ENHANCED KNOWLEDGE IN SCIENCES AND TECHNOLOGY
e-ISSN: 2773-6385

EKST

Vol. 5 No. 1 (2025) 292-297
https://publisher.uthm.edu.my/periodicals/index.php/ekst

Physicochemical Properties of Banana Peel Starch from *Musa Paradisiaca Fa. Corniculata* at Different Maturity Stages

Ani Fadhilah Mohamad Fauzi[1], Munira Zainal Abidin[1], Mohamad Zulhafiz Shafiq Zulhilmi Cheng[1]*

[1] *Department of Technology and Natural Resources, Faculty of Applied Sciences and Technology, UTHM Kampus Cawangan Pagoh, Hab Pendidikan Tinggi Pagoh, KM 1, Jalan Panchor, 86400 Pagoh, Muar, Johor, MALAYSIA.*

*Corresponding Author: mzulhafiz@uthm.edu.my
DOI: https://doi.org/10.30880/ekst.2025.05.01.035

Article Info

Received: 31 December 2024
Accepted: 23 January 2025
Available online: 30 July 2025

Keywords

Banana Peels Starch, Musa Paradisiaca Fa. Corniculata, Different Maturity Stages

Abstract

This study explores the physicochemical properties of banana peel starch from *Musa Paradisiaca Fa. Corniculata (Horn Banana or Pisang Tanduk*) is studied across different maturity stages, with a focus on its potential applications in the food and industrial sectors. The analysis encompasses parameters such as pH, moisture content, viscosity, gelatinization temperature, melting point, iodine calorimetry, and angle of repose. Starch was extracted from banana peels at unripe, ripe, and overripe stages using wet extraction methods. Results revealed significant variations in physicochemical properties based on maturity stages. Unripe starch exhibited the highest gelatinization temperature and stability which T_o was 120.70 ± 1.39^b, T_p was 128.41 ± 2.59^b, and T_c was 132 ± 2.74^b, making it suitable for high-temperature applications. In contrast, ripe starch showed optimal viscosity 0.63 ± 0.05^b, indicating its potential as a thickening agent. Overripe starch demonstrated lower amylose content and higher pH, suggesting reduced structural integrity but improved compatibility in acidic formulations. These findings highlight the unique characteristics of banana peel starch and its adaptability across diverse applications. This research not only promotes the valorisation of banana peel waste but also contributes to sustainable resource utilization in developing bio-based products.

1. Introduction

Bananas are a widely consumed fruit crop in tropical and subtropical regions, with global production rising from 70 million tons in 1999 to 117 million tons in 2019 9 [1]. Although people typically discard banana peels or use them as livestock feed, these peels offer immense potential as a high-value raw material for industrial applications, including the food sector. *Musa Paradisiaca Fa. Corniculata* (*Pisang Tanduk* or Horn Banana) is a large plantain from Southeast Asia, known for its big size and unique features [2]. The physicochemical properties of its peel starch vary significantly across different maturity stages, influencing its functional potential [3]. Banana peel starch is rich in bioactive components, including protein, carbohydrates, and fiber, making it suitable for applications in food products, biodegradable materials, and other industries [1]. However, the transformation of starch into sugars during ripening and the influence of maturity stages on its properties remain underexplored mainly studied Cavendish bananas, so there is little information about *Pisang Tanduk* peel starch [4].

This study aims to bridge this gap by examining the physicochemical properties of *Pisang Tanduk* peel starch at unripe, ripe, and overripe stages. Parameters such as moisture content, pH, viscosity, iodine calorimetry, angle of repose, gelatinization temperature, and melting point were investigated to determine their relationship with functional properties. The findings will contribute to the valorization of banana peel waste, promoting sustainable resource utilization and offering alternatives to conventional starch sources for industrial and nutritional applications.

2. Materials and Methods

2.1 Materials

Banana peels (Musa Paradisiaca fa. Corniculata) at various maturity stages were sourced from a local shop in Muar, Johor, and used as the raw material for starch extraction. Three stages of pisang tanduk—unripe, ripe, and overripe were selected for starch extraction. Analytical chemicals including citric acid and and 99.9% pure iodine solution were procured from Sigma-Aldrich.

2.2 Method

The preparation of banana peel starch was adapted from [5] with significant modifications. Banana peels at three different maturity levels were cut into small pieces (2x2 cm) and soaked in a 0.5% (w/v) citric acid (0.5 g citric acid dissolved in 100 ml distilled water for 50 g of banana peels) for 10 minutes to prevent browning. The soaked peels were then blended into a uniform mixture. The solid and liquid components were separated by filtering through a muslin cloth, discarding the solid waste and retaining the liquid filtrate. The filtrate was left undisturbed for 24 hours to allow the starch to precipitate naturally. The precipitate was collected, and any excess liquid was removed. The final starch was dried in an oven at 80°C for 6 hours, sieved through a 100-mesh screen, and stored in a sealed bag at room temperature for further analysis.

2.3 Physicochemical Properties of Banana Peel Starch

The pisang tanduk's peel starch was qualitatively evaluated for its moisture content, iodine calorimetry, angle of repose, gelatinization temperature, melting point, pH levels, and viscosity.

2.3.1 Moisture Content of Banana Peel Starch Powder

The moisture content of banana peel starch was determined using a moisture analyzer. Five grams of starch powder were used for the analysis. The moisture analyzer was set to a temperature of 180°C to ensure accurate and consistent results. Ideally, the moisture content of starch should be less than 20%, as higher levels may affect its stability and functionality. This adjustment accommodated the properties of banana peel starch and ensured precise moisture level determination for quality assessment [6].

2.3.2 Iodine Calorimetry of Banana Peel Starch

Iodine calorimetry was conducted to determine the amylose content of banana peel starch at different maturity stages. One gram of starch was dissolved in 10 ml of distilled water and stirred until fully homogenized. After dissolution, 200 microliters of 99.9% iodine solution were added to the mixture. The reaction between starch and iodine formed a complex that changed colour to dark blue or dark purple, depending on the amylose content and the maturity stage of the starch. The colour intensity of the complex was measured using a UV-Vis spectrophotometer at a wavelength of 620 nm (OD620). This optical density value was used to estimate the amylose content.

2.3.3 Angle of Repose of Banana Peel Starch

The angle of repose of banana peel starch was determined using a modified method based on [6]. Fifty grams of starch powder was used in this analysis. A piece of paper was used to seal the bottom of the funnel, and the powder was allowed to flow freely to naturally form a cone. The height between the funnel and the surface below was maintained at 5 cm. The angle of repose was measured to assess the flowability of the powder, with lower angles indicating better flow characteristics [6]. This adjustment ensures accurate results while accommodating the properties of banana peel starch. The angle of repose (a) can be calculated by using the following equation:

$$a = \text{cone height } (h)\ (\text{cm}) \,/\, \text{cone radius } (r)\ (\text{cm}) \quad (1)$$

2.3.4 Gelatinization Temperature and Melting Point

Differential Scanning Calorimetry (DSC) was used to evaluate the gelatinization temperature and melting point of banana peel starch from three different maturity stages. Approximately 5 mg of each starch sample was analysed. The temperature range started at 25°C and increased to 300°C at a controlled heating rate of 10°C per minute. This precise thermal analysis allowed the identification of phase transitions, providing critical insights into the thermal properties of the starch. The results helped compare the physicochemical differences across the maturity stages and assess the suitability of banana peel starch for various applications [6].

2.3.5 pH level of Banana Peel Starch

One gram of starch was mixed with 10 ml of distilled water and allowed to stand for 15 minutes. The pH of the solution was then measured using a pH meter. Typically, starch pH values range from 3 to 7, depending on the source and processing conditions [6].

2.3.6 Viscosity of Banana Peel Starch

Followed by [7] with some modifications, determined the viscosity of banana peel starch by weighing 15 grams of starch and mixing it with 150 ml of distilled water. Then, heated the mixture on a hot plate for 30 minutes while continuously stirring with a magnetic stirrer to induce gelatinization. Afterward, analysed the gelatinized starch using a Brookfield Viscometer (DV-II+ Pro) set to 1.0 RPM with Spindle 61.

2.3.7 Statistical Analysis

The samples underwent triplicate analysis, and the standard deviations were calculated. IBM SPSS software was utilized for data analysis, and One-way ANOVA was employed for this purpose. Additionally, Tukey's test was conducted on the responses using analysis of variance (ANOVA) at a significance level of 5% [6].

3. Result and Discussion

3.1 Physicochemical Properties

The physicochemical properties of all 3 stages of banana peel starch extraction were analysed including moisture content, iodine calorimetry, angle of repose, pH, viscosity, gelatinization temperature and melting point. The results of these physicochemical properties are presented in Table 1.

Table 1 Experimental results of physicochemical properties of banana peel starch at different maturity stages

Sample	Moisture content (%)	Iodine calorimetry (%)	Angle of repose (°)	Gelatinization temperature and melting point						pH	Viscosity (Pa.s)
				Gelatinization temperature (Tg) (°C)			Melting point (°C)				
				To	Tp	Tc	To	Te	Heat		
Unripe	11.31 ± 0.02a	2.47 ± 0.06b	40.33 ± 0.57a	120.70 ± 1.39b	128.41 ± 2.59b	132 ± 2.74b	259.64 ± 7.73c	279.06 ± 8.37b	-21.65± 4.17a	3.30 ± 0.01a	0.27 ± 0.06a
Ripe	11.35 ± 0.03a	2.47 ± 0.06b	41.90 ± 0.00b	42.60 ± 2.44a	62.24 ± 1.43a	78.31 ± 2.74a	197.28 ± 7.67a	215.41± 7.87a	-1.670 ± 0.40b	3.81 ± 0.01b	0.63 ± 0.05b
Overripe	19.47 ± 0.03b	2.23 ± 0.06a	56.90 ± 0.35c	182.24 ± 4.70c	185.42 ± 2.90c	193.59 ± 6.40c	229.18 ± 3.01b	296.44 ± 5.14b	21.10 ± 3.63c	4.19 ± 0.01c	0.17 ± 0.06a

Note: Data was expressed as the mean ± SD, with 3 replicates per sample. Different superscripted letters indicate significant differences ($p < 0.05$). One-way ANOVA and Tukey's test were performed using SPSS version 29.0.

3.1.1 Moisture Content

The mean moisture content of unripe banana peel starch in this study was 11.31 ± 0.02%, which is higher than the 6.06 ± 0.83% reported by [6] for Agung banana peel starch. This variation may result from differences in banana types, such as Agung Banana and *Musa paradisiaca Fa. Corniculata*, or maturity stages during analysis [6].

For ripe banana peel starch, this study reported a mean moisture content of 11.35 ± 0.03%, slightly exceeding the 10.49 ± 0.13% for local banana peel starch [8]. This discrepancy may be attributed to differences in banana varieties, with *Musa paradisiaca Fa. Corniculata* used in this study versus a local variety in [8] work, as well as environmental factors, farming practices, or methodological variations.

The mean moisture content of overripe banana peel starch in this study was 19.47 ± 0.03%, significantly higher than 10.49 ± 0.13% for ripe banana peel starch [8]. This increase is likely due to enzymatic activity and starch degradation at the overripe stage, retaining more water. Elevated moisture levels can promote microbial growth and reduce storage stability. Conversely, studies on cassava flour indicate that low moisture levels (~7.61%) minimize microbial growth, enhancing shelf life and quality [9].

3.1.2 Iodine Calorimetry

The iodine calorimetry results for banana peel starch revealed mean values of 2.47 ± 0.06[b] for unripe and ripe stages, and 2.23 ± 0.06[a] for overripe stages, indicating a slight decrease in amylose content during ripening. The unripe and ripe stages exhibited identical values, suggesting stable amylose content before the overripe stage.

Compared to the findings of [10], where corn starch demonstrated an iodine calorimetry mean of 2.01 ± 0.0[c], banana peel starch consistently showed higher amylose content, especially in unripe and ripe stages. This highlights the greater amylose fraction in banana peel starch relative to corn starch under the analysed conditions. The observed differences align with natural starch composition changes during ripening, with amylose stability until the overripe stage.

Besides, low-amylose foods such as sticky rice, possess softer, stickier textures, underscoring the role of amylose in texture determination. The results affirm iodine calorimetry as a reliable method for qualitative amylose assessment, with higher calorimetry means corresponding to greater amylose content in banana peel starch [11].

3.1.3 Angle of Repose

The angle of repose for banana peel starch varied with ripeness: unripe (40.33 ± 0.57°[a]), ripe (41.90 ± 0.00°[b]), and overripe (56.90 ± 0.35°[c]). These results align with [6], who reported angles exceeding 55°, indicating very poor flowability. At all ripeness stages, the starch exhibited poor flow, as it could not flow freely through a funnel [6].

Poor flowability is typical of starch due to fine particle size [12]. The increasing angle of repose from unripe to overripe stages suggests diminishing flowability with maturity, potentially caused by physicochemical changes, including increased moisture absorption and particle agglomeration. This behaviour can hinder industrial applications by causing equipment blockages, uneven mixing, and production delays [13].

Strategies to enhance flowability include reducing particle size through milling and adding glidants such as silicon dioxide or magnesium stearate, which minimize particle cohesion. These modifications are crucial for optimizing the handling and processing of banana peel starch in industrial applications.

3.1.4 Gelatinization Temperature and Melting Point

The gelatinization behaviour of banana peel starch was analysed across unripe, ripe, and overripe stages, highlighting distinct trends in onset (T_o), peak (T_p), and conclusion (T_c) temperatures. For unripe starch, T_o was 120.70 ± 1.39[b], T_p was 128.41 ± 2.59[b], and T_c was 132 ± 2.74[b]. Ripe starch exhibited significantly lower values: T_o at 42.60 ± 2.44[a], T_p at 62.24 ± 1.43[a], and T_c at 78.31 ± 2.74[a]. Overripe starch displayed the highest temperatures, with T_o at 182.24 ± 4.70[c], T_p at 185.42 ± 2.90[c], and T_c at 193.59 ± 6.40[c]. Compared to potato starch [14], which reported T_o at 86.65 ± 0.21[d], T_p at 117.38 ± 0.50[d], and T_c at 104.41 ± 0.48[d], banana peel starch differences are linked to its unique granule composition and differential scanning calorimetry (DSC) methods.

These temperature variations are influenced by amylose-to-amylopectin ratios and crystalline structures [15]. Higher amylose content increases gelatinization temperatures by reinforcing crystalline regions, while higher amylopectin lowers them by facilitating granule swelling. Overripe starch's elevated temperatures result from increased crystallinity and retrogradation during aging, enhancing granular structure. Practically, unripe starch is ideal for heat-stable applications like canned soups, while ripe starch, with lower temperatures, suits instant products such as puddings. Understanding these ripeness-dependent properties allows for targeted use of banana peel starch in temperature-sensitive food processes, emphasizing its versatility in industrial applications.

Banana peel starch exhibits distinct melting properties across maturity stages, significantly influencing its industrial applications. Unripe banana peel starch has a higher onset melting temperature (259.64 ± 7.73 °C) and enthalpy (-21.65 ± 4.17 J/g), indicative of a denser granule structure requiring more energy to melt. These characteristics make it suitable for high-temperature applications, such as biodegradable packaging materials. Ripe banana peel starch, with a lower melting temperature (197.29 ± 7.67 °C) and enthalpy (-1.67 ± 0.40 J/g), is better suited for low-thermal-processing products like food thickeners or adhesives. Overripe starch, showing increased enthalpy (21.11 ± 3.63 J/g) likely due to recrystallization, holds potential for applications requiring specific thermal behaviours [6].

Compared to cassava starch, which has a melting point of 105.47 °C and an enthalpy of 5.69 J/g, banana peel starch demonstrates significantly higher thermal stability. This difference arises from the unique starch composition and crystallinity of banana peel starch, which varies with maturity. These properties are advantageous in industries demanding thermal integrity, such as food processing and biodegradable product manufacturing. Understanding these thermal characteristics allows for the tailored selection of starch types, optimizing product performance and processing efficiency [6].

3.1.5 pH

The pH values of banana peel starch from *Musa paradisiaca Fa. Corniculata* (horn banana) vary across ripening stages: 3.30 ± 0.01[a] (unripe), 3.81 ± 0.01[b] (ripe), and 4.19 ± 0.01[c] (overripe). Conversely, [6] reported a significantly higher pH (6.15 ± 0.35) for unripe peel starch of the Agung banana. This variability highlights cultivar-specific biochemical differences, with horn bananas exhibiting higher organic acid levels, particularly at the unripe stage, compared to the lower acidity of Agung bananas. Environmental factors such as soil composition, climate, agricultural practices, and extraction techniques further influence pH differences.

The pH of starch affects product stability and compatibility. Low-pH starches like horn banana starch may enhance acidic food product shelf life but are less suitable for neutral-pH formulations due to potential reactivity. In contrast, the higher pH of Agung banana starch makes it better suited for neutral or mildly alkaline applications, such as baked goods or adhesives [6]. These findings emphasize the importance of cultivar-specific studies for optimizing banana peel starch utilization in industrial and nutritional contexts.

3.1.6 Viscosity

The viscosity of banana peel starch varies significantly with maturity, showing values of 0.27 ± 0.06[a] for unripe starch, 0.63 ± 0.05[b] for ripe starch, and 0.17 ± 0.06[a] for overripe starch. In comparison, huayno potato starch exhibits a much higher viscosity of 4524.67 ± 145.14[b] [8]. These differences are linked to starch composition, granule structure, and amylose-amylopectin ratios. The unique structural properties of banana peel starch, particularly from *Musa Paradisiaca Fa. Corniculata*, contribute to its lower viscosity. Testing methods, including viscometers versus rheometers, and factors like moisture content or polymer degradation, may also influence these measurements. These findings suggest potential applications of banana peel starch in low-viscosity products, providing an alternative to traditional starches in food formulations.

Banana peel starch demonstrates versatility across industries. Unripe starch's low viscosity suits clear beverages and sauces, while ripe starch's moderate viscosity is ideal for gravies and soups. Overripe starch, with minimal thickening properties, is suitable for specific beverages and sauces. These properties align with consumer preferences for clean-label, natural starches [17]. In cosmetics, its smooth texture enhances products like face and body powders, offering an eco-friendly alternative to talcum powder [18]. The growing demand for sustainable, natural ingredients underscores banana peel starch's potential in food and personal care markets, promoting environmental sustainability.

4. Conclusion

This study successfully investigated the physicochemical properties of banana peel starch derived from *Musa Paradisiaca Fa. Corniculata* at different maturity stages. The findings revealed that the maturity stage significantly affects the starch's pH, moisture content, viscosity, gelatinization temperature, melting point, iodine calorimetry, and angle of repose. Unripe banana peel starch exhibited the highest gelatinization temperature and stability, which is suitable for high-temperature applications, while ripe starch demonstrated optimal viscosity, making it ideal as a thickening agent. Overripe starch showed higher pH and lower amylose content, indicating potential compatibility with acidic formulations. These results highlight the unique properties of banana peel starch at various ripening stages and its adaptability for diverse applications, including food processing and biodegradable materials.

Additionally, the research underscores the broader contributions of banana peel starch in pharmaceutical fields, where its bioadhesive properties could enhance drug delivery systems, and in packaging, where it can serve as a base for bio plastics. By focusing on the valorization of banana peel waste, the study promotes sustainable utilization, addressing the dual goals of reducing food industry by-products and supporting environmental conservation. This innovative approach not only advances resource efficiency but also contributes to a circular economy by transforming agricultural waste into value-added products, paving the way for eco-friendly and commercially viable solutions.

Acknowledgement

The authors would like to thank the Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia for its support.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Ani Fadhilah Mohamad Fauzi, Mohamad Zulhafiz Shafiq Zulhilmi Cheng;* ***data collection****: Ani Fadhilah Mohamad Fauzi;* ***analysis and interpretation of results****: Ani Fadhilah Mohamad Fauzi;* ***draft manuscript preparation****: Ani Fadhilah Mohamad Fauzi, Mohamad Zulhafiz Shafiq Zulhilmi Cheng. All authors reviewed the results and approved the final version of the manuscript.*

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