	2.30
Rice	13.0	5.0	25.0	15.8	5.8	27	2.70
Tapioca	13.0	5.0	25.0	17.3	5.7	28.6	3.03

Table 3 Proximate Analysis Results for Each Type of Flour and Biji Ketapang Cookies

Parameter	Rice Flour (%)	Wheat Flour (%)	Tapioca Flour (%)	Cookies from Rice Flour (%)	Cookies from Wheat Flour (%)	Cookies from Tapioca Flour (%)
Water	10.83	11.13	12.12	3.81	3.17	2.57
Ash	0.99	1.11	1.22	1.21	1.86	1.87
Lipid	1.14	1.44	3.13	1.49	23.03	23.28
Protein	8.99	5.91	2.18	9.90	7.02	4.25
Starch	76.27	79.99	80.18	81.80	63.48	66.90
Fiber	0.49	0.99	0.74	0.78	1.08	0.99

The FTIR spectra of rice, wheat, and tapioca flour were identical (Figure 3 (a)). The peak at 3289 cm^{-1} is the water molecules. The region at 2923–1853 cm^{-1} showed the peaks of the symmetric and asymmetric modes of the CH_3 and CH_2 groups. The protein contents, which are the basis of amide I and amide II, are shown by the peaks at 1645 and 1545 cm^{-1}, respectively, corresponding to the C=O and N–H bonds. However, the vibration peak of protein in tapioca flour could not be identified well due to the low protein content. The peaks in the fifth region are at 1500–950 cm^{-1}, relating to the vibration of C–O, C–C, C–H, and C–N bonds. Vibration peaks at 950–750 cm^{-1} were assigned for starch analysis (Nandiyanto et al., 2019a).

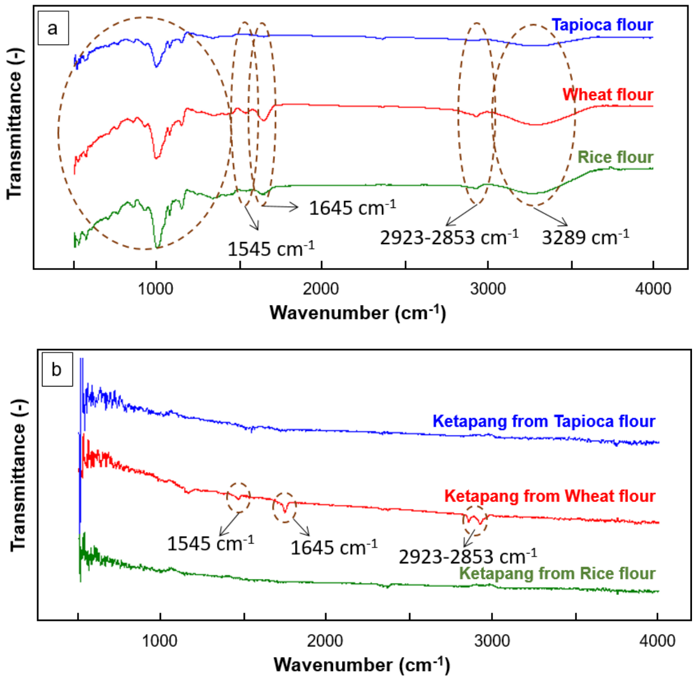

Figure 3 FTIR analysis of various flour (a) and cookie samples after the baking process (b).

Figure 3 (b) shows the FTIR of BK (after the baking process). The peak of the water molecules at 3289 cm^{-1} is unidentified because water residue evaporates during the heating process, which is in good agreement with the proximate analysis for moisture content shown in Table 3. Organic molecules of starch in BK at 950–750 cm^{-1} were also not identified. These unidentified organic molecules were related to the damage of starch molecules due to increased water absorption. This damaged starch is associated with the increase in the cookies' hardness. In addition, the characteristics of protein, asymmetry, and symmetry of the C–H bond, respectively, at vibrations of 1645, 1545, and 2923–2853 cm^{-1} had lower amounts (shown by lower intensities). Denaturation of protein and the heating process results in the disappearance of the protein structure, asymmetry, and symmetry of the C–H bond peak (Nandiyanto et al., 2019a).

3.3. Mechanical Characteristics of Biji Ketapang Cookies

Figure 4(a) shows a compressive stress–strain function plot from the hardness test of the cookies. The mechanical properties are important for predicting the hardness of the material (Dhaneswara et al., 2017). During the fracturing process, the compressive force continues to increase until cracks occur in the cookies (Nandiyanto et al., 2019b). Figure 4(a) also shows the jagged peaks, indicating the level of crispness. In addition to the identification of the jagged peaks, the stress–strain function curve shows the hardness of the samples. The area under the curve shows the hardness characteristics of the sample. The smaller area under the force curve indicates cookies with less hardness. Conversely, the larger area under the force curve shows a greater hardness level. Based on the figure, the cookies made from tapioca flour have a larger area under the force curve, implying that BK made from tapioca flour have greater hardness than those made from rice and wheat flours. Figure 4(b) shows the maximum compressive strength for cookies made from tapioca, wheat, and rice flours, which were 0.367, 0.187, and 0.1667 MPa, respectively. Protein affects the hardness of the products. The substitution of rice flour in the cookies reduces their hardness. This is due to the amount of fiber present in rice flour, which absorbs more water (Montes et al., 2015). The higher protein content in rice flour causes the dough texture and BK to become softer (Bolarinwa et al., 2019). These results are in line with the research of Tarasevičienė et al. (2020), showing that the high concentration of dietary fiber in rice flour led to moisture retention, resulting in softer cookies. Meanwhile, the lower protein content in the cookies results in smaller pores and thus a dense texture.

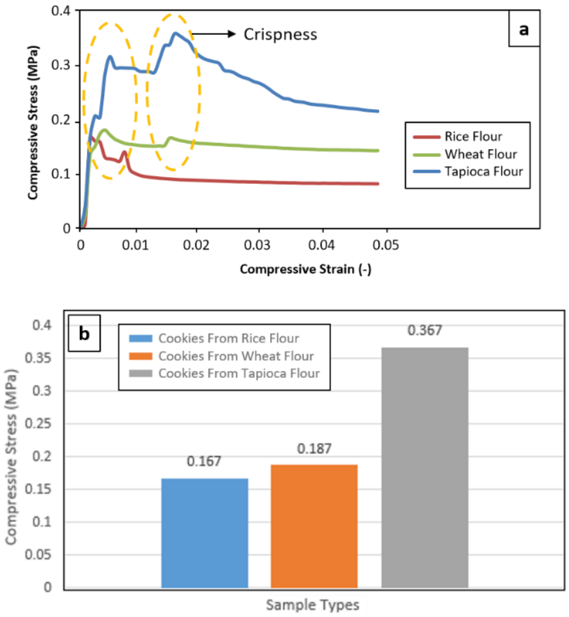

Figure 4 The compressive test: Compressive stress–strain curve (a) and compressive strength (b).

Table 4 shows the results from the pore analysis and the durometer test. Pore size was measured using a Ferret analysis of the microscope images in Figure 2. The Shore durometer test results showed greater values when the level of hardness was smaller. The cookie hardness value is based on the depth of the needle inserted into the cookie (Nandiyanto et al., 2020). A deeper stab or greater hardness value indicate more brittle cookies. Less pore formation and a small pore size gives impacts on lower absorption of water to the cookies, thereby increasing the mechanical properties of the cookies (lower durometer Shore hardness value).

Table 4 The hardness test on Biji Ketapang cookies

Sample	Average Size of Pores (μm)	Durometer Shore Hardness Scale
Cookies from Rice Flour	42	52.57
Cookies from Wheat Flour	23	45.14
Cookies from Tapioca Flour	15	35.71

3.4. Illustration of Mechanism of Preparing Biji Ketapang Cookies

An explanation of the nutrients and their roles is presented in the following (see Table 5).

Starch controls the physical properties (e.g., color, bulk density and porosity, gelatinization, viscoelasticity, and spread ratio parameters) and mechanical properties (through the retrogradation process) of cookies (Anggraeni et al., 2020a). A high starch content results in darker brown cookies and leads to a lower bulk density, affecting the spread ratio, smoothness, and density of the cookies (fewer pores) (Figure 2). It also plays an important role in the gelatinization process, determining the final quality of the product, as the most desirable sensory characteristic is the crispness of the cookies. The crispest cookies are obtained when using flour with a high starch content (Figure 4(a)) (Ramesh et al., 2018). The viscosity of the dough, which is related to its ability to bind water through hydrogen bonds, is influenced by the starch content in the flour. Flour with high amylopectin content has a high ability to hold water (Li et al., 2020). Viscosity is related to the spread ratio of the dough. A low viscosity results in a high spread ratio, allowing the production of a larger cookie diameter (Figure 2(e)). The hardening of cookies occurs through a retrogradation process. This process occurs when starch is heated in the presence of water and then cooled. The disturbed amylose and amylopectin chains gradually recombine into an ordered structure, resulting in hard cookies (Wang et al., 2015). In addition, carbohydrate absorbs a large number of water molecules, causing little damage to the starch.

Lipid contributes greatly to the texture, delicacy, and taste of the cookies as well as the dough texture. It makes the cookies softer, gives a savory taste to the product, moistens the dough, softens the product, increases the volume of the dough, and leads to the smoothest pores and highest crispiness. Cookies made from high-lipid flours, such as wheat (Figures 2 (i and j)) and tapioca (Figures 2 (m and n)), have a smoother and softer texture than those made from rice flour (Figures 2 (k and l)). Lipid acts as a lubricant, contributing to the plasticity of the dough. Lipid also prevents the development of excessive gluten during mixing, contributing to improvements in the texture and taste of the product. The hardness of cookies is also impacted by the lipid content. This is consistent with our hardness test results (Figures 4(a and b) and Table 4), which showed that cookies with a high lipid content have a high level of hardness due to their poor elasticity properties. Increases in lipid content result in increased hardness and decreased moisture content (Jacob and Leelavathi, 2007) since lipid is associated with low water absorption. Thus, cookie products with high-lipid content absorb relatively little water, resulting in a hard texture because fewer pores are produced.

Table 5 Correlation between nutrition, absorbed water, pore/crack, strength, and hardness

Type of Nutrition	Amount*	Adsorbed Water*	Pore/Crack*	Compressive Strength*	Hardness*
Starch	++++	+	+	++++	++++
	+	++++	+++++	+	+
Lipid	++++	+	+	+++++	+++++
	+	+++++	+++++	+	+
Protein	++++	++++	++++	+	+
	+	+	+	++++	++++

*Note: ++++ is high value, + is low value

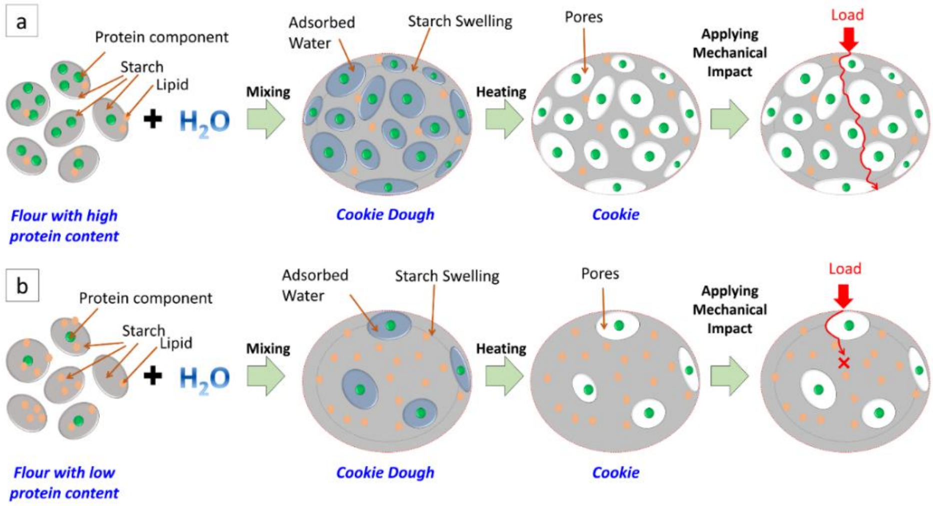

Figure 5 Illustration of hardness test on cookies with high (a) and low (b) protein content.

Protein affects the hardness of cookies since it is associated with the ability to absorb water. Low protein content in flour reduces the water absorption by the dough, resulting in less starch damage (HadiNezhad and Butler, 2009). Damaged starch has an impact on the formation of inhomogeneous internal structures in the cookies due to the formation of pores; thus, increased amounts of damaged starch are correlated to the formation of multiple pores, leading to a brittle cookie structure. Conversely, less starch damage inhibits pore formation in the internal structure, which increases the hardness of the cookies (Figure 5). The protein content in flour is inversely proportional to the amount of starch and lipid content. When the flour has a high protein content, the starch and lipid contents in the flour are lower, and vice versa. In short, protein is associated with a good water absorption capacity. A high level of water absorption results in the formation of more pores. Thus, high protein content impacts the absorption of water molecules, resulting in low compressive strength, low hardness, and the formation of brittle cookies; the opposite is true when using low-protein flour.

Water content affects the appearance, texture, and taste of cookies. The water content in flour and dough affects surface cracking. Cookies with low water content are preferable because they have better storability. A high water content can result in the growth and reproduction of bacteria, mold, and yeast, affecting the freshness and shelf life of food. An increase in the water content of cookies also reduces their hardness (loss of crispness). When the water content increases, the cookies' diameter, dough spread, and adhesion increase. At the same time, increases in the moisture content reduce the stiffness, consistency, and cohesion of the dough. Absorbed water influences the formation of pores in cookies. A high level of absorbed water results in the formation of more pores in the cookies, thereby reducing their hardness (Figures 2 (k–l)).

4. Conclusions

The effects of the starch, lipid, and protein components of flour on the mechanical properties of BK have been investigated. Three types of flours were examined (i.e., wheat, rice, and tapioca flours). The rheological properties of flour affected the spread ratio, causing the components in the cookies to be homogenously distributed and controlling the dimensions of the cookies. Nutrients influence the amount of water absorbed, while water molecules can spread the material components in the cookies, making them more homogeneous, causing the cookies to swell, and influencing their mechanical properties. BK cookies made with low-protein flours have increased hardness, crunchiness, and crispness. This study was limited to testing nutrients based on flour type and thus provides no information on the control of nutrient components, which is reserved for future work.

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