World Journal of Food Science and Technology
2025, Vol. 9, No. 2, pp. 31-38
https://doi.org/10.11648/j.wjfst.20250902.12

Research Article

Phytochemical and Anti-Nutrient Compositions of Unprocessed and Processed (Fermented, Boiled, and Roasted) Unripe Plantains (*Musa paradisiaca*)

Nwoke Prince Lekpoabari[1, *], Bonnie Kemebaradikumo Goodhope[2]

[1]Department of Chemistry, Faculty of Natural and Applied Sciences, Ignatius Ajuru University of Education, Port Harcourt, Nigeria

[2]Department of General Studies, School of Science Foundation, Bayelsa State College of Health Technology, Otuogidi, Bayelsa, Nigeria

Abstract

This study evaluates the phytochemical (qualitative and quantitative) and anti-nutrient compositions of unprocessed and processed (fermented, boiled, and roasted) unripe plantains (*M. paradisiaca*) from different markets with the city of Port Harcourt and its environment, Rivers State, Nigeria. The study involved the process and unprocessed. Standard laboratory procedures were used to check for the qualitative and phenols analysis, while the quantitative analysis was done using spectrophotometric methods. Processing methods significantly alter the concentration of bioactive compounds and anti-nutritional factors. Qualitative and quantitative analyses were conducted to assess variations in phytochemicals (alkaloids, flavonoids, tannins, saponins, phenols) and anti-nutrients (oxalates, phytates, tannins, cyanogenic glycosides). The quantitative analysis showed that Tannins: 4.12±0.15;unprocessed, 3.45±0.12;fermented, 2.31±0.11;boiled, and 2.78±0.09;roasted, Total phenols: 6.23±0.20;unprocessed, 5.67±0.18;fermented, 3.94±0.12;boiled, and 4.53±0.15;roasted, Terpenoids: 4.45±0.16;unprocessed, 3.87±0.13;fermented, 2.86±0.10;boiled, and 4.15±0.14;roasted, while the Anti-nutrients: Phytates; 1.56±0.07(unprocessed), 0.89±0.04(fermented), 1.25±0.06 (boiled), and 1.03±0.08 (roasted). The tannins, total phenols, and terpenoids were the most dominant of the different phytochemicals. The results suggest that the traditional processing methods like fermentation, and boiling effectively reduced the antinutritional factors, and also highlight the impact of processing techniques on nutritional and health-promoting properties of unripe plantains. It is necessary that processing techniques be checked to ensure the quality of the studied food is maintained.

Keywords

Unripe Plantains, Musa Paradisiaca, Phytochemicals, Anti-Nutritional Factors, Fermentation, Boiling, Roasting

1. Introduction

Plantains (*Musa paradisiaca*) are a staple food in many tropical regions including Nigeria, providing a significant source of carbohydrates [1]. However, raw plantains contain anti-nutritional factors such as phytates and tannins,

*Corresponding author: teeprince2011@gmail.com (Nwoke Prince Lekpoabari)

Received: 22 February 2025; **Accepted:** 20 March 2025; **Published:** 19 May 2025

which can impede nutrient absorption [2]. Processing methods like fermentation, boiling, and roasting are employed to enhance the nutritional value by altering the chemical composition and reducing anti-nutritional factors. They are also important for enhancing the nutritional quality, safety, and overall acceptability of food. Processing methods improve the shelf life of food products, making them more durable and reducing post-harvest losses [3]. However, poor processing techniques can have significant negative effects on both the phytochemical composition and antinutrient levels in plant-based materials. One of the primary consequences is the degradation of phytochemicals, which are often sensitive to environmental factors like heat, light, and oxygen. Improper 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. This not only diminishes the nutritional value but also reduces the health benefits these phytochemicals provide [4].

In addition to the loss of valuable nutrients, poor processing can also lead to an increase in antinutrient levels. Antinutrients such as phytates, oxalates, and lectins are naturally present in many plants and can hinder the absorption of essential nutrients like iron, calcium, and proteins. Improper methods, such as insufficient soaking, fermentation, or cooking, fail to adequately reduce these antinutrients. For instance, inadequate cooking of legumes may result in higher levels of lectins, which can be toxic and reduce protein digestibility, thus impacting overall nutrition [5].

Moreover, poor processing techniques can also affect the bioavailability of phytochemicals. In their raw forms, many beneficial compounds are in inactive or bound states, requiring specific processing methods like fermentation or enzymatic activation to release their full potential. When these methods are not properly applied, the body may be unable to efficiently absorb these compounds, thereby reducing the overall health benefits of the food. This is particularly problematic in cases where food is being processed to enhance nutritional value, as improper techniques can render the intended benefits ineffective [5, 6].

Furthermore, inadequate processing can lead to the retention of naturally occurring toxins in certain plant foods, such as solanine in potatoes or cyanogenic compounds in cassava. These toxins are usually neutralized through methods like boiling or fermenting, but poor processing practices can fail to remove them, posing health risks to consumers. Thus, the presence of toxins in improperly processed foods can not only diminish nutritional quality but also introduce potential hazards [4-6].

Fermentation involves the action of microorganisms such as yeasts and lactic acid bacteria on substrates, leading to several chemical transformations (7-8). This organic reaction leads to the breakdown of complex carbohydrates and proteins, resulting in the production of simpler sugars, amino acids, and organic acids like lactic acid [7-9]. Microbial enzymes degrade compounds like phytates and tannins, which can inhibit mineral absorption. This degradation enhances the bioavailability of essential minerals [10]. Proteolytic enzymes from microorganisms break down complex proteins into simpler peptides and amino acids, improving protein digestibility and nutritional quality [11, 12]. Additionally, fermentation produces organic acids such as lactic acid, which can lower pH and further reduce anti-nutritional factors [13, 14].

In contrast, boiling of plantains involves heating plantains 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 [15]. Heat causes starch granules to swell and gelatinize, making carbohydrates more digestible. While some minerals may leach into the water, boiling can also enhance the bioavailability of certain minerals by breaking down cell walls and facilitating their absorption [16, 17].

Similarly, roasting involves cooking plantains at high temperatures, resulting in the Maillard reaction. This is a non-enzymatic browning reaction between reducing sugars and amino acids that enhances flavour and may reduce certain anti-nutritional factors [18]. High temperatures can degrade compounds like tannins and phytates, improving nutrient availability [19, 20]. Furthermore, water loss during roasting concentrates nutrients, potentially increasing the caloric density of the plantain [21].

Antinutrients are naturally occurring compounds found in plant and animal foods that interfere with the absorption or utilization of nutrients, potentially leading to nutritional deficiencies or other health issues [22, 23]. While many antinutrients have beneficial roles in plants, such as defending against pests or pathogens [24, 25], they can be problematic for humans, especially in populations with nutrient-poor diets, when consumed in large amounts [24, 26]. For example, individuals who rely heavily on plant-based foods that contain high levels of phytates, tannins, or oxalates may be at risk for mineral deficiencies or kidney stone formation [23]. Furthermore, some antinutrients, like lectins and protease inhibitors, can cause digestive discomfort and interfere with protein absorption, leading to malnutrition [14]. Tannins and saponins have antioxidant, anti-inflammatory, and antimicrobial properties that can provide health benefits [27]. Similarly, phytates may have anticancer properties and may help prevent oxidative stress [28]. The chemistry of antinutrients is complex, and their effects can vary depending on the type of food, the concentration of the antinutrient, and the processing methods used [29].

This study aims to provide insights into how three traditional processing techniques, such as fermentation, boiling, and roasting affect the phytochemical and anti-nutrient contents of unripe plantains.

2. Materials and Methods

2.1. Sample Collection and Preparation

Unripe plantain samples were purchased from different markets in Port Harcourt, Rivers State, Nigeria. The samples were divided into three groups, each subjected to a different traditional processing method: fermentation, boiling, and roasting. Fermentation involved natural microbial activity over a specified period, boiling was conducted at 100°C until soft, and roasting was performed over an open flame until fully cooked. Processed (fermented, boiled and roasted) and unprocessed samples were then dried and ground into fine flour for analysis. The aqueous extraction of the plantain samples was distinctly gotten by soaking 10 g of the flour in 100 mL of distilled water. The solution was shaken sporadically for 24 h and filtered. The solvents were evaporated to dryness using a steam bath [30].

2.2. Phytochemical Analysis

The qualitative phytochemical assessment of the plantain was as described Rotimi and Adeyemi [31]. For the quantitative evaluation of phytochemicals in the samples, we used the spectrophotometric methods. Phytochemicals including tannin was measured as determined by Gupta and Verma [32], while terpenoid content was determined as described by Harborne [33]. The total phenol content was measured using the procedure described by Rotimi and Adeyemi [31]. The flavonoid and saponin contents were determined as described by Mattila and Kumpulainen [34] and Uematsu et al. [35] respectively.

2.3. Anti-Nutrient Analysis

Anti-nutritional factors such as phytates, tannins, oxalates, cyanogenic glycosides, and saponins were quantified as described by Abdullahi et al. [36] to assess their concentrations post-processing.

2.4. Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to assess the effects of the different processing methods on the concentrations of phytochemicals and antinutrients. The means of the different groups were compared using Tukey's post hoc test at a significance level of $p < 0.05$. All statistical analyses were performed using Statistics Package for Social Sciences (SPSS) (version 26.0), Inc., Chicago, United State of America (USA). The results are presented as mean ± standard deviation (SD), and the level of significance was set at $p < 0.05$.

3. Results

3.1. Qualitative Phytochemical Composition of Plantain Samples

The qualitative phytochemical analysis in Table 1 revealed the presence of tannins, terpenoids, phenols, flavonoids, cyanogenic glycosides, and saponins across all plantain samples (unprocessed, fermented, boiled, and roasted).

Table 1. *Qualitative Phytochemical Composition of Unprocessed and Processed Plantain Samples.*

Phytochemical Compound	Unprocessed Plantain	Fermented Plantain	Boiled Plantain	Roasted Plantain
Tannins	+++	++	++	++
Terpenoids	+++	++	++	++
Phenols	+++	++	++	++
Flavonoids	+++	++	++	++
Cyanogenic Glycosides	++	++	+	+
Saponins	++	++	+	+

+++: High concentration of the compound (dominant presence)
++: Moderate concentration of the compound (significant presence)
+: Low concentration of the compound (minimal presence)

3.2. Quantitative Phytochemical Composition of the Plantain Samples

The quantitative results indicated varying concentrations of phytochemicals across processing methods, as shown in Table 2.

Table 2. Quantitative Phytochemical Composition of Unprocessed and Processed Plantain Samples (mg/g).

Phytochemical	Unprocessed	Fermented	Boiled	Roasted
Tannins	4.12 ± 0.15	3.45 ± 0.12	2.31 ± 0.11	2.78 ± 0.09
Terpenoids	4.45 ± 0.16	3.87 ± 0.13	2.86 ± 0.10	4.15 ± 0.14
Total Phenols	6.23 ± 0.20	5.67 ± 0.18	3.94 ± 0.12	4.53 ± 0.15
Flavonoids	3.15 ± 0.10	2.89 ± 0.08	2.13 ± 0.07	2.45 ± 0.09
Saponins	3.45 ± 0.11	3.12 ± 0.09	2.47 ± 0.08	2.79 ± 0.10
Cyanogenic Glycosides	1.25 ± 0.06	0.72 ± 0.03	0.54 ± 0.02	0.63 ± 0.03

3.3. Anti-Nutrient Composition of the Plantain Samples

The anti-nutrient analysis results are presented in Table 3.

Table 3. Anti-Nutrient Composition of Unprocessed and Processed Plantain Samples (mg/g).

Anti-Nutrient	Unprocessed	Fermented	Boiled	Roasted
Phytates	1.56 ± 0.07	0.89 ± 0.04	1.25 ± 0.06	1.03 ± 0.05
Tannins	2.10 ± 0.08	1.34 ± 0.05	1.78 ± 0.07	1.62 ± 0.06
Oxalates	1.32 ± 0.06	0.85 ± 0.03	0.72 ± 0.03	1.10 ± 0.05
Saponins	1.45 ± 0.05	0.95 ± 0.04	1.20 ± 0.05	1.07 ± 0.04
Cyanogenic Glycosides	1.25 ± 0.06	0.72 ± 0.03	0.54 ± 0.02	0.63 ± 0.03

4. Discussion

4.1. Qualitative Phytochemical Composition of the Samples

The qualitative phytochemical analysis of the processed and unprocessed plantain samples revealed the presence of several bioactive compounds, which are well-known for their health-promoting properties [37, 38], and their presence in all plantain samples indicates that plantains possess a range of potential therapeutic benefits [39].

Tannins, identified in all samples, are compounds known for their antioxidant and antimicrobial activities [40]. They can bind proteins [41], potentially contributing to their protective effects against inflammation and oxidative stress [42]. The consistent presence of tannins across all processing methods (fermented, boiled, roasted, and unprocessed) suggests that plantains maintain their antioxidant and antimicrobial properties [37, 43], regardless of the processing techniques applied.

Terpenoids, another class of compounds found in all plantain samples, are recognized for their aromatic properties and biological activities, including anti-inflammatory, antimicrobial, and anticancer effects [44]. The persistence of terpenoids in processed plantains suggests that these compounds are stable during different processing methods, contributing to the overall pharmacological potential of the plantains [45].

Phenolic compounds, which are potent antioxidants, were also detected in all plantain samples. These compounds are known to protect cells from oxidative damage, reducing the risk of chronic diseases such as heart disease and cancer. The presence of phenols across all plantain samples indicates that the processing methods do not significantly affect their content, suggesting that plantains retain their antioxidant properties even after processing [45, 46].

Flavonoids, which also have antioxidant and anti-inflammatory properties [47-49], were present in all samples. These compounds are linked to a variety of health benefits, including improved cardiovascular health and potential anticancer effects [50]. The consistent presence of flavonoids in both processed and unprocessed plantains further supports the health benefits of plantains [39, 43], regardless of the processing method used.

Cyanogenic glycosides, which can release cyanide when metabolized, were also detected in the plantain samples. While these compounds can pose toxicity risks, their presence suggests the need for proper processing methods to reduce their harmful effects [51]. This finding highlights the importance of using appropriate methods, such as boiling or fermentation, to ensure the safety of plantains.

Finally, saponins were found in all plantain samples. These compounds are known for their cholesterol-lowering, immune-boosting, and anticancer activities [52]. The presence of saponins across all processing methods suggests that plantains may be the reason for these health benefits, irrespective of the processing technique [53].

4.2. Quantitative Phytochemical Composition of the Samples

The quantitative phytochemical analysis of unprocessed and processed plantain samples revealed significant variations in the concentrations of key bioactive compounds, highlighting the impact of different processing methods. The concentration of tannins was highest in the unprocessed plantain (4.12 ± 0.15 mg/g) and decreased with processing. Fermented plantains contained 3.45 ± 0.12 mg/g, boiled plantains had 2.31 ± 0.11 mg/g, and roasted plantains showed 2.78 ± 0.09 mg/g. This decline indicates that processing methods, particularly boiling, reduce tannin levels, which may affect the antioxidant and antimicrobial properties of the plantains [54, 55].

For terpenoids, the unprocessed plantains had the highest concentration at 4.45 ± 0.16 mg/g, followed by roasted plantains at 4.15 ± 0.14 mg/g, fermented plantains at 3.87 ± 0.13 mg/g, and boiled plantains with the lowest concentration of 2.86 ± 0.10 mg/g. These results suggest that roasting and unprocessed plantains retain more terpenoids, while boiling leads to a notable reduction in their concentration, which may impact the therapeutic potential of plantains [55].

The total phenolic content was highest in unprocessed plantains (6.23 ± 0.20 mg/g), followed by fermented plantains at 5.67 ± 0.18 mg/g. Boiled plantains contained 3.94 ± 0.12 mg/g, and roasted plantains had 4.53 ± 0.15 mg/g. The decrease in phenolic content with processing indicates that thermal treatments, such as boiling and roasting, may cause a loss of these antioxidant compounds, potentially reducing the health benefits associated with phenols [55, 56].

Flavonoid concentrations were highest in unprocessed plantains (3.15 ± 0.10 mg/g) and decreased across the processed samples. Fermented plantains had 2.89 ± 0.08 mg/g, roasted plantains contained 2.45 ± 0.09 mg/g, and boiled plantains showed the lowest concentration at 2.13 ± 0.07 mg/g. This reduction in flavonoid content due to processing, particularly boiling, may diminish the anti-inflammatory and antioxidant effects that flavonoids provide [57].

Saponins were detected in all plantain samples, with the unprocessed plantains containing 3.45 ± 0.11 mg/g, fermented plantains at 3.12 ± 0.09 mg/g, boiled plantains at 2.47 ± 0.08 mg/g, and roasted plantains at 2.79 ± 0.10 mg/g. Although there was a decrease in saponin levels with processing, the reduction was not as pronounced as for other compounds, suggesting that saponins are relatively stable during processing [58].

The concentration of cyanogenic glycosides was highest in unprocessed plantains (1.25 ± 0.06 mg/g). Processing significantly reduced their levels, with fermented plantains containing 0.72 ± 0.03 mg/g, boiled plantains at 0.54 ± 0.02 mg/g, and roasted plantains showing 0.63 ± 0.03 mg/g. This reduction suggests that processing methods, especially boiling and fermentation, effectively reduce the toxic potential of cyanogenic glycosides, making plantains safer for consumption [59].

4.3. Anti-Nutrient Composition of the Samples

The analysis of the anti-nutrient composition of unprocessed and processed plantain samples revealed significant variations in the levels of phytates, tannins, oxalates, saponins, and cyanogenic glycosides, depending on the processing method. These anti-nutrients, if consumed in excess, can hinder nutrient absorption and pose potential health risks. However, the results suggest that various processing methods, including fermentation, boiling, and roasting, effectively reduce the concentrations of these anti-nutrients, potentially enhancing the nutritional quality and safety of plantains.

Firstly, the concentration of phytates in unprocessed plantains was the highest at 1.56 ±0.07 mg/g, but processing methods led to varying reductions. Fermented plantains showed a notable decrease to 0.89 ± 0.04 mg/g, indicating that fermentation is particularly effective in reducing phytate levels. While boiling also resulted in a reduction (1.25 ±0.06 mg/g), roasted plantains had a moderate decrease (1.03 ± 0.05 mg/g). Phytates are known to inhibit mineral absorption, and the reduction in their levels through fermentation and boiling can improve the bioavailability of essential minerals [10, 60].

Similarly, tannins, which can bind to nutrients and impair their absorption, were most concentrated in the unprocessed plantains (2.10 ± 0.08 mg/g). Fermentation led to a significant reduction in tannins (1.34 ± 0.05 mg/g), while boiled plantains had a slightly higher concentration of 1.78 ± 0.07 mg/g, and roasted plantains contained 1.62 ± 0.06 mg/g. The decrease in tannin levels through fermentation further highlights the beneficial effects of fermentation in improving the nutrient bioavailability of plantains [55, 61].

Oxalates, another anti-nutrient that can reduce calcium absorption and contribute to kidney stone formation [62], were found in the unprocessed plantains at 1.32 ± 0.06 mg/g. Processing methods reduced oxalate concentrations, with fermented plantains containing 0.85 ± 0.03 mg/g and boiled plantains having the lowest concentration at 0.72 ± 0.03 mg/g. Roasted plantains showed a moderate reduction at 1.10 ± 0.05 mg/g. These reductions suggest that fermentation and boiling are effective in lowering oxalate levels, thus reducing the risk of calcium deficiency and kidney stones [63].

The concentration of saponins, which may interfere with nutrient absorption and have toxic effects at high levels, was highest in unprocessed plantains (1.45 ± 0.05 mg/g). However, fermentation led to a reduction to 0.95 ± 0.04 mg/g, and boiling decreased the concentration to 1.20 ± 0.05 mg/g. Roasted plantains showed a moderate decrease at 1.07 ± 0.04 mg/g. The reduction in saponins through fermentation and boiling is notable, as these methods help in reducing potential negative impacts on health while maintaining the plantains' nutritional profile [64].

Lastly, the levels of cyanogenic glycosides, which can be toxic if consumed in high amounts, were found to be highest in unprocessed plantains (1.25 ± 0.06 mg/g). However, all processing methods, including fermentation, boiling, and roasting, significantly reduced the cyanogenic glycoside content [65-67], with the lowest concentrations observed in boiled plantains (0.54 ± 0.02 mg/g). This reduction demonstrates the effectiveness of processing in reducing the toxicity associated with cyanogenic glycosides, thereby enhancing the safety of plantains for consumption [65].

5. Conclusion

This study demonstrates that traditional processing methods, particularly fermentation and boiling, effectively reduce anti-nutritional factors such as phytates, tannins, oxalates, and cyanogenic glycosides in unripe plantains while preserving or enhancing beneficial phytochemicals. Fermentation emerged as the most effective method, significantly improving the nutritional safety and health benefits of the plantains. Boiling also proved highly effective, especially in reducing harmful anti-nutrients, while roasting had a moderate impact. These findings highlight the importance of selecting appropriate processing techniques to maximize the nutritional value and safety of unripe plantains, offering practical solutions for communities consuming plantains from potentially contaminated environments.

Abbreviations

ANOVA	Analysis of Variance
SD	Standard Deviation
SPSS	Statistics Packages for Social Sciences
USA	United State of America

Conflicts of Interests

The authors declare no conflicts of interest.

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