RESEARCH ARTICLE

Plantain-starch: Microstructural, physicochemical, and morphological characteristics of two cultivars grown in Malaysia

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Starches isolated from mature green "Nangka" and "Tanduk" plantain (*Musa paradisiaca* L) cultivars grown in Malaysia were appraised for their morphological, physicochemical, and structural properties. The amylose contents of "Nangka" and "Tanduk" starches were 31.79 and 26.08% and the degree of relative crystallinity were 62.1 and 52.1%, respectively. Both cultivar starches presented an A-type diffraction pattern, which has rarely been reported for banana starches. Gelatinization temperatures evaluated by differential scanning calorimeter were higher for "Tanduk" starch than "Nangka" starch. The scanning electron micrograph of "Nangka" starch granules was larger than "Tanduk" starch with an average particle size of 38.77 and 23.91 μm, respectively. In addition, "Nangka" starch produced lower molar mass (M_w) and gyration radius (R_G) compared to "Tanduk" starch.

Keywords:
A-type diffraction pattern / Morphological / Physicochemical / Plantain-starch

1 Introduction

Starch, the primary component in several foods (cereals, tubers, legumes, and green fruits) represents between 70 and 80% of the calories consumed worldwide by humans [1]. This biopolymer is made up of two major glucose polymers; amylopectin and amylose in which their proportion and granular structures are responsible for the starch numerous functionalities. Starch serves as a multifunctional ingredient for the food or non-food industries [2]. In addition, it is an outstanding raw material for modifying food consistency and texture. The amount and type of starch (i.e., biological source) plays crucial role in the texture of any given carbohydrate food product [3].

Banana is the second most widely cultivated fruit in Malaysia with a total production of 530 000 metric tonnes (MT) per year covering about 26 000 ha [4, 5]. Plantain cultivars are triploid (i.e., they have three sets of chromosomes). Many are hybrids derived from the cross of two wild species, *Musa acuminate* and *Musa balbisiana*. However, the acceptable scientific name for all such crosses is *Musa x paradisiaca*. For every ton of banana harvested, 100 kg of fruits are rejected and about 4 t of wastes are generated [6]. It means that for every cycle of production, significant amount of wastes are generated. The processing of excess fruits into starch can minimize these wastages or losses.

Presently there are great varieties of native starches available in the market; however, increasing demand for specific starch properties necessitates new strategies or alternative novel sources [7]. Starch sources with desirable physicochemical properties are being explored by scientists with the aim of avoiding chemical modifications [8]. Thus, characterizing different starches could be a better method of selecting a particular starch for specific product end use. The unripe bananas contain large amount of starch of about 70–80% on dry weight basis, therefore, processing it into starch could be a promising resource for food and other industries [9, 10].

Cultivar differences in starches will affect various physicochemical properties of the starch as well as its aptness for

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Abbreviations: Sp, swelling power; T_c, end set/conclusion temperature; T_o, onset temperature; T_p, peak temperature; W_r, weight of wet residue; W_s, weight of dried supernatant; **XRD,** X-ray diffraction

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specific end use. Therefore, the objective of this study was to investigate the physicochemical properties of starches from "Nangka" and "Tanduk" plantains grown in Malaysia.

2 Materials and methods

2.1 Materials

Fresh mature unripe (green) "Tanduk" and "Nangka" plantain cultivars grown in Malaysia were used in this study. The bananas were obtained from a local supplier in Serdang, Selangor, Malaysia.

2.2 Plantain starch isolation

The starch isolation was done following the procedure of Millan-Testa et al. [11] with slight modification. The plantain fingers (1 kg) were washed twice, peeled and sliced into cubes (25–36 cm^3). The cubes were instantly rinsed in sodium metabisulfite solution (1.22 g/L), and then macerated (1 kg fruit cubes: 500 mL sodium metabisulfite solution) at a low speed in a Panasonic MX–900M laboratory blender for 3 min. Thereafter, the homogenate was sieved and washed through screens (40, 100, and 140 US mesh) until the wash distilled water was free from suspended solids and solutes and centrifuged at 11 000×*g* for 40 min. The white starch sediments contained a brown mucous layer at the top, which was removed with a spatula and the remaining white sediment layer was dried in oven at 40°C for 48 h. The solids were ground with a mortar and pestle to pass through a sieve (US 140 mesh). The starch was placed in a sealed plastic container and stored at room temperature (30 ± 2°C) until further analysis.

2.3 Composition

The moisture and protein contents (N*6.25) were analyzed by the micro-kjeldahl method. Lipids and ash contents were determined following the procedure of AOAC [12]. The apparent amylose contents were determined by iodine colorimeter at a wavelength of 620 nm using potato starch standard mixture [13]. The results were presented on a dry matter basis.

2.4 Color analysis

The color of plantain starch samples was measured using a HunterLab ColorFlex. The instrument was calibrated against a black and white tile. A uniformly sized starch sample was placed in a glass cell which was placed against a light source, covered with a black cover and L^* (lightness), b^* (yellow–blue), and a^* (red–green) values were recorded.

2.5 Solubility and swelling power

Solubility (S) and swelling power (SP) of the plantain starch were determined following the method of Adebooye and Singh [14]. Briefly, 0.5 g (dry basis) of starch sample was cooked in 20 mL of distilled water at temperatures of 55–95°C at an interval of 10°C for 25 min. Then, the samples were cooled to room temperature and centrifuged at 2500×*g* for 20 min. Thereafter, the supernatant was carefully decanted from the test tube to a pre-weighed evaporating porcelain dish and dried at 105°C in an oven to a constant weight. The residue obtained after pouring out the supernatant was weighed for the determination of SP. S and SP were calculated with the following formulas:

$$\mathrm{SP}\ (\mathrm{g/g}) = \frac{W_\mathrm{r}}{W - W_\mathrm{s}}$$

$$\mathrm{S}\ (\%) = \frac{W_\mathrm{s}}{W} \times 100$$

where, W is the weight of sample, W_r is the weight of wet residue, and W_s is the weight of dried supernatant.

2.6 Degree of enzymatic hydrolysis

Plantain starch (100 mg) was mixed well with 10 mL of distilled water and 2 mL of α-amylase (Sigma–Aldrich, St. Louis, MO) solution. The tube was incubated for 0, 3, 6, 12, 24, and 48 h at 37°C at every time interval, 1 mL of aliquot was taken and added to 2 mL of ethanol and it was filled up with distilled water to 10 mL mark. The mixture was centrifuged at 2500×*g* for 10 min. An aliquot of the supernatant was analyzed for soluble carbohydrate according to the phenol-sulfuric acid colorimetric method of Dubois et al. [15]. The degree of hydrolysis was expressed as the amount of maltose released per 100 mg of dry starch.

2.7 Differential thermal analysis (DTA)

The gelatinization properties of plantain starches were examined on a Mettler Toledo differential scanning calorimeter (DSC 823^e, Mettler Toledo, Switzerland) equipped with a thermal analysis data station (STARe Software, version 9.0×, Schwerzenbach, Switzerland). Nitrogen (99.99% purity) was used as the purge gas at the rate of 50 mL/min. About 8 mg of starch sample was weighed into a 40 μL capacity aluminum pan (ME-27331) and was hermetically sealed prior to heating in the DSC. An empty aluminum pan, which was also hermetically sealed, was used as reference for all DSC runs. The DSC analyzer was calibrated using indium. Sample and reference pans were heated at a rate of 10°C/ min from 27 to 180°C. The onset (T_o), peak (T_p), and end set/conclusion (T_c) temperature of

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gelatinization were automatically calculated from the thermograms of the samples. All measurements were done in duplicate for each starch sample and the results were recorded as mean values.

2.8 Size-exclusion chromatography combined with multiangle laser light scattering (SEC-MALLS)

The SEC-MALLS procedure was carried out by first solubilizing starch samples in dimethyl sulfoxide (DMSO) and later in water using a microwave oven for different time.

2.8.1 Dimethylsulfoxide treatment

Starch (1 g) was initially dissolved in 95% DMSO (20 mL) with magnetic stirring for 3 days at 30 ± 2°C. The mixture was precipitated with ethanol (60 mL) and stored overnight at 4°C. The precipitate was filtered over a glass filter (G4) and washed successively with acetone (10 mL) and diethyl ether (10 mL). The precipitate was air dried under a hood for a few hours to remove the solvents and it was finally dried in vacuo at 45°C and 50 KPa for 19 h [16].

2.8.2 Solubilization in water

The solubilization was done by adding filtered water (20 mL) to a dried dispersed starch sample (10 mg), weighed into a 45 mL Teflon cup (model 4782, polycarbonate microwave bomb, Parr Instrument Co., Moline, IL, USA). The sample was allowed to stand under nitrogen flow for 15 min. The capped Teflon cup was fitted into the bomb. The Teflon cup was placed in the microwave oven and heated for 40, 50, 60, or 70 s at 900 W. Cooling was done by immersing cup in an ice bath for 30 min. The sample was centrifuged at 31 200×*g* for 20 min at 15°C. The supernatant was filtered through a 5-μm filter paper (Millipore, Bedford, MA, USA) and dilution series were made at room temperature yielding five concentrations. These were injected into the DAWN detector (MALLS, Dawn DSP-F, Wyatt Technology Corporation, Santa Barbara, CA, USA) using the micro-batch mode. The carbohydrate concentration of the supernatant after filtration was measured by the sulfuric acid-orcinol colorimetric method [16]. The weight average molecular weight (M_w; g/mol) and z-average gyration radius (R_G; nm) were determined with the second-order Berry plot using the ASTRA software for Windows, version 4.90.07 [17].

2.9 X-ray powder diffraction analysis (XRD)

The crystalline structure of the plantain starch samples was determined using an X-ray diffractometer (Rigaku Co., Ltd., Rint-2000 type, Tokyo, Japan) at voltage of 30 kV and current of 30 mA, using Cu as target. The starch samples were stored in a sealed container for 3 weeks at a relative humidity of 85% in order to achieve constant moisture content. The powdered starch was packed tightly into the aluminum sample holder, and XRD data were collected at room temperature. The diffraction patterns were measured at a diffraction angle of 2θ over an angular range from 2° to 60°, a scanning speed of 2°/min and sampling pitch of 0.02°. The degree of percentage relative crystallinity was estimated according to the procedure of Nara and Komiya [18] using a software package (Origin 6.0 Microcal Inc., Northampton, MA, USA). The area above the smooth curve was considered as the crystalline portion and the lower area between the linear baseline and the smooth curve as the amorphous portion. The ratio of the crystalline peak area to the total diffraction area (crystalline and amorphous peak areas) on the diffractogram was calculated as percentage crystallinity.

2.10 Preparation of plantain starch pastes

Starch suspensions were prepared with distilled water at 8% w/v concentration. The suspensions were heated at 95°C in a thermostatic water bath for 30 min. The starch suspensions were stirred within the first minute of immersion during which pasting took place. The stirring was stopped and the sample was left for 30 min. Thereafter, the paste was removed and kept at 25°C.

2.11 Textural properties of plantain starch gels

The starch pastes that were maintained at 25°C in a capped test-tube were stored at 4°C for 24 h so as to bring about gelation. The gels formed were removed from the tube, and transferred into aluminum canisters, and were evaluated for their textural properties by means of a texture profile analyzer (TA/XT2i Texture Analyzer, Stable Micro Systems, Surrey, UK) using a 25-kg load cell and the application program provided with the apparatus. Each canister was placed upright on the metal plate and the gel was compressed with a cylindrical plunger of diameter 5 mm. The following experimental conditions were chosen for all TPA tests: pretest speed 5.0 mm/s, test speed 1.0 mm/s, and post-test speed 8.0 mm/s; penetration distance 5 mm and a rest period of 5 s between two cycles. The compression was repeated twice to generate a force–time curve from which hardness, cohesiveness, adhesiveness, gumminess, springiness, and chewiness were determined.

2.12 Polarized light microscopy

Birefringence of starch granules of the sample was observed under polarized light. The granules of banana starch were mounted on a microscope slide covered with a cover-slip,

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then photographed using a camera attached to an optical microscope (NIKON ECLIPSE 80T BINOCULAR) at 40× magnification. The starch granules were randomly selected under the polarized lights.

2.13 Scanning electron microscopy (SEM)

The morphology of the plantain banana starch granules were obtained by means of a scanning electron microscope (JSM–6400, SEM, JEOL Ltd., Tokyo, Japan). The starch sample was spread out thinly on an adhesive tape attached to a circular aluminum specimen stub, coated vertically with gold palladium and then mounted on a carbon sample holder. The starch samples were photomicrographed at an accelerator potential of 10 kV with magnification of 500× and 1000×, respectively.

2.14 Particle size distribution of plantain starch granules

The particle size distribution of the native plantain starches was determined by means of a laser diffraction using a Mastersizer 2000 (Malvern Instruments Ltd., Malvern, Worcestershire, UK), with the help of a Scirocco dry disperser unit used for dispersing the powders at a feed pressure of two bars and a feed rate of 40%. The obscuration was in the interval of 0.5–5%. The Fraunhofer approximation was used for estimating size distribution of the starch granules.

3 Results and discussion

3.1 Chemical composition of starches

The chemical composition, apparent amylose (AAM) contents, and color parameters of starches obtained from "Nangka" and "Tanduk" plantain cultivars are shown in Table 1. The moisture content for both plantain starches was low. However, the obtained values were within a tolerable range for a stable storage and marketable shelf life. The protein content of "Tanduk" cultivar (2.301%) was higher than that of "Nangka" cultivar (0.844%). The high protein value for "Tanduk" cultivar was similar to that reported for Macho banana starch [2]. However, other authors have reported lower protein contents for different varieties of banana starches [19–21]. The ash and fat contents in both "Tanduk" and "Nangka" starches were low and comparable with those reported by Nwokocha and Williams [20]. The ash content of "Tanduk" and "Nangka" starches was 0.659 and 0.528%, respectively, and the corresponding fat content was 0.4478 and 0.382%. The low fat, protein, and ash contents showed that the plantain starches were exceptionally pure.

Table 1. Chemical composition (% db.), amylose content (%), color parameters (L^*, a^*, b^*), gelatinization properties, and relative crystallinity (%) of starches from Tanduk and Nangka plantain cultivars grown in Malaysia ($n = 3$)

Chemical composition	Tanduk	Nangka
Moisture	8.829 ± 0.30	9.837 ± 0.85
Protein	2.306 ± 0.02	0.844 ± 0.28
Ash	0.659 ± 0.09	0.528 ± 0.06
Fat	0.448 ± 0.04	0.382 ± 0.06
Amylose	26.084 ± 0.34	31.789 ± 0.63
Color parameters		
L^*	81.870 ± 1.08	75.390 ± 0.03
a^*	3.060 ± 0.16	4.785 ± 0.12
b^*	13.550 ± 0.29	11.740 ± 0.31
Gelatinization properties		
T_o (°C)	63.13 ± 0.68	65.19 ± 0.72
T_p (oC)	83.83 ± 0.53	84.25 ± 0.99
T_e (°C)	122.67 ± 0.92	123.80 ± 0.46
Relative crystallinity	52.1 ± 0.88	61.1 ± 0.28
Textural properties		
Hardness	85.53 ± 1.27	63.81 ± 1.21
Cohesiveness	0.44 ± 0.09	0.35 ± 0.02
Gumminess	37.38 ± 0.13	22.36 ± 0.02
Springiness	0.99 ± 0.02	0.97 ± 0.03
Chewiness	36.91 ± 0.12	22.14 ± 0.12

Values expressed as mean ± standard deviation.

The "Nangka" plantain starch was considerably higher in amylose (31.789%) than "Tanduk" (26.084%). The amylose contents of these two cultivars were higher than the values reported by Nwokocha and Williams [20] and Eggleston et al. [22], respectively, for some plantain cultivars. Similarly, it was higher than the 22.2% recorded for square bananas [20] and the 19.5% for Cavendish banana [23] but lower than the 35% reported for "Terra" plantain variety [19] and the 40% for banana starches [24]. Starches with high amylose content are suitable for use as raw material in edible packaging. The variation in amylose content could possibly influence the physicochemical and morphological properties of the starches. Starches with higher amylose content are known for producing more opaque and firmer gels, thereby making them a potential raw material in meat emulsions and sausages [25, 26]. The difference in the amylose content of the plantain starches could be due to differences in agronomic and climatic conditions, as well as varietal differences.

Color is an essential property for assessing the quality of starch. The color parameters of the plantain starches are shown in Table 1. It was observed that the lightness (L^*) value of "Tanduk" cultivar starch (91.87) was higher than that of "Nangka" starch (90.39). According to Boudries et al. [27], an L^* value greater than 90 indicates a satisfactory whiteness for purity of starch. The redness (a^*) value for "Tanduk" and "Nangka" starches was 3.06 and 4.79,

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respectively, with the "Tanduk" starch possessing a higher degree of yellowness (5.55) compared to "Nangka" starch (2.74). The higher lightness values combined with low redness and yellowness of both starches evinced that they could be used conveniently in products requiring uniform and clear color.

3.2 Differential scanning calorimetry

The gelatinization properties of "Tanduk" and "Nangka" plantain starches subjected to a heating ramp by means of a differential scanning calorimeter are presented in Table 1. The gelatinization temperatures (T_o, T_p, and T_e) obtained for "Tanduk" starch (65.19, 84.25, 123.80°C) were higher compared to that of "Nangka" starch (63.13, 83.83, 122.67°C). These values were higher than those reported for white and yellow plantains varieties by Nwokocha and Williams [20] and for criollo and macho banana starches [28]. The factors influencing the thermal properties of starch granules included shape or size of starch granule, crystalline regions of different size and/or stability and chain length of amylopectin [7, 25]. "Nangka" cultivar starch being larger in size than "Tanduk" cultivar starch swelled more and therefore had lower gelatinization temperature. In addition, the variation in the gelatinization temperatures of these two starches could be due to the differences in amylose content and degree of crystallinity in both starches.

3.3 The effect of different solubilization times on the macromolecular characteristics of starches

The effect of different solubilization times on the macromolecular characteristics of plantain starches are shown in Table 2. Results have shown that heating time in the microwave and molar mass (M_w) exhibited an indirect proportionality. Similarly, increase in the heating time also decreased gyration radius (R_G). The observed behavior has been attributed to possible polymer degradation due to temperature [16]. In a previous study, Millan-Testa et al. [11] reported a similar observation for banana starch, with M_w values for banana ranging between 6.7×10^{-6} g/mol for 40 s of heating and 0.2×10^{-6} g/mol at 70 s of heating and R_G ranging from 106 nm at 40 s to 73 nm for 70 s heating time. In the current study, plantain starch ("Nangka") with the higher amylose content produced lower M_w and R_G, respectively. The fractal dimension d'_f which showed a dependence on the treatment time was not significantly ($p > 0.05$) different between the plantain starches.

3.4 Textural properties of starch gels

The textural properties such as cohesiveness, hardness, springiness, gumminess, adhesiveness, and chewiness of plantain starch gels were assessed on a texture profile analyzer and presented in Table 1. Gel textural parameters for "Tanduk" starch were lower than those recorded for "Nangka" starch. This could be attributed to its lower amylose content as reported earlier. The major factors contributing to gel strength were the degree of amylose gel network and the deformability of swollen granules [29].

3.5 Solubility and swelling power

The S and SP patterns of starch give insights to the nature of associative bonding within the starch granule [30]. Native starch granules are not soluble in cold water, but when heated in the presence of excess water, the starch granules swell as they absorb water [31]. The starch granules are composed of amylopectin and amylose as the main components and the proportion of these fractions in the starch granule as well as their mode of arrangement inside the granule affected the solubility and swelling power [30]. The S and SP of starches from different origins increased with increasing temperature. The solubility and swelling power were studied over the temperature range of 55–95°C. The results are shown in Fig. 1a and b, respectively. In Fig. 1a, relaxation of intra-granular bonds occurred faster in Nangka starch as shown by its higher rise in swelling with simultaneous increase in temperature compared to that of Tanduk starch. In addition, the SP patterns of both plantain starches showed that their granules did not swell appreciably at temperatures below 65°C. However, at temperatures above 65°C, they swelled rapidly due to the disruption of

Table 2. Macromolecular characteristics of starches isolated from plantain cultivars ("Nangka" and "Tanduk")

	Nangka				Tanduk			
Heating time (s)	40	50	60	70	40	50	60	70
M_w ($\times 10^{-6}$ g/mol)	6.2	3.1	1.4	0.2	7.4	3.6	1.6	0.3
R_G (nm)	104	90	75	74	107	94	76	73
d'_f	1.25	1.21	1.18	1.14	1.29	1.24	1.21	1.19

M_w, molar mass; R_G, gyration radius; d'_f, fractal dimension.

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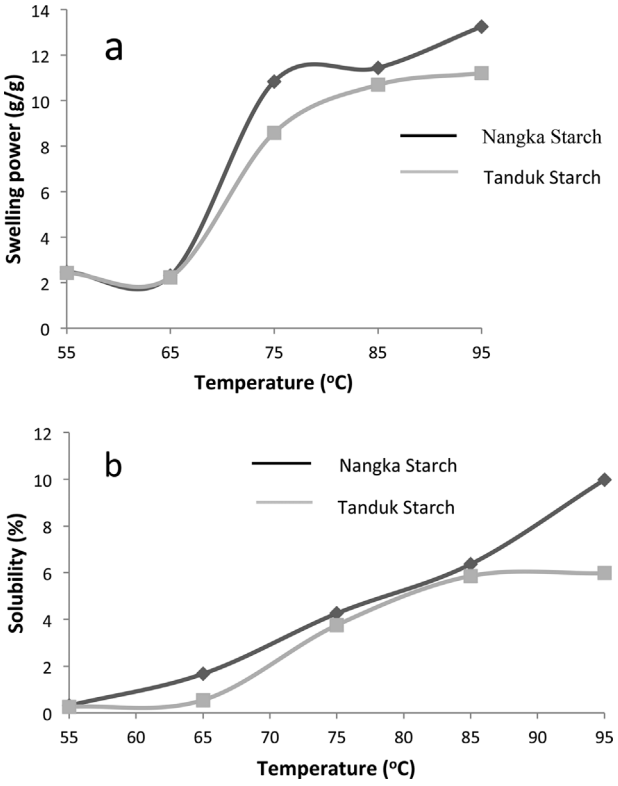


Figure 1. Effect of temperature changes on: (a) swelling power and (b) solubility of plantain starches.

intermolecular hydrogen bonds in amorphous areas which allowed progressive and irreversible water absorption as earlier reported for "macho" banana starch [2]. The increases in the swelling power of "Nangka" and "Tanduk" starches were from 2.30–13.25 and 2.23–11.21 g/g, respectively. Similarly, "Nangka" starch exhibited slightly higher solubilization than Tanduk starch at all investigated temperatures. The solubilization increased from 0.31 to 9.98% for "Nangka" starch and from 0.25 to 5.98 for "Tanduk" starch (Fig. 1b). The high swelling power and solubility exhibited by "Nangka" starch were the results of higher amylose content, higher crystallinity, and larger granular size it possessed as compared with "Tanduk" starch. Contrarily, the solubility of starch granules was chiefly influenced by the amylose (AM) content while swelling power was influenced by amylopectin (AP) content [32].

3.6 Degree of enzymatic hydrolysis

Plantain starches exhibited impressive resistance to digestion of α-amylase as compared to cassava starch (Fig. 2). The first 6 h of treatment showed a rapid increase in cassava starch hydrolysis, whereas, that of the plantain starches showed marginal increases of between 10 and 10.5%, respectively. During 48 h of in vitro hydrolysis, the degree of hydrolysis was 13% for "Nangka" starch and 14% for

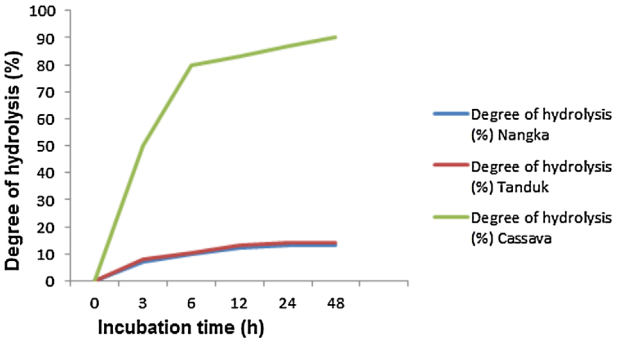


Figure 2. Degree of enzymatic hydrolysis of plantain starches ("Nagka" and "Tanduk").

"Tanduk," which were significantly lower than cassava starch hydrolysis (90%). The results have shown that the two plantain cultivars have similar ability to resist α-amylase hydrolysis. The degree of hydrolysis is often affected by granule size, amylose: amylopectin ratio, length of amylose chain, presence of amylose–lipid complexes, and degree of starch crystallinity and surface structure of starch granules [33].

3.7 X-ray diffraction (XRD)

The XRD patterns or polymorphs of the "Nangka" and "Tanduk" plantain starches are shown in Fig. 3. The dotted vertical lines were used for highlighting the three prominent intensity peaks at diffraction angles of about 15.0°, 17.5°, and 23.0°, which is indicative of A-type diffraction pattern that were typically found in cereal starches. According to Zhang et al. [9], the starches of cereals gave an A-type polymorph, tubers, retrograded starches, and amylo-maize produced a B-type pattern while certain roots and legumes exhibit a C-type pattern. Most studies have reported a B-type pattern for banana starches [34–37]. A C-type polymorph (a pattern that is a mixture of A-type and B-type patterns) has also been

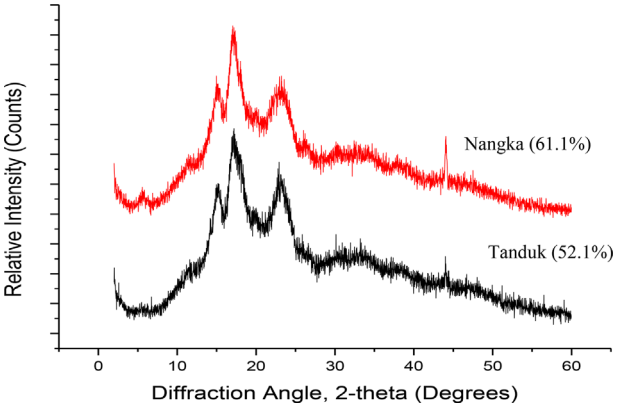


Figure 3. X-ray powder diffraction pattern of Tanduk and Nangka plantain starches with their relative crystallinity.

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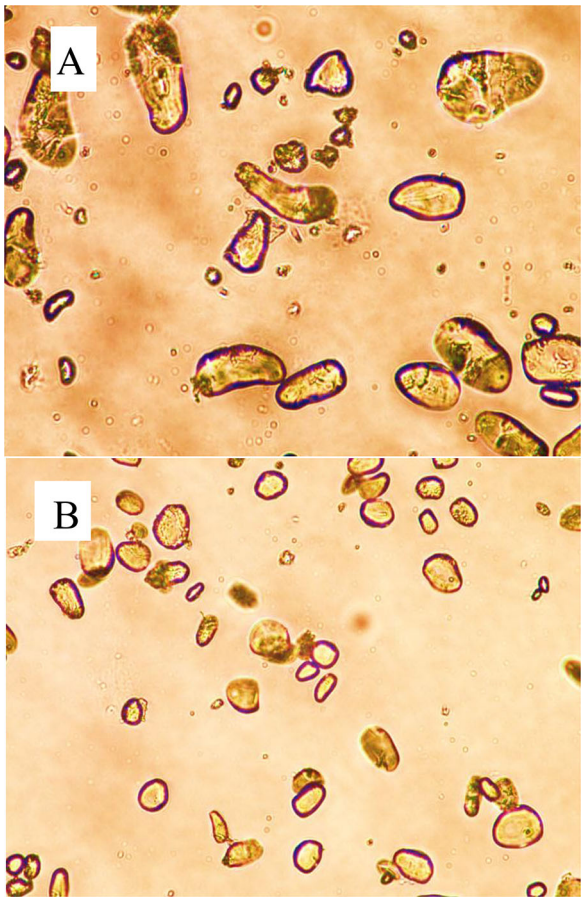


Figure 4. Polarized light micrographs of plantain starches at magnification of 40×: (A) "Nangka," (B) "Tanduk."

assigned to banana starches [34, 38–43, 46–49]. However, report of this type of diffraction pattern (A-type) found in the current study is very rare. Starches exhibiting an A-type pattern are said to be more stable and having an arrangement of helices in the unit cells with monoclinic symmetry. In addition, an A-type pattern was attributed to starches having amylopectin with a high proportion of short chains [32]. Therefore, enzymatic and digestibility studies are necessary with these types of banana starches for better clarification. The relative crystallinity of the "Nangka" starch (61.1%) was higher compared to that of "Tanduk" starch (52.1%) as presented in Table 1. The difference in crystallinity between the banana starches could be due to the differences in the proportion of long and short side-chain amylopectin and amylose.

3.8 Optical microscopy

The images obtained in the polarized light microscopy are shown in Fig. 4. Birefringence was observed under the polarized light for the starch granules of the two banana cultivars. Intact granules did not break during the starch isolation process and retain their birefringence (Maltese cross). This implies that the employed isolation method yielded starch granules with no internal breakdown.

3.9 Scanning electron microscopy

The morphological assessments revealed that the starch granules of both "Nangka" and "Tanduk" cultivars had compact granules, irregular shapes, varying from elliptical to round and to oval (Fig. 5). However, it was evident from the

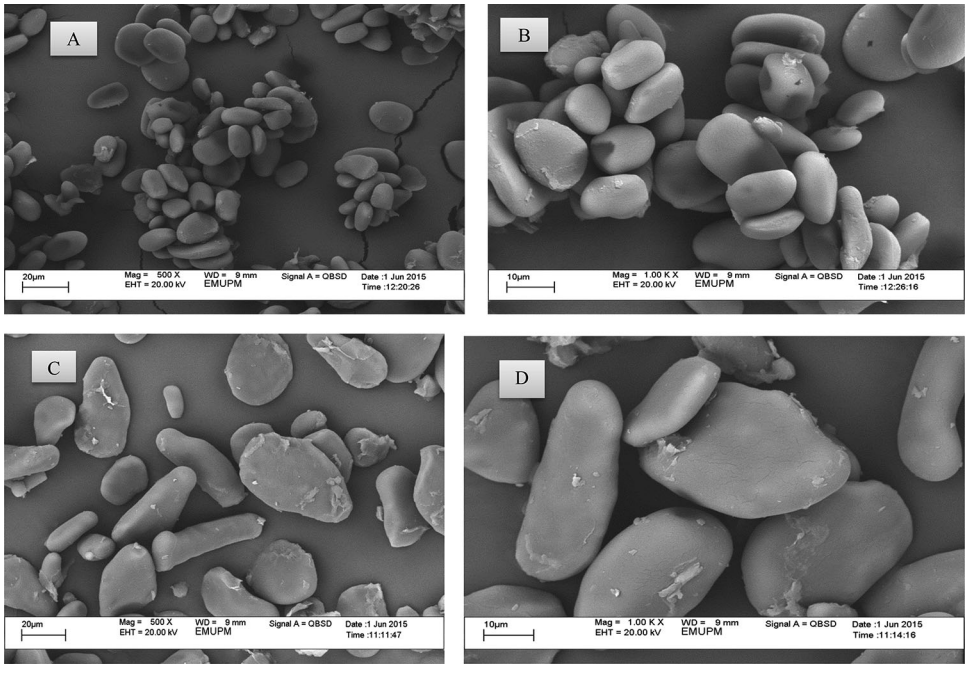


Figure 5. SEM of plantain starch granules: (A and B) "Tanduk" starch at 500× and 1000×, (C and D) "Nangka" starch at 500× and 1000×.

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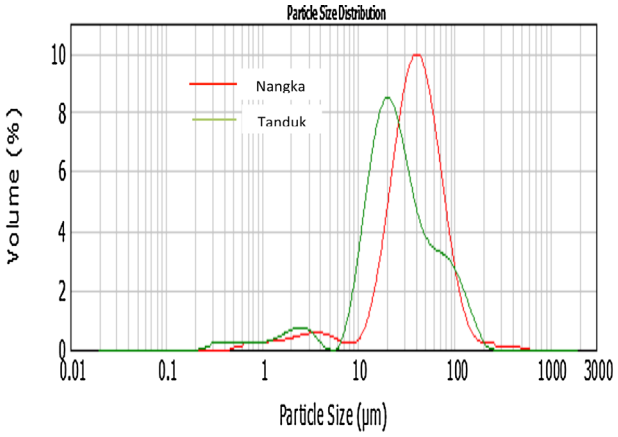


Figure 6. Particle size distribution of Tanduk and Nangka plantain cultivars starches.

micrographs that the "Nangka" cultivar starch presented a larger granule size than that of "Tanduk" cultivar with both having similar shapes. This result corroborated the particle size distribution results in Fig. 6 in which the "Nangka" starch presented a higher average particle size compared to that of "Tanduk" starch. These variations in size of starch granules of both cultivars could influence other functional properties such as gelatinization temperature, viscosity, or swelling power. The surfaces of the starch granules appeared smooth with no apparent damage. This could be an indication that the isolation process was efficient.

3.10 Particle size distribution of starch

The granule size distribution of starches from "Tanduk" and "Nangka" plantain are shown in Fig. 6. The "Tanduk" starch granules exhibited a bimodal size distribution with an average size of 23.91 μm while the "Nangka" starch granule showed a unimodal distribution with an average size of 38.97 μm, larger than that of the "Tanduk" starch. Both banana starches presented a granule size within the range reported by Eggleston et al. [22] and Coulibaly et al. [44] for various bananas, plantain hybrids, and cultivars. The variation in shape and size distribution of starch granule was related to functional properties in different food system [45].

4 Concluding remarks

The morphological and physicochemical properties of starches from "Nangka" and "Tanduk" plantains were compared. The starches differed with respect to the amylose content, the degree of crystallinity, the morphology, and the size of the granule. These differences influenced the swelling power and solubility, gelatinization properties, and textural properties of the starches. The X-ray diffraction patterns of both starches showed an A-type pattern which is rarely reported for banana starches. Swelling power, solubility, and textural properties of "Nangka" starch was higher than that of "Tanduk" and were related to amylose content. In addition, "Nangka" starch produced lower molar mass (M_w) and gyration radius (R_G) compared to "Tanduk" starch. The results indicated that the differences in physicochemical properties of the starches could possibly be due to the variation in granular shape and size, the ratio of amylopectin to amylose and the degree of crystallinity of the cultivars.

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