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Original Article

Physicochemical properties, techno-functionality, and resistant starch of green fragrant banana flour

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Abstract

The composition and properties of flour produced from green whole and pulp of fragrant bananas were studied. Two fragrant banana varieties, Gros Michel (TY) and Cavendish (TW), grown in the same area at three stages of maturity (68, 76, and 82 days after anthesis), were processed as pulp and whole banana flour. A considerable amount of RS was found (21.5% - 41.3% db). As maturity increased, RS decreased significantly. The flour had a high pasting temperature (80.2 to 82.4 ºC), peak viscosity (1,920 to 3,669 cP), and setback (562 to 1274 cP), but relatively low breakdown (0 to 920 cP) with 2.29 to 3.91 grams of water holding capacity and 6.5 to 7.8-gram oil holding capacity per gram. Varieties and maturity had no significant effect on proximate composition, water holding capacity, and oil holding capacity. All banana flour samples showed the C-type crystalline structures with 20.5% to 23.1% crystallinity.

Keywords: fragrant banana, Gros Michel, resistant starch, green banana flour

1. Introduction

"Fragrant banana" or "Kluay Hom" is a dessert banana widely grown in Southeast Asia. In Thailand, two varieties of fragrant bananas, namely Gros Michel and Cavendish, are popularly cultivated, especially in the central plain of Thailand. Both varieties belong to the group of *Musa acuminate* AAA, which is triploid. As a perennial plant, bananas can be grown and harvested throughout the year. The shift from the predominant Gros Michel cultivation to disease-resistant Cavendish occurred after the Panama disease destroyed banana plantations worldwide in the mid-20th century. Nowadays, Cavendish's production yield is about four times that of Gros Michel. In Thailand, the overall production of fragrant bananas was over 150,000 tons in 2019 (Ministry of Agriculture and Cooperatives, 2021); approximately one-third of this was Cavendish (Katchwattana, 2020). Gros Michel is preferred for fresh fruit consumers due to its superior fragrance, taste, and texture compared to Cavendish banana.

Bananas have superior nutritional value and functional quality, especially when consumed in the unripe or green stage. Many researchers have reported that unripe banana flour is a good source of macro-nutrients and trace elements. The unripe banana flour is rich in resistant starch (Kongolo *et al.*, 2017), increasing satiety and reducing hunger in healthy volunteers (Hoffmann Sardá *et al.*, 2016b). Campuzano, Rosell, and Cornejo (2018) reported that resistant starch in unripe bananas decreased from about 38 grams per 100 grams at stage 1 (one day after harvest) to about 13 grams per 100 grams at stage 4 (six weeks after harvest).

The banana peel accounts for about 40% of the total weight of banana fruit. Researches have shown the potential use of banana peel waste, for example, as a low-cost indigeneous mycological medium (Kindo, Tupaki-Sreepurna, & Yuvaraj, 2016), and bioenergy production through

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pyrolysis (Tahir, Zhao, Ren, Rasool, & Naqvi, 2019). Pereira and Maraschin (2015) reported that phytochemicals such as phenolics, carotenoids, flavonoids, biogenic amines, and phytosterols are found in banana pulp and peel. Li *et al.* (2018) reported that the dried peel contains 22.6% starch while the pulp contains 69.5% starch, but the peel starch was more resistant to hydrolysis by porcine pancreatic α-amylase. Bakar, Ahmad, and Jailani (2018) reported that the peel of four banana varieties is a good source of dietary fiber as it contains 31.5 to 37.4% of total dietary fiber. From the reviewed studies, both peel and pulp of banana are good sources of nutrients, and thus both can be potentially produced as flour for further application in food products. However, no information on the effect of harvest maturity on the physicochemical properties, techno-functionality, and resistant starch of the flour produced from green fragrant banana was found, nor was any comparison between different varieties of Gros Michel.

Therefore, this research aimed to investigate the effect of harvest maturity and varieties on the physicochemical properties, techno-functionality, and resistant starch of whole banana and banana pulp flour produced from Gros Michel bananas.

2. Materials and Methods

2.1 Banana and banana properties

Two varieties of Gros Michel bananas; TY and TW, grown in the same plantation, were studied. Each variety was harvested at 68 days, 76 days, and 82 days after anthesis. It should be noted that the regular harvest maturity for dessert bananas is usually 12 to 17 weeks or 84 to 119 days after the first day of flowering (Surya Prabha & Satheesh Kumar, 2015). The bananas were at ripening stages 1 and 2 when they were processed into flour.

The color of banana peels from at least three bananas of the same bunch and the processed flour was measured using a chromameter (Model CR-400, Konica Minolta, Inc., Japan) in L*a*b* color space. Since the value of a* and b* fell in the second quadrant of the color space, hue angle (h*) and chroma (C*) of the peel were calculated from Equations 1 and 2.

$$h^* = \arctan(b^*/a^*) \quad (1)$$

$$C^* = \sqrt{a^{*2} + b^{*2}} \quad (2)$$

Total soluble solids (TSS) and pH of the extracted liquid from the banana pulp were measured using a hand refractometer and a pH meter, respectively. Bananas from the same bunch were processed into flour labelled with the same ripeness or harvest stage.

2.2 Preparation of banana flour and flour yield

Banana fruits from all combs of the same bunch, peeled or unpeeled, were washed with water and then soaked in 0.6% (w/v) aqueous citric acid solution for 10 minutes. The soaking in aqueous citric acid solution was necessary to remove the troublesome banana sap for further banana preparation, which could also inhibit enzymatic browning. The fruits were cut into 1 mm thick slices and then dried in a locally made 20-tray dryer at 60 ºC until the water activity of the banana slices fell below 0.6. Water activity was measured using a water activity meter (Series 3 model TE, AquaLab, USA). The dried banana slices were then pulverized and sieved through a 120-mesh standard sieve. The production yield of banana flour was calculated from the amount of dried flour obtained multiplied by 100 and divided by the fresh weight of the whole banana.

2.3 Determination of chemical composition, physical property, and techno-functionality

2.3.1 Proximate analysis

Each flour sample was analyzed for its proximate composition, including moisture content, protein, lipids, ash, and crude fiber using methods described in the AOAC International Official Methods of Analysis (AOAC, 2000). Carbohydrate content was calculated by difference.

2.3.2 Determination of resistant starch and non-resistant starch by the in-vitro enzyme digestion

Resistant starch (RS) and solubilized or non-resistant starch (NRS) were analyzed using the alpha-amylase and amyloglucosidase digestion following the methods of McCleary and Monaghan (2002). One-hundred milligrams of banana flour was mixed with 4 mL of pancreatic α-amylase (30 Ceralpha Units (CU)/mL) in a buffer containing 100 mM of sodium maleate buffer (pH 6.0), calcium chloride (1mM), and sodium azide (0.02%), and 0.5 mL amyloglucosidase (24 U/mL) in the same buffer. The sample was incubated at 37°C for 16 hours. At the end of the incubation, 4 mL of 99% ethanol was mixed before the sample was centrifuged at 1,500×g for 10 minutes. The supernatant was decanted and the sediment was washed with 8 mL of 50% ethanol before centrifugation at 1,500×g for 10 minutes. This step was repeated one more time. The supernatant was collected and combined with the supernatant from the previous step. The amount of RS was determined from the sediment and NRS was determined from the supernatant.

The sediment was mixed with 2 mL of 2 M potassium hydroxide while being kept chilled in an ice-cold water bath to determine the amount of RS. After 20 minutes of mixing, 8 mL of 1.2 M acetate buffer (pH 3.8) and 0.1 mL of amyloglucosidase (3,300 Unit/mL) were added. After incubation at 30 °C for 30 minutes, the mixture was transferred to a 100-mL volumetric flask and adjusted to volume using distilled water. The mixture was centrifuged at 1,500×g for 10 minutes and 0.1 mL of the supernatant was pipetted to a test tube and mixed with 3 mL of gluocose oxidase/peroxidase (GOPOD) reagent (Megazyme® D-Glucose Assay Kit). The mixture was incubated at 50 °C for 20 minutes. The absorbance at 510 nm (ΔE) of the solution was measured using a spectrophotometer. The RS percentage was calculated following Equation 3.

$$\text{RS\% or NRS\%} = \Delta E \times (F/W) \times 90 \quad (3)$$

Where F is 100 (μg of D-glucose) divided by the GOPOD reagent absorbance at 510 nm of 100 μg D-glucose and W is the weight of sample in mg. It is noted that Equation 3 is used when the sample contains 10% of resistant starch or more.

To determine the amount of NRS, the supernatant was transferred to a 100-mL volumetric flask and adjusted to volume with 100 mM sodium acetate buffer (pH 4.5). An aliquot (0.1 mL) of this solution was incubated with 10 μL of dilute amyloglucosidase solution (300 U/mL) in 100 mM sodium maleate buffer (pH 6.0) at 50 °C for 20 minutes. The mixture was then mixed with 3.0 mL of GOPOD reagent and incubated in a water bath at 50 °C for 20 minutes. The absorbance at 510 nm of the solution was measured using a spectrophotometer. The NRS percentage was calculated following Equation 3. The percentage of total starch (%TS) was the sum of RS and NRS.

2.3.3 Determination of water holding capacity and oil holding capacity

The water-holding capacity (WHC) and oil-holding capacity (OHC) of banana flour at an ambient temperature (about 30 ºC) were determined by placing 250 milligrams of banana flour (w) in a centrifugal tube to which 25 mL of distilled water or olive oil was added and mixed. The tube was allowed to stand at room temperature for 1 hour before centrifugation at 1,500×g for 10 minutes. The supernatant was decanted. The precipitate was weighed (w_p). WHC and OHC were calculated as follows:

$$\text{WHC or OHC (g/g dry flour)} = \frac{w_p}{w} \qquad (4)$$

2.3.4 Pasting test

The pasting property of starch suspension (3.0 g dry flour in 25 mL distilled water) was investigated by pasting under the conditions specified by standard profile 1 using the Rapid Visco-Analyser (RVA; Newport Scientific, Pty. Ltd., Australia). Pasting parameters were recorded.

2.3.5 X-Ray diffractometry and scanning electron microscopy

Crystallographic pattern analysis was performed using an X-Ray Diffractometer (Model D8 Discover, Bruker AXS, Germany) equipped with the VÅNTEC-1 detector. Samples were scanned in the range of 2 to 50 degrees 2-theta angle at 0.02-degree step and 2 degrees per minute scan rate. The percentage of crystallinity was calculated from the peak area representing the crystallites divided by the total area as given in Tattiyakul, Naksriarporn, and Pradipasena (2012). The morphology of the starch granules was observed using a scanning electron microscope (Model IT5R, JEOL Ltd., Japan) at an accelerating voltage of 15 kV and 500x magnification.

2.4 Experimental design and statistical analysis

The experiment was conducted in a 2×2×3 factorial design with two replications. All analyses were performed in duplicate. Analysis of variance was performed using IBM SPSS statistical software (version 22). Duncan's Multiple Range Test was used for mean comparison. $P<0.05$ was considered significantly different.

3. Results and Discussion

3.1 Banana and banana properties

Whole TY and TW bananas at 68 days after flowering had moisture contents of 58.8±0.3% and 67.4±0.4%, respectively. When the fruits ripened, the moisture content increased to 72.0±0.3% and 72.0±0.1% at 82 days after anthesis, respectively. The hue angle and chroma of banana peel from different harvest periods from 68 to 82 days after anthesis did not differ significantly ($P\geq 0.05$) for the two banana varieties, with the hue angle and chroma varied in the range of 115.2±8.2 to 131.4±7.5 and 20.3±1.0 to 27.0±4.6, respectively, which indicated green color. Total soluble solids of pulp increased insignificantly from 1.0 Brix to 1.2 Brix, consistent with that reported by Alison Alves Oliveira, Carlos Chamhum SalomÃO, Lopes De Siqueira, & Roberto Cecon (2016). The pH of fresh banana pulp varied insignificantly ($P\geq 0.05$) in the range of 5.5 to 6.0. Comparable values were reported for the banana harvested at 18 weeks of maturity (Siqueira, Barbosa, Cordenunsi, Hassimotto, & Resende, 2018).

3.2 Banana flour yield

Dry milling processing of TY and TW flour yielded an average of 17.5%±1.6% and 13.6%±1.0% pulp flour and 21.5%±1.3% and 18.4%±0.7% whole banana flour, respectively. The yield of whole banana flour was about 5% to 6% higher than that of banana fruit pulp flour. A trend of yield increase with maturity was observed for both banana cultivars (data not shown). The banana raw material used in this study was at the end of the early stage and the beginning of the mature stage (68-82 days, with the appropriate maturity at 84-119 days). These stages were selected to avoid fast ripening during transportation and storage that can cause starch conversion into sugars. The increase in flour yield could be anticipated due to increasing maturity.

3.3 Chemical composition, physical property, and techno-functionality

3.3.1 Proximate composition

Table 1 shows the proximate composition and the total starch, non-resistant starch, and resistant starch of the flour from whole banana and pulp from TY and TW banana. It should be noted that the flour was processed with an entire bunch, which inevitably differed. Therefore, variation in properties was expected. This resulted in a non-significant difference in proximate compositions except for the samples' moisture content and total starch and resistant starch content. Although the whole banana flour had a higher crude fiber content and a lower carbohydrate content due to the presence of the peel, which is higher in crude fiber, no significant difference ($P\geq 0.05$) was discovered. It is noteworthy that the samples of unripe banana flour in this study contained a lower

Table 1. Color, proximate composition, and resistant starch of flour from unripe whole banana and pulp of TY and TW banana

Variety	Day after anthesis	Raw material	Moisture content (% wb)$^{(1)}$	Protein ^{ns} (% db)	Lipids ^{ns} (% db)	Crude fiber ^{ns} (% db)	Ash ^{ns} (% db)	Carbohydrates ^{ns} (% db)	Resistant starch (% db)$^{(1)}$	Non-Resistant starch ^{ns} (% db)	Total starch (% db)$^{(1)}$
TY	68	Banana pulp	9.3±0.4 ^{b}	0.40±0.03	0.69±0.01	1.39±0.09	0.61±0.71	96.5±0.4	41.3±8.8 ^{a}	28.3±7.8	69.6±16.6 ^{a}
	76		10.0±0.1^{a}	0.43±0.12	0.71±0.01	1.20±0.11	1.11±0.02	96.6±1.1	25.5±4.3 ^{b}	22.4±8.0	47.8±12.3 ^{ab}
	82		11.6±2.8 ^{a}	0.45±0.01	0.75±0.01	0.62±0.14	1.13±0.05	97.1±3.3	24.7±3.3 ^{c}	14.4±2.8	39.1±6.0 ^{b}
	68	Whole banana	8.0±0.9 ^{b}	0.43±0.04	0.89±0.01	1.95±0.20	1.10±0.01	94.8±0.4	33.5±2.3 ^{a}	28.3±0.0	61.7±2.2 ^{a}
	76		9.8±0.2 ^{a}	0.55±0.02	0.95±0.01	1.85±0.44	1.09±0.03	97.6±0.5	28.4±0.8 ^{b}	24.1±4.1	52.5±3.2 ^{ab}
	82		10.2±0.0 ^{a}	0.50±0.03	0.99±0.01	1.54±0.00	1.14±0.02	95.9±0.0	24.4±1.7 ^{c}	19.6±1.5	44.0±0.2 ^{b}
TW	68	Banana pulp	9.7±0.3 ^{b}	0.41±0.02	0.70±0.00	1.32±0.12	1.10±0.01	96.6±0.5	35.8±5.1 ^{a}	18.1±5.4	53.8±0.3 ^{a}
	76		9.9±0.3 ^{a}	0.47±0.00	0.72±0.01	1.05±0.12	1.12±0.03	97.4±0.3	34.9±4.6 ^{b}	17.7±7.4	52.6±12.0 ^{a}
	82		10.0±0.0 ^{a}	0.50±0.03	0.74±0.01	0.98±0.41	1.08±0.03	96.8±0.5	21.5±0.6 ^{c}	17.2±0.1	38.7±0.1 ^{b}
	68	Whole banana	8.5±0.0 ^{b}	0.52±0.00	0.93±0.01	1.84±0.23	1.10±0.01	95.6±0.3	35.0±1.6 ^{a}	23.6±6.2	58.6±7.8 ^{a}
	76		8.9±0.2 ^{a}	0.52±0.01	0.94±0.01	1.48±0.23	1.11±0.02	95.5±0.0	30.2±1.0 ^{b}	21.2±8.3	47.5±9.3 ^{a}
	82		9.4±0.2 ^{a}	0.52±0.01	0.97±0.01	1.46±0.57	1.18±0.11	96.4±0.7	25.7±5.0 ^{c}	16.3±3.2	42.0±8.2 ^{b}

$^{a, b, c}$ Values in the same raw material group with different superscripts are significantly different (P<0.05). ^{ns} Values in the column do not differ significantly (P≥0.05). ND means "Not Determined". $^{(1)}$ Only maturity had a significant effect on moisture content.

amount of protein (0.40 to 0.55 %), lipids (0.69 to 0.97 %), and ash content (0.61 to 1.18 %) compared to those reported elsewhere (Amini Khoozani, Birch, & Bekhit, 2019). The bananas used in this study were harvested 68, 76, and 82 days after anthesis, the earliest stage of the appropriate harvest maturity, around 84 to 119 days after anthesis. This resulted in a lower accumulation of nutrients. Fertility of the plantation could be another cause of the nutrient content of the fruits. Variations in the proximate composition of 12 commercial samples of unripe banana flour and a standard unripe banana flour have been reported in previous studies (Hoffmann Sardá *et al.*, 2016b).

3.3.2 Resistant starches and non-resistant starches

According to the EU Directive 2008/100/EC, resistant starches (RS) are defined as dietary fibers (Włodarczyk & Śliżewska, 2021). RS can be divided into five types (Amini Khoozani *et al.*, 2019). Unripe bananas are mainly known for their high content of RS2, which is raw starch granules. Flour from the pulp of TY and TW contained 24.7 to 41.3 % RS and 21.5 to 35.8% RS, respectively, while flour from whole unripe TY and TW contained 24.4 to 33.5 % RS and 25.7 to 35.0% RS, respectively. No significant difference (P≥0.05) on resistant starch was observed between the flour from different banana varieties at the same harvest time. The flour production with or without banana peel had no significant effect (P≥0.05) on the resistant starch content. The level of RS only reduced with increasing maturity (P<0.05) as shown in Table 1. The levels of resistant starch found in the samples of this study are consistent with those reviewed by Amini Khoozani *et al.* (2019). In their review, banana at green stages (stages 1 and 2) contains 17.5 to 48% (db) resistant starch in the pulp and 8.2 to 8.6% (db) resistant starch in the peel.

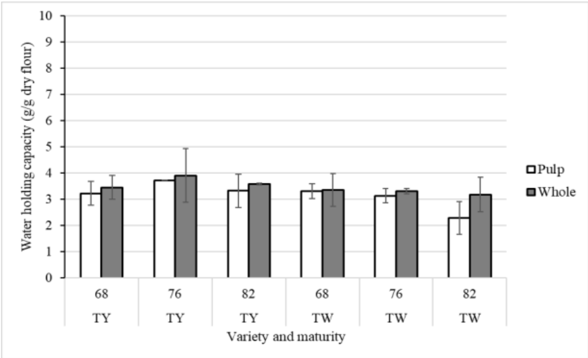
Non-resistant starch (NRS) is the starch that is hydrolyzable by enzymes and gives off saccharides in the digestive tract. A trend of decreasing NRS with increasing maturity could be observed in Table 1. However, the change of NRS with different maturity levels, varieties, and processing methods, with or without peel, was not significantly different (P≥0.05).

TY banana pulp flour contains 69.6±16.6%(db) total starch when processed from 68-day-old bananas. The total starch of TY banana pulp flour reduced to 39.1±6.0%(db) when processed from 82 days old banana. A similar trend was observed for TW banana pulp flour; at 68 days, the pulp contained 53.8±0.3%(db) total starch, which decreased to 38.7±0.1%(db) at 82 days harvest. The total starch content of the flour from the pulp of both banana cultivars was not significantly different (P≥0.05) when processed from the banana from the same harvest period, as shown in Table 1. The total starch content of the flour from the whole banana was slightly lower than the total starch content of the pulp flour from the two banana varieties (P≥0.05). The total starch content decreased significantly with increasing maturity (P<0.05) owing to the conversion of starch to sugar (Hoffmann Sardá *et al.*, 2016a). Gao, Huang, Dong, Yang, and Yi (2016) concluded that β-amylase played a crucial role in starch degradation in Plantain and Cavendish bananas. As noted in previous studies, starch conversion results include sugars, e.g., sucrose, glucose, fructose (Cordenunsi-Lysenko *et al.*, 2019; Hoffmann Sardá *et al.*, 2016a). Pereira, Arruda, Molina, and Pastore (2018) found that fructo- and xylooligosaccharides are major oligosaccharides in banana pulp and peel. Hoffmann Sardá *et al.* (2016b) reported that a significant variation in resistant starch (4 to 62%) found in commercial unripe banana flour could be due to variations in maturity and processing method.

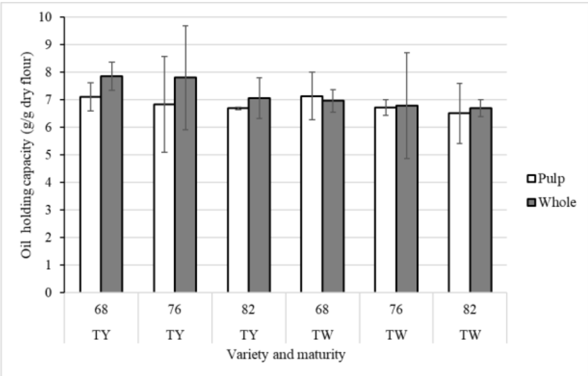
3.3.3 Water-holding capacity and oil-holding capacity

Physical properties such as water-holding capacity and oil holding capacity define the use of all starches in industry. Flours and starches with good water-holding capacity and oil holding capacity can reduce moisture and fat loss, thus improving the mouthfeel of foods.

Figures 1 (a) and (b) show the water-holding capacity (WHC) and oil-holding capacity (OHC) of unripe banana flour from TY and TW bananas, respectively. The flour samples from TY's pulp and whole banana tended to have an insignificant higher WHC (3.2 to 3.9 g/g dry flour) when compared to the WHC of the flour from TW's pulp and whole banana (2.3 to 3.4 g/g dry flour). A higher range of



(a)



(b)

Figure 1. (a) Water holding capacity (WHC) and (b) oil holding capacity (OHC) of flour from unripe whole banana and pulp of TY and TW banana. No significant difference ($P \geq 0.05$) was found regarding variety, maturity, and processing with or without peel.

OHC was observed for the flour from both banana varieties; 6.7 to 7.9 g/g dry flour and 6.5 to 7.1 g/g dry flour for TY and TW, respectively. Unripe banana flour samples, produced with banana pulp or whole banana, showed superior WHC and OHC compared to other flours. The WHC of unripe banana flour is comparable to that of sweet potatoes subjected to heating at 60°C (Kusumayanti, Handayani, & Santosa, 2015). The ability to absorb water and oil of unripe banana flour might be due to starch, which accounts for 38.7 to 69.6% db of the total weight of banana flour and non-starch dietary fibers such as fructans and cellulose. Varieties, maturity, and processing with or without peel showed no significant effect on WHC and OHC of the banana flour in this study.

3.3.4 Pasting properties

Table 2 shows the pasting properties of unripe banana flour. The pasting temperature of the samples varied in a narrow range (80 to 82 °C) and did not differ significantly ($P \geq 0.05$). Banana varieties and peel presence did not affect the flour samples' pasting temperature ($P \geq 0.05$). An increasing maturity tended to result in decreasing peak viscosity and marginally increasing breakdown and setback. However, no significant difference ($P \geq 0.05$) was observed in peak viscosity, breakdown, and setback of the flour from pulp and whole bananas of different varieties. The decrease in peak viscosity with increasing maturity possibly comes from the decrease in starch content. When raw starches are subject to heat with water, they imbibe water, swell, and become more viscous due to "gelatinization," a functional property specific to starches. As maturity increases, the total starch content decreases; thus, the peak viscosity, which was attributed from starch gelatinization, decreases.

The unripe banana flour from this study shows high pasting temperatures that were slightly lower but higher peak viscosity and lower breakdown than that of flour from cereals and pulses reported earlier (Emmambux & Taylor, 2013). Compared to flour and starches from tubers, such as potato, sweet potato, taro, and cassava, the unripe banana flour from this study has a higher pasting temperature and comparable peak viscosity and final viscosity. This information marks superior pasting properties of unripe banana flour that could be applied as a texture enhancer or stabilizer. The ability to yield high peak viscosity is directly impacted by the high water holding capacity of the flour, while the ability to withstand heat and shearing during pasting tests might come from the hydrocolloids, i.e., non-starch carbohydrates. Hydrocolloids possibly interact with leached starch molecules and strengthen the network through polymer entanglement.

Table 2. Pasting properties of flour from unripe whole banana and pulp of GM and CV banana

Variety	Day after anthesis	Raw material	Pasting temperature ^{ns} (°C)	Peak viscosity (cP)	Trough (cP)	Breakdown (cP)	Final viscosity (cP)	Setback (cP)
GM	68	Banana pulp	80±0.4	3534±4 ^{a}	3233±37 ^{a}	301±13 ^{c}	4074±24 ^{b}	841±61 ^{b}
	76		80±0.4	3445±16 ^{b}	2978±29 ^{b}	468±13 ^{b}	4159±48 ^{a}	1182±20 ^{a}
	82		82±0.2	2828±9 ^{c}	2262±16 ^{c}	566±2 ^{a}	3420±59 ^{c}	1158±43 ^{a}
	68	Whole banana	80±0.5	3662±45 ^{a}	3220±13 ^{a}	443±32 ^{a}	4493±36 ^{a}	1274±22 ^{a}
	76		82±0.5	3524±18 ^{b}	3160±11 ^{b}	365±8 ^{c}	3722±21 ^{c}	562±10 ^{b}
	82		81±0.6	3379±5 ^{c}	2997±11 ^{c}	382±6 ^{b}	4263±18 ^{b}	1266±7 ^{a}
CV	68	Banana pulp	82±0.0	3670±12 ^{a}	3001±18 ^{a}	669±30 ^{b}	4025±15 ^{a}	1024±33 ^{a}
	76		82±0.1	3602±16 ^{b}	2683±11 ^{b}	920±5 ^{a}	3653±23 ^{b}	970±13 ^{b}
	82		81±0.3	1921±16 ^{c}	1922±16 ^{c}	0±0 ^{c}	2528±15 ^{c}	606±1 ^{c}
	68	Whole banana	80±0.2	3145±22 ^{b}	2901±30 ^{a}	244±8 ^{b}	3929±15 ^{a}	904±21 ^{a}
	76		80±0.2	2250±19 ^{c}	2003±11 ^{c}	247±8 ^{b}	2707±10 ^{c}	705±1 ^{b}
	82		81±0.2	3449±24 ^{a}	2834±21 ^{b}	616±44 ^{a}	3740±26 ^{b}	906±47 ^{a}

$^{a, b, c}$ Values in the same raw material group with different superscripts are significantly different ($P<0.05$).
^{ns} Values in the column do not differ significantly ($P \geq 0.05$).

3.3.5 X-ray diffraction (XRD) pattern and scanning electron microscopy (SEM)

Figure 2 shows the X-ray diffraction pattern of banana flour samples. All samples showed significant peaks at around 3.5°, 5.6°, 15°, 17.2°, 23°, and 24°, indicating a C-type crystallographic pattern, which was consistent with earlier reports (Babalola & Odeku, 2014). The flour from the pulp of TW and TY had an estimated crystallinity of 20.5 %-21.0% and 20.5 %-23.1%, respectively. Varieties, maturity, and the presence of peel did not have a significant effect on the crystallinity (P≥0.05). The values of crystallinity found in our study are slightly lower than that reported by Bi *et al.* (2017).

SEM micrographs in Figure 3 revealed that the shape of banana starch granules is irregularly lenticular oblong with a smooth surface and around 10 to 50 µm size range. Large starch granule size could be responsible for a remarkable ability to swell and give rise to higher water holding capacity, which resulted in higher peak viscosity than the flour from cereals and pulses. The same observation for cassava and potato starch had been reported elsewhere (Bangar *et al.*, 2021). The impurities in the micrographs, the non-starch components such as proteins, cellulosic material, and pectineus substances, are seen as the dry-milling process was employed.

4. Conclusions

Processing whole banana yielded flour with comparable proximate composition, resistant starch, and functional properties with banana pulp but with a 5% to 6% higher flour yield. The flour of unripe banana, pulp or whole, is high in resistant starch. The resistant starch content decreased with increasing maturity. Varieties and maturity had no significant effect on proximate composition and functional properties of unripe banana flour. Unripe banana flour can be used in instant drinks and meals due to its excellent nutritional value and high resistant starch content. The flour also promises baking goods for its remarkable water- and oil-holding capacity and pasting properties. However, a sensorial quality test should be carried out to assess the appropriate level of whole banana flour usage in food products as the astringency from the peel could interfere with the consumer's acceptance.

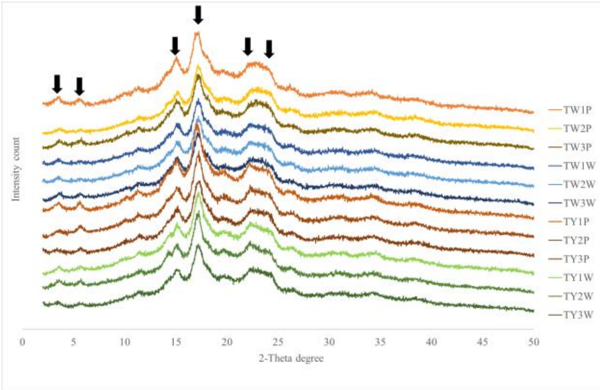


Figure 2. X-ray crystallographic pattern of banana flour samples

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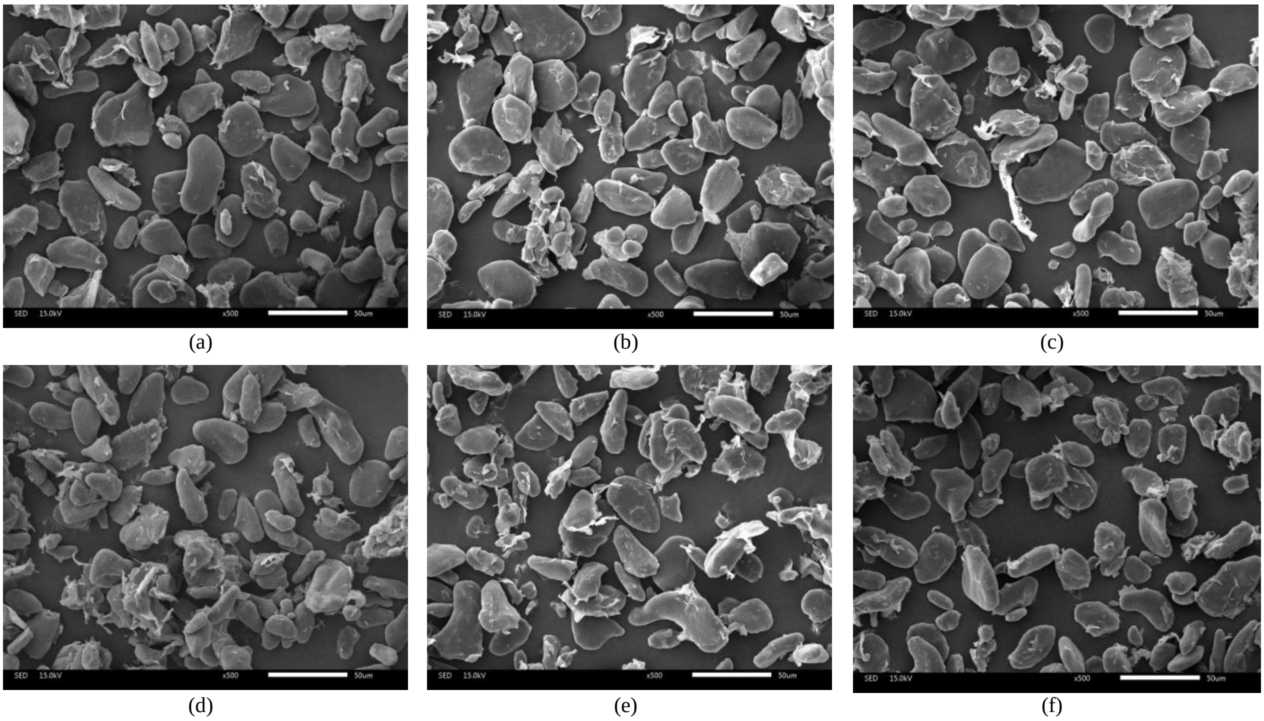

Figure 3. TW pulp flour from (A) 68, (B) 76, and (C) 82 days harvest and TY pulp flour from (D) 68, (E) 76, and (F) 82 days harvest

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