

Original Research Article

Effect of boiling on the micronutrient and phytochemical contents of peeled and unpeeled unripe plantain (*Musa parasidiaca*)

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Abstract

Purpose: To explore the outcome of boiling on the micronutrient availability and phytochemical potentials of peeled and unpeeled unripe plantain (*Musa Parasidiaca*).

Methods: The mature raw unripe plantain fingers were divided into four batches: raw unripe peeled plantain, raw unripe unpeeled plantain, boiled unripe peeled plantain and boiled unripe unpeeled plantain. Standard laboratory procedures were used to analyze the minerals, vitamins and anti-nutrients in the samples. Potassium, calcium, magnesium, iron and manganese analyses were carried out using atomic absorption spectrophotometer (AAS), while UV-spectrophotometer was used for phosphorus determination. Vitamins A, C, B1, B2, B3, B5, and B9 were quantified using AAS, while phytate, oxalate and tannin concentrations in the samples were determined using standard procedures.

Results: The minerals analyzed were significantly higher in the unpeeled samples when compared with the peeled samples ($p < 0.05$). Vitamin contents were significantly higher in unpeeled samples when compared with peeled samples ($p < 0.05$). Furthermore, vitamins were positively affected by the boiling process, while anti-nutrients (phytate, oxalate and tannin) concentrations were significantly reduced following the boiling process ($p < 0.05$).

Conclusion: Unpeeled unripe plantain has been revealed as a good source of micronutrients and vitamins. Boiling is suggested for processing unripe plantain, as it has shown adequate reduction of anti-nutrient levels, with conservation of the micronutrient levels.

Keywords: Boiled, Peeled, Unpeeled, Unripe plantain, Vitamin, Anti-nutrient

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INTRODUCTION

Malnutrition has been recognized as a major cause of common disease conditions among all categories of individuals in the world's growing population [1]. While over-nutrition entails excessive consumption of nutrients, which may lead to disease conditions such as obesity and

overweight, under-nutrition encompasses deficiencies in important macro and micro-nutrients, which are prerequisite for life development and sustainability [1]. Micronutrients, including essential vitamins and minerals, play critical roles in biological and biochemical processes, and their deficiencies constitute a major public health challenge,

affecting more than 2 billion people worldwide, with pregnant women and children under five years being the most vulnerable [2]. In most cases, since the attendant health risks of micronutrient deficiency develop progressively and asymptotically, they are referred to as hidden hunger [1]. In Nigeria, the incidence of micronutrient deficiencies is multifactorial, affecting both the health care system and the economy of the country [3].

In view of the substantial affliction of micronutrient deficiencies in the health care system, interventions to address these menaces are non-negotiable [4]. Consequently, Nigeria has fast embraced the consumption, as well as the supplementation of diets with some domestically grown staple foods, including plantain, as a measure in boosting the recommended dietary allowance for these essential micronutrients. *Musa paradisiaca* (Plantain) pulp, member of Musaceae family, is a good source of nutrients and bioactive compounds. Mature and consumed unripe, half-ripe, and ripe fruits are processed, either as peeled, unpeeled, boiled, roasted, grilled or fried [5]. Due to its low glycemic index, unripe plantain meals are consumed by diabetic patients, implicating the plant in the management of many disorders such as blood pressure and muscle cramps [5].

However, the presence and utilization of micronutrients in plantain pulp are hampered by anti-nutrients such as tannin, phytate, oxalate, etc. This interferes with the absorption and utilization of the nutrients, resulting in micronutrient deficiencies [6]. For instance, phytates, oxalates, and tannins have been implicated in the leaching of iron, calcium, and proteins, with reduction in their bioavailability [7]. Despite the reported nutritional potentials of unripe plantain pulp, studies on the effect of the traditional processing methods on the availability and utilization of the essential micronutrients are limited. Hence, the present study investigated the micronutrient and anti-nutrient compositions of raw and processed peeled or unpeeled plantain.

EXPERIMENTAL

Sample collection and identification

The mature fingers of unripe plantain, used in the present study, were purchased on April 16th, 2025, from Watt Market, Calabar South Local Government Area, Cross River State, Nigeria (GPS: 4° 45'41" North, 8° 21'53" East), were identified and authenticated by Dr. Effah Effah of the Department of Botany at the University of

Calabar in Cross River State, Nigeria, with voucher number Bot/Herb/UCC/0566.

Sample preparation

Twelve (12) raw fingers of unripe plantain were washed and divided into four batches of three fingers 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 the RUUP samples were cut into equal parts without peeling.

The BUPP samples were unpeeled, while the BUUP samples were peeled and the peel discarded. Both samples were separately cut into equal parts and placed in a stainless-steel pot and boiled with a cooking stove for 15 minutes at 100 °C independently. Using the edge of a clean knife, samples were confirmed properly cooked with soft cores and separately drained and allowed to cool in a desiccator. The RUPP, RUUP, BUPP and BUUP samples were pulverized by a laboratory mortar and pestle, separately, oven-dried at 50 °C in an air-circulating oven for 24 hours, ground into fine powder with an electrical blender, and separately stored in a dry air-tight bag for analyses.

Mineral analysis

The potassium, calcium, magnesium, iron and manganese analyses were carried out using an atomic absorption spectrophotometer (AAS), while UV-spectrophotometer was used for phosphorus determination. The concentration of each element was extrapolated from the calibration curves prepared with their respective standard solutions [8].

Vitamin analysis

Vitamins A, C, B1, B2, B3, B5, and B9 analyses were performed according to the method of Onwuka [8], using AAS.

Antinutrient analysis

Phytate, tannin, soluble and insoluble oxalates were determined using the method of Adeniyi et al [9].

Statistical analysis

All analyses were replicated thrice. The data was analyzed by 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), to determine the significant difference in the values at 95 % probability level ($p < 0.05$). All data were expressed as Mean $\pm$ Standard Error of Mean (SEM).

RESULTS

Mineral composition of raw and boiled peeled and unpeeled unripe plantain samples

The potassium (K) content in all the samples was significantly ($p < 0.05$) different and RUUP sample recorded the highest K value, while BUPP sample recorded the lowest potassium value. The phosphorus (P) content was significantly ($p < 0.05$) higher in the BUPP samples, compared to other samples, except in the case of BUUP sample. However, the RUUP sample had the lowest phosphorus level. Also, the calcium (Ca) and magnesium (Mg) contents in all the four samples were significantly ($p < 0.05$) different, and RUUP recorded the highest (189.45 ± 0.03 mg/100 g; 92.45 ± 0.03 mg/100 g) value, while BUPP sample recorded the lowest (69.53 ± 0.01 ; 69.53 ± 0.01 mg/100 g) calcium and magnesium values respectively. The BUUP sample recorded a significantly ($p < 0.05$) high iron (Fe) content, while the RUUP sample had the least iron concentration, when compared to other samples. Also, the manganese (Mn) content of RUPP sample was significantly ($p < 0.05$) higher compared to that of other samples (Table 1).

Vitamin composition of raw and boiled, peeled and unpeeled unripe plantain

Vitamins A, C and B complex (B1, B2, B3, B5 and B9) were found to be present in all the samples in a considerably varied amount. The vitamin A concentration was significantly ($p < 0.05$) higher in RUUP sample, compared to other samples. Also, vitamins C, B1, B2, B3, B5 and B9 were significantly ($p < 0.05$) higher in the BUUP sample, compared to other samples (Table 2).

Anti-nutrient composition of raw or boiled peeled or unpeeled unripe plantain sample

Phytate, oxalate (soluble and insoluble) and tannin were found to be present in varied concentrations in all the samples. The phytate concentration was significantly ($p < 0.05$) higher (0.67 ± 0.02 mg/100 g) in the RUPP sample, compared to other samples. Both soluble and insoluble oxalate concentrations were significantly ($p < 0.05$) lower in the BUUP sample, compared to other samples. However, RUPP sample recorded the highest tannin value, which was significantly ($p < 0.05$) different from samples (Table 3).

DISCUSSION

The results of this study showed that peeled or unpeeled raw or boiled unripe plantain contained considerable quantities of minerals, vitamins and anti-nutrients, which are critical in preventing and managing the growing challenge of micronutrient deficiency,

Table 1: Mineral composition of peeled and unpeeled unripe raw and boiled plantain sample

Sample	Potassium (mg/100g)	Phosphorus (mg/100g)	Calcium (mg/100g)	Magnesium (mg/100g)	Iron (mg/100g)	Manganese (mg/100g)
RUPP	230.67 $\pm$ 0.03 ^a	98.35 $\pm$ 0.05 ^a	164.47 $\pm$ 0.17 ^a	78.3 $\pm$ 50.05 ^a	0.67 $\pm$ 0.01 ^a	2.84 $\pm$ 0.01 ^a
RUUP	245.77 $\pm$ 0.03 ^b	65.42 $\pm$ 0.14 ^b	189.45 $\pm$ 0.03 ^b	92.45 $\pm$ 0.03 ^b	0.62 $\pm$ 0.00 ^b	1.79 $\pm$ 0.00 ^b
BUPP	189.35 $\pm$ 0.03 ^c	105.75 $\pm$ 0.03 ^c	69.53 $\pm$ 0.01 ^c	69.53 $\pm$ 0.01 ^c	0.68 $\pm$ 0.01 ^a	2.24 $\pm$ 0.00 ^c
BUUP	194.76 $\pm$ 0.02 ^d	105.41 $\pm$ 0.01 ^c	148.74 $\pm$ 0.01 ^d	73.79 $\pm$ 0.01 ^d	0.77 $\pm$ 0.01 ^c	2.17 $\pm$ 0.01 ^d

Values are expressed as Mean $\pm$ SEM of triplicate determinations. Means in the same column with different letters are significantly different at $p < 0.05$. RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

Table 2: Vitamin composition of peeled and unpeeled unripe raw and boiled plantain sample

Sample	Vitamin A (μ g/g)	Vitamin C (mg/100 g)	Vitamin B1 (mg/100g)	Vitamin B2 (mg/100g)	Vitamin B3 (mg/100g)	Vitamin B5 (mg/100g)	Vitamin B9 (μ g/100g)
RUPP	3.69 $\pm$ 0.01 ^a	4.29 $\pm$ 0.01 ^a	0.05 $\pm$ 0.00 ^a	0.03 $\pm$ 0.00 ^a	0.72 $\pm$ 0.00 ^a	1.77 $\pm$ 0.01 ^a	1.08 $\pm$ 0.00 ^a
RUUP	4.91 $\pm$ 0.01 ^b	4.75 $\pm$ 0.03 ^b	0.05 $\pm$ 0.00 ^a	0.04 $\pm$ 0.03 ^b	0.76 $\pm$ 0.01 ^b	1.55 $\pm$ 0.01 ^b	1.53 $\pm$ 0.01 ^b
BUPP	2.93 $\pm$ 0.01 ^c	5.18 $\pm$ 0.01 ^c	0.05 $\pm$ 0.00 ^a	0.05 $\pm$ 0.00 ^c	0.36 $\pm$ 0.03 ^c	1.45 $\pm$ 0.00 ^c	1.44 $\pm$ 0.02 ^c
BUUP	3.76 $\pm$ 0.01 ^d	5.89 $\pm$ 0.01 ^d	0.09 $\pm$ 0.00 ^b	0.06 $\pm$ 0.00 ^d	0.86 $\pm$ 0.00 ^d	2.63 $\pm$ 0.01 ^d	1.65 $\pm$ 0.00 ^d

Values are expressed as Mean $\pm$ SEM of triplicate determinations. Means in the same column with different letters are significantly different at $p < 0.05$. RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

Table 3: Anti-nutrient composition of peeled and unpeeled unripe raw and boiled plantain sample

Sample	Phytate (mg/100g)	Soluble oxalate (mg/100g)	Insoluble oxalate (mg/100g)	Tannins (mg/100g)
RUPP	0.67 ±0.02 ^a	0.42±0.00 ^a	0.67±0.00 ^a	1.38±0.00 ^a
RUUP	0.59±0.01 ^b	0.50±0.00 ^b	0.87 ±0.00 ^b	1.43±0.00 ^b
BUPP	0.53±0.02 ^c	0.30±0.00 ^c	0.70±0.00 ^c	1.19±0.01 ^c
BUUP	0.49±0.01 ^d	0.35 ±0.00 ^d	0.75±0.01 ^d	0.84±0.01 ^d

Values are expressed as Mean ± SEM of triplicate determinations. Means in the same column with different letters are significantly different at $p < 0.05$. RUPP=Raw Unripe Peeled Plantain; RUUP=Raw Unripe Unpeeled Plantain; BUPP=Boiled Unripe Peeled Plantain; BUUP=Boiled Unripe Unpeeled Plantain

thus, sustaining a healthy living among individuals. The minerals analyzed were significantly ($p < 0.05$) higher in the unpeeled samples when compared with the peeled samples. The potassium content obtained in this study was higher in the RUUP sample and the reason for the high potassium content might have been due to the conservation of the mineral in the peels, as Shadrach *et al* [5] have reported high potassium content in unripe plantain peels. The recommended daily allowance (RDA) of potassium for adults is 4700 mg [10]. In this study, RUUP has the capacity to contribute nearly 5.4 % of the potassium RDA. This shows that consuming unripe, unpeeled plantain with other mineral sources like leafy vegetables may contribute significantly to potassium RDA. Potassium has been reported to have biochemical importance in managing high blood pressure, cardiovascular disorders, and electrolyte regulation [11].

The high phosphorus content obtained in BUPP and BUUP samples in the present study was in agreement with the recent study of Onyenibe and Udogadi *et al* [12] who reported high phosphorus content in processed unripe plantain pulp. The phosphorus RDA is between 200 to 1000 mg [10]. From the present study, boiled peeled or unpeeled unripe plantain has the capacity to contribute a large portion (50 %) of the phosphorus RDA. Phosphorus plays critical metabolic roles in the body, including calcium absorption, body fluid buffer, kidney function regulation, nerve impulses transmission, as well as strengthening bones and teeth and in the upkeep of muscle growth [13].

The reason for the high calcium content in the unpeeled raw and boiled plantain samples might have been due to the concentration of calcium conserved in the peel part of the plant and the findings of the present study are in line with the submission of Onyenibe and Udogadi *et al* [12], who reported high calcium content in unripe plantain peel. Also, boiling was observed to reduce the calcium content of the samples and this could have been due to the leaching of the mineral during the process of boiling. Calcium

has been known to play a critical role in the biological system such as development and nourishment of strong bones and teeth; thereby preventing osteoporosis among elderly individuals [14], maintenance of muscle contraction and relaxation, maintenance of nerve impulses and absorption of cyanocobalamin (vitamin B12), thus, activating coagulation of blood as it initiates the conversion of prothrombin to thrombin [10].

Magnesium concentration was also high in the RUUP sample and was observed to be negatively affected by boiling process and the results of this finding were relatively higher than the value reported by Shadrach *et al* [5] for unripe plantain. However, the reason for the variation in the magnesium value may be attributed to the species of plantain and the processing methods employed, as the plantain was unpeeled in the present study, against the peeled sample used in the previous study. This also supported the earlier claim of Onyenibe and Udogadi *et al* [12] that plantain peel is a good source of magnesium. Magnesium RDA is 450 mg [13] and the raw, unpeeled, unripe plantain in the present study has the capacity to contribute more than 20 % of the magnesium RDA, thereby placing the sample as a good source of the mineral, especially when consumed with known magnesium sources such as vegetables and other sauces. Magnesium functions in cardiac regulation, diabetic management, nerve impulse communication, as well as bone and teeth development [13].

The iron concentration was higher in BUUP sample and this confirmed the earlier claim of Onyenibe and Udogadi [12], who reported that boiling increased the iron concentration of unripe plantain. Iron RDA is 18 mg and the BUUP sample can provide about 0.04 %, indicating BUUP as a fair source of iron, and consuming it with vegetables may boost the iron content. Iron has been implicated in many biological processes, including hemoglobin and enzyme synthesis and oxygen transport [11].

Manganese concentration was observed to be higher in raw samples and is in line with the report of Shadrach *et al* [5] who revealed high manganese content in raw unripe plantain peel. Manganese has a recommended daily allowance of 2.30 mg and the element is implicated in biological systems, functioning as catalyst and co-factor for many enzymes, growth and development of skeletal muscle, and formation of prothrombin along with vitamin K [12].

The vitamin concentrations in this study were significantly ($p < 0.05$) higher in the unpeeled samples when compared with the peeled samples and were positively affected by the boiling process. The high vitamin A content recorded in the RUUP and BUUP samples was contrary to the earlier report of Onyenibe and Udogadi [12], who revealed low (1.67 ± 0.03 µg/g) vitamin A content in unripe plantain. The reason for the high vitamin A content in the present study might have been due to some amount of the vitamin conserved in the peel of the unripe plantain. Also, boiling was observed to decrease the level of vitamin A and this is in support of the recent study of Agiang *et al* [14] who reported loss of vitamins in cooking, citing leaching of the vitamin into the water during boiling as a reason for the reduction. The functions of vitamin A include maintenance of the integrity of epithelial tissue, growth and the regulation of the retina and immune system [11]. The RDA for vitamin A is between 600 - 700 µg/day [15] and consuming BUUP sample can provide 0.8 % of the needed vitamin A. This has shown that unripe plantain is not a good source of vitamin A; however, consuming it with vegetables and sauces could boost the vitamin A RDA.

The result of the vitamin C content in the present study is in line with the report of Ezeigbo and Ezeigbo [16]. The high vitamin C content in the unpeeled samples is an indication that unripe plantain peel may have reserved a good amount of the vitamin and this may not have allowed the effect of the boiling to be expressed in the vitamin's concentration. According to FAO [15], the recommended daily requirement for Vitamin C is between 45.83 mg/day to 68.50 mg/day for adults. In this regard, the BUUP sample can contribute up to 13 % of the vitamin's RDA, making it a good supplement of the vitamin, a boost in supplying the needed vitamin C value. Vitamin C has been implicated in the regulation of numerous biochemical processes, including serving as an antioxidant and coenzymes in many biological reactions, synthesis of collagen and tissue regeneration, hormonal regulation, enhancing iron absorption and utilization and

facilitating drug metabolism, as well as carnitine synthesis [11]; hence, vitamin C consumption is essential for maintaining the body's physiological system.

Thiamine (vitamin B1) and riboflavin (vitamin B2) are good examples of water-soluble vitamins with vast biochemical roles. For instance, both vitamins serve as coenzymes in the intermediary metabolism, leading to cellular energy production. They also serve as activators in the synthesis of niacin, as well as regulating appetite [16]. From this study, both vitamins were higher in BUUP sample, implying conservation of the vitamins in the peel of the unripe plantain and the values were within those reported by Ezeigbo and Ezeigbo [16] for unripe plantain pulp. Also, the high vitamin B1 and B2 contents in the BUUP sample might have contributed to the high vitamin B3 content in the sample, as vitamins B1 and B2 have been implicated in the synthesis of vitamin B3. However, from this study, consuming BUUP provides up to 8, 5 and 7 % of the 1.2 mg/day, 1.3 mg/day and between 14 to 16 mg/day RDA requirements for vitamins B1, B2 and B3, respectively, for healthy adults.

Again, the vitamins B5 and B9 values in the BUUP sample were remarkably high, and this might have been due to the fact that the peels of the unripe plantain contributed to the increased level of these vitamins and these results support the earlier study of Onyenibe and Udogadi [12]. Both vitamins B5 (pantothenic acid) and B9 (folic acid) have been involved in the regulation of many physiological and biochemical processes, thereby sustaining healthy living in human beings. For instance, folic acid serves as a cofactor in the one-carbon metabolic process, assisting deoxyribonucleic acid production, methylation reactions, and antioxidant defenses [10]. This, therefore, shows that adequate intake of these vitamins is essential for cellular processes in the body. Consequently, the intake of BUUP provides up to 53 % and 0.4 % of the 5 mg/day and 400 µg/day RDA requirements for vitamins B5 and B9, respectively, for normal physiological adult. Though water-soluble vitamins are known to be heat sensitive, however boiling process did not negatively affect the levels of all the vitamin B-complex in this study and this result supports the earlier report of Onyenibe and Udogadi [12]. The reason for the high levels of these vitamins after boiling might have been due to the minimal amount of water used for the boiling, as well as the low temperature and cooking time employed in the present study.

The anti-nutrients composition of the samples was observed to be drastically reduced following the boiling process and this affirms the earlier report of Lekpoabari and Goodhope [6], who revealed that boiling and cooking reduced anti-nutrient levels in unripe plantain. Phytate content was uniformly low in the boiled samples, compared to the raw samples, suggesting boiling as a good processing method for reducing phytate levels. In all the samples, phytate levels were within the safe limit of 200 mg/day, which has the ability to influence mineral bioavailability [7]. The decreased phytate level in the BUUP sample might have contributed to the bioavailability of calcium, magnesium and iron in the sample (Table 1), thereby suggesting the inability of phytate to prevent calcium crystallization in the kidney.

The reductions in both soluble and insoluble oxalate levels in the BUPP samples align with the recent submission of Agiang *et al* [14], who reported that boiling is effective in reducing oxalate levels. In this study, oxalate levels were within the safe limit of 50 mg/day, which has been implicated in the risk of calcium deficiency, kidney stone formation, hyperoxaluria, as well as systemic oxalosis [7]. Also, the tannin level in this study was drastically reduced following boiling, and the values obtained in this study are in line with those of Lekpoabari and Goodhope [6]. This finding also complements the recent study of Inyang *et al*, who revealed that processing methods influence the anti-nutrient and phytochemical content of *Dacryodes edulis* [17,18]. The level of tannin obtained in this study was above the 0.1 - 0.5 mg/day safe limit [13], except in the case of BUUP sample, which had a slightly tannin value, signifying the importance of boiling in reducing tannin level in unripe plantain. However, 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. Hence, boiling is recommended for processing unpeeled unripe plantain, which has been revealed as a good source of minerals capable of reducing micronutrient deficiency among all categories of individuals.

CONCLUSION

Unpeeled unripe plantain has been revealed by this study as a good source of minerals and vitamins, capable of preventing micronutrient deficiency. However, boiling is recommended as a significant processing method for unripe plantain, following its ability to reduce anti-

nutrients, as well as conserving the essential micronutrients in the plantain.

DECLARATIONS

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Ethical approval

Not applicable

Use of Artificial intelligence/Large language models

The authors declare that neither Generative artificial intelligence (AI) nor AI-assisted technologies were used in writing the manuscript.

Availability of data

The datasets used/or analyzed 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

No conflict of interest is associated with this work.

Authors' Contributions

We declare that this work was done by the author(s) listed in this article, and all liabilities pertaining to claims relating to the content of this article will be borne by the authors. Conceptualization and design: Margaret A. Agiang and Aniekeme N. Inyang; Acquisition, analysis, and interpretation of data: Margaret A. Agiang, Aniekeme N. Inyang and John E. Mgbang; Drafting, revision, and resources: Aniekeme N. Inyang, Obazi A. Oham, Ubong G. Etim and Ediye O. Ottoho. All the authors read the manuscript and the authors' list and consented to the publication.

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