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## FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

# Physicochemical characteristics and microbiological quality of senescent plantain products

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**Abstract:** Senescent plantains have relatively very rapid deterioration rate compared to plantains at other ripening stages. In Ghana, they are used for products which are consumed either as a snack or a main meal. This paper presents results of a study conducted in five regions of Ghana to investigate processing of senescent plantain products and evaluate their physicochemical characteristics and microbial quality. Survey data were collected on product types and processing methods. Freshly prepared products obtained from respondents were packaged in Ziploc bags and transported in a clean ice chest to the lab for physicochemical and microbial analyses. Samples were stored in the refrigerator (5°C) prior to analyses. Products made by respondents include *Apitsi* or *Apiti*, *Bodongo*, *Akankyie*, *Ofam*, *Kumaku*, *Agbetenya*; which were either baked or steamed. There were variations in cooking methods, time, type and quantity of ingredients used to produce these products. The products had relatively high moisture (47.63% – 68.42), appreciable crude fat (0.06% – 9.50%), crude protein (1.66% – 7.87%) contents and were good sources of energy (129.64 kcal/g – 241.19/g). The products were slightly acidic, with pH ranging from 4.53 to 5.38. Aerobic plate count, yeast and mold, coliform and *E. coli* ranged between <10 to  $1.7 \times 10^5$  CFU/g; 0 and  $3.9 \times 10^5$  CFU/g; 0 and  $1.5 \times 10^2$  CFU/g; and 0 and <10 CFU/g, respectively. The bacteriological quality of samples A to I are more superior than samples J and K. Product standardization is required.

**Subjects:** Microbiology; Nutrition; Food Chemistry

**Keywords:** senescent plantain; physicochemical composition; microbial quality; process variability; *Apiti*

### ABOUT THE AUTHOR

Doreen Dedo Adi is an early career scientist and a PhD candidate in the Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology. Her research focuses on value addition to food commodities with emphasis on indigenous traditional food, food processing and preservation and new product development.

### PUBLIC INTEREST STATEMENT

Overripe plantain products in Ghana are quite diverse. Processing of overripe plantain has become a means of reducing the postharvest loss of the fruit. Some of the products include *apiti*, *bodongo*, *ofam*, and *akankyie*. This study provides basic information on the processing methods of some indigenous foods from overripe plantain. Some food properties (physicochemical characteristics and microbial quality) of the products were also studied. The study indicated slight differences in the preparation of these traditional foods. The products were also generally safe for consumption. Research into indigenous African foods is necessary for their enhancement and shelf life stabilization to meet the needs of current sophisticated consumers.

## 1. Introduction

Plantain (*Musa paradisiaca* AAB) is an economically important food security crop especially in developing countries such as Ghana. With current production of over 3,500,000 tonnes per year, Ghana is currently the highest producer of plantain in West Africa and the third in Africa after Uganda and Rwanda (FAO, 2010; FAOSTAT, 2013). Over 90% of plantain cultivated in Ghana is by small-scale farmers growing the crop either for home consumption and/or for sale on the local market (Dzomeku, Dankyi, & Darkey, 2011; Frison & Sharrock, 1998). Plantain now contributes significantly (13.1%) to the Ghanaian Agricultural gross domestic product (AGDP) and is ranked third after yam and cassava (FAO, 2010; FAOSTAT, 2013). It is a very vital source of income for the rural folks, and its significance as a cash crop is increasing with increasing urbanization and utilization; impacting on the Gross National Product (GNP) (Frison & Sharrock, 1998; Hailu, Workneh, & Belew, 2013; Nkendah & Akyeampong, 2003).

Main cultivars of plantain in Ghana are classified as French horn plantain (*apempa*, *oniaba* and *nyeretia apem*), false horn plantain (*borodewuo*, *apantu pa*, *borode sebo* and *osoboaso*), or true horn plantain (*asamienu* and *aowin*). All these varieties are classified as triploids with the genomic group AAB (Ahiekpor, 1996; Hemeng, Banful, & Twumasi 1996). The most common of these varieties on the market are the *apantupa* (*apantu*), *apempa* (*apem*) and *oniaba*, cultivated mainly in the Eastern, Ashanti, Western, Brong Ahafo, Central and Volta regions of the country.

As yearly production quantities increase, so does its consumption with significant surplus quantities left, which need to be processed and/or exported (Dzomeku et al., 2011). Due to the perishable nature of plantain, it is mostly marketed and consumed immediately after harvest. Plantain can be consumed either unripe, semi-ripe, ripe, overripe and even at senescence with varying preparation methods which include frying, boiling, roasting, pounding, baking and steaming (Abiodun-Solanke & Falade, 2011; Séverin et al., 2013).

Fruit ripening is an irreversible phenomenon involving a series of biochemical, physiological, and sensory changes, culminating in the development of a soft edible product with desirable quality attributes in terms of colour, aroma, flavour and texture (Grierson, 1998; Singal, Kumud, & Thakral, 2012; Sogo-Temi, Idowu, & Idowu, 2014). When plantain fruit is harvested at the mature but unripe stage, it ripens within two to seven days (Abiodun-Solanke & Falade, 2011). This makes plantain a highly perishable crop. Its rate of perishability peaks at the overripe stage (Robinson, 1996). At maturity, the fruit goes through about 9 different stages of ripening (Dadzie & Orchard, 1997). Every ripening stage has its characteristic peel colour. At stages 1 and 2 the crop is all green (unripe); stage stages 3 to 5 (semi-ripe to ripe) there are varying mixtures of green and yellow colours; stages 6 and 7 the plantain is fully yellow; stage 8 the plantain starts developing flecks with shades of brown-black spots (overripe), and stage 9 with more black peels than yellow. Beyond stage 7, there is senescence, where there is rapid deterioration coupled with the growth of microorganisms as a result of drastic softening of the fruit tissue (Robinson, 1996). The rate of these colour changes is temperature dependent, and it affects the texture and sweetness of the plantain (Dadzie & Orchard, 1997; John & Marchal, 1995).

Senescent plantain is relatively cheaper on the market due to its high perishability. It is used in the preparation of a number of local dishes or snacks as a means of putting it to profitable use and reduce losses. The most common of these local dishes are *ofam*, *tatale* and *klaklo* and serve as means for value addition and subsequent shelf life enhancement. Dishes prepared from senescent plantain are quite well known in Ghana. But there is variability in senescent plantain products in terms of ingredients and cooking methods used, which will undoubtedly influence the product characteristics. In addition, the microbial safety of these products needs to be verified as moldy plantain are sometimes used in product formulation. Also, product preparation may be done under unsafe hygienic conditions. In order to improve the quality of senescent plantain products, it has become imperative to know the traditional processing parameters and the product characteristics. This will form the basis for future optimization of the process and subsequent shelf-life extension of these products.

The objective of this study was to determine the processes in making senescent plantain products and evaluate their physicochemical characteristics and microbial quality.

## 2. Materials and methods

### 2.1. Sample source

Senescent plantain products were obtained from producers across Ghana (viz., Eastern region—Odumase; Western region—Effikuma; Central region—Brafo Yaw; Eguase and Moree junction; Ashanti region—Akropong and Kumasi; Brong-Ahafo—Berekum). These regions were selected because they are the major areas of plantain production in the country. The snowball sampling technique (Johnson, 2005) was used for the selection of respondents who produce senescent plantain products for sale. One respondent was selected per town. They were interviewed on the types of senescent plantain products they produce, and their respective processing methods. Freshly prepared products, which were collected from respondents hot (90°C) were packaged in Ziploc bags and transported within 4 h in clean ice chests to the lab for physicochemical and microbial analyses. Samples were stored in a refrigerator at 5°C prior to analyses. Sample names with their respective codes and sources are presented in Table 1.

### 2.2. Source of raw materials

Plantain was obtained unripe, either from farm gates or local markets and stored in sacks to ripen and soften. The false horn plantain cultivar locally known as *apantu* was the main plantain cultivar used by the respondents, although the French horn and *apem* cultivars may be added when available. Items and/or ingredients such as leaves of the Miracle berry plant (*Thaumatococcus daniellii*), corn, cassava flour (*kokonte*), spices, onion and palm oil were all procured from local markets close to the respondents.

### 2.3. Processing methods

Processing methods were generally similar with slight variations. Generally, the products were prepared through the following unit processes chronologically: Procurement of unripe fruits, ripening, washing, peeling, pureeing, mixing, packaging and cooking. The differences in the processing methods were the pureeing and cooking methods used. In processing method I, the plantain was pounded to obtain a puree and was cooked by steaming. Products obtained by processing method II were also pounded but baked, while products prepared from processing method III were pureed using a disc attrition mill and cooked by baking. Ingredients used for the various samples are presented in Table 1 and a process flow diagram is shown in Figure 1. Unfermented corn dough was processed by steeping dried corn for about 24 h, washing and milling with a commercial disc attrition mill. The oven temperature ranged between 180 and 220°C.

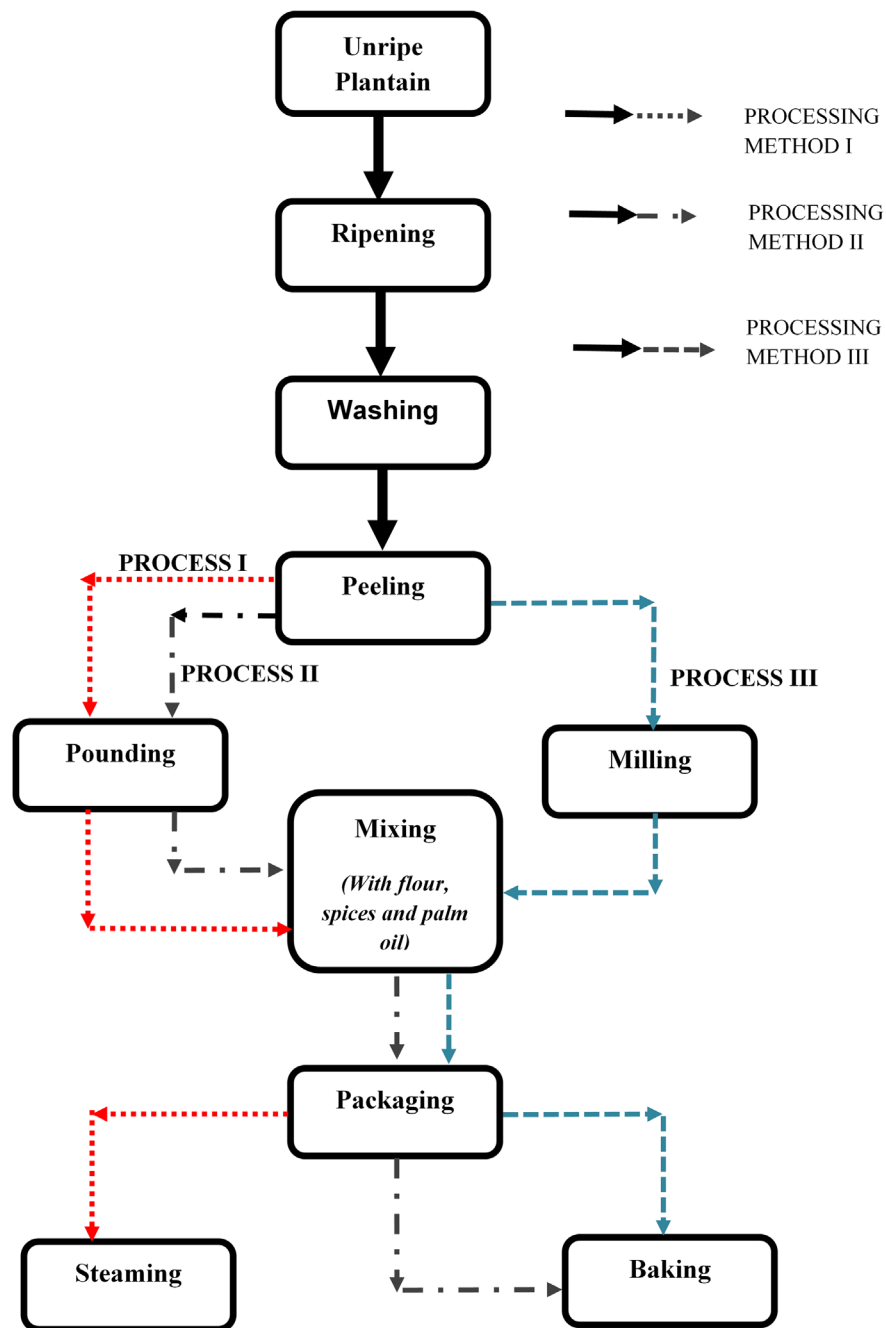
### 2.4. Chemical analysis

The moisture content of the sample was determined using a thermostatically controlled oven (OV-169, Gallenkamp, U.K) at 105°C for 24 h, according to AOAC method 925.10 (AOAC, 1990). Crude Protein content of the sample was determined by the Kjeldahl method (AOAC, 1990). Crude fat was determined by the Soxhlet extraction method, using petroleum ether as the extraction solvent (AOAC, 2000). The total ash content was determined by the dry ashing method (AOAC, 2000) and it entailed weighing two grams (2 g) of the samples into porcelain crucibles and incinerating the samples in a Muffle furnace (Carbolite, 3216/P1P5, Thermal Engineering Services, U.K) preheated to 600°C for 2 h. Total carbohydrate was determined by the difference method which involved adding the total values of crude protein, lipid, moisture and ash constituents of the sample and subtracting it from 100. The energy value was calculated as the sum of the mean protein, fat and carbohydrate values multiplied by their respective Atwater factors 4, 9 and 4 (Osborne & Voogt, 1978).

**Table 1. Sample codes for various senescent plantain products from selected regions and towns listing the ingredient and processing methods**

Region	Town	Sample name	Sample code	Ingredient	Processing method
Central	Eguase	Apitsi	A	Plantain puree, unfermented corn dough, onion, pepper, palm oil salt	I
	Moree Junction	Apitsi	B	Plantain puree, unfermented corn dough, onion, pepper, palm oil salt	I
		Apitsi	C	Plantain puree, unfermented corn dough, onion, pepper, salt	I
Western	Effikuma	Apitsi	D	Plantain puree, unfermented corn dough, onion, pepper palm oil salt	I
		Bodongo	E	Plantain puree, unfermented corn dough, onion, pepper, ginger, palm oil, salt	I
Brong-Ahafo	Brekum	Apiti	F	Plantain puree, unfermented corn dough, onion, pepper, palm oil salt	I
		Apiti	G	Plantain puree, kakonte, onion, pepper, palm oil, salt	I
		Ofam	H	Plantain puree, kakonte, onion, pepper, palm oil, salt, ginger	I
Ashanti	Akropong	Akankye	I	Plantain puree, kakonte, onion, pepper, palm oil, salt, ginger	II
	Kumasi	Apiti	J	Plantain puree, unfermented corn dough, onion, spring onions, pepper, palm oil, salt	III
Eastern	Odumase (Mampong)	Agbetenya	K	Plantain puree, Kakonte and salt	II

Figure 1. Process flow diagram for different types of senescent plantain products.



### 2.5. pH Determination

This was done by homogenizing ten grams (10 g) of the sample in 100 mL of distilled water. The mixture was allowed to stand for 10 min after which it was filtered through a cheesecloth. The pH of the filtrate was determined using the Super Scientific pH meter (840087, Taiwan) (AOAC, 2000).

### 2.6. Total soluble solids

Ten grams (10 g) of the sample was homogenised in 100 mL of distilled water and filtered. A drop of the filtrate was placed on the prism of hand refractometer (RHB-32ATC, Westover, USA) and reading for the total soluble solids was taken (Dadzie & Orchard, 1997).

## 2.7. Microbial analysis

All microbial analyses were conducted in accordance with AOAC methods (AOAC, 2000). One gram (1 g) of the sample was homogenised with 9 mL saline peptone water in a stomacher bag for 30 s. A serial dilution of  $10^{-1}$  to  $10^{-6}$  was prepared. All plating was done by the pour plate method.

Aerobic plate count (APC) was performed using AOAC method 990.12. One mL (1 mL) aliquots of each serial dilution were pipetted into sterile petri dishes having a label corresponding to the dilution. To each dilution in the sterile petri dish, 15 mL of molten PCA media were added to cover the base of the petri dishes. The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. Plates were incubated (Thermo SR 3000, Fisher Scientific, France) at 37°C for 24 h.

Yeast and mold count (YMC) was determined by AOAC method 995.21. To each dilution in the sterile petri dish, 15 mL of molten Oxytetracycline—Glucose Yeast Extract agar (OGYE) were added to cover the base of the petri dishes. The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. All plates were incubated at 25°C for 3–5 days.

Total coliforms and *E. coli* were simultaneously measured by AOAC method 983.25. To each dilution in the sterile petri dish, 15 mL of molten tryptone soya agar were added to cover the base of the petri dishes. The petri dishes were swirled clockwise and anticlockwise to ensure uniform mixing and allowed to set. This was followed by addition of Violet Red Bile Agar which was also allowed to set after clockwise and anti-clockwise swirling. Plates were incubated at 37°C for 24 h. Colonies between 50 and 150 which looked dark purple with clear zones around them were counted.

As confirmatory tests, five suspected colonies were picked randomly into a test tube containing already sterilised Brilliant Green Bile Broth and incubated at 37°C for 24 h. Test tubes that showed gas production were certified as positive for coliforms. About 0.1 mL of broth from tubes that tested positive for coliforms were transferred into a Violet Red Bile broth (*E. coli* broth). Covas reagent was added and incubated at 44°C for 24 h. Tubes that showed red rings were marked as positive for *E. coli*

## 2.8. Data analysis

Analysis of variance (ANOVA), and mean separations were conducted using SPSS (version 21). Significant differences were determined at  $p < 0.05$ . Sigma Plot (version 12) was used in the graphical representations.

## 3. Results and discussion

### 3.1. Description of senescent plantain products

#### 3.1.1. Source and nature of plantain used

It was observed that all respondents obtained their plantain unripe. The plantain was ripened in covered sacks at ambient room temperature, which, according to the respondents creates a conducive atmosphere for rapid ripening. This ripening method was consistent with what was used by indigenous banana and plantain sellers (Ajayi & Mbah, 2007). In these studies, ripening was not aided by ripening agents including carbide and old batteries which are potential sources of heavy metals such as lead as reported for previous studies (Sogo-Temi et al., 2014). Respondents indicated that the plantains were removed from sacks at the semi-ripe stage (Stages 5 and 6) and allowed to continue ripening up to stage 7 and beyond for usage. A marginal variation was observed in the nature of the plantain used for the products, which ranged between stage 8 and 9 according to the banana ripening chart (Dadzie & Orchard, 1997). The ripening duration depends on the maturity at harvest, but it was reported to range between 4 to 9 days. All respondents indicated that they did not use rotten or moldy plantain.

### 3.1.2. Indigenous names of senescent plantain products

There are different indigenous names given to senescent plantain products in Ghana. Respondents from the various regions indicated different products with their indigenous names; these include *apiti* (Ashanti and Brong Ahafo regions), *akankyie* (Ashanti and Brong Ahafo regions), *ofam* (Ashanti and Brong Ahafo regions), *apitsi* (Central and Western regions) and *bodongo* (Western region). Products such as *agbetenya*, *kumaku*, *akpiti* and *kwadaa mamu* were all mentioned by the Eastern regional respondents. All the products were either baked or steamed (Table 2) with the exception of *kwadaa mamu* which is dried, milled and reconstituted into a thick paste for consumption.

### 3.1.3. Processing variability

There were four main sources of variation in the samples under study; the type and quantity of flour used, the addition of spices and other ingredients, the cooking method used and the size reduction method used to obtain a smooth plantain paste. There were no variations in the variety of plantain used by the respondents. The main plantain variety used by the respondents was the *apantu*. However, this variety is mixed with *apem* when available (in season). *Apantu* is mostly preferred because, it has a higher pulp to peel ratio, and hence it gives a better yield than *apem*. It is noteworthy that a respondent indicated that, products become dark when too much *apem* is used.

**Table 2. Types of senescent plantain products, cooking methods and ingredients used in five regions**

Product name	Language	Region	Cooking method	Type of flour used	Other ingredients added
<i>Apiti</i>	Twi	Ashanti	Baking (in <i>Thaumatococcus daniellii</i> leaves)	Unfermented Corn dough	Onion and/or spring onion (optional)
				Kokonte	Pepper (optional)
					Palm oil (optional)
	Salt				
<i>Apitsi</i>	Fante	Central and Western	Baking (in <i>Thaumatococcus daniellii</i> leaves)	Unfermented Corn dough	Onion and/or spring onion (optional)
					Pepper (optional)
					Palm oil (optional)
	Salt				
<i>Bodongo</i>	Fante	Western	Baking (in <i>Thaumatococcus daniellii</i> leaves)	Unfermented Corn dough	Onion, pepper, ginger, palm oil, salt
<i>Ofam</i>	Twi	Ashanti	Baking (in baking tins)	Kokonte	Onion, pepper, ginger, palm oil, salt
<i>Akankyie</i>	Twi	Ashanti Brong—Ahafo	Steaming (in <i>Thaumatococcus daniellii</i> leaves)	Kokonte	Onion, pepper, ginger, salt
<i>Agbetenya</i>	Damgbe	Eastern	Steaming (in either fresh or dried plantain or banana leaves)	Kokonte	Salt
<i>Kumaku</i>	Damgbe	Eastern	Steaming (in <i>Thaumatococcus daniellii</i> leaves)	Cornmeal (akple flour)	Salt
<i>Akpiti</i>	Damgbe	Eastern	Baking (in <i>Thaumatococcus daniellii</i> leaves)	Roasted corn flour	Pepper, palm nut extract or palm oil, salt
<i>Kwadaa mamu</i>	Damgbe	Eastern	Dried and milled into flour	Roasted corn flour	Pepper, ginger, cloves

#### 3.1.4. Type and quantity of flour used

The types of flour used for the products were unfermented corn dough, cassava flour (*kokonte*) and roasted corn flour. *Apiti* (Twi), *apitsi* (Fante) and *bodongo* were predominantly mixed with unfermented corn dough. However, some *apiti* producers used cassava flour (*kokonte*). *Ofam*, *akankyie* and *agbetenya* were also mixed with cassava flour. While some respondents used cassava flour for *ofam*, others used wheat flour to formulate the product. Roasted corn flour was used in the processing of *akpitsi* and *kwadaa mamu*. There were also variations in the quantity of flour added to the mixture (Table 2).

The addition of cassava flour in baked products of acceptable sensory qualities has been widely reported. They are used mostly in composite with wheat flour, with up to 30% substitution level producing baked products of acceptable sensory quality (Eddy, Udofia, & Eyo, 2007; Eduardo, Svanberg, Oliveira, & Lilia, 2013; Falade & Akingbala, 2008; Gan et al., 2006; Sanful & Darko, 2010).

Corn flour has also been used in the formulation of *dockounou* (Flore, Rose-Monde, Severin, & Sebastein, 2013) an Ivorian dish similar to *Apitsi*. But the use of corn dough and roasted corn flour in the Ghanaian equivalent may contribute to significant variations in their sensory and physicochemical properties.

The flour added to the mixture serves as a source of starch which helps to form the structure of the product. The type of flour used has an effect on the texture of the finished product (Lii, Tsai, & Tseng, 1996). This is because these different flours have different starches and variations in granule sizes, amylose and amylopectin contents, which determine their cooking behaviour (Fredriksson, Silverio, Andersson, Eliasson, & Åman, 1998). The amylose content of maize has been reported to be more than that of cassava (Bolade & Adeyemi, 2012). Studies on consumer sensory (textural) preferences of these products will form a basis of how much of which type of flour will produce the best product.

#### 3.1.5. Addition of other ingredient

All respondents used onion, pepper and salt to season their products. These seasonings were used too to enhance the taste and aroma (flavour) of their products. Producers of samples E, H and I added ginger in addition to the onion, pepper and salt. Ginger is a common root spice used in Ghana. It is normally used for spicy products. The essential oils present in ginger have been found to have anti-microbial effect, helping in food preservation. A study by Adesokan, Abiola, and Ogundiya (2010) indicated that incorporation of 5% ginger into *ogi* (a Nigerian maize pap) significantly improved on the sensory attributes and product shelf life stability. The overall spiciness of the product is dependent on the type and quantity of spices used. This implies that samples E, H and I may taste better than the rest of the samples for consumers who prefer spicy products. According to the respondents, other spices such as African pepper (*Xylopiya aethiopica*), calabash nutmeg (*Monodora myristica*) and cloves (*Syzygium aromaticum*) may be added by choice. Sample K did not have any form of seasoning at all. This sample may be ideal for consumers who do not like spicy products or have to refrain from spices for health reasons. The presence of palm oil in the products will play a very important sensory role in giving the product a tender bite, moist mouthfeel and lubricity (Stauffer, 2005).

#### 3.1.6. Pulp crushing method

There were two pulp crushing methods used; pounding in a traditional mortar and milling with the disc attrition mill. With the exception of sample J, all the other samples were pounded. The size reduction method used influences the consistency of the paste produced (Fellows, 2000). Size reduction of the senescent plantain pulp is essential so as to obtain similar particle sizes with flour and all other ingredients used for effective mixing. The size reduction also affects the texture of the final product (Fellows, 2009).



The cleanliness of the mortar used may also compromise the microbial safety of the product. According to Sinayobye and Saalia (2011), the main challenges with the use of the disc attrition mill are microbial and chemical contamination. The microbial load of the samples, however, may subsequently be reduced by the cooking (baking or steaming) step.

### 3.1.7. Packaging material used

The leaves of *Thaumatococcus daniellii* were mainly used to wrap the formulated products for cooking. Only one respondent used plantain leaves (Table 2). It was indicated that both fresh and dried plantain leaves could be used, subject to availability. *T. daniellii* leaves have been traditionally used as packaging material in Ghana. Aside *apiti*, it is also used in packaging ready-to-eat foods such as *waakye*, rice and stew, *akyeke* and *abolo*, imparting some peculiar flavour characteristics to these products.

Although these packing materials have been the primary and traditional choice, it is not likely to attract Peri-urban consumers with the increasing quest for ready-to-eat and minimally processed products. Furthermore, the leaves which serve as a containment lacks the ability to protect the product from environmental conditions which facilitate food contamination and spoilage.

### 3.1.8. Cooking method and time

The main cooking method used by the respondents were baking and steaming. This was different from the work of Flore et al. (2013) where most senescent plantain producers boiled their products. The duration of cooking ranged from 45 min to 2 h 30 min. All the respondents indicated that they used the aroma of the products as a determinant of their readiness. These differences in cooking time may be as a result of the type and quantity of flour that is added to the mixture and also the cooking temperature (especially for the baked products). The baking temperature will determine the chemical reactions that are likely to take place in the food that impacts flavour development. According to Kroh (1994), caramelization occurs in sugar-containing foods which are exposed to a baking temperature of more than 120°C or at pH above 9 and below 3, whereas Maillard reaction occurs at above 50°C and pH ranging between 4 and 7. However, colour and flavour development is more intense in Maillard reaction products compared to caramelisation.

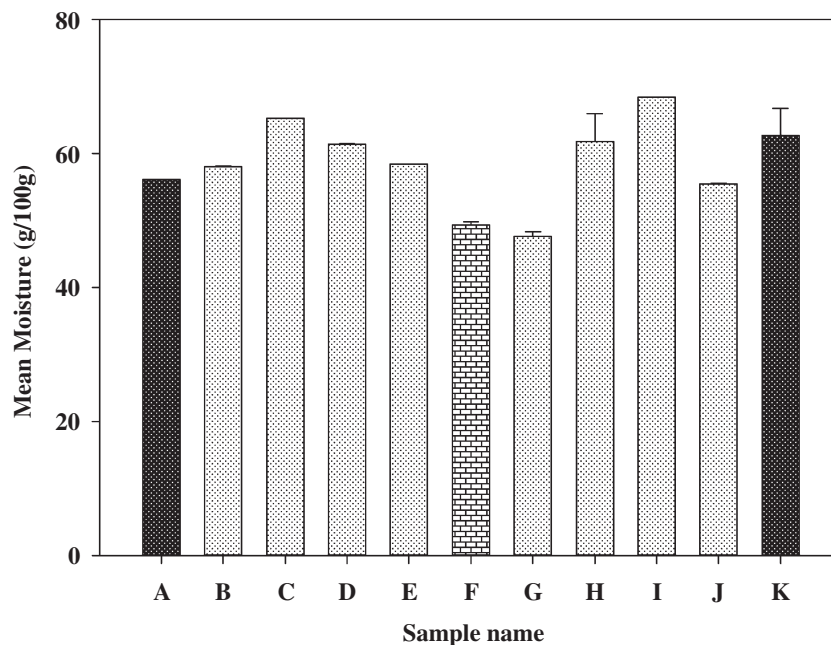
## 3.2. Chemical analysis

### 3.2.1. Moisture content

There was high variability in the moisture contents of the samples analysed ( $p < 0.05$ ), ranging from 47.63% (G—a baked sample) to 68.42% (I—a steamed sample). Statistically, the difference in the moisture contents of samples F and G was not significant, likewise samples A, B, D E and J ( $p > 0.05$ ) (Figure 2). The variation in the moisture contents of the samples may be attributed to differences in the processing method. It expected that steam products have higher moisture contents than their baked alternatives. The high moisture values recorded for the products suggest they may be highly perishable and have low shelf stability (Belitz, Grosch, & Schieberle, 2009). The mean moisture contents of perishable food items such as unripe plantain (65%) cooked beef (62%), chicken (62%), cooked rice (65–66%), *Ga kenkey* (64.5%), *Fante kenkey* (65–69%), and *abolo* (63–64.6%), are comparable to the mean moisture values recorded for products C, D, H, I and K (Sanni, Kolawole, Akingbala, & Kuye, 1999; Watson, 1971). The results are also comparable to both boiled (67.68%) and baked (60.40%) *dockounou* (also a derivative from senescent plantain) (Séverin et al., 2013). The perishability of food contributes to the choice of preservation methods such as drying, canning, freezing, etc., to give shelf life stability. Even though the moisture contents of the products were relatively high and their shelf life unstable, they served as a basis for reconstitution when such products are processed into powdered mixes.

The moisture contents of foods serve as an appropriate heat transfer medium for cooking the samples which are either baked or steamed. The high temperature at which the samples are baked or steamed converts the liquid water into steam which leavens the products upon escaping

**Figure 2. Mean moisture contents of senescent plantain products.**



(McWilliams, 2011; Potter & Hotchkiss, 2012). Being predominately a carbohydrate food with a significant amount of starch (FAO, 2012), the relatively high mean moisture content of the samples will enhance gelatinisation. The distribution of moisture in foods has been reported to affect starch gelatinisation (Altay & Gunasekaran, 2006). Inadequate moisture content may influence the distribution of raw and gelatinised starch in the samples which may have also have an effect of the sensory acceptability of samples. For example, according to research by Daomukda, Moongnarm, Payakapol, and Noisuwan (2011), the amount of water used in cooking brown rice had an effect of the degree gelatinisation, hardness, chewiness and cohesiveness of the product.

A relationship between moisture content and the texture of food has been established (Blahovec, 2007). For the samples evaluated, the moisture content may influence the moistness, hardness and mouthfeel. The relatively higher moisture contents of the samples also indicate low dry matter content.

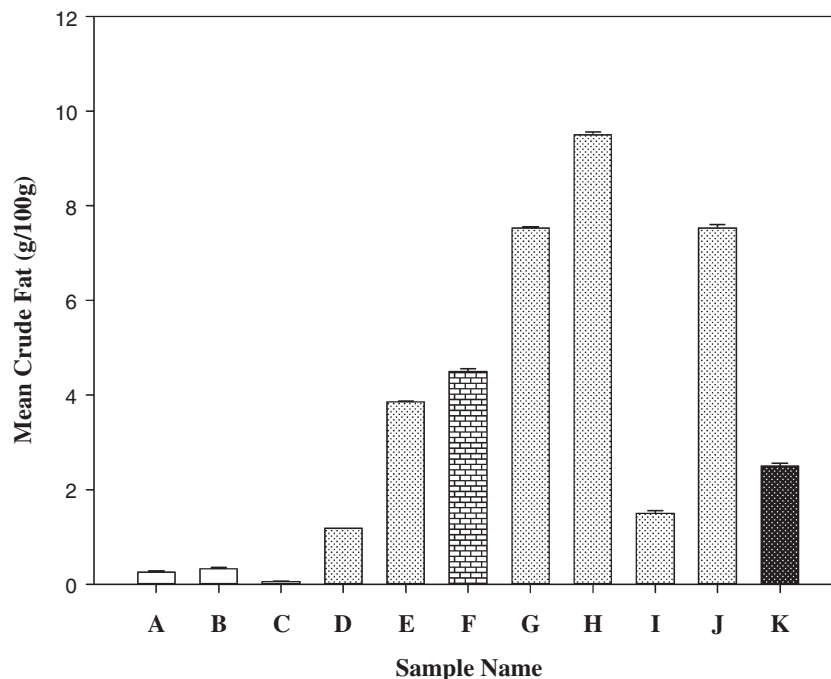
### 3.2.2. Crude fat content

The crude fat content of the samples ranged between 0.06% (Sample C) and 9.50% (Sample H) (Figure 3). The wide variations in the crude fat content of the senescent plantain products is an indication of the variability of the amount of palm oil added. Sample H, G and J have relatively higher mean fat contents since more palm oil was added. The addition of the palm oil does not only influence the colour of the product but also makes the product more tender (Fellows, 2009). The palm oil present in the samples will be a good source of antioxidants for consumers, i.e. carotenoids and Vitamin E (Chow, 1992). Even though palm oil has high saturated fatty acids, moderate consumption is not harmful to consumers (Imoisi, Ilori, Agho, & Ekhator, 2015). It is noteworthy that the palm oil in the presence of moisture may also predisposes the samples to both oxidative and hydrolytic rancidity. The variability in the crude fat content of the samples was statistically significant ( $p < 0.05$ ) with the exception of samples G and J which had the same crude fat contents.

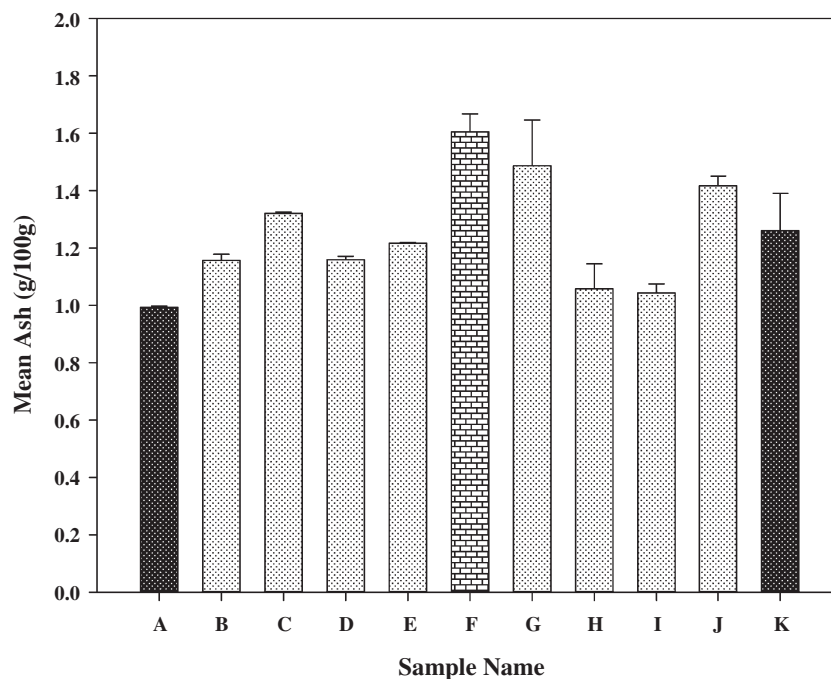
### 3.2.3. Total ash content

The total ash contents of the samples ranged from 0.99% to 1.6% (Figure 4). The total ash content of the samples is the indication of their mineral content. The ash content of sample A was comparable to instant plantain flour (0.98%) (Adegunwa, Adebowale, Bakare and Ovie, 2014), boiled plantain

**Figure 3. Mean crude fat contents of senescent plantain products.**



**Figure 4. Mean ash contents of senescent plantain products.**



(1.10%), and baked plantain (0.99%) (Séverin et al., 2013). However, the other samples (samples B–K) recorded relatively higher values similar to fermented banana products (1.34%–1.46%) samples analysed (Ayo-Omogie & Ogunsakin, 2013). Minerals such as potassium, magnesium and phosphorus are reported to constitute the majority of the total mineral contribution of plantain and banana (Ayo-Omogie, Adeyemi, & Otunola, 2010; Mohapatra, Mishra, & Sutar, 2010; Zakpaa, Al-Hassan, & Adubofour, 2010). The variability of the ash content of the samples under study was significant ( $p < 0.05$ ). This could be due to the differences existing in the types and quantities of ingredients used.

### 3.2.4. Crude protein content

The mean protein values ranged from 1.66% (samples D and E) to 7.87% (Samples F) (Figure 5). There was wide variability in the mean crude protein values of the samples ( $p < 0.05$ ). Crude protein values of 2.6% have been recorded for soft ripe plantain by Onwuka and Onwuka (2005). The variation of the protein content of the samples from that of soft ripe plantain could be as a result of the differences in the other ingredients used. The pulp protein of plantain has amino acids such as arginine, aspartic acid, glutamic acid, methionine, tryptophan and cysteine (Ketiku, 1973). The presence of these amino acids is important for the Maillard browning reactions which occur in food. However, Maillard reaction leads to reduction of amino acid availability and protein digestibility (Corzo-Martinez, Corzo, Villamiel, & Dolores Del Castillo, 2012).

Protein contents of samples A, B, C and D were fairly comparable to values recorded for dessert banana (2.2%), ripe *apem* flour (2.6%), unripe *apem* (2.19%) (Dzomeku, Bam, Abu-Kwarteng, & Ankomah 2006; Mohapatra et al., 2010; Zakpaa et al., 2010). The protein contents recorded for samples F, G, H, I, J and K were comparable to some *Dioscorea sp* (Agbor-Egbe & Treche, 1995; Opatá, Asiedu-Larbi, Ellis, & Oduro, 2009; Wanasundera & Ravindran, 1994). The relatively low protein content of the samples makes their consumption with roasted groundnuts (which is high in protein—about 26%), nutritionally appropriate to meet the protein needs of consumers.

### 3.2.5. Carbohydrate

Sample H recorded the lowest carbohydrate content (19.74%) whereas sample A recorded the highest (40.46%) (Figure 6). The variations in samples B, C, D, E, F, G were not statistically significant ( $p > 0.05$ ). The carbohydrate contents of these samples are comparable to dried African locust beans (33.00%), raw cassava tuber (35.60%), and boiled cassava tuber (37.4%), while the carbohydrate content of sample H is comparable to raw taro tuber (19%) and boiled taro tuber (20%) (FAO, 2012). These relatively high values are to be expected since the main ingredients used for the preparation of the samples (i.e. flours and plantain) have carbohydrate as the chief nutrient (FAO, 2012). Thus, the plantain products are good sources of energy like other carbohydrate-based foods.

### 3.2.6. Energy content

A significant amount of energy (calories) were obtained, ranging from 129.64 kcal/100 g to 241.19 kcal/100 g (Figure 7). The wide variations in the caloric value of the products may be attributed to the variations in the type and quantity of flour used as well as the amount of palm oil added

**Figure 5. Mean crude protein contents of senescent plantain products.**

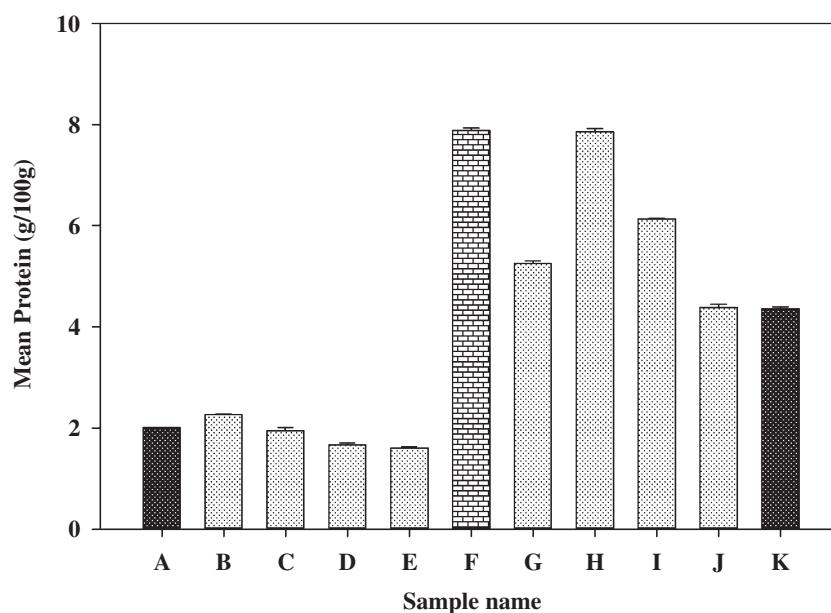


Figure 6. Mean carbohydrate contents of senescent plantain products.

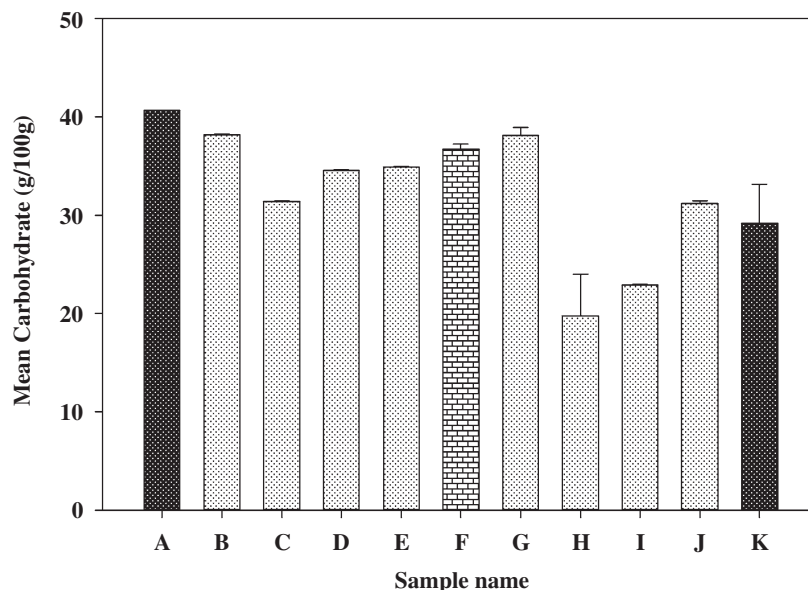
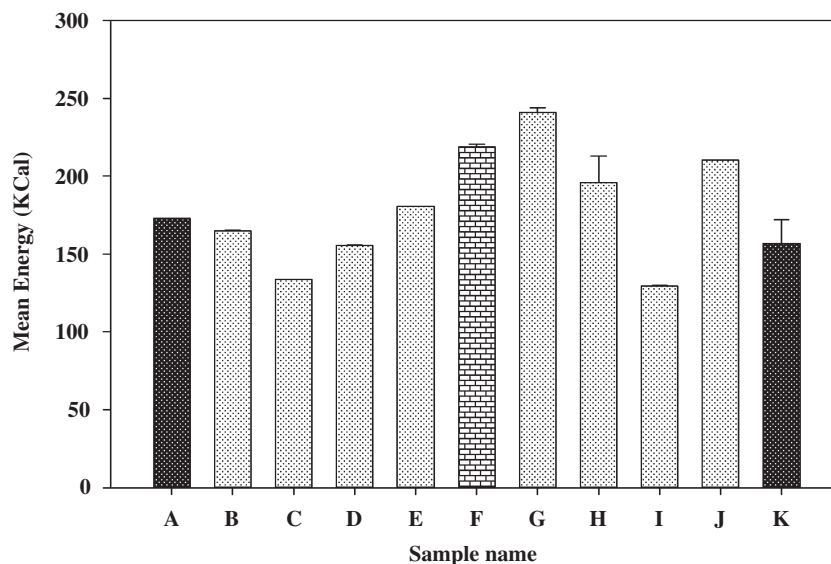


Figure 7. Mean Energy values of senescent plantain products.



to the samples. The energy values recorded for these samples indicate that they can be a good source of energy for consumers

3.2.6.1. *Total soluble solids.* The total soluble solid content of the samples is an indication of the total dissolved solids in the samples (Magwaza & Opara, 2015). Sample J recorded the lowest total soluble content of 1%. Samples A, B, C, D and E recorded total soluble solids contents of 1.5% (Table 3). The sample with the highest total soluble content was sample I with a value of 2%. The variability in the total soluble content of the samples was statistically significant ( $p < 0.05$ ).

3.2.6.2. *pH.* The food samples were slightly acidic with pH values of 4.53 to 5.38 (Table 3). The variation in the pH of the samples was statistically significant ( $p < 0.05$ ). The slightly acidic nature of the products combined with the presence of sugars will enhance Maillard browning and caramelization reactions in the products (Kroh, 1994), which are important for colour and flavour development.

3.2.6.3. *Microbial quality of samples.* The total bacteria count of the samples ranged from less than 10 CFU/g to  $1.7 \times 10^5$  CFU/g for samples A–E and samples J. The mold count ranged from <10 CFU/g for samples A–E to  $3.9 \times 10^5$  CFU for sample J. The total coliforms present in samples A, B, C, D, and E were less than 10 CFU/g. Samples I and J recorded coliform counts of  $1.3 \times 10^1$  and  $1.5 \times 10^2$  respectively. Coliforms were not detected in samples F, G, H, and K (Table 4). Enterobacteriaceae which includes coliforms should not be more than  $10^4$  CFU/g in ready-to-eat foods. Coliform counts ranging between  $10^2$  and  $10^4$  CFU/g are considered to be at the borderline while values less  $10^2$  CFU/g are satisfactory ([www.foodstandards.gov.au](http://www.foodstandards.gov.au)). Therefore, the coliform counts in samples A–E are satisfactory while samples I and J are at the borderline of acceptable limits. *E. coli* was not detected in samples F, G, H, I, J and K which is very satisfactory. The *E. coli* counts for samples A, B, C, D and E were marginal ([www.foodstandards.gov.au](http://www.foodstandards.gov.au)). The presence of coliforms in food no matter how insignificant is an indication of faecal contamination as a result of poor hygienic practices. According to Gilbert et al. (2000), the limit for aerobic plate count set for cooked plant product is  $<1.0 \times 10^4$ . As per such limits, samples J and K are bacteriologically not fit for consumption. Sample J was milled in a commercial disc attrition mill. Its high microbial load corroborates the findings of Sinayobye and Saalia (2011). Sample K was steamed in dried plantain leaves, which could be an additional source of contamination. The presence of bacteria, yeast and mold in most of the samples may be due to

**Table 3. Total soluble solids and pH of senescent plantain products**

Sample	Total soluble solids (g/100 g)	pH
A	1.50 <sup>b</sup>	4.58 <sup>b</sup>
B	1.50 <sup>b</sup>	4.66 <sup>d</sup>
C	1.50 <sup>b</sup>	4.88 <sup>g</sup>
D	1.50 <sup>b</sup>	4.90 <sup>h</sup>
E	1.50 <sup>b</sup>	4.92 <sup>i</sup>
F	2.00 <sup>e</sup>	4.81 <sup>f</sup>
G	1.87 <sup>d</sup>	4.53 <sup>a</sup>
H	1.80 <sup>c</sup>	4.62 <sup>c</sup>
I	2.00 <sup>e</sup>	4.75 <sup>e</sup>
J	1.00 <sup>a</sup>	5.38 <sup>k</sup>
K	1.80 <sup>c</sup>	5.05 <sup>j</sup>

Note: Values not statistically different at ( $p > 0.05$ ) share the same letters.

**Table 4. Microbial quality of senescent plantain products**

Sample	Aerobic plate count (CFU/g)	Yeast and mold count (CFU/g)	Coliform count (CFU/g)	<i>E. coli</i> count (CFU/g)
A	<10	<10	<10	<10
B	<10	<10	<10	<10
C	<10	<10	<10	<10
D	<10	<10	<10	<10
E	<10	<10	<10	<10
F	$2.2 \times 10^2$	ND	ND	ND
G	$9.0 \times 10^1$	ND	ND	ND
H	$8.0 \times 10^1$	ND	ND	ND
I	$8.2 \times 10^2$	$1.9 \times 10^2$	$1.3 \times 10^1$	ND
J	$1.7 \times 10^5$	$3.9 \times 10^5$	$1.5 \times 10^2$	ND
K	$6.9 \times 10^4$	$2.2 \times 10^2$	ND	ND

Note: ND—Not detected.

the presence of residual moisture which provides a conducive environment for their growth. The growth of yeast and mold on the samples may result in softening of the products and off-flavour development (Rose-Monde et al., 2013). Yeast and mold growth have been associated with the formation of heat stable mycotoxins which are a major concern for food safety (Dalié, Deschamps, & Richard-Forget, 2010). The bacteriological quality of samples A–I are more superior than samples J and K. All samples cooked in *Thaumatococcus daniellii* leaves except for sample J were of a better microbiological quality than sample K which was cooked in dried plantain leaves.

#### 4. Conclusion

The processing methods employed by the respondents in producing senescent plantain products are comparable. Samples E, I and J which contains ginger in addition to all other spices present in the other samples, may have better sensory attribute than the other samples. From the microbiological perspective, the products appear to be generally safe for consumption at the production point except for products J and K. The products packaged and cooked in *Thaumatococcus daniellii* leaves had satisfactory microbial levels. The products may require refrigeration so as to slow down the growth of the microorganisms detected. There were variations in the physicochemical compositions, such as moisture, crude fat and protein, ash, carbohydrate, total soluble solids and pH. This study forms the basis for further investigation into process optimization, packaging and shelf life extension of the senescent plantain products.

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