Exploring the Nutritive and Phytochemical Significance of Peeled and Unpeeled Processed Unripe Plantain (*Musa parasidiaca*) Paste

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ABSTRACT

Background: *Plantain as a staple food is essential for food availability and security, as well as fighting malnutrition, and these potentials are* **inherent** *in the distribution of the dietary value of the food.*
Objective: *This study evaluated the nutritive and phytochemical significance of peeled and unpeeled processed unripe plantain paste.*
Methodology: *Mature raw unripe plantain fingers obtained from the popular Watt market in Calabar, Cross River State, Nigeria, were divided into four batches: raw unripe peeled plantain (RUPP), raw unripe unpeeled plantain (RUPP), boiled unripe peeled plantain (BUPP), and boiled unripe unpeeled plantain (BUUP). The paste samples were produced using standard methods.* ***The proximate composition, carbohydrate fractions, phytochemical constituents, and anti-nutrient contents of the samples were determined using standard laboratory procedures with reference to the Association of Official Analytical Chemists (AOAC).***
Results: *The peeled and unpeeled raw or boiled unripe plantain paste contained an appreciable amount of anti-nutrients and phytochemicals, which were significantly (p<0.05) altered by boiling. The nutrient analysis showed the following ranges: moisture 9.50±0.02-12.97±1.77 g/100g for RUUP and BUPP; crude protein 4.28±0.00-6.16±0.00 g/100g for BUUP and BUPP; dietary fibre 2.47±0.01-3.32±0.01 g/100g and crude fat 1.73±0.01-3.66±0.04 g/100g for RUUP and RUPP, respectively; total carbohydrates 72.10±1.99-78.91±0.01 g/100g for BUPP and RUUP. The carbohydrate fractions (starch, glucose, sucrose, and fructose) increased according to the following ranges: RUUP-RUPP-BUUP-BUPP. A greater amount of these nutrients and phytonutrients was present in the raw, unripe, unpeeled plantain and boiled, unripe, unpeeled plantain pastes samples.*
Conclusion: *Unpeeled samples retained a good concentration of nutrients; hence, the formulation and consumption of meals with unpeeled unripe plantain paste is*

Keywords: Nutritive, Anti-nutrient, Processed plantain, Sugar fraction, Phytochemicals

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INTRODUCTION

The current trend in meeting individuals' daily nutritional needs is the promotion of dietary diversity using locally accessible diets. Nature is gifted with varieties of staple foods and, by extension, their processed products. Plantain (*Musa paradisiaca*) is one of the significant basic diet crops eaten in the tropics, in addition to rice, wheat, and maize, and is available in about 120-130 tropical countries in the world (1). With approximately 60 % of universal plantain production, the major cultivators are in Central (42 %) and West Africa (40 %), where Nigeria is the biggest producer of plantains, with mainstream of production and harvesting occurring in the Southern part of the country (2). Regardless of the large tonnage of plantains harvested yearly in Nigeria, more than 50 % of the harvested plantains are lost due to the unavailability and inaccessibility of appropriate storage facilities to prevent post-harvest losses (3). This large production volume and post-harvest losses necessitate the need to develop new and suitable technologies for processing and preservation of plantain products for future use.

Plantains are also referred to as a multipurpose crop, which is rich in various nutritional and chemical compounds, ranging from proximate profile, starch fractions, minerals, vitamins, and phytochemicals/antioxidants that have a positive effect on human health (3,4,5). However, the availability and quantity of these nutrients differ due to the species, ripening stage, edible portion, geographical setting, weather, agricultural practices, and processing methods (6). Plantain can be eaten immature, half-ripe, mature, peeled, boiled, roasted, grilled, or fried, and the ripe fruit can also be consumed raw (7). In Nigeria, among other plantain-producing countries, the entire pulp of the fruit, either unripe or half ripe are roasted and consumed with either avocado, grilled fish, or meat, and occasionally in combination with hot sauce/stew (4). However, the trend in the intake of treated plant products globally cannot be supplied by local production (8). Lately, it has been published that unripe plantain can be processed into flour through slicing and sun drying for some days and cooked into a sticky paste delicacy called "*Amala ogede"* (Yoruba), and "*Ebue*" (Ogonis) in Nigeria (8). This paste can be consumed with vegetable soups or sauce, and the unripe plantain flour rarely affects the sensory characteristics of blended flours, hence consumers accept products with this flour (9). Unripe plantain can also be processed into chips, and food/foodstuffs such as breakfast cereals, and baby complementary foods (10,11). The International Institute for Tropical Agriculture (IITA) revealed post-harvest losses of plantain as one of the main problems affecting the availability/accessibility of the fruit, which is a staple for many Nigerian families (12).

According to research (13), some heat processing methods, including boiling (or blanching), roasting, and others, alter some nutrients, inactivate some toxic substances and organisms, thereby enhancing digestibility, palatability, and improving keeping quality, as well as making the food safer for consumption. Also, (14) reported that boiling of plantains involves heating the fruits in water, leading to the leaching of water-soluble anti-nutritional factors like certain sugars and organic acids, thereby reducing their concentration in the plantain. Heat causes starch granules to swell and gelatinize, making carbohydrates more digestible. However, poor processing techniques can have significant negative effects on the phytochemical composition levels in plant-based materials (13). One of the primary consequences of heating is the degradation of phytochemicals, which are often sensitive to environmental factors like light and oxygen. Unsuitable processing, such as excessive heating or prolonged cooking, can lead to the loss of beneficial compounds like polyphenols, flavonoids, and carotenoids, which contribute to the plant's antioxidant, anti-inflammatory, and antimicrobial properties (15). This, not only diminishes the nutritional value but also reduces the health benefits these phytochemicals provide (16). Also, according to (17), complete and/or slightly processed foods offer protection against numerous metabolic diseases. The medicinal properties of the unripe plantain are attributed to the array of phytochemical composition of the plant, and the major pharmacological properties of unripe plantain include hepatoprotective, diuretic, analgesic, anti-ulcer, wound healing, hair growth promoter, and haemostatic activity (18). Literatures have reported some studies on the nutritional values of peeled unripe plantain in addition to their products; however, studies on the unpeeled unripe plantain are scanty. Therefore, this study assessed the nutritional and phytochemical composition of peeled and unpeeled raw and processed unripe plantain paste.

MATERIALS AND METHODS

Samples preparation

Mature raw unripe plantain fingers were obtained from the popular Watt market in Calabar metropolis, Cross River State, Nigeria. The raw unripe plantain samples were washed under a running tap water, and then divided into four batches of one hundred kilograms (100 kg) each: raw unripe peeled plantain (RUPP), raw unripe unpeeled plantain (RUUP), boiled unripe peeled plantain (BUPP), and boiled unripe unpeeled plantain (BUUP). The RUPP samples were peeled and cut into sizeable pieces using a clean knife, and the peel was discarded, while RUUP samples were cut into equal parts without peeling. Both samples were separately oven dried at 50 ^{0}C in an air-circulating oven for 24 hours to remove moisture. The raw samples were then blended into a fine powder with an electric blender.

The BUUP samples were washed unpeeled, while the BUPP samples were washed and peeled, and the peel was discarded. The BUPP and BUUP samples were cut into sizeable parts and placed in a stainless-steel pot and boiled separately using a cooking stove for 15 minutes at 100 °C. Using the edge of a clean knife, the cooked samples were confirmed to be properly cooked when the cores were soft. The different cooked samples were then separately drained and allowed to cool, and then oven dried at 50 ^{0}C to remove moisture until crisp, after which they were milled and sieved to obtain the flour.

In each case, 10 g of the flour was mixed with 25 ml of boiling water in a stainless-steel pot to obtain the paste. The paste was heated with stirring for 5 minutes, using an electric cooker, set at medium temperature, until it was properly cooked. The paste was allowed to cool to between 40 and 45 °C in a food flask before being used for evaluation. The paste from each sample was divided into two portions. The first portion was extracted using ethanol and used for phytochemical analysis, while the second portion was used for the proximate and carbohydrate analyses.

Proximate analysis

Proximate analysis was carried out on the samples according to the methods of the Association of Official Analytical Chemists (19). For moisture determination, five grams of the flour were weighed into a weighed moisture can. The can and its content were dried in the oven at 105 ^{0}C for 3 hours in the first instance. It was cooled in a desiccator and reweighed. The weight was recorded while the sample was retained in the oven for further drying. The drying, cooling, and weighing were continued repeatedly until a constant weight was obtained. The moisture content was calculated thus: weight of can and sample before drying, minus weight of can and sample after drying, all divided by weight of sample before drying minus weight of empty moisture can, multiplied by 100.

For ash evaluation, a measured weight (5g) of the sample was put in a previously weighed porcelain crucible. The sample in the crucible was put in a muffle furnace and set at 550 ^{0}C and allowed to burn for 2-3 hours (until the sample became a grey ash). The sample in the crucible was carefully removed from the furnace and cooled in a desiccator. It was reweighed, and the weight of ash was obtained as a percentage. It was determined thus: weight of empty crucible and ash, minus weight of crucible, divided by weight of sample used and multiplied by 100.
The crude protein was determined by the Kjeldahl digestion method, and total nitrogen was determined and multiplied by the factor 6.25 to obtain the protein content. About 0.5 g of the sample was mixed with 10 mls of concentrated sulphuric acid in a Kjeldahl digestion flask.

However, the fat content of the sample was determined by the continuous solvent extraction method using a Soxhlet apparatus, while the carbohydrate content was calculated by difference as the nitrogen-free extractive. The energy value was calculated by multiplying the mean values of protein, fat, and carbohydrate by their respective Atwater factors (4, 9, and 4, respectively) and taking the sum of the products. All data were obtained in triplicate.

Carbohydrate analysis

Starch fractions were measured enzymatically, according to the method described by (20). Soluble sugars were extracted three times with 80 % ethanol at 80 ^{0}C. The supernatants were combined, and the ethanol was evaporated under vacuum. The soluble sugar was properly diluted in distilled water and analyzed by high-performance liquid chromatography with pulse amperometric detection (HPLC-PAD) (Dionex, Sunnyvale, Calif., U.S.A.), using a PA1 column (Dionex) in an isocratic run of 18 mM NaOH for 25 minutes. Total soluble sugars were given as the sum of glucose, fructose, and sucrose values. The carbohydrates in the cell wall were extracted with 10 % (w/v) water at 90 ^{0}C, precipitated with 96 % ethanol, hydrolyzed with 1 M H_2SO_4/121 8 ^{0}C for 1 h, then separated by HPLC-PAD on a PA1 column, using the same conditions described above.

Phytochemical and anti-nutrient analyses

The amounts of phytochemicals and anti-nutrients in the sample were determined using methods described by (21, 22, 23).

Statistical analysis

All determinations were replicated thrice. Data, upon analysis using one-way ANOVA with Post hoc corrected two-tailed t-tests using the IBM SPSS Statistics software version 22 (SPSS: Statistical Package for Social Sciences), were expressed as mean ± standard deviation, and differences at $p < 0.05$ were considered significant.

RESULTS

Proximate composition of plantain paste samples

The results of the moisture content of the four paste samples showed that the RUUP paste had a significantly ($p<0.05$) higher value (12 97 ±1.77 %) while the RUPP sample recorded the lowest value (9.50 ± 0.02%). The dry matter content was not significantly ($p>0.05$) different among the four samples; however, RUPP recorded the highest value, and BUUP samples had the lowest dry matter content. The ash content in all the samples was not significantly ($p > 0.05$) different, except in the case of BUPP, which had the lowest ash content ($p<0.05$) (2.17±0.01 %). The crude protein in the paste samples was significantly ($p < 0.05$) different; the BUUP sample recorded the highest value (6.16±0.00 %), while BUPP had the lowest value (4.28±0.00 %). In addition, crude fibre and crude fat contents were significantly ($p < 0.05$) higher (3.32±0.01 %; 3.66±0.04 %) in the RUUP samples, respectively. Also, the total carbohydrate value of the BUPP sample was significantly ($p < 0.05$) higher (78.91±0.01 %), and the RUPP sample recorded the highest energy value (360.45±4.97 kCal), which was significantly ($p < 0.05$) different from other samples (Table 1).

Carbohydrate fractions of plantain paste samples

The starch, glucose, and sucrose contents of all the past samples were significantly ($p < 0.05$) different; the RUUP paste recorded the highest value (22.65 ± 0.05 mg/100g, 10.73±0.01 mg/100g, and 6.81±0.01 mg/100g, respectively), while the BUPP sample had the lowest value (14.83±0.02 mg/100g, 6.37±0.01 mg/100g, and 4.77±0.01 mg/100g, respectively). Also, fructose concentration was significantly ($p < 0.05$) higher in the RUUP sample, and BUPP recorded the lowest value (Table 2).

Table 1: Proximate composition of plantain paste samples (g/100g)

Parameters	RUPP	RUUP	BUPP	BUUP
Moisture content	9.50 ± 0.02^a	12.97 ±1.77^b	9.85±0.02^a	10.18±0.1^c
Dry matter	90.50±0.02^a	89.83±0.14^a	90.15±0.02^a	89.82±0.01^a
Ash	2.67±0.03^a	2.91±0.04^a	2.17±0.01^b	3.26±0.01^a
Crude protein	5.63±0.01^a	6.02±0.09^b	4.28±0.00^c	6.16±0.00^d
Crude fibre	2.47±0.01^a	3.32±0.01^b	2.91±0.01^c	2.74±0.01^d
Crude Fats	1.73±0.01^a	3.66±0.04^b	1.88±0.01^c	1.76±0.00^a
Total carbohydrates	77.99±0.07a	72.10±1.99^b	78.91±0.01^a	75.90±0.00^c
Energy value (kcal)	360.45±4.97^a	343.32±9.38^b	349.70±0.11^b	344.05±0.03^b

Values are mean ± standard deviation of triplicate determinations. Means in the same row with different letters are significantly different ($p<0.05$). RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

Table 2: Carbohydrate fractions of plantain paste samples (mg/100g)

Parameters	RUPP	RUUP	BUPP	BUUP
Starch	19.27±0.07^a	22.65 ± 0.05^b	14.83±0.02^c	17.65 ±0.03^d
Glucose	9.66±0.03^a	10.73±0.01^b	6.37±0.01^c	8.64±0.1^d
Sucrose	5.27±0.01^a	6.81±0.01^b	4.77±0.01^c	5.8±0.06^d
Fructose	5.67±0.07^a	6.77±0.02^b	5.53±0.03^a	6.50±0.00^c

Values are mean ± standard deviation of triplicate determinations. Means in the same row with different letters are significantly different ($p<0.05$). RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

Phytochemical and anti-nutrient compositions of plantain paste samples

The tannin content in the paste samples was significantly ($p<0.05$) different; the RUUP paste recorded the highest value (1.43 ±0.00 mg/100g), while the BUPP sample had the lowest value (0.84 ± 0.01 mg/100g). The flavonoid concentration in the RUUP sample was significantly ($p < 0.05$) higher, compared to other samples, with the RUPP sample recording the lowest value. In addition, saponin content was significantly ($p< 0.05$) different among the four samples, with BUUP recording the highest value (0.65±0.00 mg/100g), while the RUPP sample had the least saponin value (0.48±0.00 mg/100g). Hydrogen cyanide concentration in all the samples differed significantly ($p < 0.05$); the BUUP had the highest value, and the RUUP sample recorded the lowest value. Also, alkaloid concentration was significantly ($p < 0.05$) higher in RUUP samples, compared to BUPP, which had the lowest alkaloid value. Moreover, phenol content was significantly ($p < 0.05$) higher in the RUUP sample, with BUUP recording the least phenol value. Phytate content in the four different paste samples was significantly ($p < 0.05$) different; the BUPP sample recorded the highest value (0.38±0.00 mg/100g), while the BUUP had the lowest (0.25±0.00 mg/100g) phytate value (Table 3).

Table 3: Phytochemical and anti-nutrient composition plantain paste samples (mg/100g)

Parameters	RUPP	RUUP	BUPP	BUUP
Tannins	1.38 ± 0.00^{a}	$1.43\ \pm0.00^{b}$	1.19 ± 0.01^{c}	$0.84\ \pm0.01^{d}$
Flavonoids	0.49±0.00a	1.24 ± 0.01^{b}	0.62 ± 0.00^{c}	0.79 ± 0.01^{d}
Saponins	0.48 ± 0.00^{a}	0.61 ± 0.01^{b}	0.63 ± 0.01^{c}	0.65 ± 0.00^{d}
Hydrogen cyanide	0.84 ± 0.00^{a}	0.72 ± 0.00^{b}	0.79 ± 0.01^{c}	1.44 ± 0.01^{d}
Alkaloids	0.69 ± 0.00^{a}	0.86 ± 0.00^{b}	0.43 ± 0.01^{c}	0.78 ± 0.00^{d}
Phenols	0.74 ± 0.00^{a}	0.74 ± 0.01^{a}	0.68 ± 0.00^{b}	0.56 ± 0.00^{c}
Phytates	0.34 ± 0.00^{a}	0.28 ± 0.00^{b}	0.38 ± 0.00^{c}	0.25 ± 0.00^{d}

Values are mean ± standard deviation of triplicate determinations. Means in the same row with different letters are significantly different ($p<0.05$). RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

DISCUSSION

The findings of the present study suggest that peeled or unpeeled raw or boiled unripe plantain paste is a promising source of nutrients and bioactive substances, proficient for improving healthy living. Proximate composition was considerably higher in the unpeeled samples, in comparison with the peeled samples. The moisture content obtained in this study was higher in the RUUP sample and agrees with the reports of (1) and (24), who revealed high moisture content in fresh unripe plantain pulp and unpeeled unripe plantain formulated diet, respectively. This implies that RUPP may have a lower shelf life, thereby being susceptible to spoilage if stored longer. The decrease in the moisture content of the paste samples after boiling could be attributed to protein denaturation and contraction, which squeeze out water from the cells, by direct heat application of the boiling method, thus suggesting meals formulated with BUPP paste, as a shelf-stable food with less susceptible to microbial attack. Dry matter evaluation, with no significant ($P<0.05$) difference among the samples, was found to be higher in relation to the 33.0 % value reported by (11) for boiled peeled unripe plantain pulp, suggesting method and duration of boiling as the major reasons for the variation.

Ash and protein contents obtained in this study were higher in the BUUP paste and were in agreement with the recent study (25) who reported high ash and protein contents in processed unripe plantain pulp. The ash content has been regarded as an index of evaluation of mineral composition; hence, the appreciable amount of ash value in BUUP paste suggests that diets from the paste could be useful in combating the growing issue of micronutrient deficiency, as revealed in a recent finding (26). Also, the high protein value in the unpeeled samples could be attributed to some amount of the nutrient conserved in the plantain peel, as reported by (27). Boiling was observed to reduce the protein content in the BUPP paste, linking the leaching of proteins during heating as the major reason for the protein reduction in the processed sample. However, the fair amount of protein revealed in both the raw and boiled unpeeled pastes suggests them as a moderate source of protein, capable of contributing to the recommended dietary allowance for protein when properly supplemented with animal protein, as plant protein is usually of low biological value.

The high crude fibre content in the RUUP paste was in agreement with the recent study (24) who reported high crude fibre content of an unpeeled unripe plantain-based diet. From the present study, it was observed that the fibre content of unripe peeled and unpeeled plantain pastes increased with the increase in moisture content. High fibre contents have been implicated in the digestion and absorption processes, with the view of inhibiting constipation (28). The high-fiber content of either raw or boiled unripe unpeeled plantain pastes suggests that the paste-based meal would be an excellent meal for obese and diabetic patients.

The decreased crude fat content in the processed samples is in line with a recent study (25)' which reported decreased lipid content in unripe boiled plantain pulp. The decrease in the lipid content may be due to the heat process, as (29) reported that heating reduced fat content in food, following the breakdown of lipid into glycerol and fatty acids. The low crude fats recorded in the present study show that diets from these pastes may not be able to meet the recommended dietary intake (15 - 20 %) for adults; hence, formulation of meals with unripe unpeeled plantain paste should be supplemented with good fatty sources. Also, the increased carbohydrate content in the raw unripe plantain pastes as observed in this study is consistent with the study (24), which recorded higher carbohydrate content of unripe peeled plantain pulp. The increased carbohydrate content in the raw samples may be attributed to the decrease in moisture content, which led to the high concentration of nutrients, including caloric value, as observed in this study. Also, the increased carbohydrate content in the raw samples agrees with the earlier study (14), which reported that boiling of plantains leads to the leaching and reduction of sugars. In addition, the unpeeled raw or boiled samples were found to also contain more starch and sugar contents when compared with the peeled samples, indicating that these carbohydrate fractions must have been stored in the peel portion of the plant. The increased starchy content in the unpeeled pastes projects the meal as a healthy, resistant starch food with promising functional properties, which provides a good feed for the animals.

The results of the present study showed that unripe plantain paste contained appreciable amounts of phytochemicals (flavonoid, saponin, phenol, alkaloid), anti-nutrients (phytate and tannin), and hydrogen cyanide. However, most of these phytonutrients were found to be present in a higher concentration in the RUUP sample and were also observed to be reduced following the boiling process, and this supports the recent report (30), which revealed that processing reduced anti-nutritional composition of foods, thereby promoting nutrient availability. This finding was also in consonance with the recent report (15), which reported the reduction effect of processing on anti-nutrient content of unripe plantain pulp. The significant decrease in these anti-nutrient contents of the boiled samples may be attributed to the combined effects of degradation by moist heat and the leaching of these compounds into the boiling water. However, the phytochemicals present in these pastes have been implicated in ethno-medicine, contributing to the management and treatment of various diseases, thereby validating the pharmacological properties of unripe plantain paste (31). For instance, most of these bioactive compounds, such as flavonoids and phenols, possess hepatoprotective, anticancer, antioxidant, anti-inflammatory, neuroprotective, cardio-protective, and antiviral properties (26, 32). In addition, alkaloids may provide essential biochemical functions in biological systems, including antimicrobial activity (15). Thus, the presence of these compounds demonstrates the therapeutic potential of the peeled and unpeeled raw and boiled unripe plantain paste.

Implication of the findings

This study has revealed that consumption of meals made from unpeeled unripe plantain paste can contribute to the recommended dietary allowance of macro-nutrients, and provide the necessary therapeutic properties, capable of managing and preventing the growing metabolic disorders.

Limitation of the study

The study focused basically on the proximate and phytochemical contents of the *Musa parasidiaca* species of plantain grown in the Southern part of Cross River State. Hence, studies on other cultivars, antioxidants, and bioactive compounds of peeled and unpeeled unripe plantain paste should be carried out.

CONCLUSION

Unpeeled samples conserved a good concentration of nutrients; hence, formulation and consumption of meals with unpeeled unripe plantain paste, as well as animal studies on the effect of the meal, are recommended.

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DECLARATIONS

Ethical approval

Not applicable

Availability of data

The datasets used/or analysed during the current study are available from the corresponding author on reasonable request.

Consent of publication

Not applicable, as human subjects were not used

Conflict Of Interests

The authors declare no conflict of interest

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Authors' contributions

All the authors listed in the articles contributed to the identification of the title, study design, literature review, supervision of the work, principal investigation, data collection, data analysis, and writing and reviewing of the manuscript, as well as funding. All the authors read the manuscript and the authors' list and consented to the publication.

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