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Full Length Research Paper

An investigation into the feasibility of production and characterization of starch from "apantu" plantain (giant horn) grown in Ghana

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The aim of this research project is to develop a new product (plantain starch) as another way of extending the shelf-life of plantain and to determine the quality of plantain starch based on physicochemical properties, as well as, to determine whether plantain starch has unique characteristics compared to other sources of starch. Plantain starch was extracted from mature unripe plantain (*Musa sapientum*) of a variety known as "Apantu" (Giant horned). The parameters determined were; percentage starch yield (5.59), pH (4.82), percentage moisture (12.87), percentage ash (0.24), percentage amylose (27), and percentage water binding capacity (54.07). The percentage solubility and swelling (g/g) were 5.28 and 10.20 respectively. Pasting properties (on-set of gelatinization) were determined and the gelatinization temperature was determined to be 67.6°C, and had gelatinization time of 12.05 min, peak viscosity 677 BU, which corresponds to the maximum hydrated swollen volume fraction of starch granules. In addition, the paste stability of plantain starch at temperatures of 95 and 50°C were 66 and 22 Bu respectively. The starch obtained was of good quality with no unique pasting properties compared to other standard starch sources.

Key words: Plantain starch, *Musa sapientum*, Giant horned plantain, food product development, starch extraction, functional properties, Ghana.

INTRODUCTION

Plantain belongs to the genus *Musa* in the family Musaceae. Plantain (*Musa* spp. AAB group) are triploid {2n = 3x = 33, where x = 11} is a gaint perennial herb. It has a natural inter-specific crosses between the two wild species *Musa acuminate* colla which contributes genome A and *Musa. balbisiana* colla, which contributes genome B (Simmonds and Shepherd, 1955; Stover and Simmonds, 1987). It is believed that plantain originated from the hot tropical region of Southern Asia into the humid tropics of Western and Central Africa where some 116 named cultivars have been identified (Sweinen, 1990). It has a life span of about 15 years (Philips, 1982).

In Ghana, the two main cultivars are the "Apem" (French horned) and "Apantu" (Gaint horned). In Nigeria, there are the "Agbagba" (a medium false horned plantain), "Obino L'ewai" (medium French plantain) and "Big Ebanga" (a gaint false horned plantain) which are morphologically distinct. They differ in several features such as plant size, bunch orientation and bunch type. Although there is a big morphological diversity among plantain, there is poor genetic diversity as revealed by molecular markers (Tezenas du Montcel, 1987; Hemeng and Banful, 1993; Jarret and Gawel, 1995).

The chemical composition of plantain varies with variety, maturity, degree of ripeness and where it is grown (soil type). The water content in the green plant is about 61% and increases on ripening to about 68%. The increase in water is presumably due to the break down of carbohydrate during respiration. Green plantain contains starch which is in the range 21 to 26% (Jaffe et al., 1963; Marriott and Lancaster, 1983). The starch in the unripe plantain consist of mainly amylase and amylopectin and

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this is replaced by sucrose, fructose, and glucose during ripening due to the hydrolysis of fat. The carbohydrate content reduces to between 5 and 10% when ripe. The sugar content is 0.9 to 2% in the green fruit but is more prominent in the ripe state (Marriott et al., 1981; Marriott and Lancaster, 1983).

The protein content of unripe fruit is between 0.5 and 1.6% and no significant change in the ripening fruit has been detected. The amino acid component includes β-alanine amino-butyric acid, glutamine, aspagirine, histidine, serine, arginine, and leucine. The ascorbic acid content is high compared to banana.

The major change during the ripening process in both bananas and plantains is the conversion of starch to sugar. In unripe plantains, starch comprises over 80% of the dry weight of the pulp (Marriott et al., 1981). The two main components of this starch are amylose and amylo-pectin, present in a ratio of around 1:5. Sugars comprise only about 1.3% of the total dry matter in unripe plantain, but this rises to around 17% in the ripe fruit (Ogazi, 1996). During ripening, the sugars are in the approximate ratio of glucose, 20: fructose, 15: sucrose, 65. Only traces of other sugars are found (Sweinen, 1990).

The fat content of plantains is very low, less than 0.5% and so fats do not contribute to the energy content (Jaffe et al., 1963; Marriott and Lancaster, 1983). Although the total lipid content remains essentially unchanged during ripening, the composition of fatty acids, especially within the phospholid fractions has been observed to change, with a decrease in their saturation (Ogazi, 1996).

Plantain is grown in 52 countries with world production of 33 million metric tonnes (FAO, 2005). Plantain is an important staple crop, supplying up to 25% of the carbohydrates for approximately 70 million people in the humid zone of sub-Saharan Africa. Crops are grown mostly on small-scale farms, in backyards, or on farm lots of less than 0.5 hectares. A major problem of plantain and banana is that the fruits are highly perishable. At ambient tropical temperatures, plantain and banana have an average market life of 1 to 10 days, compared with several weeks for yam, for example. The difficulties associated with the short storage life of plantain are worsened by the marketing system. Locally, plantain constitute about 13% of the country's agricultural gross domestic product (SRID-MOFA, 2006; Zakpaa et al., 2010), and ranks third in volume of production among starchy staples and that Ghana is one of the top five largest producers in West and Central Africa . In the agricultural sector, plantain is ranked fourth in Ghana (FAO, 2005). Total annual national production is 2.00 million tonnes (SRID-MOFA, 2006) with per capita consumption of 101.8 kg (SRID-MOFA, 2006; FAO, 2005; Lescot, 2000). In Ghana, there are two main seasons: The glut and lean seasons. During the glut season, that is, late August to late April before the "Easter storms" set in, local markets are filled with vehicles laden with loads of the fruits from the remote or production centers (Zakpaa et al., 2010). The marketing system in Africa usually involves several retailers. Buying and selling takes time and leads to increased crop damage. Transport is often delayed, and can fail altogether, because of poor conditions of vehicles and roads. The environment within the market is also not suited to long-term storage. A com-bination of high perishability, high ambient temperatures, slow marketing systems, and poor market conditions leads to losses in fruit quality, and ultimately to post-harvest losses (Fagbohu et al., 2010). This situation is rather unfortunate and needs to be addressed critically if the interest of farmers in production is to be sustained. Technological improvement in methods for long term preservation could thus be ways of attending to this problem (Anon, 1991).

Researchers, therefore, look for ways to extend storage life (Zakpaa et al., 2010; Ogazi, 1996; Hemeng and Banful, 1993). Several methods can be used to extend storage life, for example, mature unripe plantain can be made to chips and sundried to reduce the moisture content to a barest minimal. This will discourage the growth of spoilage organisms (Fayemi, 1999). The most important physiological function affecting product quality during storage is respiration and transpiration. To extend storage life, these functions should be reduced. This can be done by controlling temperature, humidity, ventilation, and atmospheric composition during storage. However, the type of method employed should make economic sense. The longest average storage life so far recorded is six months under cool chain system. Although feasibility studies have been conducted, this system is very expensive to run under the peasant farming system in Ghana and the West African sub-region, since the farming areas are scattered without any proper records. Therefore, the aim of the research project is to develop a new product (plantain starch) as another way of extending the shelf-life of plantain and to determine the quality of plantain starch based on physicochemical properties, as well as, to determine whether plantain starch has unique characteristics compared to other sources of starch (Swinkels, 1985).

MATERIALS AND METHODS

Mature plantain fruits (maturity age of 3.5 months) were obtained from the CSIR (Center for Scientific and Industrial Research, Ghana), Crop Research Institute: Plantain Research Project, at Fumesua-Kumasi, Ghana. The cultivar was "Apantu" (Giant horn).

Methodology for the extraction of starch from plantain

The methods involved in the extraction of starch from plantain are given in Figure 1.

Determination of percentage starch yield

Starch yield of each extraction method was determined as percentage starch recovered after extraction from a weighted kilo-gram of sample. Starch samples obtained using the local method

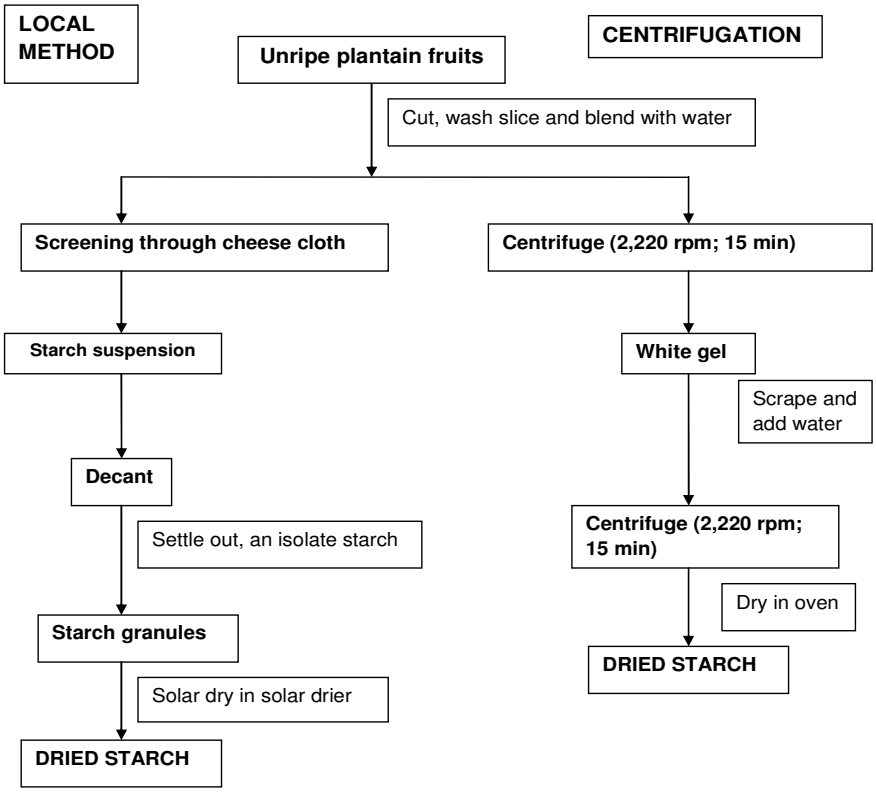

Figure 1. Flow diagram for extraction of plantain starch.

method was then subsequently used in the determination of the various physicochemical properties.

Determination of pH

2 g of the plantain starch was weighed and added to 20 ml of water in a volumetric flask. The mixture was shaken for 3 min and then filtered using a filter paper. The filtrate was then tested for acidity and alkalinity using a pH meter (Beckman Instruments, Fullerton CA).

Determination of percentage moisture

2.0 g of starch was accurately weighed into a previously dried and weighed glass crucible. This was placed in a controlled drying oven at 105°C for 5 h. The crucible was removed, cooled in a desiccator and weighed. The moisture content was then determined by the difference in weight and expressed as a percentage (AOAC, 1990).

Determination of swelling power and solubility

Swelling and solubility determinations were carried out based on modification on the method of Leach et al. (1959). One gram of the plantain starch was transferred into a weighed graduated centrifuge tube (50 ml). Distilled water was added to give a total volume of 40 ml. The suspension was stirred sufficiently and uniformly, avoiding excess speed to prevent fragmentation of the starch granules. The sample in the centrifuge tube was heated at 85°C in a thermostatically controlled water bath for 30 min with constant stirring. The tube was then removed, wiped dry on the outside and cooled to room temperature. It was then centrifuged for 15 min at 2,200 rpm. The solubility was determined by evaporating the supernatant and weighing the residue. The sediment paste was weighed and the percentage solubility and swelling power was then calculated.

Determination of percentage amylose and amylopectin in plantain starch

The amylose content of starch was determined based on the iodine colorimetric method described by McCready and Hassid (1943).

Preparation of standard curve for amylose

Different concentrations of pure amylose were prepared as follows: 10, 30, 50, 70 and 0 mg of pure amylose were weighed into separate 100 ml volumetric flasks and wetted with 1 ml of ethanol, 10 ml of distilled water and 2 ml of 10% NaOH was added. The flask with its content was heated in a water bath until a clear solution was formed. It was then cooled and diluted to the mark. 5 ml of this solution was measured into a 500 ml volumetric flask and about 100 ml of distilled water added and acidified slightly with drops of 6 M HCl. The flasks were then shaken to mix the contents and 5 ml of iodine solution was added and then made to the mark with distilled water. The absorbance of each standard solution was measured on the Ultraviolet light spectrophotometer (LKB Biochrom Ultrospec II, Model 4050, Cambridge, England) at 640 nm. Absorbance was plotted against percentage amylose. Linear regression analysis was carried out to derive an equation for the determination of percentage amylose.

Sample preparation for amylose determination

100 mg of plantain starch was introduced into a 100 ml volumetric flask, wetted with 1 ml of ethanol and 10 ml of distilled water was added, followed by 2 ml of 10% NaOH solution and heated in a water bath until a clear solution was formed. The flask with its content was cooled and diluted to the mark with distilled water. A 5 ml portion of the alkaline solution was introduced into a 500 ml volumetric flask and 100 ml of distilled water added and acidified slightly with 3 drops of 6 M HCl. The contents were well mixed by shaking the flask and 5 ml of iodine solution added and diluted to the mark with distilled water. The absorbance of the solution was read against a controlled solution, which contained no starch, with a UV spectrophotometer (LKB Biochrom Ultrospec II, Model 4050, Cambridge, England) at 640 nm. The concentration of amylose was determined using the equation derived from the standard curve.

Determination of water binding capacity

Water binding capacity of the plantain starch was determined in duplicate according to the method of Yamazaki (1953) as modified by Medcalf and Gilles (1965). An aqueous suspension of the starch was made by dissolving 2.0 g of starch in 40 ml of water. The suspension was agitated on a Griffin flask shake (Griffin and George limited, Great Britain), after which it was centrifuged for 10 min at 2,200 rpm. The free water was decanted from the wet starch, drained for 10 min and the wet starch weighed. The water binding capacity was then calculated.

Determination of pasting characteristics

The pasting characteristics of the plantain starch sample were determined using the Brabender visco-amylograph (Brabender OHG Duisburg, Kulturstrabe 51-55.D-4100 Duisburg 1). An aqueous suspension was made by dissolving 40.0 g of plantain starch on dry basis in 420 ml of distilled water. The suspension was heated at a rate of 1.5°C per min by means of a thermo regulator. When the suspension reached 95°C it was held constant for 20 min (first holding period) while being continuously stirred. The paste was then cooled down to 50°C at a rate of 1.5°C per minute and held at this temperature for another 20 min (second holding period). The following were read from the viscograph/amylogram obtained, pasting temperature, peak temperature, viscosity at 95°C, and viscosity after 20 min at 95°C, viscosity at 50°C, and viscosity after 20 min at 50°C. All analysis were carried out in triplicate. Statistical analysis (ANOVA) of data obtained was computed using Microsoft Excel 2007 Programme.

Determination of granule size and shape

The shape and size of the plantain starch granules were determined using the light microscope. The granules size was determined according to the method of MacMaster (1964). The measurements were made by means of a stage micrometer, eyepiece micrometer and measuring eyepiece. A small quantity of starch was spread on a slide and a drop of distilled water was added. A cover slip was carefully applied and sample observed under the microscope at 400× magnification for individual starch variety. The diameters of three granules were measured and the mean granule size calculated.

RESULTS AND DISCUSSION

The results of the determinations of the various parameters for plantain starch are presented in Table 1. The yields of starch from plantain were 4.5 and 5.59% for both local method and centrifugation respectively. This low yield could be attributed in part to the rather simple methods that were used in the extraction process. For example, it was difficult to sieve the starch through the cheese cloth and a considerable amount of starch still remained with the fibrous material that was discarded, the fine starch granules resulted in the loss of starch during the decantation process as they were resuspended in the washing water with the least disturbance. Starch comprise over 80% of the dry weight of the pulp (Ozaki, 1995), and it is hope that with the use of simple engineered machines this yield of starch could be improved by several folds.

Percentage moisture determines the water content of a material compound that volatilize under the same physical conditions as water would, and a low level ensures good shelf life. Moisture content of food or processed product gives an indication of its shelf life and nutritive values. Low moisture content is a requirement for long storage life. The moisture content of a fresh fruit is related to its dry matter content and therefore to the yield obtained from a particular crop or cultivar. The moisture value obtained was 12.75%, which falls within acceptable range of 10 to 13.5% (Onwueme, 1982) for good quality starch.

Ash content indicates presence of mineral elements in the sample and level of surface contamination. The value of 0.24% obtained for plantain starch is within the range for quality and pure starch.

Amylose levels in starches range between 21 to 30% (Michael, 1990). A value of 24.7% of amylose in plantain starch is within this range. Higher amylose levels are associated with mealiness, while a high amylopectin level increases pasting due to the tendency to hydrate. The 80% ethanol used extracted carbohydrates of lower molecular weight (amylose) and further treatment with hot water removed most of the amylose and dextrins leaving amylopectin as residue. Also during the experiment, ethanol and distilled water were added before the addition of 10% NaOH to ensure proper dissolution, so as to prevent formation of sticky precipitate between the sample and NaOH solution.

The pH of the plantain starch was determined to be 4.82, which falls within the acceptable range of 4.74 to 5.30 (Onwueme, 1982). The pH of a plant material plays an important role in the browning phenomenon, therefore lowering natural pH to about 4 will appreciably decrease the rate of browning. The use of mineral acid or phosphoric acid is advisable as it is more effective. No browning was observed during the processing of plantain starch because the extraction was done under water. However, sulfur dioxide (SO_2) gas can be used to prevent browning caused by enzyme tyrosinase which oxidizes the amino acid tyrosine into 3,4-dihydroxyphenyalanine and finally into brown melanoidin compounds.

Water binding capacity (WBC) is important in determining the quality and texture of some food products because

Table 1. Physicochemical properties of plantain starch.

Properties	Values obtained
pH	4.82 (at 30°C)
Moisture (%)	12.75 (± 0.410)
Ash (%)	0.24 (± 0.021)
Solubility (%)	5.28 (± 0.830)
Swelling power (%)	10.20 (± 0.054)
Water binding capacity (%)	54.07 (± 0.220)
Granule size (µm)	24.30
Amylose (%)	24.7
Starch yield (%)	4.53, 5.55

Table 2. Pasting properties of starch from various plant sources.

Starch sample	Pasting temperature (°C)	Peak viscosity (BU)
Potato	62.5	3000
Maize	77.5	600
Wheat	82.5	300
Cassava	50.9	966
Plantain	67.6	677

Source: Ciacco et al. (1997).

it stabilizes them against effects such as syneresis which sometimes occur during retorting and freezing (Wooten and Bamnuaruchi, 1978). The WBC of plantain starch obtained was 54.07%. WBC depends on the type of cultivar used, and environmental growing conditions; ultra-structural composition of starch molecules such as degree of association of amylose and amylopectin, degree of available water binding sites (OH groups and glucose oxygen atoms).

A good quality starch has low solubility and high swelling power, which is indicative of high paste stability on cooking (Swinkels, 1985). The experimental value obtained were solubility 5.28% and swelling power 10.20 gg^{-1}. The swelling behaviour of most starches significantly affects their end use. Swelling power depends on processing conditions such as temperature, time, stirring and centrifugation (Wooten and Bamnuaruchi, 1978). The low values obtained might be due to the formation of amylose-lipid complex which restricted solubilization. This is because as the temperature of the aqueous starch suspension is raised above the gelatinization range, hydrogen bonds continue to be disrupted; water molecules become attached to librated hydroxyl groups and the granules continues to swell. There is therefore a parallel increase in starch solubility as a direct result of granule swelling.

Starch granules contain many starch molecules and are birefrigent, indicating a high degree of internal disorder. Plantain starch granules obtained were very large (24.3 µm) thereby increasing swelling behaviour and also minor components of the starch granules affect the functional performance (pasting and gelling behaviour). Large starch granules tend to build higher viscosity, which is delicate because the physical size of the granule makes it more sensitive to shear.

Pasting characteristics depends on granule size and amylose content. Results from the various determinations on plantain starch indicated large granule size and low amylose content. Larger granules have a lower surface area to volume ratio and therefore the association between hydrogen bond and granules are very weak, hence enhanced swelling. They can also reassociate more easily which affect the retrogradation (setback) tendency. The value obtained for plantain starch was 415 BU.

The pasting temperature of plantain starch is 67.6°C and below this the starch is essentially insoluble in water. The value obtained for peak viscosity was 677 BU which corresponds to the maximum hydrated swollen volume fraction of the starch granules at the temperature of 91.4°C. Therefore further heating and swelling beyond this point results in rupture of granules which decrease viscosity and release macromolecules (basically amylose) into solution.

Conclusion

From ANOVA analysis of the comparison of plantain starch with those of other common plant starches (Tables 2 - 6), it was determined that there is no significant difference between plantain starch and the other starches ($F_{calculated}$ lower than the $F_{critical}$). Plantain starch from the

Table 3. ANOVA (single factor) for pasting property (peak viscosity) for plantain and cassava.

Source	Sum of squares	Df	Mean square	F-Ratio	P-value	F crit
Between groups	0.1225	1	0.1225	2.94E-06	0.998788	18.51282
Within groups	83434.345	2	41717.17			
Total (Corr.)	83434.4675	3				

Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Column 1	2	1643	821.5	41760.5
Column 2	2	1643.7	821.85	41673.84

Table 4. ANOVA (single factor) for pasting property (peak viscosity) for plantain and wheat.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-value	F critical
Between groups	0.09	1	0.09	21.27 E-06	0.999205	18.51282
Within groups	142279.88	2	71139.94			
Total (Corr.)	142279.97	3				

Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Column 1	2	977	488.5	71064.5
Column 2	2	977.6	488.8	71215.38

Table 5. ANOVA (single factor) for pasting property (peak viscosity) for plantain and maize.

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-value	F crit
Between groups	0.25	1	0.25	8.43 E-05	0.993507	18.51282
Within groups	5929	2	2964.5			
Total (Corr.)	5929.25	3				

Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Column 1	2	1277	638.5	2964.5
Column 2	2	1278	639	2964.5

Table 6. ANOVA (single factor) for pasting property (peak viscosity) for plantain and potato.

Source	Sum of squares	Df	Mean Square	F-Ratio	P-value	F crit
Between groups	0.202500001	1	0.2025	7.51E-08	0.999806	18.51282
Within groups	5396096.705	2	2698048			
Total (Corr.)	5396096.908	3				

Summary				
Groups	**Count**	**Sum**	**Average**	**Variance**
Column 1	2	3677	1838.5	2698165
Column 2	2	3677.9	1838.95	2697932

cultivar “Apantu” possess good physicochemical properties indicative of good quality starch with high potential for industrial use when compared to other sources of plant starches in common use.

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