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Development of Cookies Made from Breadfruit (*Artocarpus altilis*) and Plantain (*Musa paradisiaca* L.) with Different Levels of Ripeness

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A B S T R A C T

Indonesians still depend heavily on wheat flour for cookies, while the use of local foods such as breadfruit and plantain is not yet optimal. Breadfruit is a source of carbohydrates that is high in fiber and low in glycemic index. On the other hand, plantains at a certain level of ripeness contain natural sugars that can act as sweeteners while also affecting the glycemic index. Therefore, the combination of these two ingredients has the potential to produce healthier, functional cookies suitable for diabetics. This study aims to evaluate the effects of using breadfruit and plantain flours at different levels of ripeness on the physicochemical characteristics and glycemic index of cookies. The study used a Completely Randomised Design (CRD) with 4 treatments based on plantain ripeness (green, greenish yellow, yellow, and yellow with black spots) and 3 replicates. The parameters observed included physical and chemical analysis. Based on the results of the study, it was found that the ripeness level of plantain in cookie formulations significantly affected the moisture content, fat content, protein content, carbohydrate content, dietary fiber content, starch content, total sugar content, glycemic index test, hardness test, colour test, and organoleptic test (colour, aroma, texture, and taste). But does not significantly affect the ash content in the cookie products. The best treatment was D, which used bananas with a yellow ripeness level and black spots. Thus, it can be concluded that the ripeness level of plantain has a significant effect on the quality of the cookies produced, except for the ash content of the cookies. Cookies made with plantain with the highest ripeness level have the best balance of colour, taste, aroma, and texture, making them the most preferred by the panelists.

Contribution to Sustainable Development Goals (SDGs):
SDG 2: Zero Hunger
SDG 3: Good Health and Well-Being
SDG 12: Responsible Consumption and Production

1. INTRODUCTION

1.1. Research Background

Cookies are one of the most popular bakery products because of their sweet taste, crunchy texture, and convenience. This product is generally made from wheat flour through a baking process and has a sweet, crispy texture that is not too dense [1]. According to data from the Badan Pusat Statistik, the consumption of cookies in Indonesia is 18,406 kg/year. The high demand for this product has increased the need for raw materials, especially wheat flour [3].

Indonesia is not yet able to produce wheat independently due to unfavourable geographical conditions, so its wheat flour needs are still met through imports from countries such as Australia, Canada, and the United States. The demand for wheat flour has increased by around 5.4%, equivalent to 5.4 million tons [2], and

the total volume of wheat imports during the 2020-2022 period reached 12.9 million tons [3]. This high reliance on imported materials has prompted efforts to use local food sources as alternatives to wheat flour with low glycemic indices and gluten-free properties. One such ingredient with potential is breadfruit.

Breadfruit (*Artocarpus altilis*) is a local commodity abundant in Indonesia and rich in carbohydrates. National breadfruit production in 2020 reached 190,551 tons, an increase from the previous year [3]. Breadfruit flour contains 78.9 g of carbohydrates, 3.6 g of protein, and is rich in fiber, vitamin C, antioxidants, and essential minerals [4]. In addition, breadfruit has the advantages of being gluten-free and having a low glycemic index [5], making it a potential ingredient in healthy cookies. In cookie-making, granulated sugar is typically used as the main sweetener. However, excessive sucrose consumption can have negative health effects, such as an increased risk of diabetes mellitus. Therefore, natural sweeteners are needed as a substitute for granulated sugar. One potential ingredient is plantain (*Musa paradisiaca* L.), which has a natural sweetness and is widely available.

The ripeness level of plantain greatly affects its chemical composition, particularly starch and sugar content. During ripening, the enzyme amylase hydrolyses starch into simple sugars such as glucose, fructose, and sucrose, increasing sugar content as ripeness progresses [6]. These differences in ripeness levels can affect the physical, chemical, and sensory characteristics of the resulting cookies. The use of breadfruit flour as a substitute for wheat flour, and ripe plantain flour at different ripeness levels as a natural sweetener to replace granulated sugar, is expected to produce cookies with a low glycemic index that are safe for consumption by diabetics, while still acceptable to consumers at a certain level of sweetness.

1.2. Objective

The objectives of this study are to:

1. Develop cookies formulated from breadfruit (Artocarpus altilis) flour as a partial or full substitute for wheat flour.
2. Evaluate the effect of plantain (Musa paradisiaca L.) at different levels of ripeness on the physicochemical, nutritional, and sensory characteristics of the cookies.
3. Determine the optimal ripeness level of plantain that provides natural sweetness while maintaining desirable texture, flavor, and consumer acceptability.
4. Assess the potential of breadfruit–plantain–based cookies as a low-glycemic, gluten-free functional product suitable for consumers requiring healthier alternatives, including individuals at risk of diabetes.

2. MATERIALS AND METHODS

2.1. Research Design

The research method used was a Completely Randomized Design (CRD). The treatment used was four levels of plantain ripeness, namely green, greenish yellow, yellow, and yellow with black spot

s. This treatment was carried out with three replicates to ensure the results were valid.

2.2. Preparation of Rice Crackers

The procedure for making cookies with breadfruit and plantain flours at different levels of ripeness is as follows: weigh each ingredient. Then add 59 g of eggs, 50 g of margarine, 0.5 g of salt, 1 g of baking powder, and 1 g of vanilla, and mix using a mixer for 2-3 minutes. Then slowly add the flour, mixing until the dough is homogeneous. Next, roll out the dough with a rolling pin, cut into desired shapes, and place on a baking sheet. Bake the cookie dough at 125°C for 30 minutes. Immediately cool the baked cookies to lower their temperature, then package them.

2.3. Analysis

The cookies were made from breadfruit and plantain flours at different levels of ripeness. Observations made on the cookies included chemical analysis, physical analysis, organoleptic testing, and in vitro glycemic index testing. The chemical analyses conducted included moisture content, ash content, protein content, fat content, carbohydrate content, dietary fibre testing, starch content testing, crude fibre testing, and total sugar content testing. The physical analysis included hardness testing and colour testing. The hedonic organoleptic testing included colour, aroma, taste, and texture testing of the cookies.

3. RESULT AND DISCUSSION

3.1. Analysis of Raw Material

The moisture content of plantain flour ranged from 7.99–8.50%, decreasing as ripeness increased, with the highest value in treatment A and the lowest in treatment D. This moisture content complies with SNI 01-3841-1995 and is lower than that reported by Ref. [7]. The decrease in moisture content is associated with pectin degradation, which facilitates the evaporation of free water [8], and a moisture content below 10% can increase shelf life [9].

The ash content ranged from 2.16 to 2.49%, with the highest value in black-spotted yellow bananas and the lowest in green bananas. This value is higher than in previous studies and reflects total mineral levels, including magnesium, phosphorus, and potassium [10]. The ash content increased with ripeness.

The fat content of plantain flour ranged from 0.17–0.75%, with the highest value observed in treatment D. This value is higher than that reported [11]. The increase in fat may be due to cell membrane degradation, the breakdown of complex lipids, and lipase activity that produces free fatty acids [12].

The protein content was 1.90–2.86% and lower than that reported [13]. This change was influenced by proteolytic enzymes, starch degradation, and a decrease in water content, which increased the relative protein concentration [14]. Protein also plays a role in the colour and texture of cookies through the Maillard reaction.

The carbohydrate content was 85.92–87.27% (by difference) and was in line with that reported [10]. The decrease in carbohydrates in ripe bananas occurs due to the hydrolysis of complex starch into simple sugars by the enzymes amylase and amyloglucanase [14]. Starch in young bananas will be hydrolyzed into simple sugars during ripening [15] [16].

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Table 1. Results of analysis of water content, ash content, fat content, protein content, and carbohydrate content

Analysis	Type of Plantain			
	A	B	C	D
Moisture content	8.50 ± 0.24	8.14 ± 0.20	8.07 ± 0.21	7.99 ± 0.02
Ash content	2.16 ± 0.70	2.33 ± 0.48	2.49 ± 0.25	2.49 ± 0.24
Fat content	0.17 ± 0.07	0.33 ± 0.07	0.67 ± 0.11	0.75 ± 0.13
Protein content	1.90 ± 0.25	2.25 ± 0.00	2.51 ± 0.12	2.86 ± 0.12
Carbohydrate content	87.27 ± 0.28	86.95 ± 0.21	86.26 ± 0.70	85.92 ± 0.27

Table 2. Results of analysis of water content, ash content, fat content, protein content, carbohydrate content, dietary fiber, crude fiber, starch, total sugar, and glycemic index

Behavior	Water content (%)	Ash content (%)	Fat content (%)	Protein content (%)	Dietary Fiber (%)
Green bananas	12.57 ± 2.32 b	3.22 ± 0.51	32.71 ± 1.26 a	6.39 ± 0.15 a	16.33 ± 0.15 c
Yellowish-green bananas	9.95 ± 0.79 ab	3.45 ± 0.69	34.29 ± 0.39 ab	6.57 ± 0.13 a b	16.14 ± 0.15 c
Yellow bananas	9.33 ± 1.38 a	3.56 ± 0.51	34.48 ± 0.78 ab	6.67 ± 0.24 a b	15.33 ± 0.18 b
Yellow bananas with black spots	8.52 ± 1.00 a	3.67 ± 0.67	35.11 ± 1.26 b	7.09 ± 0.45 b	13.66 ± 0.16 a

Continued **Table 2.**

Behavior	Crude Fiber (%)	Starch (%)	Total Sugar (%)	Glycemic Index (%)
Green bananas	5.29 ± 0.98	43.03 ± 0.65 c	1.33 ± 0.08 a	42.08 ± 2.04 a
Yellowish-green bananas	5.02 ± 1.07	36.05 ± 1.23 b	8.43 ± 0.59 d	54.32 ± 2.80 d
Yellow bananas	4.33 ± 0.61	29.93 ± 2.07 a	12.16 ± 0.76 b	66.20 ± 2.16 b
Yellow bananas with black spots	3.84 ± 0.77	28.58 ± 1.79 a	19.21 ± 1.04 c	71.57 ± 1.90 c

Table 4. Results of texture and colour tests

Behavior	Texture (N/cm^2)	Colour (^{0}Hue)
Green bananas	116.68 ± 0.23	57.33 ± 0.95 Yellow Red
Yellowish-green bananas	125.36 ± 0.83	54.39 ± 0.86 Red
Yellow bananas	146.41 ± 0.23	51.22 ± 0.62 Red
Yellow bananas with black spots	167.06 ± 0.41	49.88 ± 0.85 Red

Table 5. Results of Organoleptic Analysis

Behavior	Average ± Standard Deviation			
	Colour	Aroma	Taste	Texture
A = Green bananas	4.16 ± 0.69	3.92 ± 0.70	2.76 ± 0.59	3.48 ± 0.83
B = Yellowish-green bananas	4.04 ± 0.54	3.68 ± 0.63	3.59 ± 0.58	3.56 ± 0.58
C = Yellow bananas	3.68 ± 0.56	3.84 ± 0.69	3.56 ± 0.65	3.56 ± 0.65
D = Yellow bananas with black spots	3.72 ± 0.74	4.20 ± 0.71	3.92 ± 0.67	3.88 ± 0.70

3.2 Analysis of Chemical

3.2.1 Moisture Content

Moisture content is a characteristic used to determine the amount of water in food ingredients and affects appearance, texture, and taste. According to the reported [17], moisture content is influenced by the chemical composition of raw materials, processing time, and storage conditions. The average moisture content of cookies ranged from 8.52 to 12.57%, with the lowest value in treatment D (8.52%) and the highest in treatment A (12.57%). This is thought to be because the moisture content of plantain flour decreased as plantains ripened.

According to Ref. [18], a higher plantain flour ratio resulted in higher cookie moisture content, ranging from 4.785–9.08%. The study by Ref. [19] showed that the moisture content of plantain flour after 7 hours of drying ranged from 7.35–7.89%, whereas this study dried green bananas for 5 hours. The decrease in moisture content was also due to the fibre and starch content of the plantain flour.

The high fiber content in young bananas can bind large amounts of water, making it difficult for the water to evaporate [20]. As bananas ripen, their fibre content decreases, reducing their ability to retain water and lowering the cookies' moisture content. The decrease in starch content in ripe bananas also plays a role, as starch breaks down into simple sugars with a lower water-binding capacity than whole starch, thereby reducing the cookies' moisture content.

3.2.2 Ash Content

Ash content measurement aims to determine the mineral content in cookies. Ash is an inorganic residue that contains various types

of minerals [21]. Ash content is determined by weighing the mineral residue after burning the organic components at 550°C and is included in the proximate analysis to assess nutritional content. Ash is obtained by calcination until all carbon is removed, leaving only inorganic minerals [22].

The ash content of cookies ranged from 3.22% to 3.67%, with the lowest value in treatment A and the highest in treatment C. This value is higher than that reported [18], which ranged from 1.27% to 1.65% for cookies made from plantain flour and mocaf. The ash content of plantain flour in this study also increased with increasing banana ripeness.

The riper the banana, the higher the ash content of the cookies, due to increased mineral salt content. The reported [24] ash content of plantain flour of 1.99% and stated that the drying process increases the ash content by breaking down the water-binding components, thereby increasing the mineral content.

3.2.3 Fat Content

Fat is necessary because it provides high energy (1 g of fat = 9 kcal) and dissolves vitamins A, D, E, and K [25]. The fat content of cookies in this study ranged from 32.71% to 35.11%, with the highest value in treatment D and the lowest in treatment A. This value is higher than that reported [26], which was 22.74% to 32.09%. The increase in fat content occurred as the plantain flour ripened. Plantain flour has a fat content of 0.17%–0.75% [24].

The high fat content is also influenced by additives such as margarine and egg yolks. Margarine contains 81 g of fat per 100 g [27], while egg yolks contain 35% fat [28]. Fat plays a role in making cookies softer, improving their structure, development, softness, and aroma.

3.2.4 Protein Content

Protein is a macromolecular compound composed of amino acids, and the composition of the ingredients influences the protein content of a product. The protein content of cookies ranged from 6.39% to 7.09%, with the lowest in treatment A and the highest in treatment D. All treatments met the quality requirements of SNI 01-2973-2022 [29] (minimum 4.5%). The protein content of plantain flour is 3.04%, and the results of this study are higher than those reported [23], which range from 2.80–4.04%.

Protein sources such as eggs increase the protein content of cookies. Free-range chicken egg yolks contain 1,229.5 mg/mL of protein and broiler chicken yolks contain 930.9 mg/mL [30]. Environmental factors such as humidity and temperature also affect protein content: lower humidity increases measured protein content, higher temperatures decrease it, and sufficient humidity can activate enzymes that break down protein and starch [23]. The reported [31] also stated that the lower the moisture content, the higher the measured protein content.

3.2.5 Dietary Fiber

Dietary fiber is an indigestible carbohydrate consisting of cellulose, hemicellulose, pectin, gum, oligosaccharides, and wax [32]. The dietary fiber content of cookies ranged from 13.66 to 16.33%, with the highest value in treatment A and the lowest in treatment D. The higher the ripeness of the banana, the lower the dietary fiber content of the cookies tended to be. Plantain flour has a dietary fiber content of 7.77% and 10.2 g/100 g in young white plantains [33]. These results are in line with the reported [34], which showed an increase in dietary fiber as the proportion of plantain flour increased.

The water-soluble fiber content of cookies ranges from 9.82–11.17% and decreases with increasing banana ripeness. In young bananas, soluble fiber is higher because the cell walls are rich in pectin and hemicellulose. As the fruit ripens, enzymes such as pectinase break down pectin into simpler compounds, thereby reducing soluble fiber. The hydrolysis of starch into sugar also contributes to the reduction of soluble fiber. Plantain flour contains around 3.68% soluble fibre [35].

The heating process during flour production can increase dietary fiber, especially resistant starch. The fiber content of bananas changes according to the level of ripeness: young bananas are rich in cellulose and hemicellulose, while ripe bananas undergo fiber degradation into soluble starch and simple sugars [36].

3.2.6 Crude Fiber

Crude fiber is an indigestible component of food that plays an essential role in digestive health and disease prevention. Its main components are lignin and cellulose, which remain intact until they reach the large intestine [37]. The results showed that the crude fibre content of cookies decreased as plantain ripeness increased. Treatment A (green bananas) produced the highest crude fiber content of 5.29%, while treatment D (black spotted bananas) produced the lowest content of 3.84%.

Physiological changes influence this decrease during ripening. In young bananas, the cell walls are still rich in cellulose, hemicellulose, and pectin. However, as the fruit ripens, enzyme activity degrades these components, thereby decreasing crude fibre [38]. In addition, structural polysaccharides are primarily converted into water-soluble simple sugars [39]. Plantain flour itself has a crude fiber content of about 2.86% [40].

3.2.7 Starch

Starch is a complex carbohydrate composed of amylose and amylopectin, which affects the physical and chemical properties of materials such as viscosity and water absorption [41]. The results showed that the starch content of cookies decreased as plantain ripeness increased. Treatment A (green bananas) had the highest starch content at 43.69%, while treatment D (black-spotted bananas) had the lowest at 28.58%.

This decrease is due to changes in carbohydrate levels during ripening. In young bananas, starch content is very high, serving as an energy reserve. However, during ripening, starch is hydrolysed into simple sugars, resulting in flour from ripe bananas with a lower starch content [42]. Banana flour itself generally contains a total starch content of around 73.36% [43]. In addition to ripening, baking also accelerates starch degradation through gelatinisation and the Maillard reaction, especially in ingredients high in sugar, thereby reducing the starch content in the final cookies [44].

3.2.8 Gula Total

Total sugar is the sum of reducing and non-reducing sugars, which determine the sweetness and energy availability of a food product. The results showed that the total sugar content of cookies ranged from 1.33 to 19.21% and increased with the ripeness of the plantains used. This occurs because during ripening, the starch in plantains breaks down into simple sugars.

These results are in line with previous studies, in which ripe plantain had a total sugar content of around 11.46% [45] and plantain flour had a content of 18.24–21.04% [46]. In addition to

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the ripeness of the ingredients, the baking process also increases the total sugar content through the Maillard reaction and caramelisation, which involve the reduction of sugars and proteins, resulting in additional soluble sugars and the characteristic colour and aroma of cookies [47].

3.2.9 Glycemic Index (In Vitro)

The glycemic index (GI) describes the rate at which blood glucose levels rise after consuming a food. Research results show that the GI of cookies ranges from 42.08 to 71.57, increasing with the ripeness of the plantains. This increase is influenced by the rise in total sugar content in ripe bananas, as during ripening starch is hydrolysed into simple sugars by the enzyme amylase [6]. In addition, young bananas have high levels of resistant starch, whereas in ripe bananas resistant starch decreases, making carbohydrates more easily converted into glucose, which increases the GI [48]. The baking process also increases GI by increasing starch gelatinisation and fibre degradation, making starch granules easier to break down into glucose.

3.2 Analysis of Physical

3.2.1 Texture Test

Hardness testing using a Texture Analyser measures the force required to break a cookie. The hardness values of the cookies in Table 4 ranged from 116.68 to 167.06 N/cm², with the highest hardness in treatment A (green bananas) and the lowest in treatment D (black spotted bananas). The analysis of variance results showed that banana ripeness level had a significant effect on hardness at the 5% level.

Cookies made from young bananas are harder because the flour contains resistant starch and high amylose, making the dough denser and the gelatinization process stronger. Conversely, in ripe bananas, the starch is hydrolyzed into simple sugars [49]. The higher sugar content is hygroscopic, making the dough softer and producing crispier cookies [50]. These findings are in line with the reported [51], who stated that an increase in sugar and a decrease in starch in ripe bananas reduce the hardness of baked products.

3.2.2 Colour Test

The colour of the cookies was significantly influenced by the banana ripeness level at 5%. Based on the data in Table 4, the colour values ranged from 49.88 to 57.33°Hue, with the highest value in treatment A (green bananas) and the lowest in treatment D (black spotted bananas). A low Hue value indicates a redder colour, so cookies made from ripe bananas appear darker than cookies made from young bananas. This change is caused by an increase in reducing sugars during banana ripening. During baking, reducing sugars react with proteins through the Maillard reaction and caramelization, forming a dark brown colour [52]. Young bananas have lower reduced sugars, resulting in a brighter yellowish cookie colour.

3.3. Organoleptic

3.3.1 Colour

Colour is an important parameter in quality assessment because it influences panellists' initial perceptions before they assess other attributes. The average liking scores in Table 5 ranged from 3.68 to 4.16, with the highest score for treatment A and the lowest for treatment C. Overall, the cookies were still liked by the panelists. The colour of the cookies tended to darken as the bananas ripened. This is triggered by an increase in reducing sugars in ripe bananas, which accelerates the Maillard reaction and caramelization during baking [53]. According to [54], the higher content of simple sugars, such as glucose and fructose, in ripe bananas accelerates the formation of melanoidin brown pigments, resulting in a darker colour.

Cookies made from overripe bananas generally receive lower colour preference scores because dark colours are considered less appealing. In addition, ripe bananas have lower water content and higher sugar content, so they absorb heat more quickly, accelerating the browning of the cookie surface. This contributes to differences in colour intensity between treatments.

3.3.2 Aroma

Organoleptic aroma tests were conducted to determine panellists' preferences for the distinctive aroma of cookies made from kepok banana flour at different levels of ripeness. Aroma affects consumer acceptance because it is related to volatile components formed during baking and is subjective [55]. Based on Table 5, the liking scores ranged from 3.68 to 4.20, with the lowest score for treatment B and the highest for treatment D, indicating that the cookies were well-liked by the panelists.

During banana ripening, starch is hydrolyzed into reducing sugars such as glucose, fructose, and sucrose [56]. When baked, these sugars undergo Maillard reactions and caramelisation, producing sweet, caramel-flavoured volatile compounds such as furfural, maltol, and acetaldehyde [53]. The fats and proteins in the dough also contribute through thermal oxidation and Maillard reactions, which form savoury aromas [57]. The combination of volatile compounds from ripe bananas and the aroma from baking produces a complex aroma profile preferred by the panellists in the ripe banana treatment.

3.3.3 Taste

Organoleptic taste tests were conducted to determine panellists' preferences for cookies made from plantain flour at different levels of ripeness. Taste is a significant factor in product acceptance because it is determined by the perception of basic taste sensations, such as salty, sour, bitter, and sweet [58]. Based on Table 5, the liking scores ranged from 2.76 to 3.92 (neutral to like), with the highest score for treatment D and the lowest for treatment A.

During ripening, banana starch is hydrolysed into simple sugars (glucose, fructose, and sucrose) by the enzyme amylase [56]. Ripe bananas, which have higher sugar content, increase the natural sweetness of cookies, thereby increasing panellist acceptance. Conversely, green bananas with high starch and low sugar content produce a blander taste and a slight astringency due to tannins and organic acids [54]. Thus, the riper the bananas used, the more desirable the cookies' taste, due to the high levels of reducing sugars and compounds resulting from the browning reaction, which impart a sweet, caramel, and banana-like flavour.

3.3.4 Texture

Organoleptic texture tests were conducted to determine panellists' preferences for the crispness of cookies made from plantain flour at different levels of ripeness. Texture is an important attribute of cookie quality because it determines the product's brittleness and crispness [59]. The average preference scores in Table 5 ranged from 3.48 to 3.88, with the highest score for treatment D and the

lowest for treatment A, indicating that the panelists were in the "like" category.

The riper the banana, the crispier the cookies. This is because starch is hydrolysed into simple sugars during ripening, so that when baked, the sugars caramelise and reduce the water-binding capacity, making the cookies crispier [56]. Conversely, green bananas with high starch and low sugar content produce harder cookies because the dough is denser, and the high amylose content strengthens the molecular bonds within the starch [54]. Thus, ripe bananas produce cookies with a crispier texture that panellists prefer over those made with young bananas.

4. Conclusion

Based on the research that has been conducted, the following conclusions can be drawn:

1. The ripeness level of plantain in cookie formulations significantly affects the moisture content, fat content, protein content, carbohydrate content, dietary fiber content, starch content, total sugar content, glycemic index test, hardness test, colour test, and organoleptic test (colour, aroma, texture, and taste). Still, it does not significantly affect the ash content in cookie products.
2. The best formulation was found in treatment D (yellow bananas with black spots), which obtained fairly high scores in the hedonic test with a colour score of 3.72 (like), aroma 4.20 (like), texture 3.88 (like), and taste 3.92 (like), which were in the "like" category. In the physical analysis, this treatment had a hardness value of 116.68 N/cm² and a colour of 49.880 Hue. From the chemical analysis, it contained 8.52% moisture, 3.56% ash, 7.09% protein, 35.11% fat, 13.66% dietary fiber, 28.58% starch, 19.21% total sugar, and a glycemic index of 71.57%.

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