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Studies on some physico-chemical and engineering properties of *Musa* spp (ABB) starch flour

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This study investigated some physicochemical and engineering properties of *Musa* spp (ABB) starch flour using standard procedures with a view to providing data that will aid in process design, control and bulk handling of *Musa* spp (ABB) starch flour. Loose and packed bulk densities, the least gelation concentration, density ratio and porosity ranged between 0.47 to 0.70 g/mL, 0.60 to 0.95 g/mL, 8 to 16% (w/v), 74.25 to 77.26%, and 22.73 to 25.74% respectively. Similarly, the Carr index had a range of 29.11 to 35.78% and Hausner ratio ranged from 1.29 to 1.36. The amylose-amylopectin ratio content obtained range from 0.45 to 0.50. Also, the thermal properties of the samples measured using differential scanning calorimeter ranged between 79.3 and 92.8°C, 106.4 and 121.2°C, 106.2 and 122.8°C, 56.75 and 278.6 J/g, 21.4 and 94.743.5°C, 10.95 and 20.28 J/(gK), 0.50 and 0.705 W/m°C, and 0.090 and 0.094 m²/s for onset temperature, peak temperature, end temperature, enthalpy, temperature range, specific heat capacity, thermal conductivity and thermal diffusivity, respectively. This study therefore provides engineering data in relation to process design, control and bulk handling with a view to extending the usage of *Musa* spp (ABB) starch samples in food process industries.

Key words: *Musa* spp (ABB), Starch, physico-chemical and engineering properties, bulk handling.

INTRODUCTION

Musa spp (ABB) also known as bluggo (common name) is a perennial crop that grows quickly and bears fruit all year round in the tropics and sub-tropics of Asia, America, Africa and Australia where favourable conditions for its growth are met. Its harvest falls in the dry season when most other starchy staple foods are in short supply. It is grown in about 130 countries with an annual output of 106 mt annually (FAO, 2005; Idoko and Nwajiaku, 2013). In most regions of the world, the fruits

are largely cultivated on small plots, garden and orchards where statistics is poorly documented (Uma, 2006). In many tropical countries, the bulk of the fruits produced are consumed and traded locally, thereby playing a crucial role in food security (Daniells et al., 2001). In Nigeria, its cultivations are concentrated in the Southern part of the country with approximately 60% postharvest loss due to lack of appropriate technologies for handling, storage and processing (FAO, 2005). It is widely

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consumed by millions of people in the tropics to serve as a good source of carbohydrate and vitamins which competes favourably with that of sweet potato, cassava and potato (Daramola and Osanyinlusi, 2006; Adeniji et al., 2007; Adeniji and Tenkouano, 2008). It is also a good source of mineral especially iron, calcium and potassium which meets daily diet recommendation (Aurand, 1987; USDA, 2009; Yarkwan and Uvir, 2015); and also serves as a commercial source of starch for food, textiles, cosmetic, paper, pharmaceutical and beverages industries.

The diverse industrial usage of starch is premised on its availability at low cost, high caloric value, inherent excellent physicochemical properties and ease of its modification to other derivatives (Omojola et al., 2010). There are a number of chemical modifications made to starch to produce many different functional characteristics. Starches are modified to change the properties of unmodified starch, and chemical modification on starches has markedly altered physicochemical properties compared with their parent starches (Rusli et al., 2004).

It has been shown that when native starch is modified, it generally shows better paste clarity, better stability, increased resistance to retrogradation and increased freeze-thaw stability (Zheng et al., 1999). Starch citrate has also been reported as a resistant starch in food industry (Xie and Liu, 2004).

Recent advances in computer software and micro-electronics are now applied to bulk handling of particulate, powdered and liquid foods using PLC based logic controllers to avoid risk of contamination and other benefits associated with the advances. Therefore, information needed by the PLC based logic controllers are obtained from sensors which detect, measure and interpret engineering properties related to bulk handling of foods. Therefore, studying of physico-chemical and engineering properties of *Musa* spp (ABB) starch flour will provide data to aid in process design, control and bulk handling with a view to extending the usage of *Musa* spp (ABB) starch flour in food process industries.

MATERIALS AND METHODS

Sources

Freshly harvested matured bunches of *Musa* spp (ABB) also known as bluggoe banana (Plate 1) at stage one maturity using colour as basis of classification (Ahenkora et al., 1997; Dadzie and Orchard, 1997) were obtained from Obafemi Awolowo University Teaching and Research Farm, Ile-Ife. Commercial potato starch flour was purchased from Niji Foods Farms and all chemicals used were of analytical grades.

Samples preparation

About 4 kg of freshly harvested debunched *Musa* spp, (ABB) fruits were sorted and extraneous materials removed. The cleaned fruits

were debarked using a stainless steel kitchen knife and the pulp diced while immersed in an aqueous solution of sodium metabisulphite (1.25 g/L) to prevent enzymatic browning reaction (Gbadamosi and Oladeji, 2013). The pulp was drained and rinsed with portable water. The pulp was then macerated at low speed using a Stephan universal machine (Western Germany, Model No-P33/E) for 5 min. The homogenate slurry obtained was sieved using an electrical SWECO separator (Belgium, Model No- S18). The filtrate was subsequently left to settle for 3 h in a stainless decanting bowl, after which the supernatant was discarded. The starch slurry was then oven dried using a hot air oven (Uniscop, SM9053, England) at 50°C for 24 h. The starch flakes were milled using laboratory milling machine (sieve size 500 µm aperture) to get native starch flour (Figure 1). The native starch yield was expressed in percentage dry weight of native starch per weight sample used. The native starch obtained was divided into two portions: the first lot was stored in a labelled Ziploc bag and kept in an air tight jar till the time of usage while the second lot was modified according to the method documented by Atichokudomchai and Varavinit (2003).

Starch modification using acid

The starch modification of the native starch sample was done using method documented by Atichokudomchai and Varavinit (2003). Acid hydrolysis of the native starch was carried out by suspending 200 g (dry basis) of native starch in 400 mL of 6% (w/v) HCl solution at 27 ± 2°C for 1 h without stirring. After hydrolysis, the suspension was neutralized with 10% (w/v) sodium hydroxide solution to terminate the reaction. The slurry was washed three times with distilled water, dried in a hot air oven at 45°C for 24 h and then milled using laboratory milling machine (sieve size 500 µm aperture) to get acid modified starch flour. The acid modified starch was kept in a labelled Ziploc bags and kept in an air tight jar till the time of usage. The yield of acid hydrolyzed starch was expressed on dry basis as percentage dry weight of recovered starch per dry weight of native starch.

Physico-chemical properties determination

The physicochemical properties such as bulk density, amylose and amylopectin ratio, flow property and its least gelation concentration was carried out on both the native and modified starches using standard procedure.

Moisture content

The moisture content determination was carried out using AOAC (2005). The sample (3 g) was placed in moisture cans of known weight and dried in a hot air oven at 105 ± 1°C for 6 h, cooled in a desiccator and subsequently re-weighed. The moisture content was determined using Equation 1 below:

$$M. C_{db} = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

Where: W_1 = weight of the starch powder before drying (g); W_2 = weight of the starch powder after drying (g); M.C db = moisture content on dry basis (%).

Packed bulk density

The bulk density was determined according to the method documented by Okezi and Bello (1988). A 10-mL graduated

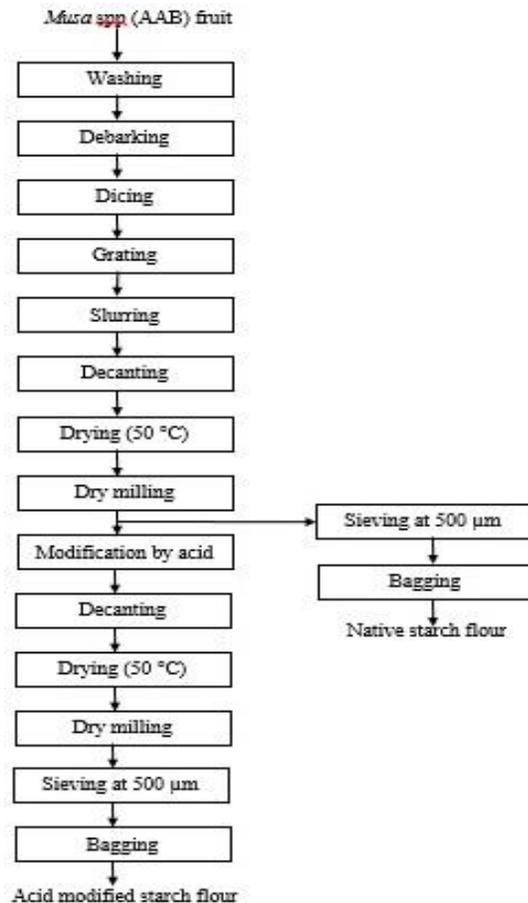


Figure 1. A schematic diagram showing extraction of *Musa* spp (ABB) native and acid modified starch. Source: Gbadamosi and Oladeji (2013).

cylinder was gently filled with a known weight of the sample and the bottom of the cylinder was gently tapped several times on a laboratory work bench until there was no further diminution of the sample level after filling to the 10-ml mark of the cylinder. Bulk density then was calculated using Equation 2.

$$BD = \frac{m}{v} \quad (2)$$

Where: BD = bulk density (g/mL); m = weight of sample (g); v = volume occupied by sample (mL).

Loose bulk density

The method documented by Yusuf (2004) was used for the determination of the loose bulk density. A 10-mL graduated cylinder was gently filled with the starch sample. This was not tapped. The volume occupied was recorded. The loose bulk density was then calculated using Equation 2.

Gelation and least gelation concentration

Least gelation concentration was determined by the method documented by Coffman and Garcia (1977). The flour suspension

(10 ml) in distilled water (2-20%) was transferred into test-tube, heated in a boiling water-bath for 1 h and cooled. The sample in test-tube was further cooled for 2 h at 4°C and the least gelation concentration (LGC) was taken as concentration when the sample from the inverted test tube did not fall or slip.

Determination of density ratio and porosity

The density ratio (D_r) and porosity of the sample flours were determined using Equations 3 and 4 (Mohsenin, 1986):

$$D_r = \left(\frac{\rho_B}{\rho_T} \right) \times 100 \quad (3)$$

$$P = \left(1 - \left(\frac{\rho_B}{\rho_T} \right) \right) \times 100 \quad (4)$$

Where:

D_r = bulk ratio; P = porosity (%); ρ_B = packed bulk density of the sample (g/mL); ρ_T = tapped density of the sample (g/mL).

Flowability properties

Flowability as a function of compression and compaction of the samples was determined from packed bulk and loose bulk densities data. The Hausner ratio and Carr index of the flour samples were determined using Equations 5 and 6, respectively. The values of Hausner ratio and Carr index were used to classify the flour samples compression, compaction and flowability as excellent, good, fair, or poor (Paksoy and Aydin, 2004).

$$HR = \frac{\rho_\infty}{\rho_0} \quad (5)$$

$$C.I = \frac{\rho_B - \rho_b}{\rho_b} \times 100 \quad (6)$$

Where:

HR = Hausner ratio; ρ_∞ = Asymptotic constant density after certain amount of taps; ρ_0 = Initial bulk density; C.I = Carr Index; ρ_B = Packed bulk density, g/mL and ρ_b = Loose bulk density, g/mL.

Amylose and amylopectin contents

The amylose content was determined using method documented by Thomas et al. (2013). Sample (100 mg) was measured into 100-mL standard flask, 1.0 mL of ethanol (95%) and 9.0 mL of 1.0 M NaOH was added, and the mixture was heated on a boiling water-bath for 10 min to gelatinize the starch. The gelatinized starch solution (5.0 mL) was subsequently transferred to a 100-mL standard flask; further, 1.0 mL of 1.0 M acetic acid and 2.0 mL of stock iodine solution were added to it and the volume was made up to the mark with distilled water. The content was thoroughly vortex and allowed to settle for 20 min. The resultant colour was allowed to develop and the absorbance read at 620 nm using a UV-Spectrophotometer (Model - 752S). The amylose content was then calculated from the standard curve of potato amylose, expressed in percentage. The amylopectin content was obtained by subtracting the value of amylose content determined from 100.

$$APC = 100 - AC \quad (7)$$

Where: APC = Amylopectin content (%) and AC = Amylose content (%).

Thermal properties

The thermal properties of the starch flour samples were measured using a KD2 Pro Thermal Properties Analyser (Decagon Devices Inc., Pullman, WA), a portable field and laboratory equipment that use the transient line heat source method. The 30-mm long, 1.28-mm diameter, and 6-mm spacing dual needle SH-1 sensor measures the onset temperature, peak temperature, end temperature, gelatinization enthalpy, and specific heat capacity (heat capacity). An interval of 5 min was provided between each reading.

Thermal diffusivities of the flour samples were thereafter determined from the temperature - time data of the samples generated by the DSC using Equation 8 according to Leniger and Beverloowere (Man et al., 2013) and then employed to determine thermal diffusivity which was calculated using Equation 8 given by Leniger and Beverloowere

$$-\log \frac{T_{max} - T_i}{T_{max} - T} = \frac{1}{2.303} \left[\frac{5.78}{R} + \frac{\pi^2}{L^2} \right] \alpha t \quad (8)$$

Where: T_{max} = Maximum processing starch flour temperature (K); T_i = Initial starch flour temperature (K); T = Starch flour temperature at any time (K); R = Radius of the crucible (m); L = Length of the starch flour in the crucible (m); t = time (s); and α = thermal diffusivity (m^2/s).

Thermal conductivity was calculated mathematically using Equation 9

$$k = \rho \alpha C_p \quad (9)$$

Where: α = thermal diffusivity (m^2/s); k = thermal conductivity ($W/m^{\circ}C$); C_p = specific heat capacity ($J/(gK)$) and ρ = density (g/mL).

Coefficient of friction of the starch flour

The coefficient of friction of starch flour sample was determined using the method documented by Bahnasawy (2007). The coefficient of friction was tested against plywood, stainless steel, galvanized steel and glass surfaces. A bottomless cylinder of 5 cm diameter and 10 cm height was filled with the starch sample and placed over the different surfaces which were in turn placed on an inclined plain system. The surfaces were gently raised using a jack and the angle at which the powder motion began as the plain inclined was read off with a calibrated protractor in degrees. The coefficient of friction was calculated using Equation 10.

$$\mu = \tan \alpha \quad (10)$$

Where: μ = coefficient of friction and α = angle, in degrees.

Angle of repose

The method documented by Garnayak et al. (2008) was used in determination of angle of repose. A bottomless cylinder of 5 cm diameter and 10 cm height was placed over a plain surface and the starch flour sample was placed in the cylinder. The cylinder was raised slowly allowing the sample to flow down and form a natural slope. The angle of repose was calculated using Equation 11.

$$\theta = \tan^{-1} \left(\frac{2h}{D} \right)$$

Where: θ = angle of repose ($^{\circ}$); h = height (cm) and D = diameter (cm).

Statistical analysis

The data obtained were analyzed descriptively and inferentially using Turkey's post test procedures of GraphPad Prism version 4.00 for Windows.

RESULTS AND DISCUSSION

The yield of native and modified starch flour samples were 45.3 and 93.43%, respectively. The values obtained were higher than 40.9% reported by Tribess et al. (2009) for native *Musa* spp (ABB) starch but lower than 58.5% documented by Suntharalingam and Ravindran (1993). The difference in the yield values could be attributed to difference in variety or specie and geographical location as reported by Ravi and Mustafa (2013).

Ambigaipalan et al. (2011) reported that the yield of starches from faba bean (32.94 - 36.34%), black bean (27.53 - 29.89%) and pinto bean (27.41 - 31.16%) varied. Akanbi et al. (2009) also reported 14.26% for bread fruit starch. The value obtained from *Musa* spp (ABB) was higher than legume starches reported by authors because legumes have less starch content compared to cereals, tubers and starchy berries. This result indicates that *Musa* spp (ABB) can serve as an alternative source of starch in the food industry and other allied industries.

The physico-chemical properties such as moisture, bulk density, gelation and least gelation concentration, porosity, density ratio, and flow properties of native and modified *Musa* spp (ABB) starch are presented in Table 1.

The moisture content values were 2.07 and 1.35% (d.b) for native and modified starches, respectively. The values obtained compared favorably with 2.85% of commercial potato starch with no significant difference ($p \leq 0.05$). Flour is considered shelf stable if its moisture content is below 11% (Gbadamosi et al., 2012). Hence, the shelf stability of the starch flour investigated could be considered shelf stable for moisture related deterioration.

The bulk densities of native and modified *Musa* spp starch flour were 0.65 and 0.63 g/mL (loose) and 0.84 and 0.85 g/mL (packed), respectively. The values obtained compared favourably with 0.51 and 0.66 g/ml (commercial potato starch) for loose and packed densities, respectively. Acid hydrolysis of the *Musa* spp starch resulted in increased packed bulk density. There is no significant difference ($p \leq 0.05$) between native and modified starch bulk density values but there is significant difference when compared with the value of commercial potato starch. The values obtained compared favourably with 0.64, 0.68 and 0.68 g/mL for cassava starch, cocoyam and breadfruit flours, respectively (Gbadamosi and Oladeji, 2013).

The bulk density either loose or packed, measures quantity of material that can be packed within a pre-specified packing space (Gbadamosi and Oladeji, 2013). It depends on the combined effect of interrelated factors

Table 1. Physico-chemical properties of *Musa* spp. starch.

Parameters	Native starch	Modified starch	Potato starch
Loose bulk density (g/mL)	0.65±0.03 ^a	0.63±0.01 ^a	0.51±0.03 ^b
Packed bulk density (g/mL)	0.84±0.06 ^a	0.85±0.03 ^a	0.66±0.04 ^b
Carr index (%)	29.11±4.03 ^a	35.78±5.53 ^a	30.61±7.36 ^a
Hausner ratio	1.29±0.03 ^a	1.36±0.05 ^a	1.31±0.07 ^a
Density ratio (%)	77.26±2.36 ^a	74.25±2.75 ^a	76.53±4.21 ^a
Porosity (%)	22.73±2.36 ^a	25.74±2.75 ^a	23.47±4.21 ^a
Angle of repose (°)	31.6±3.31 ^b	31.91±1.99 ^b	39.78±1.74 ^a
Moisture content (%)	2.07±0.19 ^a	1.35±1.35 ^a	2.85±0.07 ^a
Compressibility	Fair	Very good	Good
Flowability	Free flowing	Free flowing	Free flowing

Values are mean ± standard deviation in triplicate. Mean values within each row bearing different superscript roman letter are significantly different ($p \leq 0.05$).

Table 2. Pearson Correlation Matrix between properties of *Musa* spp. and potato starch flours.

Variables	LBD	PBD	C. I	H.. R	D. R	P	A. R	AMY	APEC	M. C	LGC
LBD	1	0.9856	0.1922	0.2558	-0.1748	0.1736	-0.9968	0.9935	-0.9935	-0.8192	-0.6068
PBD	0.9956	1	0.3554	0.4156	-0.3388	0.3377	-0.9960	0.9984	-0.9984	-0.9044	-0.7325
C. I	0.1922	0.3554	1	0.9979	-0.9998	0.9998	-0.2702	0.3027	-0.3027	-0.7202	-0.8966
H. R	0.2558	0.4156	0.9979	1	-0.9966	0.9965	-0.3325	0.3642	-0.3642	-0.7640	-0.9236
D. R	-0.1748	-0.3388	-0.9998	-0.9966	1	-1.0000	0.2532	-0.2858	0.2858	0.7079	0.8887
P	0.1736	0.3377	0.9998	0.9965	-1.0000	1	-0.2520	0.2847	-0.2847	-0.7070	-0.8881
A. R	-0.9968	-0.9960	-0.2702	-0.3325	0.2532	-0.2520	1	-0.9994	0.9994	0.8625	0.6686
AMY	0.9935	0.9984	0.3027	0.3642	-0.2858	0.2847	-0.9994	1	-1.0000	-0.8792	-0.6934
APEC	-0.9935	-0.9984	-0.3027	-0.3642	0.2858	-0.2847	0.9994	-1.0000	1	0.8792	0.6934
M. C	-0.8192	-0.9044	-0.7202	-0.7640	0.7079	-0.7070	0.8625	-0.8792	0.8792	1	0.9530
LGC	-0.6068	-0.7325	-0.8966	-0.9236	0.8887	-0.8881	0.6686	-0.6934	0.6934	0.9530	1

such as the intensity of attractive inter-particle forces, particle size and number of contact points (Gbadamosi and Oladeji, 2013). Bulk density plays essential role in dispersion rate of food powder, which is related to starch reconstitution.

The angle of repose values were 31.6, 31.91 and 39.78° for the native, modified and commercial potato starch flour samples, respectively (Table 1). The angle of repose is an indication of the flow rate of the starch powder extracted. It correlates with the values for loose bulk density, packed bulk density and the moisture content as seen in Table 2. According to Carr (1965, 1970) and Raymus (1985), angle of repose below 30° indicated good flowability, 30° - 45° some cohesiveness, 45° - 55° true cohesiveness and above 55° sluggish or very high cohesiveness and very limited flowability. To this end, the native and modified starches of *Musa* spp (ABB) and that of potato starch exhibited some cohesiveness. Since there are about eight different methods of measuring the angle of repose which give somewhat different values, the published values of angles of repose are seldom comparable (Gbadamosi

and Oladeji, 2013).

Using the Pearson correlation matrix (Table 2), loose bulk density correlates significantly ($p \leq 0.05$) to packed bulk density (0.9856), angle of repose (-0.9968), amylose (0.9935), amylopectin (-0.9935) and moisture content (0.8.19) as shown in Table 2. Packed density on the other hand, exhibit significant ($p < 0.01$) correlation with loose bulk density (0.9858), angle of repose (-0.9960), amylose (0.9984), amylopectin (-0.9984), moisture content (-0.9044) and least gelation concentration (-0.7325).

The density ratio of native and modified starch samples were 0.77 and 0.74% respectively. These values compared favourably with that of commercial potato starch which had a density ratio of 0.76% (Table 1). Paksoy and Aydin (2004), reported similar values of density ration at 0.73, 0.76, and 0.79% for breadfruit starch flour, *Musa* spp starch flour and wheat starch flour, respectively.

The porosity values of native and modified starch samples were 22.73 and 25.74% respectively with no significant difference ($p \leq 0.5$). The porosity values

Table 3. Gelation and least gelation of *Musa* spp and potato starch flours.

Concentration	Native starch	Modified starch	Potato starch
2	--	--	--
4	--	--	--
6	--	--	--
8	--	++	--
10	--	++	--
12	--	++	--
14	++	++	--
16	++	++	--
18	++	++	++
20	++	++	++
LGC	14%	8%	16%

-- No gelation, --viscous, ++full gelation, LGC least gelation concentration.

Table 4. Starch characterization of *Musa* spp. starch flour.

Parameter (%)	Sample		
	Native starch	Modified starch	Potato starch
Amylose	31.27±0.17 ^a	33.26±0.04 ^a	29.77±0.11 ^a
Amylopectin	68.73±0.17 ^a	66.74±0.04 ^a	70.23±0.11 ^a
Amylose/amylopectin	0.45±0.01 ^a	0.50±0.01 ^a	0.42±0.01 ^a

Values reported are means ± standard deviation in triplicate. Mean values within each row bearing a different superscript roman letter are significantly ($p \leq 0.05$) different

obtained compared favourably with 23.47% of commercial potato starch flour. The values obtained also compared favourably with 24.1 and 23.8% for mug bean and sorghum starch powders, respectively (Gupta and Das, 1997; Altuntas and Yildiz, 2007). Porosity measures the percentage of voids of an unconsolidated mass of materials often needed in air and heat flow studies as well as other application. The Pearson correlation matrix showed significant correlation between porosity and Carr index (-0.9998), Hausner ratio (-0.9966) and least gelation concentration (-0.8881) (Table 2).

Carr index and Hausner ratio for the native and modified starch flour samples were 29.11 and 1.29; 35.78 and 1.36, respectively (Table 1). The values compared favourably with 35.78 and 1.31 for commercial potato starch. The Carr index and Hausner ratio indicate the flow properties of flour samples. Using Carr index assessment, the native starch showed fair compactness and compressibility but poor flowability, while modified starch sample indicated higher compressibility but poor flow properties and potato starch indicated a fair level of compressiveness but a poor flow property (Table 1). As reported by Falade and Ayetigbo (2014), most hydrocolloids are known to have good compressibility but very poor flow ability properties when it is based on their Carr index. When Hausner ratio and angle of repose are used as flow property index, it was seen that the starch samples were free flowing and compressible. Acid

hydrolysis did not improve the flowability of modified starch but improved the compressibility. Similar trends were reported by Olorunsola et al. (2011) for native and acid hydrolyzed sweet potato starch.

The Carr index provides an indirect measure of material fluidity, and the higher its value, the more cohesive the substance (Riley et al., 2008). Hausner ratio correlated significantly with Carr index (0.998), porosity (0.997) and least gelation concentration (-0.9236).

The gelation and least gelation concentration of the native and modified starch samples were shown in Table 3. The least gelation concentration of native and modified starch samples occurred at 14 and 8% (w/v), respectively whereas the acid modification of the starch resulted in the intermolecular repulsion to occur in the starch-gel accounting for its lower gelation concentration. The least gelation concentration result obtained for the modified starch is consistent with the report by Oladebeye et al. (2014), which suggest the rapid tendency of starch granules to swell at an elevated temperature within a short time. The low gelation concentration of the modified starch enhances its application as a bulking agent in food formulations such as chocolate and confectioneries. It is used as an index of gelation capacity.

The result for the amylose and amylopectin content and amylose- amylopectin ratio of the starches are presented in Table 4. The result indicates that the amylose content of the samples ranged between 29.77 - 33.26% which

Table 5. Thermal properties of *Musa* spp. starch flour using differential scanning calorimetry (DSC)

Parameter	Native starch	Modified starch	Potato starch
Onset Temperature, TO	92.8°C	79.3°C	72.7°C
Peak Temperature, TP	109.5°C	121.2°C	106.4°C
End Temperature, TE	114.2°C	122.8°C	106.2°C
Enthalpy, H	56.75 J/g	81.25 J/g	278.6 J/g
Temperature Range	21.4°C	43.5°C	35.5°C
Specific Heat Capacity, C _p	14.24 J/(gK)	20.28 J/(gK)	10.95 J/(gK)
Thermal conductivity, k	0.5 w/m°C	0.705 w/m°C	0.305 w/m°C
Thermal diffusivity, α	0.09 m ² /s	0.094 m ² /s	0.095 m ² /s
Density, ρ	0.84 g/mL	0.85 g/mL	0.66 g/mL

falls within the values (24.41 to 36.87%) reported for different *Musa* cultivars (Mustaffa, 2013). The high amylose content of the modified starch indicates high amylose-amylopectin ratio and hence, slowly digestible. The amylopectin content range from 66.74 to 70.23% (Table 4), with the potato starch having the highest amylopectin content. The amylose content values were within the reported range of 24.41 - 36.87% for various *Musa* spp cultivars (Mustaffa, 2013).

Amylose-amylopectin ratio for the native and modified starch samples and commercial potato starch sample were 0.45, 0.5 and 0.42%, respectively. The lower the amylose-amylopectin content range, the lower the glycemic index of the starch making it ideally consumable by diabetic patients. It is also an indication that hydrolysis of the starch is slow showing that the starch is a slowly digestible resistant starch (Jenkins et al., 1981). Amylose plays an important role in the starch internal structure and its digestibility is readily present in the amorphous region during modification. This region can be easily assessed than the amylopectin side chains, thus the amylose content is subject to change during modification (Man et al., 2013). The structural difference between amylose and amylopectin is said to be the backbone of starch during utilization. Starch with high amylose content tend to show a high degree of flakiness, however food materials prepared with starch that has a low amylose content becomes hard sticky and hard to chew (Karmakar et al., 2014). The amylose content of starch is an important characteristic that affects its functionality.

The onset temperature, peak temperature, end temperature, gelatinization enthalpy, temperature range, specific heat capacity and density of native and modified starch flour samples were 92.8°C, 109.5°C, 114.2°C, 56.75 J/g, 21.4°C, 14.24 J/(gK) and 0.84 g/mL; and 79.3°C, 121.2°C, 122.8°C, 81.25 J/g, 43.5°C, 20.28 J/(gK), and 0.85 g/mL, respectively (Table 5). The values obtained compared favourably with commercial potato starch values of 72.7°C, 106.4°C, 106.2°C, 278.6 J/g, 33.5°C, 10.95 J/(gK) and 0.66 g/mL for its onset temperature, peak temperature, end temperature, gelation enthalpy, temperature range, specific heat capacity and

density, respectively. As shown in Table 5, the gelatinization enthalpy (ΔH) for the potato starch is greater than that of native starch and modified starch, with native starch having the least enthalpy value. Singh et al. (2009), in their report, related gelatinization enthalpy to degree of crystallization. Starch with high gelatinization enthalpy possess higher degree of crystallization and hence, low swelling power. The variation in ΔH in starches as result of modification and starch type may be due to differences in quantity of longer chain amylopectin (Singh et al., 2003). The high gelation temperature range value of the modified starch indicates the presence of crystallite of difference stability within the crystalline region of the starch granule (Hoover et al., 1997). Density of the samples which is a function of mass and volume differed significantly between native and modified starch and potato starch. Native and modified starches had significantly similar densities.

The static coefficient of friction of dried starch samples was determined against glass, wood, galvanized steel and stainless steel. The coefficient of static friction for native and modified *Musa* spp (ABB) starch samples against glass, wood, galvanized steel and stainless steel were 0.46 and 0.40°; 0.41 and 0.48°; 0.36 and 0.45°; and 0.40 and 0.45° respectively (Table 5). This compares favourably with commercial potato starch sample which had 0.51, 0.66, 0.61, and 0.57° for glass, wood, galvanized steel and stainless steel respectively (Table 6). The values obtained for coefficient of static friction are similar to those documented by Carman (1996) for glass (0.40 - 0.45°), wood (0.40 - 0.50°), and galvanized steel (0.4 - 0.5°). No significant difference ($p \leq 0.5$) was observed among the starch samples. Each sample was statistically different from the other as shown in Table 5. The static co-efficient of friction data is helpful in designing storage facilities and other bulk handling devices such as impelling unit and augers.

Conclusion

This study investigated some engineering and

Table 6. Coefficient of friction.

Sample	Glass (°)	Wood (°)	G. Steel (°)	S. Steel (°)
Native starch	0.46±0.03 ^{ab}	0.41±0.05 ^c	0.36±0.03 ^b	0.40±0.06 ^b
Modified starch	0.40±0.02 ^b	0.48±0.04 ^b	0.45±0.02 ^b	0.45±0.02 ^b
Potato starch	0.51±0.07 ^a	0.66±0.03 ^a	0.61±0.09 ^a	0.57±0.03 ^a

G. steel – galvanized steel, S. Steel – stainless steel. Mean values within each row bearing different superscript letter are significantly different ($p < 0.05$).

physicochemical properties of *Musa* spp (ABB) starch flour samples in relation to its bulk handling. The study therefore provides engineering data in relation to process design, control and bulk handling needed by PLC logic controllers obtained from sensors that detect, measure and interprets these data with a view to extending the usage of *Musa* spp (ABB) starch samples in food process industry.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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