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# FROM WASTE TO WORTH: BLENDING PLANTAIN AND PINEAPPLE CORE FLOUR FOR A SUSTAINABLE NEXT-GEN INGREDIENT

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## Abstract

This study scrutinized the physicochemical properties of plantain and pineapple core flour (PF, PCF) and its feasibility as a nutritious and sustainable product. PCF demonstrated greater ($p<0.05$) crude fibre and crude fat (67.86% and 1.82%) than PF (0.13% and 0.40%), suggesting divergent nutritional applications. The finer particle of PF may enhance its hydration capabilities. Morphological analysis revealed coarser PCF due to increased fibre content. The energy requisite for gelatinization diminished with the addition of PCF, indicating potential energy savings in food preparation. The combination of PF and PCF offers enhanced functional ingredients while promoting the utilization of agricultural byproducts.

**Keywords**: Plantain; Pineapple Core, Waste Management, Sustainability, SDG 9

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## Introduction

Plantain is a crop from the genus Plantains (*Musa* x *paradisiaca*), a banana family member. Plantain flour has the distinct advantage of being gluten-free, possessing essential nutrients, and being especially rich in phenolic compounds with substantial antioxidant effects while being low in protein and fat (Patel et al., 2023). The pineapple (*Ananas comosus*) is the most prevalent edible member of the Bromeliaceae family, thriving in tropical and subtropical environments. Protein variations are frequently used to modify the characteristics of food ingredients, with regards to enzymes as a solution for the low protein content issues of plantain flour. Utilizing the pineapple core, a byproduct of fruit processing, can help alleviate the environmental difficulties caused by these wasted pieces.

The primary objective was to explore the feasibility of plantain flour, pineapple core flour and both flour blends in yielding a nutritious and sustainable product. This study aligns with Sustainable Development Goal (SDG) 9: Industry, Innovation, and Infrastructure, as the development of innovative pineapple core flour contributes in fostering technological advancements primarily in food systems.

## Methods

Green (stage 2 of ripening: all green) Maiden (Tanduk) bananas and fresh pineapple cores were purchased from a local supermarket in Shah Alam and processed into flour using modified methods adapted from Shiau et al. (2015). The bananas were washed, peeled, and separated into pulp and peel. To minimize enzymatic browning, the pulps were blanched at 70°C for 2 minutes, rinsed, and dried overnight, 24 hours, in a cabinet dryer at 60°C. The dried pulps were then ground using a Retsch Mill Laboratory (Retsch AS200) and passed through 45 mesh screens to produce PF. Similarly, the pineapple cores were washed, sliced into 1 cm thick pieces, and blanched at 100 °C for 15 minutes to ensure microbial safety and enzyme inactivation. The blanched slices were drained and dried in a cabinet dryer at 60°C for 72 hours until a consistent weight was achieved. The dried cores were ground into powder

using the Retsch Mill Laboratory (Retsch AS200) and filtered through an 18-mesh screen to obtain PCF.

Both flour were stored in airtight plastic bags at room temperature for subsequent analyses. Both flour preparations aimed to retain maximum physicochemical properties and ensure suitability for further experimental analysis.

**Proximate analysis**

The moisture, crude protein, crude fibre, crude fat, and ash contents were determined using the procedures of 925.10, 2001.11, 920.86, 920.39, and 923.03; respectively (AOAC International, 2007).

Equation (1) was used to calculate the percentage of moisture content in both flours.

Moisture content (%) = [(Weight of sample before drying (in grams) - Weight of sample after drying (in grams)) / Weight of sample before drying (in grams)] x 100 …(1)

Equation (2) was used to obtain the value of crude protein. The conversion factor used is 6.25.

Crude protein content (%) = % Nitrogen content x Conversion factor …(2)

Equation (3) was used to obtain the value of crude fibre in flours.

Crude fibre content (%) = [(Dry weight of sample (in grams) - Weight of sample (in grams)) / Weight of sample (in grams)] x 100 …(3)

Equation (4) was used to determine the crude fat content (g) per 100 g sample.

Crude fat content (%) = (Weight of fat in sample (in grams) / Weight of sample taken (in grams)) x 100 …(4)

Equation (5) was used to to calculate the amount of ash (g) in a 100 gram sample.

Ash content (%) = (Weight of ash in sample (in grams) / Weight of sample taken (in grams)) x 100 …(5)

**Particle Size Analysis (PSA)**

The particle size distribution of the flour samples was examined with an Analysette 22. The device was outfitted with a laser beam to identify the individual particles. The approach followed ISO 13320-1 (1999), the international standard for laser diffraction. The results are for the flour samples with particle sizes of d(0.1), d(0.5), and d(0.9). d(0.1) denotes the particle size for which 10% of the sample is less than this size; d(0.5) indicates the particle size for which 50% of the sample is smaller and 50% is larger than this size; and d(0.9) indicates the particle size for 90% of the sample (Rajab, 2018).

**Scanning Electron Microscopy (SEM)**

The microstructure of the flour was observed using a scanning electron microscope (SEM, TM3030Plus) (Xiao et al., 2012). The samples were dispersed as a monolayer on an SEM specimen stub with double-sided conductive tape. After fixation and dehydration, the samples were coated with gold to make the sample conductive, and the images were taken at an accelerating potential of 10 kV. Micrographs were recorded at 1000x and 2000x magnification to ensure clear images (Rajab, 2018).

**Differential Scanning Calorimetry (DSC)**

The sample's thermal characteristics were determined with a Mettler Toledo DSC and a thermal analysis data station (STARe Software, version 9.0x), using the approaches of Nurul Azira and Azura (2012) and Lasekan and Hussein (2018), with some modifications. The purge gas was nitrogen (99.99% purity) flowing at a rate of 50 ml/min. Approximately 10 mg of flour samples were placed into 40 µL aluminium pans and hermetically sealed before heating. An empty, sealed aluminium pan served as a reference. The DSC was calibrated using indium. The sample and reference pans were heated at 10°C each minute from 10°C to 300°C. The thermograms were used to calculate the onset (To), peak (Tp), and end (Te) temperatures of gelatinization.

**Statistical analysis**

The data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 29.0. P-values ($p<0.05$) were considered significant. An independent t-test was used to compare the nutritional compositions of PF and PCF.

## Result and Discussion

**Proximate composition**

The proximate composition of PF and PCF differed significantly ($p<0.05$), as indicated in Table 1. Production of PF and PCF stimulating agricultural production through market expansion, making one of the critical aspect is in determining its nutritional value. The moisture level of flour is a crucial factor in determining its shelf life and quality. PF showed a significantly ($p<0.05$) lower moisture content ($6.38 \pm 0.08\%$) than PCF ($7.03 \pm 0.10\%$). Megías-Pérez et al. (2014) discovered that PCF's higher sugar content increases water retention, resulting to its higher moisture content. Pineapple cores have more water than plantains, which are denser (Adi et al., 2018; Nordin et al., 2023). The findings suggest that raw material composition and drying procedures play an important role in defining flour properties. The lower moisture content, as shown in both flours, can increase storage stability and reduce susceptibility to microbial deterioration, increasing the potential for a longer shelf life.

Table 1. Proximate composition of PF and PCF

| Sample | Moisture Content (%) | Crude Protein Content (%) | Crude Fibre Content (%) | Crude Fat Content (%) | Ash Content (%) | Carbohydrate Content (%) |
|---|---|---|---|---|---|---|
| PF | 6.38 ± 0.08b | 3.82 ± 0.25a | 0.13 ± 0.02b | 0.40 ± 0.00b | 2.93 ± 0.02a | 86.29 ± 0.33a |
| PCF | 7.03 ± 0.10a | 3.34 ± 0.27a | 67.86 ± 0.02a | 1.82 ± 0.02a | 2.14 ± 0.03b | 18.76 ± 2.12b |

Note: Values are the means and standard deviation of three replicate analyses. Mean values with different superscripts are significantly different at $p<0.05$.

PF had slightly higher crude protein content ($3.82 \pm 0.25\%$) compared to PCF ($3.34 \pm 0.27\%$), although the difference was not statistically significant ($p>0.05$). Plantains comprise more complex carbohydrate and proteins, whereas pineapples are predominantly made up of sugars and fibre (Cordenunsi et al., 2010). This finding is in line with the known nutritional profiles of plantains and pineapple cores, where pineapple cores mainly have significantly higher ($p<0.05$) crude fibre content as indicative by the value of 67.86%.

PCF is naturally high in dietary fibre due to its fibrous composition as proven in SEM (Figure 2), with studies finding high crude fibre levels in pineapple byproducts (Santos et al., 2021) and stiffer fiber content in the centre, contributing to their higher crude fibre content (Cordenunsi et al., 2010). The crude fat content of PF and PCF differed significantly, with PF containing $0.40 \pm 0.00\%$ and PCF containing $1.82 \pm 0.02\%$. A statistical study ($p<0.05$) verified the variation, possibly due to changes in the botanical origins of the two flours. The crude fat content in PCF exceeds values reported by Tortoe et al. (2014), who revealed that crude fat content in pineapple cores often does not surpass 0.5%. PF revealed a substantially greater ($p<0.05$) ash content ($2.93 \pm 0.02\%$) compared to PCF ($2.14 \pm 0.03\%$). Previous studies report comparable values for PF and PCF, often within close ash content values, indicating that mineral content across both flours tends to be similar despite minor differences in specific analysis conditions (Adegunwa et al., 2024; Santos et al., 2021).

The carbohydrates by difference content of PF and PCF highlights their different compositional differences, which are influenced by their botanical origins. PF has much higher ($p<0.05$) carbohydrate by difference ($86.29 \pm 0.33\%$) than PCF ($18.76 \pm 2.12\%$), as this sharp disparity can be traced to the two raw materials' basic biochemical composition. The drying process has a further impact on these carbohydrate levels since plantains maintain more complex carbohydrate, but pineapple cores' fibrous character leads to a lower carbohydrate yield (Santos et al., 2021; Wulan et al., 2026).

**Particle size distribution**

The particle size distribution of PF and PCF and their blends was analyzed using laser diffraction, which provides insights into the physical properties of the flours and their potential influence on functional and processing characteristics. The results, as shown in Table 2, demonstrate notable differences in particle size parameters (d10, d50, d90) values across the samples.

The PF sample demonstrated a d10 value of 9.74 µm, a median particle size (d50) of 31.85 µm, and a d90 value of 367.42 µm. The d10 value represents the particle diameter at which 10% of the total volume of particles is smaller, while d90 indicates the particle diameter at which 90% of the total volume of particles is smaller. The comparatively tiny particle size of PF is consistent with observations that PF often has smaller particle sizes because of its reduced fibre content, allowing for finer milling (Hernández-Santos et al., 2022).

The PCF sample showed larger particle sizes, with a d10 value of 31.22 µm, a average particle size (d50) of 240.13 µm, and a d90 value of 522.43 µm. This bigger particle size can be linked to the increased fibre content in PCF, as fibre-rich materials resist fine grinding due to structural rigidity (Benvenutti et al., 2025). According to Bekele and Emire (2023), lower fibre content in pineapples will contribute to finer powder particles. The blend with 90% PF + 10% PCF had a (d50) of 48.23 µm, while the blend with 70% PF + 30% PCF had a (d50) of 79.76 µm. This trend demonstrates that adding PCF increases the overall particle size while narrowing the distribution range due to the structural influence of PCF's fibre content (Wu & Shiau, 2015). Blends with controlled particle size distributions can combine the advantages of both flours, providing increased functionality for specific applications.

Table 2. Basic laser diffraction graph statistics

| Sample | Parameter | Value (µm) |
|---|---|---|
| PF | d10 | 9.74 |
| | d50 = median | 31.85 |
| | d90 | 367.42 |
| PCF | d10 | 31.22 |
| | d50 = median | 240.13 |
| | d90 | 522.43 |
| 90 (PF) + 10 (PCF) | d10 | 11.82 |
| | d50 = median | 48.23 |
| | d90 | 439.47 |
| 80 (PF) + 20 (PCF) | d10 | 11.13 |
| | d50 = median | 65.07 |
| | d90 | 422.93 |
| 70 (PF) + 30 (PCF) | d10 | 11.87 |
| | d50 = median | 79.76 |
| | d90 | 447.90 |

Note: 90 PF + 10 PCF : 90% (PF) + 10% (PCF), 80 PF + 20 PCF: 80% (PF) + 20% (PCF) and 70 PF + 30 PCF: 70% PF + 30% (PCF).

**Morphological observation**

The SEM analysis of PF, PCF and their blends reveal important microstructural features including distinct changes in particle shape and surface texture that determine their physicochemical properties. The SEM images of PF show mainly round and elongated shapes at 1.0K magnification (Figure 1). When PF is examined with a greater magnification of 2.0K, more detailed characteristics emerge. The particles obviously show round and elongated, which is due to the presence of starch granules and fibre remains. Some particles have fissures or cracks that may have formed during the drying or milling operations. These qualities are important as it may altered the flour's water absorption capacity and behaviour, eventually influencing product quality (Soares et al., 2011).



Figure 1. SEM images of the PF, with the 1.0K (left) and 2.0K (right) resolution

In contrast, SEM images of PCF (Figure 2) at 1.0K magnification revealed irregularly shaped particles with coarse texture and a heterogeneous size distribution. The rough and pitted surfaces are typical of fibrous materials, owing to the high fibre content of the pineapple core. Individual particles display detailed surface patterns at 2.0K magnification, including micro-scale characteristics like microscopic fissures and cracks. The presence of fibrous structures shows the high fibre content of PCF as mentioned in Table 1 on crude fibre content, which is critical for its water retention ability and functioning in dough formulations (Benvenutti et al., 2025).

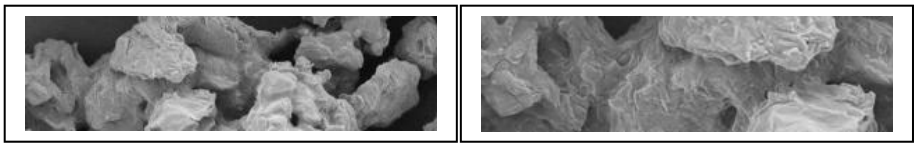


Figure 2. SEM images of the PCF, with the 1.0K (left) and 2.0K (right) resolution

The blends containing varying ratios (Figure 3, 4 and 5) of PF and PCF also demonstrate distinct morphological characteristics at both magnifications. The images represent the percentage ratio of the mixture showing more and higher elongated structure, meaning the majority of samples contain elongated structure than fibrous structure. As the proportion of PCF increases in the blends, the particle size distribution shifts towards larger sizes while maintaining a relatively uniform texture compared to PF alone.

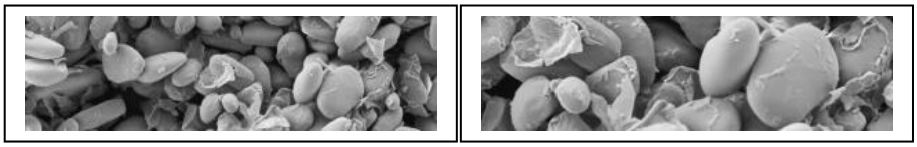


Figure 3. SEM images of the 90% (PF) + 10% (PCF), with the 1.0K (left) and 2.0K (right) resolution

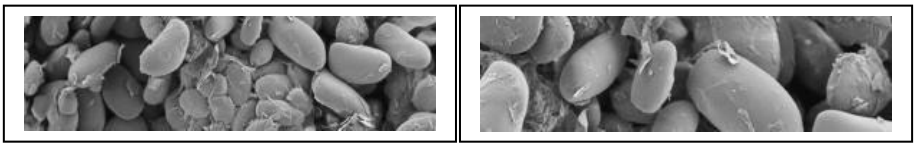


Figure 4. SEM images of the 80% (PF) + 20% (PCF), with the 1.0K (left) and 2.0K (right) resolution

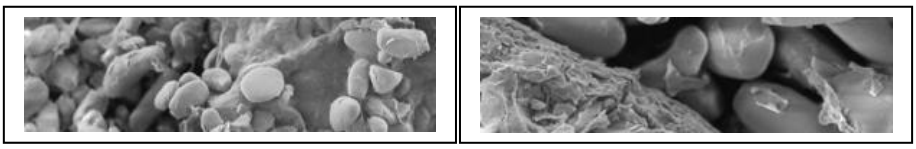


Figure 5. SEM images of the 70% (PF) + 30% (PCF), with the 1.0K (left) and 2.0K (right) resolution

**Thermal profile**

The thermal analysis using DSC results indicate notable differences in the thermal properties of PF and PCF and their blends (Table 3). DSC was used to detect heat flow into or out of a sample using a regulated temperature profile, providing information about the sample's thermal behaviour. These variations are closely tied to the compositions of the samples.

Table 3. Thermal profile of flours

| Sample | Enthalpy (Jg-1) | To(°C) | Tp(°C) | Te(°C) |
|---|---|---|---|---|
| PF | 1164.87 | 73.30 | 98.73 | 109.37 |
| PCF | 891.45 | 66.60 | 98.14 | 110.72 |
| 90 (PF) + 10 (PCF) | 1040.62 | 69.10 | 98.74 | 110.19 |
| 80 (PF) + 20 (PCF) | 105.42 | 39.82 | 69.62 | 100.14 |
| 70 (PF) + 30 (PCF) | 83.43 | 25.05 | 63.74 | 92.47 |

Note: 90 PF + 10 PCF : 90% (PF) + 10% (PCF), 80 PF + 20 PCF: 80% (PF) + 20% (PCF) and 70 PF + 30 PCF: 70% PF + 30% (PCF). To = Onset Temperature, Tp = Peak Temperature, Te = End Temperature.

The DSC data indicates that PF has the maximum enthalpy, 1164.87 J/g, with an onset temperature of 73.30°C and a peak temperature of 98.73°C, which demands significant energy to break intermolecular hydrogen bonds during gelatinization. Meanwhile, PCF displayed lower enthalpy (891.45 J/g) and onset temperature (66.60 °C), consistent with its higher content of fibre. The reduction in thermal properties is linked to the increased levels of fibre, which disrupt the starch matrix and lower the energy needed for gelatinization. Blends of PF and PCF demonstrated a progressive decrease in enthalpy and thermal transition temperatures as the proportion of PCF increased. For example, 90% PF + 10% PCF exhibited an enthalpy of 1040.62 J/g, while 70% PF + 30% PCF had the lowest enthalpy (83.43 J/g) and onset temperature (25.05 °C); corresponding to decrease in thermal stability. This behaviour is consistent with observations in pineapple byproducts, where high fibre content influence thermal behaviour (Yildiz et al., 2013). The reduced gelatinization temperature and enthalpy in the blends indicates its potential in enhancing the processing efficiency of flour-based products while offering practical advantages such as reduced energy consumption during processing.

## Conclusion

The findings demonstrated that the inclusion of PCF significantly altered the flour blends' composition, particularly by increasing fibre and fat content while reducing starch content. These changes influence the blends' hydration, thermal properties, and potential applications in food formulations. The PSA and SEM analysis further highlighted structural differences between PF and PCF, which may affect their functional performance in food systems. Additionally, DSC revealed that increasing PCF levels reduced the energy required for gelatinization, indicating its potential to enhance the processing efficiency of flour-based products. In conclusion, the incorporation of PCF into PF blends offers a promising approach to improving functional and nutritional properties while promoting the valorization of pineapple waste. It also provides alternative in managing the post-harvest losses worldwide, specifically on the plaintain cultivar. These findings support the potential of PCF-enriched PF blends as sustainable ingredients with diverse applications in processing and functional benefits for industrial use. Future research should focus on investigation of the optimal ratio blends, related mineral composition analysis and insights into consumer acceptance as well as preference testing in order to expand and commercialized the sustainable product for the future prospect.

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### Author Contribution

MA Anis Najihah - Formal analysis, Investigation, Writing - original draft; R Asmeda - Supervision, Writing - review and editing.

### Conflict of Interest

Authors declare no conflict of interest.

### Declaration on the Use of Generative AI

The authors employed generative AI (Gemini) specifically for the purpose of formatting of the manuscript according to the Journal of Academia (JoA) template, without compromising the originality, intellectual

contribution, or scientific integrity of the work.

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