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Chemical, functional and pasting properties of banana and plantain starches modified by pre-gelatinization, oxidation and acetylation

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Abstract: Starches extracted from banana (*Honduras* variety) and plantain (*Agbagba* variety) were modified by pre-gelatinization, oxidation and acetylation. Native and modified starches were evaluated for chemical, functional and pasting properties. Total starch (TS) and amylose (AM) were higher for native and modified banana starches (TS: 48.78–69.39%; AM: 21.91–42.07%) than for plantain starches (TS: 35.30–63.90%; AM: 13.87–38.79%). Pre-gelatinization significantly ($p < 0.05$) increased the water absorption capacity of banana and plantain starches by 18.94 and 72.87% respectively and the oil absorption capacity by 51.20 and 4.10% respectively. Modification significantly ($p < 0.05$) increased the emulsion ability of plantain starch by 66.89% (pre-gelatinization), 64.24% (oxidation) and 11.85% (acetylation). Modification significantly ($p < 0.05$) reduced the peak, trough, final and setback viscosities of banana and plantain starches but increased the breakdown viscosity of banana starches.

Subjects: Food Science & Technology; Food Chemistry; Food Analysis

Keywords: banana; plantain; starch; modification; pre-gelatinization; oxidation; acetylation; functional properties; pasting properties

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PUBLIC INTEREST STATEMENT

Starch contributes to textural properties of many foods and is widely used in food and industrial applications as thickener, stabilizer and gelling agent. Cereals and tubers have been the main botanical sources of starch; however, development of new products in the industries may require exploration of starches with different or improved functional properties. Consequently, sourcing starches from non-conventional botanical sources such as banana and plantain, and characterization of their functional properties is important. In the unmodified form, starches have limited use in the food industry. The present study was conducted to characterize some important chemical and functional properties of native starches from *Agbagba* plantain and *Honduras* banana and the effect of physical treatment (pre-gelatinization) and chemical modification (oxidation and acetylation) on starch properties. This study provides information on appropriate modification method to improve specific properties of banana and plantain starches. It also suggests potential uses for these products in processed foods.

1. Introduction

Starch or amylum is a polysaccharide carbohydrate that consist of a large number of glucose units joined together by glycosidic bonds. Starch is the main reserve carbohydrate in tubers, cereals and legumes (Guilbot & Mercier, 1985). The relative proportion of amylose and amylopectin and the organization within the starch granules determine the functional properties of the starch and consequently its wide range of industrial applications in foods, pharmaceuticals, adhesives, etc. (Tharanathan, 2005). Cereals and tubers have been the main botanical sources of starch, however, the promotion of regional economies has motivated the exploration of alternative botanical sources of starch. In addition, development of new products in the industries may require exploration of starches with different or improved functional properties of water absorption and oil absorption capacities, viscosity, solubility, as well as retrogradation and syneresis tendencies. Consequently, progress have been made in obtaining starches from non-conventional botanical sources such as banana and plantain, and characterization of their functional properties (Pelissari, Andrade-Mahecha, Sobral, & Menegalli, 2012; Utrilla-Coello et al., 2014; Zhang, Whistler, BeMiller, & Hamaker, 2005).

Banana is a general term for a number of species or hybrids of the genus *Musa* of the family *Musaceae*. It is produced in large quantities in tropical and subtropical regions. Banana is a seasonal and highly perishable fruit and surplus fruits are often available all year around. Asia is the world's leading producer of bananas with a share of 52.1% with China contributing 18.4 million tonnes (average 1993–2013) (FAOSTAT, 2016). Although an exact production figure is not available, Nigeria may also have contributed a considerable amount to the 14.5% production share of Africa, the third leading producer by region. Since unripe bananas contain large amounts of starch (over 70% of dry weight), their processing into starch is of interest as a possible resource for food and other industrial purposes. Starch contributes greatly to textural properties of many foods and is widely used in food and industrial applications as thickener, stabilizer and gelling agent (Marriott, Robinson, & Karikari, 1981).

In the unmodified form, starches have limited use in the food industry. Native starches retrograde easily when cooked and therefore cannot withstand conditions of processing such as high temperature, the gel also easily undergo syneresis (Kaur, Ariffin, Bhat, & Karim, 2012). Various modification methods including acetylation, oxidation and pre-gelatinization, to mention a few, have been applied to improve starch properties for specific food and industrial applications (Bemiller, 1997; Miyazaki, Van Hung, Maeda, & Morita, 2006; Tharanathan, 2005). Acetylation involves esterification of the hydroxyl functional groups of the starch and provides sol-stability and functional properties such as hydrophilic, cationic or anionic character at relatively low cost (Adebowale & Lawal, 2003). Acetylation increased the swelling power and solubility of starches from cassava (Osundahunsi, Seidu, & Mueller, 2014) and Bambara groundnut (Adebowale, Adeniyi Afolabi, & Lawal, 2002). The least gelation capacity and free-thaw stability of starches have also been improved by acetylation (Osundahunsi et al., 2014). Oxidation involves the introduction of carbonyl and carboxyl groups and the degradation of starch molecules, hence oxidized starches exhibit low viscosity due to depolymerization and improved stability of starch dispersion from the presence of functional groups (Sangseethong, Termvejsayanon, & Sriroth, 2010). Hypochlorite is the most common oxidizing agent used on an industrial scale and the reaction depends mainly on pH, although other factors such as oxidant concentration, temperature and starch origin also influence hypochlorite oxidation (Sangseethong et al., 2010). Pre-gelatinized starches are pre-cooked starches that can be used as thickener in cold water; along with cold-water-soluble starches, they enable users to disperse starch without going through the heating process (Jane, 1995).

Studies of characteristics of native and modified banana and plantain starches have been reported extensively (Alimi, Workneh, & Sibomana, 2016a, 2016b; Hernández-Jaimes, Bello-Pérez, Vernon-Carter, & Alvarez-Ramirez, 2013; Kayisu, Hood, & Vansoest, 1981; Waliszewski, Aparicio, Bello, & Monroy, 2003). From study, the physicochemical and functional properties of banana and plantain starch has been shown to depend on variety as well as factors such as regional climatic conditions and harvesting periods (Bello-Pérez, Agama-Acevedo, Sánchez-Hernández, &

Paredes-López, 1999). The most abundant local plantain variety that is commercially traded in the South-Western region of Nigeria is "Agbagba". On the other hand, Honduras variety of banana is a hybrid, and is neither available on a large scale nor widely consumed due to its relatively soft texture, its cultivation is currently limited to research fields. Information on the functional properties of native and modified starches from these varieties of banana and plantain is limited in literature. The aim of this work was to characterize some important chemical and functional properties of native starches from *Agbagba* plantain and *Honduras* banana and the effect of physical treatment (pre-gelatinization) and chemical modification (oxidation and acetylation) on starch properties. This is with a view to provide information about potential uses for these products in processed food.

2. Materials & methods

2.1. Materials

Unripe banana (*Honduras* variety) was purchased from the Federal University of Agriculture, Abeokuta, farms (DUFARMS) while unripe plantain (*Agbagba* variety) was purchased from a major fruits market, Oje Market in Ibadan, Oyo State, Nigeria. All chemicals used were of Analytical grade.

2.2. Methods

2.2.1. Starch extraction

Starches were extracted from each of banana and plantain fruits using a slightly modified procedure of Kim, Wiesenborn, Orr, and Grant (1995). The fruit was peeled, cut into cubes, and immediately immersed in citric acid solution (0.5 g/L). The cubes were macerated with distilled water at low speed in a waring blender (5 kg of fruit to 5 L of water) for 2 min. The resultant slurry was sieved through 100 mesh screen. The starch suspension was left overnight under refrigeration (6–8°C), washed several times with distilled water and centrifuged at 3,000 rpm for 15 min. The sediment was dried at 40°C for 48 h in a convection oven (GP/100/CLAD/F/250/HYD, Leader, Merseyside), milled and stored at room temperature (30 ± 2°C) in sealed glass jars until required.

2.2.2. Pre-gelatinization

Pre-gelatinization of native starches was conducted as described by Waliszewski et al. (2003); 300 g of starch was suspended in 1 L of distilled water and heated to 80°C for 15 min with slow mixing. Pre-gelatinized starch was placed into stainless steel tray in form of thin film (1–2 mm) and dried in a convection oven at 40°C for 48 h, milled to pass through a 100 mesh screen and stored at room temperature (30 ± 2°C) in sealed glass jars.

2.2.3. Oxidation

Oxidation of native starches was carried out using the method of Forssell, Hamunen, Autio, Suortti, and Poutanen (1995) as modified by Lawal (2004). Starch slurry was prepared by adding 100 g of starch to 500 ml of distilled water in a 1 L reaction vessel. The pH of the slurry was adjusted to 9.5 with 2 M NaOH. Sodium hypochlorite (10 g), was slowly added into the slurry over a period of 30 min while maintaining the pH range at 9.0–9.5, with constant stirring at 30 ± 2°C. The reaction proceeded for 10 min after addition of NaOCl. After the reaction, the pH of the slurry was adjusted to 7.0 with 1 M H_2SO_4 and the oxidized starch was filtered, washed four times with distilled water and air-dried at 30 ± 2°C for 48 h.

2.2.4. Acetylation

The method of Sathe and Salunkhe (1981) as described by Lawal (2004) was used. Starch (100 g) was dispersed in 500 ml of distilled water and the mixture was stirred magnetically for 20 min. The pH of the slurry was adjusted to 8.0 using 1 M NaOH. Acetic anhydride (10.2 g) was added over a period of 1 h, while maintaining a pH range of 8.0–8.5. The reaction was allowed to proceed for 5 min after the addition of acetic anhydride. The pH was adjusted to 4.5 using 0.5 M HCl. It was filtered, washed four times with distilled water and air-dried at 30 ± 2°C for 48 h.

2.3. Sample analysis

2.3.1. Chemical composition

Standard methods of the Association of Official Analytical Chemists (AOAC, 1996) were adopted for estimating moisture, protein, fat, crude fibre, ash contents. Carbohydrate (%) was calculated by difference [100 − (% moisture + % protein + % fat + % crude fibre + % ash)].

2.3.2. Total starch

Starch content was determined following phenol-sulphuric acid method of DuBois, Gilles, Hamilton, Rebers, and Smith (1956). About 50 g of starch was extracted with hot 80% ethanol to separate the sugar. About 1.0 ml of the sugar extract was pipetted into a test tube and diluted to 2.0 ml with distilled water. About 1.0 ml of 5% phenol was added and the tube was allowed to stand for 10 min. The mixture was vortexed and allowed to stay for another 20 min. Absorbance was read at 490 nm. A standard curve was plotted using 0–100 µg glucose. A standard solution of glucose was prepared by dissolving 10 mg of glucose solution in 100 ml distilled water. About 0.20, 0.40, 0.60, 0.80 and 1.00 ml of standard glucose solution was pipetted into a test tube and treated following the procedure for sugar extract. The amount of sugar in the dilution factor and weight of sample was taken into consideration. Starch was calculated using the formula:

$$\text{Starch } (\%) = \frac{0.05 \times A \times 1/M}{\text{Weight of sample}} \times 0.9$$

where A = absorbance, M = slope of curve.

2.3.3. Amylose content

Amylose was determined following the rapid colorimetric method of Williams, Kuzina, and Hylinka (1970) as described by Lawal (2004). Starch samples (20 mg) were weighed into a 50 ml beaker and 10 ml of 0.5 N KOH solution was added. The mixture was stirred with a stirring rod until the starch was fully dispersed in the solution. The dispersed mixture was transferred into a 100 ml volumetric flask and diluted to mark with distilled water. An aliquot (10 ml) was pipetted into a 50 ml volumetric flask, 5 ml of 0.1 N HCl was added, followed by 0.5 ml of iodine reagent. The volume was diluted to 50 ml and the absorbance was measured at 625 nm after 5 min. The amylose was determined from a standard curve developed using amylose and amylopectin blends.

2.3.4. Water absorption capacity

Water absorption capacity (WAC) was determined by the method of Sosulski, Garratt, and Slimkard (1976) as described by Akubor (1997). Starch sample (2 g) was mixed with 20 ml distilled water and allowed to stand at room temperature (30 ± 2°C) for 30 min, then centrifuged for 30 min at 2,000 rpm (527 ×*g*). The volume of decanted supernatant fluid was measured and volume of water retained/bound per g of sample calculated. WAC was expressed as g of water bound/100 g of starch.

2.3.5. Oil absorption capacity

Oil absorption capacity (OAC) was determined by the method of Sosulski et al. (1976). Starch sample (2 g) was mixed with 20 ml Sunflower oil and allowed to stand at room temperature (30 ± 2°C) for 30 min, then centrifuged for 30 min at 2,000 rpm (527 ×*g*). The volume of decanted supernatant fluid was measured and volume of oil retained/bound per g of sample calculated. OAC was expressed as g of oil bound/100 g of starch.

2.3.6. Swelling capacity and solubility index

Swelling capacity and solubility index of the starch were estimated as described by Aina, Falade, Akingbala, and Titus (2009). A starch-water slurry (0.35 starch in 12.5 ml of distilled water) was heated in a water bath at 60°C for 30 min, with constant stirring. The slurry was centrifuged at 3,000 rpm for 15 min (1,207 ×*g*), the supernatant was decanted into a weighed evaporating dish and dried at 100°C to constant weight. The difference in weight of the evaporating dish was used to

calculate the water solubility. Swelling power was obtained by weighing the residue after centrifugation and dividing by original weight of the starch on dry weight basis.

2.3.7. Emulsion activity

The method of Yasumatsu et al. (1972) was used. The emulsion (2 g sample, 20 ml sunflower oil, and 20 ml distilled water) was prepared in a calibrated centrifuge tube; the emulsion activity (%) was calculated as the ratio of the height of the emulsion layer to the total height of the mixture.

2.3.8. Least gelation concentration

The method of Sathe and Salunkhe (1981) was used. Samples of starch (2, 4, 6, 8, 10, 12, 14, 16, 18 and 20% [w/v]) were dispersed in distilled water in test tubes. The dispersions were heated in a water bath at 80°C for 1 h, followed by rapid cooling under running cold water. The test tubes were set at 4°C for 2 h. Least gelation concentration was determined as the concentration at which the sample from the inverted test tube did not slip.

2.3.9. Pasting properties

The pasting properties of starch suspensions (14%, moisture basis) were analyzed using a Rapid Visco Analyzer (TMB 2102529, Tecmaster Perten, Australia). The sample slurries were maintained for 1 min at 50°C, then heated from 50 to 95°C at the rate of 6°C/min. After holding at 95°C for 5 min, the sample pastes were cooled to 50°C at the same rate of 6°C/min. The pasting temperature, peak viscosity, breakdown point, and final and setback viscosities were recorded.

2.3.10. Colour

Colour properties (L^*, a^*, b^*) of starch was determined by using a Chroma Meter CR-14 (Konica Minolta Inc., Japan). A standard white tile was used to calibrate the instrument. The starch was uniformly packed in clean Petri plates with lid. The instrument head was placed on the plate and exposures conducted. Readings were displayed as L^*, a^*, and b^* colour parameters according to the CIELAB system of colour measurement. The L values ranged from 0 (black) to 100 (white), a values from −80 green to +100 (red), while the b value ranged from −80 blue to +70 yellow.

2.4. Statistical analysis

Values were presented as means of duplicate analysis. The data was subjected to analysis of variance (ANOVA) to determine if significant difference exists among the starch samples as a result of the modifications. Duncan's multiple range tests was used to separate means where significant ($p < 0.05$) difference existed. Statistical Software (SPSS version 17.0) was used to perform the analysis.

3. Results and discussion

3.1. Chemical composition

Native *Honduras* banana starch had higher moisture (13.60%), fat (0.72%) and ash (0.92%) contents, while native *Agbagba* plantain starch had higher protein (2.53%), fibre (0.72%) and total carbohydrate (84.49%) contents (Table 1). The moisture (13.60%) and protein (2.16%) contents of native banana starch were generally higher than 7.03–9.27 and 0.22–0.98% respectively reported for different varieties (Utrilla-Coello et al., 2014; Waliszewski et al., 2003), while the fat (0.72%) and ash (0.92%) contents were within the range reported in literature (Pelissari et al., 2012; Utrilla-Coello et al., 2014; Waliszewski et al., 2003). The proximate composition of native plantain starch was higher than values reported by Pelissari et al. (2012) for *Tera* plantain. The moisture and ash contents of native plantain starch were 11.20 and 0.62% respectively, however, Kiin-Kabari, Sanipe, and Owuno (2014) reported values of 13.15 and 0.45% respectively for starch from the same variety (*Agbagba*) of plantain. These authors did not report other proximate components of the starch. Generally, chemical composition of isolated starches depends on factors such as regional climate, agronomic methods, harvesting conditions, and isolation methods among others (Lawal, 2004; Lawal et al., 2011). Also, differences in moisture content may be due to different drying methods

Table 1. Proximate composition of banana and plantain starch as influenced by modification

Sample	Moisture (%)		Protein (%)		Fat (%)		Crude fibre (%)		Ash (%)		Carbohydrate (%)	
	BN	PT	BN	PT	BN	PT	BN	PT	BN	PT	BN	PT
NS	13.60^{c}	11.20^{b}	2.16^{b}	2.53^{c}	0.72^{c}	0.44^{b}	0.47^{b}	0.72^{c}	0.92^{b}	0.62^{a}	82.13^{c}	84.49^{c}
PS	9.10^{a}	10.50^{a}	2.54^{d}	2.51^{c}	0.79^{d}	0.14^{a}	0.41^{a}	0.62^{b}	0.66^{a}	0.91^{b}	86.50^{d}	85.32^{d}
OS	13.40^{b}	12.30^{c}	2.44^{c}	2.32^{b}	0.17^{a}	0.43^{b}	0.70^{d}	0.52^{a}	2.41^{c}	2.46^{c}	81.99^{b}	73.00^{a}
AS	15.40^{d}	14.00^{d}	2.10^{a}	2.12^{a}	0.21^{b}	0.47^{c}	0.66^{c}	0.92^{d}	2.85^{d}	2.83^{d}	78.78^{a}	79.66^{b}

Notes: BN-banana, PT-plantain, NS-native starch, PS-pregelatinized starch, OS-oxidized starch, AS-acetylated starch.

Values are means of triplicate determinations.

Mean values followed by different alphabets are significantly ($p < 0.05$) different.

and/or conditions of temperature and time used in the different studies reported. In addition, a lower content of protein, fat and ash indicates higher purity of starch which may be directly linked to method of starch isolation (Pelissari et al., 2012; Utrilla-Coello et al., 2014).

The values of total starch and amylose were generally higher for native and modified banana starches compared to plantain starches (Table 2). The total starch (69.39%) of native *Honduras* banana starch was lower than 82.7–98.0% for six Thai bananas (Vatanasuchart, Niyomwit, & Wongkrajang, 2012). The amylose content (42.70%) of native *Honduras* banana starch was higher than 19.32–26.35% for *Enano, Morado, Valery* and *Macho* banana varieties in Mexico (Utrilla-Coello et al., 2014) but within 38.6–42.7% for different cultivars of Thai bananas (Vatanasuchart et al., 2012). The total starch (63.90%) of native *Agbagba* plantain was lower than 94.8% for *Terra* plantain, while the amylose (38.79%) was higher than 30.91% for *Agbagba* plantain (Kiin-Kabari et al., 2014) and 35.0% for *Terra* plantain (Pelissari et al., 2012). The amylose contents of native banana (42.07%) and plantain (38.79%) starches as well as that of oxidized (26.05%) and acetylated (36.73%) banana starches are higher than 20–25% for cereal and root and tuber starches (Lawal, 2004; Lawal et al., 2011; Noda et al., 2004; Utrilla-Coello et al., 2014; Wani et al., 2013). The difference in amylose content affects functional and physico-chemical properties, with starches of higher amylose contents producing firmer and more opaque gels, and making them a potential ingredient in sausages and meat emulsions requiring such properties for texture. Materials with high amylose content are also suitable as raw material for edible packaging (Pelissari et al., 2012). The effect of modification on total starch and amylose was similar for both banana and plantain starches. Modification significantly ($p < 0.05$) reduced the total starch and amylose content of banana and plantain starches. This is expected as modification involves degradation of starch granules with the extent depending on type of modification (Adebowale et al., 2002; Lawal, 2004). Native banana and plantain starches had the highest total starch and amylose followed by acetylated, then oxidized, with pre-gelatinized starches having the least values. High amylose starches can be used to give crunchy or crispy mouth feel to extruded and fried snack products (Sajilata & Singhal, 2004).

Table 2. Total starch and amylose of banana and plantain starch as influenced by modification

Sample	Total starch (%)		Amylose (%)	
	BN	PT	BN	PT
NS	69.39^{d}	63.90^{d}	42.07^{d}	38.79^{d}
PS	48.78^{a}	35.30^{a}	21.91^{a}	13.87^{a}
OS	49.87^{b}	38.53^{b}	26.03^{b}	16.82^{b}
AS	63.06^{c}	41.67^{c}	36.73^{c}	18.74^{c}

Notes: BN-banana, PT-plantain, NS-native starch, PS-pregelatinized starch, OS-oxidized starch, AS-acetylated starch.

Values are means of triplicate determinations.

Mean values followed by different alphabets are significantly ($p < 0.05$) different.

3.2. Functional properties

The WAC of native banana and plantain starches were 136.53 and 130.45% respectively (Figure 1). Pre-gelatinization significantly ($p < 0.05$) increased the WAC of both banana and plantain starches by 18.94 and 72.87% respectively. Oxidation and acetylation significantly ($p < 0.05$) reduced the WAC of banana starch by 5.11 and 5.95% respectively, although there was no significant ($p > 0.05$) difference between acetylated and oxidized banana starches. Oxidation significantly ($p < 0.05$) increased the WAC of plantain starch by 21.32% while acetylation reduced it by 10.60%. Acetylated banana and plantain starches had the least WAC. Higher WAC suggests weak association of amylose-amylopectin (Otegbayo, Lana, & Ibitoye, 2010) which allows permeability of water into the granule structure. The OAC of native banana and plantain starches were 136.77 and 194.05% respectively (Figure 1). Pre-gelatinization significantly ($p < 0.05$) increased the OAC of both banana and plantain starches by 51.20 and 4.10% respectively. Oxidized and acetylated plantain starches were not significantly ($p > 0.05$) different in their oil absorption capacities. Confectioneries and food ingredients such as thickeners will require starch with higher WAC while products such as batter for frying and mayonnaise will require starch with appropriate OAC (Alimi et al., 2016b).

The swelling capacity of native and modified banana starches ranged between 1.38 and 2.14 g/g while that of plantain starches ranged between 1.08 and 1.99 g/g (Table 3). Native banana starch had a swelling capacity of 1.38 g/g which was lower than values reported by Alimi et al. (2016a) for South African cooking banana (1.63 g/g) and Waliszewski et al. (2003) for *Valerie* banana (1.8–8.7 g/g) at 50–90°C. Swelling capacity is the ability of starch granules to hydrate and increase in size under excess water conditions. Ratnayake, Hoover, and Warkentin (2002) described starch solubility and swelling power as being directly related to the relative proportion of amylose and amylopectin. Modification did not have any significant ($p > 0.05$) effect on solubility index of banana and plantain starches (Table 3). Waliszewski et al. (2003) also reported low solubility power for native banana starch, however, the authors reported that it was improved by chemical modification and pre-gelatinization. The differences in the effect of modification may be due to differences in the type of chemical modification and conditions of pre-gelatinization used in the different studies. The least gelation capacities of both banana and plantain starches were relatively high (10.00–16.00% w/v) (Table 3). Native and acetylated starches had the highest least gelation capacities for each of banana and plantain while their oxidized starches had the lowest values. Native and modified banana and plantain starches may not be suitable for products that require strong gelation ability particularly at low concentrations.

The emulsion ability (EA) of banana starches ranged between 44.22 and 52.09 ml while that of plantain starches ranged between 41.86 and 69.86 ml (Figure 2). Oxidation significantly ($p < 0.05$) increased the EA of banana starch by 7.71%. Modification significantly ($p < 0.05$) increased the EA of

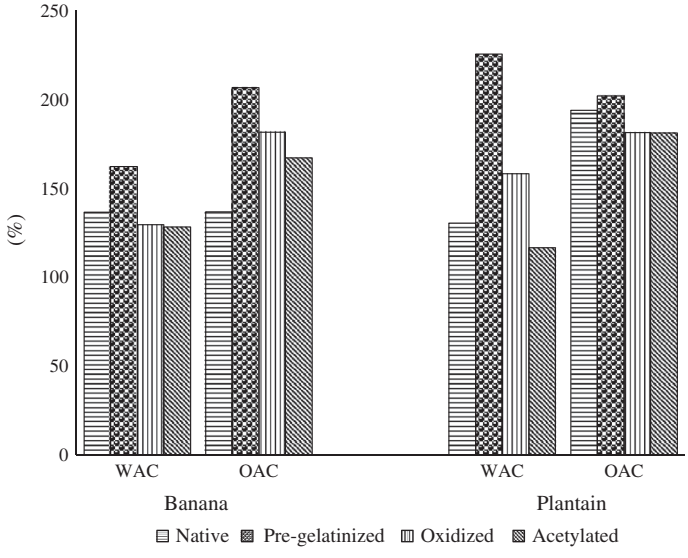

Figure 1. WAC and OAC of native and modified banana and plantain starches.

Table 3. Swelling capacity, least gelation concentration and solubility index of banana and plantain starch as influenced by modification

Sample	Swelling capacity (g/g)		Least gelation concentration (% w/v)		Solubility index	
	BN	PT	BN	PT	BN	PT
NS	1.38^{a}	1.99^{c}	16.00^{c}	14.00^{c}	0.30^{a}	0.80^{a}
PS	1.58^{ab}	1.68^{b}	12.00^{b}	12.00^{b}	0.60^{a}	0.30^{a}
OS	1.94^{bc}	1.08^{a}	10.00^{a}	10.00^{a}	0.20^{a}	1.30^{a}
AS	2.14^{c}	1.52^{ab}	16.00^{c}	14.00^{c}	0.50^{a}	0.40^{a}

Notes: BN-banana, PT-plantain, NS-native starch, PS-pregelatinized starch, OS-oxidized starch, AS-acetylated starch.
Values are means of triplicate determinations.
Mean values followed by different alphabets are significantly ($p < 0.05$) different.

plantain starch by 66.89% (pre-gelatinization), 64.24% (oxidation) and 11.85% (acetylation). There was no significant ($p > 0.05$) difference between native and acetylated starches for each of banana and plantain. Although literature reports that emulsion ability depends directly on protein as a result of rapid adsorption, unfolding and reorientation of the protein at the oil-water interface (Carvalho, García, & Amaya-Farfán, 2006), however, factors such as pH and heat processing have also been reported to influence the emulsion ability of foods containing protein (Abbey & Ibeh, 1988). Therefore, the improved emulsion ability of modified banana and plantain starches which are apparently limited in protein, may be due to other factors such as pH and heat employed during modification. Consequently, modified banana and plantain starches could be used to improve the emulsion ability of food products that do not have the required presence or quantity of protein for emulsification.

3.3. Pasting properties

Pasting properties describe the behaviour of starch and starch-based products during heat processing in the presence of water. Generally, modification significantly ($p < 0.05$) reduced all the paste viscosities of banana and plantain starches except for breakdown viscosity of banana starches which was significantly ($p < 0.05$) increased (Table 4). The influence of modification on peak viscosity, trough and final viscosity was similar for both banana and plantain starches, as well as on setback viscosity of banana starches. All the native starches had the highest paste viscosities except the breakdown viscosity of banana starch. The peak viscosity (241.34 RVU) for native *Agbagba* plantain starch in this study was closer to 252.6 RVU for *Terra* plantain (Pelissari et al., 2012), but higher than 161.17–163.17 RVU reported by Kiin-Kabari et al. (2014) for *Agbagba*, *Cadaba* and *French horn* plantain varieties. Higher peak and final viscosities at high temperatures indicate the potential for application as thickeners in products requiring sterilization such as sauces and baby foods (De la Torre-Gutiérrez, Chel-Guerrero, & Betancur-Ancona, 2008). According to Guerra-DellaValle, Sanchez-Rivera, Zamudio-Flores, Mendez-Montealvo, and Bello-Perez (2009), peak viscosities of oxidized and acetylated banana starches were similar and higher than native starches. Such a similarity was also observed in the present study (oxidized-248.01 RVU and acetylated-254.38 RVU), however, these

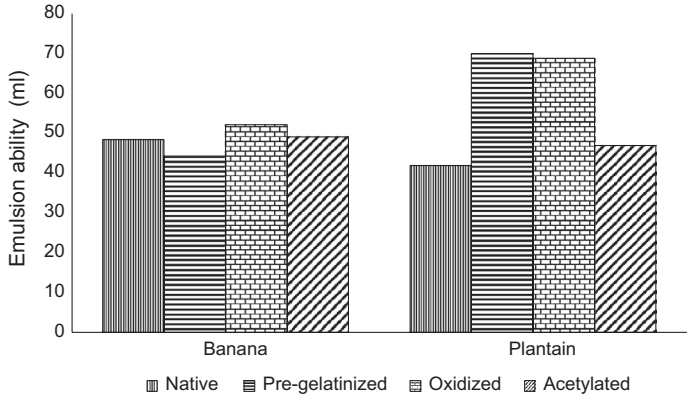

Figure 2. Emulsion ability of native and modified banana and plantain starches.

Table 4. Pasting properties of banana and plantain starch as influenced by modification

Sample	Peak viscosity (RVU)		Breakdown viscosity (RVU)		Trough (RVU)		Final viscosity (RVU)		Setback viscosity (RVU)		Pasting temperature (°C)		Peak time (min)	
	BN	PT	BN	PT	BN	PT	BN	PT	BN	PT	BN	PT	BN	PT
NS	272.33^{d}	241.34^{c}	2.21^{a}	110.88^{c}	270.13^{d}	133.44^{d}	399.80^{d}	197.78^{d}	129.67^{d}	57.65^{b}	82.73^{d}	81.37^{a}	6.37^{b}	4.72^{a}
PS	31.67^{a}	16.49^{a}	10.75^{c}	3.64^{a}	20.92^{a}	13.07^{a}	73.58^{a}	27.42^{a}	52.67^{a}	13.98^{a}	93.63^{a}	87.13^{b}	7.00^{d}	7.00^{b}
OS	248.01^{c}	27.57^{a}	7.55^{b}	1.35^{a}	235.97^{b}	26.13^{b}	327.96^{b}	38.37^{b}	90.84^{b}	11.91^{a}	82.38^{c}	87.04^{b}	6.44^{c}	6.99^{b}
AS	254.38^{c}	90.11^{b}	15.22^{d}	35.03^{b}	239.78^{c}	54.42^{c}	332.90^{c}	68.00^{c}	93.61^{c}	14.04^{a}	81.77^{b}	81.42^{a}	6.32^{a}	4.79^{a}

Notes: BN-banana, PT-plantain, NS-native starch, PS-pregelatinized starch, OS-oxidized starch, AS-acetylated starch.

Values are means of triplicate determinations.

Mean values followed by different alphabets are significantly ($p < 0.05$) different.

values were lower than that of native banana starch (272.33 RVU). The opposite trend may be due to different degree of oxidation and acetylation in each of the studies.

Native banana and plantain starch had trough values of 270.13 and 133.44 RVU respectively. The trough for native plantain starch was within 85.08–141.75 RVU for plantain varieties (Kiin-Kabari et al., 2014). The trough, also known as holding strength, is the ability of granules to remain undisrupted when the starch is subjected to a period of constant high temperature and mechanical shear stress, this hold period is often accompanied by a breakdown in viscosity. Breakdown viscosity gives the fragility of starch upon the application of heat and shear force. The breakdown viscosity of both native and modified banana and plantain starches is very low (2.21–35.03 RVU) except for native plantain starch (110.88 RVU) which appears to have the greatest relative tendency to withstand high temperature and shear force during processing. Kiin-Kabari et al. (2014) reported breakdown viscosity of 28.17–48.42 RVU for starches from plantain varieties. Modification increased the breakdown viscosity of banana starches. The decrease in breakdown viscosity as a result of modification for plantain starches was also reported by Alimi et al. (2016a) for heat-moisture treated banana and plantain starches.

The higher setback viscosity values of native and modified banana starches (52.67–129.67 RVU) suggests a lower tendency for retrogradation than plantain starches (11.91–57.65 RVU). Pelissari et al. (2012) reported a setback viscosity of 169.1 RVU for *Terra* plantain banana. Final viscosity is an important parameter in predicting and defining the final and textural quality of foods (Bourne, 1982). Native banana starch had a final viscosity of 399.80 RVU while native plantain starch had a value of 197.78 RVU. Final viscosity of 145.25–247.33 RVU were reported for plantain starches (Kiin-Kabari et al., 2014). All the pre-gelatinized starches had the lowest paste viscosities except the breakdown viscosity of both banana and plantain starches. Acetylated starches generally have higher paste viscosities than oxidized starches.

The range of pasting temperature was 81.77–93.63°C for banana starches and 81.37–87.13°C for plantain starches. Lower pasting temperature indicates that lower thermal energy will be required for breakdown of starch granules and formation of paste. Peak time, the time required for starch granules to attain the highest paste viscosity during heating, was 6.32–7.00 and 4.72–7.00 min for banana and plantain starches respectively. Pre-gelatinized starches had the highest pasting temperature and peak time for both banana and plantain starches in spite of the very low viscosities.

3.4. Colour properties

The lightness (L^*) values of native and modified plantain starches (31.94–64.74) were generally lower than those of banana starches (47.17–81.23) (Table 5). Modification reduced the L^* value of both banana and plantain starches; native starches had the highest L^* values while pre-gelatinized starches had the least values. Waliszewski et al. (2003) reported that L^* values of banana starch was low (73.60) and that modification increased the darkness with L^* values of 57.26–66.30 for chemical (phosphate, cross-liked phosphate and hydroxyl) modification and 48.21 for pre-gelatinization. According to the authors, low L^* values implies that such starches cannot be used for clear starchy products.

Table 5. Colour properties of banana and plantain starch as influenced by modification

Sample	*L**		*a**		*b**	
	BN	PT	BN	PT	BN	PT
NS	81.23[d]	64.74[d]	3.37[b]	2.32[b]	−3.59[a]	−8.11[a]
PS	47.17[a]	31.94[a]	4.19[d]	1.71[a]	−0.25[d]	−6.98[a]
OS	75.28[b]	50.05[b]	3.23[a]	6.82[d]	−1.11[c]	−2.72[b]
AS	76.23[c]	57.76[c]	3.80[c]	3.29[c]	−3.08[b]	−7.00[a]

Notes: BN-banana, PT-plantain, NS-native starch, PS-pregelatinized starch, OS-oxidized starch, AS-acetylated starch.

Values are means of triplicate determinations.

Mean values followed by different alphabets are significantly ($p < 0.05$) different.

4. Conclusion

Native banana starch was characterized by relatively higher values of fat, ash, total starch, amylose, peak viscosity, trough, final viscosity, setback viscosity and *L** while native plantain starch was characterized by higher values of crude fibre, swelling capacity, solubility index, breakdown viscosity and peak time. Pre-gelatinization significantly increased the water and oil absorption capacities of banana and plantain starches. Pre-gelatinization and oxidation significantly improved emulsion ability of both banana and plantain starches. For weaning foods and similar products, where low viscosities are desired, modified banana and plantain starches would be preferred compared to the native forms. The relatively high total starch and amylose of the native starches suggests that they could be employed to give crunchy and crispy mouthfeel to extruded and fried snack products. Native and modified banana starches with their higher setback viscosity values than those of plantain starches suggests a lower tendency for retrogradation and so may be employed to reduce staling in baked products.

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References

Abbey, B. W., & Ibeh, G. O. (1988). Functional properties of raw and heat processed cowpea (*Vigna unguiculata*, walp) flour. *Journal of Food Science, 53*, 1775–1777. doi:10.1111/j.1365-2621.1988.tb07840.x

Adebowale, K. O., Adeniyi Afolabi, T., & Lawal, O. S. (2002). Isolation, chemical modification and physicochemical characterisation of Bambarra groundnut (*Voandzeia subterranean*) starch and flour. *Food Chemistry, 78*, 305–311. doi:10.1016/S0308-8146(02)00100-0

Adebowale, O. K., & Lawal, O. S. (2003). Functional properties and retrogradation behavior of native and chemically modified starch of Mucuna bean (*Mucuna pruriens*). *Journal of Science of Food & Agriculture, 83*, 1511–1516. doi:10.1002/jsfa.1569

Aina, A. J., Falade, K. O., Akingbala, J. O., & Titus, P. (2009). Physicochemical properties of twenty-one Caribbean sweet potato cultivars. *International Journal of Food Science & Technology, 44*, 1696–1704. doi:10.1111/j.1365-2621.2009.01941.x

Akubor, P. I. (1997). Proximate composition and selected functional properties of African breadfruit and sweet potato flour blends. *Plant Foods for Human Nutrition, 51*, 53–60. doi:10.1023/A:1007948400685

Alimi, B. A., Workneh, T. S., & Sibomana, M. S. (2016a). Effect of hydrothermal modifications on functional, pasting and morphological properties of South African cooking banana and plantain. *CyTA-Journal of Food, 14*, 489–495. doi:10.1080/19476337.2015.1137356

Alimi, B. A., Workneh, T. S., & Sibomana, M. S. (2016b). Effect of hydrothermal modifications on functional, pasting and structural properties of false banana (*Ensete ventricosum*) starch. *Food Biophysics, 11*, 248–256. doi:10.1007/s11483-016-9435-6

Association of Official Analytical Chemists. (1996). *Official methods of analysis* (15th ed.). Washington, DC: Author.

Bello-Pérez, L. A., Agama-Acevedo, E., Sánchez-Hernández, L., & Paredes-López, O. (1999). Isolation and partial characterization of banana starches. *Journal of Agricultural and Food Chemistry, 47*, 854–857. doi:10.1021/jf980828t

Bemiller, J. N. (1997).Starch modification: Challenges and prospects. *Starch - Stärke, 49*, 127–131. doi:10.1016/j.tifs.2008.10.003

Bourne, M. C. (1982). *Food texture and viscosity* (pp. 17–20). Cambridge: Academic Press.

Carvalho, A. V., García, N. H. P., & Amaya-Farfán, J. (2006). Physico-chemical properties of the flour, protein concentrate, and protein isolate of the cupuassu (*Theobroma grandiflorum Schum*) seed. *Journal of Food Science, 71*, S573–S578. doi:10.1111/j.1750-3841.2006.00156.x

De la Torre-Gutiérrez, L., Chel-Guerrero, L. A., & Betancur-Ancona, D. (2008). Functional properties of square banana (*Musa balbisiana*) starch. *Food Chemistry, 106*, 1138–1144. doi:10.1016/j.foodchem.2007.07.044

DuBois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 28*, 350–356. doi:10.1021/ac60111a017

FAOSTAT. (2016). Retrieved November 19, 2016, from Faostat3.fao.org/browse/Q/QC/E

Forssell, P., Hamunen, A., Autio, K., Suortti, P., & Poutanen, K. (1995). Hypochlorite oxidation of barley and potato starch. *Starch - Stärke, 47*, 371–377. doi:10.1002/star.19950471002

Guerra-DellaValle, D., Sanchez-Rivera, M. M., Zamudio-Flores, P. B., Mendez-Montealvo, G., & Bello-Perez, L. A. (2009). Effect of chemical modification type on physicochemical and rheological characteristics of banana starch. *Revista Mexicana de Ingenieria Quimica, 8*, 197–203. Retrieved from http://repositoriodigital.academica.mx/jspui/handle/987654321/86806

Guilbot, A., & Mercier, C. (1985). Starch. In G. O. Aspinall (Ed.), *Polysaccharides* (Vol. 3, pp. 209–282). New York, NY: Academic Press.

Hernández-Jaimes, C., Bello-Pérez, L. A., Vernon-Carter, E. J., & Alvarez-Ramirez, J. (2013). Plantain starch granules morphology, crystallinity, structure transition, and size evolution upon acid hydrolysis. *Carbohydrate Polymers, 95*, 207–213. doi:10.1016/j.carbpol.2013.03.017

Jane, J. (1995). Starch properties, modifications, and applications. *Journal of Macromolecular Science, Part A, 32*, 751–757. doi:10.1080/10601329508010286

Kaur, B., Ariffin, F., Bhat, R., & Karim, A. A. (2012). Progress in starch modification in the last decade. *Food Hydrocolloids, 26*, 398–404. doi:10.1016/j.foodhyd.2011.02.016

Kayisu, K., Hood, L. F., & Vansoest, P. J. (1981). Characterization of starch and fiber of banana fruit. *Journal of Food Science, 46*, 1885–1890. doi:10.1111/j.1365-2621.1981.tb04511.x

Kiin-Kabari, D. B., Sanipe, P., & Owuno, F. (2014). Physico-chemical and pasting properties of starch from three plantain cultivars grown in Nigeria. *African Journal of Food Science, 8*, 484–489. doi:10.5897/AJFS2014.1205

Kim, Y. S., Wiesenborn, D. P., Orr, P. H., & Grant, L. A. (1995). Screening potato starch for novel properties using differential scanning calorimetry. *Journal of Food Science, 60*, 1060–1065. doi:10.1111/j.1365-2621.1995.tb06292.x

Lawal, O. S. (2004). Composition, physicochemical properties and retrogradation characteristics of native, oxidised, acetylated and acid-thinned new cocoyam (*Xanthosoma sagittifolium*) starch. *Food Chemistry, 87*, 205–218. doi:10.1016/j.foodchem.2003.11.013

Lawal, O. S., Lapasin, R., Bellich, B., Olayiwola, T. O., Cesàro, A., & Yoshimura, M. (2011). Rheology and functional properties of starches isolated from five improved rice varieties from West Africa. *Food Hydrocolloids, 25*, 1785–1792. doi:10.1016/j.foodhyd.2011.04.010

Marriott, J., Robinson, M., & Karikari, S. K. (1981). Starch and sugar transformation during the ripening of plantains and bananas. *Journal of the Science of Food and Agriculture, 32*, 1021–1026. doi:10.1002/jsfa.2740321011

Miyazaki, M. R., Van Hung, P. V., Maeda, T., & Morita, N. (2006). Recent advances in application of modified starches for breadmaking. *Trends in Food Science & Technology, 17*, 591–599. doi:10.1016/j.tifs.2006.05.002

Noda, T., Tsuda, S., Mori, M., Takigawa, S., Matsuura-Endo, C., & Saito, K. (2004). The effect of harvest dates on the starch properties of various potato cultivars. *Food Chemistry, 86*, 119–125. doi:10.1016/j.foodchem.2003.09.035

Osundahunsi, O. F., Seidu, K. T., & Mueller, R. (2014). Effect of presence of sulphurdioxide on acetylation and sorption isotherm of acetylated starches from cultivars of cassava. *Food Chemistry, 151*, 168–174. doi:10.1016/j.foodchem.2013.11.020

Otegbayo, B., Lana, O., & Ibitoye, W. (2010). isolation and physicochemical characterization of starches isolated from plantain (*Musa paradisiaca*) and cooking banana (*Musa sapientum*). *Journal of Food Biochemistry, 34*, 1303–1318. doi:10.1111/j.1745-4514.2010.00354.x

Pelissari, F. M., Andrade-Mahecha, M. M., Sobral, P. J., & Menegalli, F. C. (2012). Isolation and characterization of the flour and starch of plantain bananas (*Musa parasidiaca*). *Starch - Stärke, 64*, 382–391. doi:10.1002/star.201100133

Ratnayake, W. S., Hoover, R., & Warkentin, T. (2002). Pea starch: Composition, structure and properties—A review. *Starch - Stärke, 54*, 217–234. doi:10.1002/1521-379X(200206)54:6<217::AID-STAR217>3.0.CO;2-R.

Sajilata, M. G., & Singhal, R. S. (2004). Specialty starches for snack foods. *Carbohydrate Polymers, 59*, 131–151. doi:10.1016/j.carbpol.2004.08.012

Sangseethong, K., Termvejsayanon, N., & Sriroth, K. (2010). Characterization of physicochemical properties of hypochlorite- and peroxide-oxidized cassava starches. *Carbohydrate Polymers, 82*, 446–453. doi:10.1016/j.carbpol.2010.05.003

Sathe, S. K., & Salunkhe, D. K. (1981). Isolation, partial characterization and modification of the great northern bean (*Phaseolus vulgaris* L.) starch. *Journal of Food Science, 46*, 617–621. doi:10.1111/j.1365-2621.1981.tb04924.x

Sosulski, F. W., Garratt, M. O., & Slimkard, A. E. (1976). Functional properties of ten legume flours. *Canadian Institute of Food Science and Technology Journal, 9*, 66–69. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US201303046604 http://dx.doi.org/10.1016/S0315-5463(76)73614-9

Tharanathan, R. N. (2005). Starch—Value addition by modification. *Critical Reviews in Food Science and Nutrition, 45*, 371–384. doi:10.1080/10408390590967702

Utrilla-Coello, R. G., Rodríguez-Huezo, M. E., Carrillo-Navas, H., Hernández-Jaimes, C., Vernon-Carter, E. J., & Alvarez-Ramirez, J. (2014). In vitro digestibility, physicochemical, thermal and rheological properties of banana starches. *Carbohydrate Polymers, 101*, 154–162. doi:10.1016/j.carbpol.2013.09.019

Vatanasuchart, N., Niyomwit, B., & Wongkrajang, K. (2012). Resistant starch content, *in vitro* starch digestibility and physico-chemical properties of flour and starch from Thai bananas. *Maejo International Journal of Science & Technology, 6*, 259–271. Retrieved from http://www.thaiscience.info/Article%20for%20ThaiScience/Article/62/10023839.pdf

Waliszewski, K. N., Aparicio, M. A., Bello, L. A., & Monroy, J. A. (2003). Changes of banana starch by chemical and physical modification. *Carbohydrate Polymers, 52*, 237–242. doi:10.1016/S0144-8617(02)00270-9

Wani, A. A., Singh, P., Shah, M. A., Wani, I. A., Götz, A., & Schott, M. (2013). Physico-chemical, thermal and rheological

properties of starches isolated from newly released rice cultivars grown in Indian temperate climates. *LWT-Food Science and Technology, 53*, 176–183. doi:10.1016/j.lwt.2013.02.020

Williams, P. C., Kuzina, F. D., & Hylinka, I. (1970). A rapid colorimetric method for estimating amylose content of starches and flours. *Cereal Chemistry, 47*, 411–421. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=US201301199916

Yasumatsu, K., Sawada, K., Moritaka, S., Misaki, M., Toda, J., Wada, T., & Ishii, K. (1972). Whipping and emulsifying properties of soybean products. *Agricultural and Biological Chemistry, 36*, 719–723. doi:10.1080/00021369.1972.10860321

Zhang, P., Whistler, R. L., BeMiller, J. N., & Hamaker, B. R. (2005). Banana starch: Production, physicochemical properties, and digestibility—A review. *Carbohydrate Polymers, 59*, 443–458. doi:10.1016/j.carbpol.2004.10.014

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