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Research Article

Physicochemical and Morphological Characteristics of Starch and Flour Obtained from Green Banana cv. *Raja* (*Musa paradisiaca* cv. *Raja*) in West Sumatra, Indonesia

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Abstract

Background and Objective: Banana cv. *Raja* is widely cultivated in West Sumatra, Indonesia. The physicochemical properties of starch and flour were investigated to determine their functional food prospects in industrial food. **Materials and Methods:** Starch and flour of banana cv. *Raja* was characterized using proximate analysis, Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Fourier-Transform Infrared (FT-IR), X-Ray Fluorescence (XRF) and Rapid Visco-Analyzer (RVA). **Results:** Banana cv. *Raja* starch contains 40.73% starch, 17.49% amylose, 55.5% water, 0.66% ash, 0.83% protein and 0.18% fat. The size of the granules is ranging from 20-30 μm in irregular and ellipsoidal-truncated shapes. The structure of crystallinity belongs to the type B while the gelatinization temperature is 74.9°C. Furthermore, the starch composed of 41.06% potassium, 12.85% phosphorus, 12.74% iron, 9.4% calcium and 7.5% magnesium. **Conclusion:** The morphological and physicochemical starch characteristics of Banana cv. *Raja* and has similar characteristics with its flour. Meanwhile the swelling power and the solubility value of the flour were higher than the starch. The gelatinization temperatures of starch and flour were 74.9 and 73.4°C, respectively.

Key words: Banana cv. *Raja*, AAB genome, crystallinity, gelatinization, XRF, XRD, FTIR

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Banana is an important horticultural crop in world trade, because of its significant contribution to economic growth, nutrition and public health. Bananas contain nutrients in the form of soluble and insoluble fiber, minerals, vitamins, antioxidants and polyphenols[1]. In addition, bananas also have potential to be developed as functional food for some degenerative diseases due to unhealthy lifestyles and diet.

Banana is known to be rich in resistant starch and may have a prebiotic function[2]. According to Sajilata *et al.*[3] resistant starch is typically non-hydrolized starch product that enters the large intestine or colon to be fermented by gut microflora. Resistant starch is classified as a source of fiber[4] and is known to reduce cholesterol and glycemic index[5]. Due to the conversion process mediated by gut microflora, this resistant starch is converted into short-chain fatty acid compounds (butyric acid). This condition may prevent colon cancer, reduce gallstone formation and enhance the mineral absorption minerals[5].

Banana cv. *Raja* (*Musa paradisiaca* cv. *Raja*) is one of the most widely cultivated banana cultivars in West Sumatra. This cultivar has the AAB genome and belongs to the dessert group as it can be freshly consumed or cooked into fried bananas. Banana cv. *Raja* have opportunity to be developed as a functional food by processed into various product, such as puree, powder, dried fruit, chips, bread, jam and juice[6] or as a substitute for wheat flour to provide added value from this banana product. Research on the functional and physicochemical properties of banana cv. *Raja* starch and flour has not been intensively carried out, therefore the aim of this research was to determine the morphological, physicochemical and functional properties of starch and flour from banana cv. *Raja*.

MATERIALS AND METHODS

Time and location of study: The research was carried out at Laboratory of Agricultural Product Technology, Faculty of Agricultural Technology Andalas University, Indonesia, Laboratory of Metallurgical, Faculty of Mechanical Engineering Andalas University, Indonesia, Laboratory of Chemical and Physics, Faculty of Math and Science, Padang State University, Indonesia and LLDIKTI Integrated Laboratory Region X, Indonesia. This research was conducted from February, 2018 to April, 2019.

Sample preparation: Green banana cv. *Raja* was harvested from the farmland District IV Koto, Agam Regency, West Sumatra, Indonesia located on the altitude of 850-2750 m above sea level. Fruit used for sample was chosen in the stage 1 mature, indicated by green and hard peel with firm texture and angle. The pulp was further characterized to determine its starch and flour characteristic.

Determination of starch, amylose, proximate analysis: Starch content was determined using protocol based on Sudarmadji *et al.*[7]. Amylose content was measured using protocol based on Syukriani, *et al.*[8]. Macronutrients composition was evaluated using standard proximate analysis based on AOAC[9] to measure its moisture, ash, lipid, biomass and protein content.

Determination of Minerals Contents of Green Banana Starch. Mineral content was carried out using EPSILON-3 (PANalytical) X-Ray Fluorescence Spectrometer

Characterization of morphology granules: Granules shape and size was observed using S-3400N Scanning Electron Microscope (Hitachi, Japan). Starch was previously sputter coated with gold and the starch morphology was observed at 200 times.

Crystallinity: Crystalline structure of banana starch was studied using X-ray diffractometer (Xpert Powder PANalytical PW 30/40). The X-ray diffraction system was operated at 40 kV and 30 mA and the starch diffractogram was recorded from 5°2-50°2⊖ with a scanning speed of 0.002°/sec and a scanning step of 0.02°. Relative crystallinity was calculated by the ratio of the crystal area to the total diffraction area.

FTIR: Functional group of banana starch was evaluated using FTIR Frontier Spectrometer (Perkin Elmer, Inc, USA). The spectrum was recorded in transmission mode from 600 to 4,000 cm^{-1}.

Characterization of pasting properties: Starch viscosity was evaluated using Rapid Visco Analyzer (RVA-Tech master, 2009, Newport Scientific Pty. Ltd, Australia) and the calculation was performed using Thermocline for Windows v3.0 (TCW3).

Characterization of starch solubility and swelling capacity: Capacity of granule swelling was determined using method proposed by Nattapulwat *et al.*[10] with a slight modifications. A total of 0.1 g sample was dissolved in 10 mL water. The suspension was heated at different temperatures, 50, 60, 70, 80 and 90°C in a water bath for 30 min, stirring vigorously every 5 min. The starch gel was then centrifuged at 3,000 rpm for 15 min. Swelling power was calculated using this following Eq:

$$\text{Swelling power (\%)} = \frac{\text{Weight of wet sediment}}{\text{Weight of dry sediment}} \times 100$$

Solubility (S) of banana starch was measured using the method described by Anderson *et al.*[11] with a slight modification. A total of 0.5 g sample was mixed with 6 mL distilled water, incubated in a water bath at 30°C under continuous shaking for 30 min, then centrifuged at 1,000 rpm for 15 min. The supernatant was placed in a hot air oven (105°C) for drying. The weight of wet sediment and dry supernatant were calculated to determine the percentage of its water absorption capacity and solubility using these following Eq:

$$\text{Solubility (\%)} = \frac{\text{Weight of dry supernatant}}{\text{Weight of dry sample}} \times 100$$

RESULTS

Starch composition and proximate analysis of banana cv. *Raja*: Based on its starch composition (Table 1), banana cv. *Raja* contained 40.73% (±1.27) starch, 17.49% (±0.97) amylose and 82.5% (±0.97) amylopectin. Regarding the chemical composition, this cultivar showed a 55.5% (±1.24) moisture, ash content obtained in this experiment is 0.66%. The Ash content is a parameter that describes the mineral proportion contained in a food ingredient. The proteins and lipids were 0.83 and 0.18%, respectively.

Mineral composition of banana cv. *Raja* starch: In order to unravel the mineral composition of banana cv. *Raja* starch, the XRF technique was applied. This technique can provide fast, accurate and non-destructive data. The Banana cv. *Raja* has 14 minerals which were divided into macro minerals and trace minerals (Table 2). The Banana cv. Raja was mainly composed of several macro minerals such as potassium (41.06%), phosphorus (12.85%), sulfur (12.74%), calcium (9.4%) and 7.5% magnesium, Chlorine (5.28%) and various trace minerals which were also detected in lower level likes Silicon, Iron, Manganese and Zinc.

Morphology of banana cv. *Raja* starch and flour granules: Starch and flour resulted from stage 1 mature banana cv. *Raja* exhibited similar shape (irregular and ellipsoidal-truncated shapes) and size with range of 20-30 μm Fig. 1. The surface texture starch exhibited finer surface compared to flour.

Crystalline structure of banana cv. *Raja* starch and flour: X-ray diffraction pattern of both starch and flour showed similar angle of the highest peak. Based on the angle recorded Fig. 2, the diffraction peaks is at about 5°, 6°, 15°, 17°, 22° and 24°2 both patterns were classified as the B-type crystalline starch. The diffraction peaks at 5°2 theta angle were not clearly visible in banana flour when compared to the diffraction peaks of banana starch.

Functional groups composing the banana cv. *Raja* starch: The functional group compositions of the banana cv. *Raja* starch were presented in Fig. 3. It presents the absorption at a wave number 3297 cm^{-1} indicating the presence of the O-H group. Absorption in the area of 2925 cm^{-1} indicated the presence of alkaline compounds which is in line with the presence of stretching C-H in the area of 2850-3000 cm^{-1}. In addition, the C-O groups are also detected at the wave number of 800-1300 and 1004 cm^{-1}.

Pasting properties of banana cv. *Raja* starch and flour: The profile of Banana cv. *Raja* starch gelatinization and its flour were presented in Table 3. The data showed that the starch has a higher peak viscosity and a longer gelatinization duration than the flour. Final viscosity is a parameter that shows the ability of starch to form a thick paste or gel after heating and cooling and the resistance of the pasta to shearing forces during stirring. The results of the final viscosity

Table 1: Characteristics of starch and proximate analysis of banana cv. *Raja*

Parameter	(%)
Starch	40.731.27
Amylose	17.490.97
Amylopectin	82.50.97
Moisture	55.51.24
Ash	0.660.27
Proteins	0.830.06
Lipids	0.180.04

Table 2: Minerals composition detected in banana cv. *Raja* starch based on XRF measurement

Mineral composition	Concentration (%)
Macrominerals	
Potassium (K)	41.061
Phosphorus (P)	12.848
Sulfur (S)	12.738
Calcium (Ca)	9.404
Magnesium (Mg)	7.523
Chlorine (Cl)	5.276
Trace minerals	
Silicon (Si)	4.068
Iron (Fe)	0.947
Manganese (Mn)	0.146
Zinc (Zn)	0.119

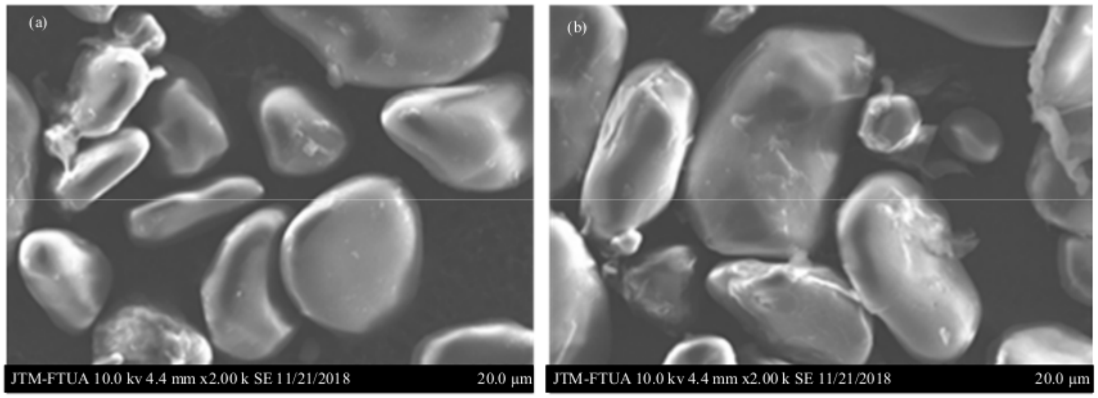

Fig. 1(a-b): Comparison of granule morphology between (a) Starch and (b) Flour of banana cv. *Raja* based on SEM pictures (magnitude 200 times)

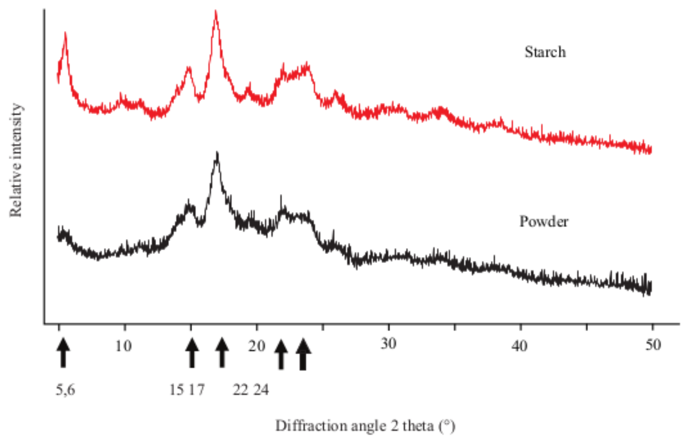

Fig. 2: Pattern of X-ray diffraction comparing the crystalline structure of banana cv. *Raja* starch and flour

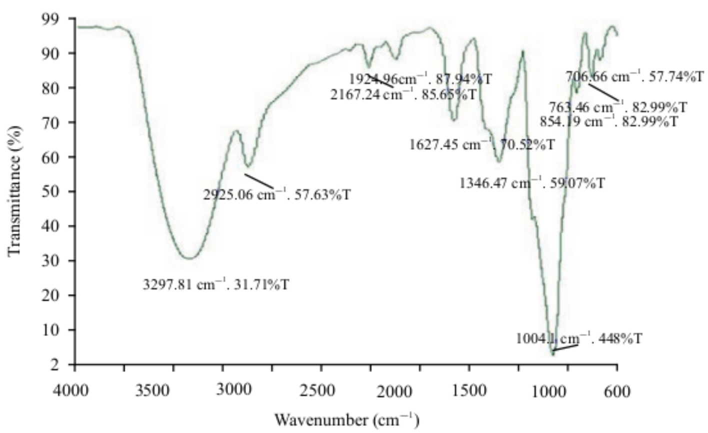

Fig. 3: FT-IR spectrum of banana cv. *Raja* starch

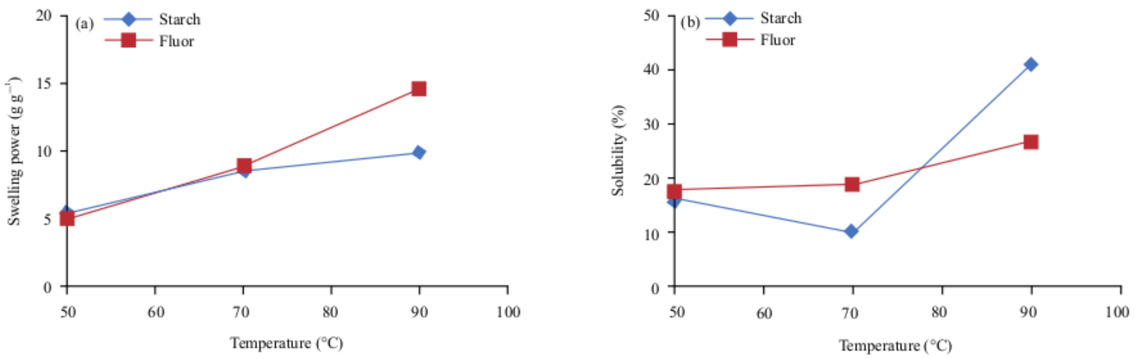

Fig. 4(a-b): Differences in swelling (a) Capacity and (b) Solubility between banana cv. *Raja* starch and flour

Table 3: Gelatinization profile of banana cv. *Raja* starch and flour

	Viscosity (cP)						
Sample	Peak	Trough	Breakdown	Final	Setback	Time (min)	Temperature (°C)
Starch	4040	3360	680	5660	2300	9.13	74.9
Flour	3800	2828	972	4145	1317	8.67	73.4

analysis showed the starch is higher than the flour. Trough viscosity is the minimum viscosity at a constant temperature phase and the indicator of starch ability to withstand breakdown during the heating process. The viscosity of the starch is higher than the flour. An increase in the breakdown viscosity value indicates that starch was increasingly resistant to heating and stirring. This shows that the starch is more resistant to heating and stirring.

Characterization of starch solubility and swelling capacity: Based on its swelling capacity, starch of banana cv. *Raja* reached its maximum swelling power under 90°C with 14.6 g g^{-1} (Fig. 4). In contrast, this starch showed lower solubility compared to flour of banana cv. *Raja* under 90°C (Fig. 4). Swelling power is the ability of starch to expand in water, while solubility is the ability of starch to dissolve in water.

DISCUSSION

Starch content of fruit is one the important characteristic of banana. This study found that the starch content of banana cv. *Raja* is 40.73% (Table 1), which is lower than *Pacovan* banana (61%) (AAB)[12] and *Mysore* banana (52.22%) (AAB)[13]. The amylose content of the starches from the five *EAHB* cultivars was in the range of 11.96-12.83%[14] which were lower than the amylose content of banana cv. *Raja*. Other studies on the amylose content *Tanduk* and *Nangka* plantain cultivars were 26.08 and 31.78, respectively[15], 20.78% for *Musa sapientum*[16]. The difference in starch and amylose content in bananas is due to differences in cultivar, growth condition[17] and maturity level[18]. The difference in starch and amylose content will affect their physicochemical and rheological properties in the development of a food product[19].

The water content in this plantain showed the optimal level of starch maturity, where water is an important component of food and affects the quality of food. The amount of water can affect the rate of damage to food through microbiological, chemical and enzymatic processes. The water content in Raja Banana was lower than *Nangka* cultivar (60.1%)[20]. The high level of the maturity in banana was closely related to the higher water content[18]. Many studies reported that total protein, fat and ash contamination in the extraction method is <5%, indicating that the isolated starch has a high level of purity[4,21]. This indicates that Raja Banana starch can be further developed as a food product.

The ash content obtained in this experiment is 0.66%, which is much higher than White Manzano bananas 0.08% and Vietnam Dwarf Cavendish 0.09%[17] and the protein content found in this study is 0.83% which is four times more higher than the White Manzano bananas (0.22%) and Dwarf Cavendish (0.34%). This result shows that the mineral and protein content in the plantain banana is higher than White Manzano and Vietnam Dwarf Cavendish.

The mineral content of phosphorus, calcium and iron based on the AAS method is 34.37, 1.25 and 23.04 mg/100g, respectively for banana cv. Nedran[22]. This mineral composition is needed by the body for growth and development, so therefore it is very well developed as a nutritious food product.

This granule shape is similar with the results of a study conducted by Montoya-Lopez *et al.*[23] but with a larger granule size of 29.3-48.53 μm. The same granule size ranging from 20-30 μm was obtained in the of study of Chavez-Salazar *et al.*[24]. Banana starch granule size was quite large (20-60 μM)[25] compared to starch from cereals and tubers. The large size of starch granules imply to the slow hydrolysis by digestive enzymes[26]. Banana starch is a type 2 resistant starch which has resistance to digestion[5].

The same texture was also obtained in a research conducted by Menezes *et al.*[1] and Bi *et al.*[27] where in banana flour granules, there is an integument layer on the surface of the granule which is thought to be the amyloplast membrane that wrapped starch granules in banana fruit cells. Whereas whole starch grains, without fracture, indicate that the process used for starch isolation is efficient[15]. Unlike starch, flour tends to be less solid due to the damage occurred during drying and grinding processes[28].

These results were in line with several studies conferring similar crystalline structure between banana flour and starch[29-32]. The type B and C starches are more difficult to digest than the type A one because they have a longer branched chain length than type A[33]. Miao *et al.*[34] mentioned that crystalline structure of starches might differ based on its crystal size, amylopectin proportion and length of branch chain. In addition, genotypes and environmental factors might also affect the type of starch.

This low breakdown viscosity indicated that banana cv. *Raja* starch is more resistant to heating and stirring[35] compared to the flour. Regarding its gelatinization temperature, starch required higher temperature (74.9°C) compared to flour (73.4°C) (Table 3). The need of this high temperature might be associated with its gelatinization duration. The longer the duration of gelatinization, the higher the temperature required to reach its peak viscosity. High gelatinization temperature indicated higher stability of starch molecules[36].

Solubility of a starch might be affected by the swelling behavior where the greater solubility might lead to higher swelling power[37]. Swelling capacity was determined by the amylopectin content composing a starch, hence affecting its ability to expand in water. When water molecules had a direct contact with starch granule, the hydrogen interaction among both molecules would break, thus enabling the granules to absorb water and expand. As this expansion would suppress the granules, amylose would be released due to granules breakdown[38].

CONCLUSION

Starch and flour extracted from the plantain Green Banana cv. *Raja* (*Musa paradisiaca cv. Raja*) showed similar morphological and physicochemical characteristics. It has granules with size of 20-30 μm and crystallinity of type B, hence it is categorized as resistant digesting starch. There are differences in pasting properties, where the starch has a higher peak viscosity, longer gelatinization time and higher gelatinization temperature compared to its flour. This starch and plantain flour can be developed as a functional food.

SIGNIFICANCE STATEMENT

This study found that the morphology and crystallinity structure of banana cv. Raja flour and starch have similar characteristics, characterizing with large granule size and type B crystallinity. Such character determines its starch digestibility. This research will help researchers to uncover critical areas of mineral content found in banana cv. Raja starch which is still underexplored.

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