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Nutritional Characteristics of Plantain Flour Harvested in Anivorano Nord, Antsiranana II District, Region of DIANA, Madagascar

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Abstract — *In Madagascar, plantain (Musa spp.) constitutes a fundamental food resource, particularly in the form of flour used in complementary infant feeding. However, its precise nutritional characteristics, especially at the local level, remain poorly documented. This study aims to determine the nutritional characteristics of plantain flour harvested in the Rural Commune of Anivorano Nord. To achieve this objective, local plantains were harvested, then processed into flour using transformation processes, and the resulting flour was analyzed by appropriate methods to ascertain its nutritional characteristics. The results obtained reveal that the flour of plantains harvested in Anivorano Nord is a notable source of energy (324.34 kcal/100 g), mainly due to its high carbohydrate content (81.17%). It is distinguished by an exceptionally high potassium content (2434.34 mg/100 g) and low content of lipids (2.61%), proteins (3.06%), and sodium (3.97 mg/100 g). The Ca/P (0.0497) and Na/K (0.0016) ratios of this flour are very low. Its Potential Renal Acid Load is strongly negative (– 45.2928). In conclusion, the plantain flour from Anivorano Nord presents an interesting nutritional profile, particularly adapted to hyper-energetic and hypotensive diets. Its alkalizing effect and richness in essential minerals confirm its potential for the valorization of local agricultural products and the fight against nutritional insecurity.*

Keywords — *Plantain banana, Flour, Nutritional characteristic, Anivorano Nord, Madagascar.*

I. INTRODUCTION

The banana (*Musa* spp.), which belongs to the Musaceae family, represents one of the most important fruit productions on a global scale, ranking as the fourth basic agricultural commodity after rice, wheat, and maize (Lassoudière, 2007; Lassois *et al.,* 2009). With over 106 million tonnes produced annually, it plays a crucial role in the food security of numerous populations (Lassois *et al.,* 2009; FAO, 2025). Among the thousands of existing varieties, the plantain distinguishes itself by its culinary uses. Longer, angular, and richer in starch than the dessert banana, it is generally consumed only after cooking. Its carbohydrate composition, which evolves from starch to sucrose during maturation, confers great versatility (Haydersah, 2012).

In Madagascar, plantain is a pillar of agriculture and nutrition. The climatic conditions of several Regions, notably the hot and humid climate of the DIANA Region (Diégo Suarez, Ambilobe, Nosy Be, and Ambanja), are conducive to its cultivation (Lassois *et al.,* 2009; Madagascar Destination, 2025). Anchored in culinary traditions, it is consumed at different stages of maturity, in savory dishes such as fries or in sweet preparations (Rakotondramanana, 2024). Its texture and neutral flavor make it an excellent substitute for other starchy foods and a base for flour production.

In the Rural Commune of Anivorano Nord (Antsiranana II District), plantain flour is traditionally used in complementary feeding for young children, a common practice in a context of concerning infant malnutrition. However, despite its widespread use, the precise nutritional composition of this local resource remains poorly documented. This absence of reliable scientific data constitutes a hindrance to its optimal valorization and the formulation of adequate nutritional recommendations.

The present study therefore aims to fill this gap by determining the nutritional characteristics of plantain flour harvested in Anivorano Nord. The objective is to provide quantitative data on its energy value, its macronutrient composition (carbohydrates, proteins, lipids), and essential minerals, as well as other nutritional parameters. These results will allow for the scientific valorization of plantain, a local product, and provide databases for its integration into dietary diversification strategies and the fight against malnutrition.

II. MATERIALS AND METHODS

2.1. Study Site

2.1.1. Geographic and Administrative Context

The study was conducted in the Rural Commune of Anivorano Nord, located in the District of Antsiranana II, within the DIANA Region. This Commune was selected due to the high prevalence of infant malnutrition and the socio-economic importance of plantain. Geographically, it is located at coordinates 12°44′00″ South and 49°14′00″ East, on National Road 6, 75 km south of Antsiranana I. The population numbers approximately 18,447 souls with a density rising to 28.98 inhabitants/km². In general, 90% of the population are farmers. The Rural Commune of Anivorano Nord plays a role as a crossroads for agricultural products serving the major centers of the Region (Zafitsara, 2019; Ranjanirina *et al.,* 2025).

2.1.2. Pedological and Hydrographic Characteristics

The terroir of Anivorano Nord is characterized by volcanic relief and soils of remarkable fertility, resulting from the alteration of recent basaltic lava flows (Tercinier, 1952; Zafitsara, 2019; Ranjanirina *et al.,* 2025). The soils, described as brown, deep, and non-stony, possess a chemical composition rich in oxides of iron, aluminum, manganese, magnesium, and phosphorus. Their clay structure in stable aggregates ensures excellent water retention while maintaining good permeability, creating ideal conditions for agriculture (Tercinier, 1952; Ranjanirina *et al.,* 2025). The potential of the zone is reinforced by a dense hydrographic network, including the Irodo River and Lake Antagnavo.

2.1.3. Socio-economic and Agricultural Context

Thanks to the pedoclimatic potential of the Rural Commune of Anivorano Nord, agriculture constitutes the main economic activity for 90% of the local population (Zafitsara, 2019). While rice cultivation is predominant, soil fertility allows for great diversification of crops, including market garden crops, legumes (beans), maize, and cassava. Despite these assets, the Region faces significant challenges, notably a seasonal water deficit and water management complicated by the effects of climate change (Tercinier, 1952; Zafitsara, 2019; Ranjanirina *et al.,* 2025). This context reinforces the interest in studying resilient crops with high nutritional value like plantain.

2.2. Plant Material and Flour Preparation

2.2.1. Sample Collection

A sample of approximately 4.9 kg of plantains (Musa spp., local variety) was collected from a field in the Rural Commune of Anivorano Nord. The collection was carried out manually at an early stage of maturity, characterized by completely green skin and firm pulp. The fruits thus collected were immediately transported to the processing site in polyethylene bags to preserve their integrity and minimize post-harvest alterations.

2.2.2. Transformation of Fruits into Flour

Flour production followed a standardized protocol inspired by local practices. The different processes used are as follows:

- Sorting and Weighing: Bananas were sorted to keep only fruits of homogeneous size. The initial mass of selected fruits was recorded using a JINDING brand scale.
- Preparation: Fruits were peeled manually using stainless steel knives. In accordance with local practices aimed at obtaining white-colored flour, the central part (placental axis) of each fruit was removed.
- Washing and Cutting: The pulps were washed in clear water, then rinsed in lukewarm water to eliminate latex residues and limit enzymatic browning. They were then cut into thin semi-circular slices to facilitate drying.
- Drying: The slices were spread in a thin layer on a support covered with black polyethylene film and exposed to the sun for two days. Periodic turning was performed to ensure homogeneous drying. The end of drying was determined by organoleptic indicators: whitish color, brittle texture, and curved shape of the slices.
- Grinding and Sieving: Before grinding, the dried slices underwent a final desiccation of three hours to further reduce their residual moisture. They were then ground in a traditional wooden mortar until a ground material was obtained. This was manually sieved to obtain a fine and homogeneous flour.
- Packaging: The flour thus obtained was packaged in hermetically sealed glass jars, labeled, and stored in a dry place protected from light until analyses were performed.

2.3. Physico-Chemical and Nutritional Analyses

The physico-chemical and nutritional analyses of the plantain flour samples were carried out at the National Center for Environmental Research (CNRE) in Antananarivo, Madagascar.

2.3.1. Determination of Water and Dry Matter Content

Water content or moisture (*MC*) and dry matter (*DM*) were determined by the gravimetric method by oven drying, according to the AOAC standard (1989). Approximately 5 g of flour was placed in an oven at 130 °C for 4 hours. Moisture corresponds to the loss of mass relative to the initial mass of the sample.

Moisture was determined using equation (1), and dry matter content was calculated by applying equation (2) (AOAC, 1989).

$$\%MC = \frac{m_{CD} - m_{EC}}{m_{CS} - m_{EC}} \times 100 \quad (1)$$

$$\%DM = 100 - \%MC \quad (2)$$

Where $\%MC$ is the moisture content (%), m_{EC} is the mass of the empty crucible (g), m_{CS} is the mass of the crucible with the initial sample (g), m_{CD} is the mass of the crucible after oven-drying (g), and $\%DM$ is the dry matter content (%).

2.3.2. Determination of Crude Ash Content

Crude ash content, representing total mineral matter, was determined by incineration. Approximately 5 g of sample was calcined in a muffle furnace at 550 °C for 4 hours until whitish ashes were obtained (AOAC, 1970). The result was expressed as a percentage of fresh matter.

Taking into account the masses obtained before and after incineration, the following formula was used to determine the percentage of crude ash in the sample (AOAC, 1970; Joslyn, 1970).

To calculate the crude ash content, the specific formula adapted for this analysis was used. This formula accounts for the masses obtained before and after incineration to determine the percentage of crude ash in the sample (AOAC, 1970 and Joslyn, 1970).

$$\%CA = \frac{m_{CA} - m_{EC}}{m_{CS}} \times 100 \quad (3)$$

Where $\%CA$ is the crude ash content on a fresh weight basis (%), m_{EC} is the mass of the empty crucible in (g), m_{CA} is the mass of the crucible with the ash after incineration (g), and m_{CS} is the mass of the initial sample (g).

2.3.3. Determination of Organic Matter Content

Similarly, the method described by AOAC (1970) and Joslyn (1970) was used to quantify the organic matter content.

Organic matter and mineral matter are the two main components constituting the total matter of a product. The mineral matter content corresponds to the crude ash content. By subtracting the crude ash content from the total dry matter, the organic matter content is obtained, according to the formula below.

$$\%OM = \%DM - \%CA \quad (4)$$

Where $\%OM$ is the organic matter content (%), $\%DM$ is the dry matter content on a fresh weight basis, and $\%CA$ is the crude ash content.

2.3.4. Determination of Crude Protein Content by the Kjeldahl Method

According to the international standard ISO 20483, second edition 2013, crude protein content was determined by quantifying total nitrogen using the Kjeldahl method. The protocol included three steps:

- Mineralization: 5 g of sample was digested hot (≈340 °C) with concentrated sulfuric acid (H_2SO_4) in the presence of a catalyst ($CuSO_4/K_2SO_4$).
- Distillation: Ammoniacal nitrogen was released by alkalinization with sodium hydroxide (NaOH), then distilled and collected in a boric acid solution (H_3BO_3).
- Titration: The ammonia trapped in the boric acid solution was titrated with a standardized sulfuric acid solution (0.1 N).

The total nitrogen content (%) of the sample was determined from equation (5). This includes a calculation constant, derived from stoichiometry and units, equal to 1.4 when the normality of the acid is 0.1 N and the result is expressed as a percentage. The value obtained was then converted into crude protein percentage by applying the nitrogen-to-protein conversion factor of 6.25, in accordance with equation (6).

$$\%N_T = \frac{1.4 \times V \times n}{m_{PE}} \times 100 \quad (5)$$

$$\%CP = \%N_T \times 6.25 \quad (6)$$

Where N_T is the total nitrogen content (%), V is the volume of sulfuric acid at 0.1 N during titration, n is the normality of sulfuric acid which is equal to 0.1 N, m_{CS} is the mass of the test portion (g), and CP is the crude protein content (%).

2.3.5. Determination of Crude Fat Content by the Soxhlet Method

Lipid content (Crude Fat) was determined by continuous extraction using a Soxhlet apparatus (Wolf *et al.,* 1991). Approximately 5 g of sample was extracted with 120 ml of hexane for 6 hours. After evaporation of the solvent at 80 °C, the lipid residue was weighed to determine the crude fat content.

The following formula allows calculating the lipid content (Crude Fat) of the sample (Wolf *et al.,* 1991).

$$\%CF = \frac{m_{FD} - m_{EF}}{m_{CS}} \times 100 \quad (7)$$

Where MG is the crude fat content (%), m_{EF} is the mass of the empty flask (g), m_{FD} is the mass of the flask with the drying extract (g), and m_{CS} is the mass of the initial sample (g).

2.3.6. Determination of Total Carbohydrate Content

Total carbohydrate content was estimated by the difference method, by subtracting the percentages of moisture, crude protein, crude fat, and crude ash from 100% (Antia *et al.,* 2006).

The following equation was used to determine the total carbohydrate content.

$$\%TC = 100 - (\%MC + \%CP + \%CF + \%CA) \quad (8)$$

Where TC is the total carbohydrate content (%), MC is the moisture content (%), CP is the crude protein content (%), CF is the crude fat content (%), and CA is the crude ash content (%).

2.3.7. Determination of Metabolizable Energy Value

The energy value was calculated using the specific Atwater factors proposed by Atwater and Rosa (1899). The metabolizable energy (*ME*) of foods is obtained by summing the energy contributions of carbohydrates, lipids, and proteins. For each nutrient, metabolizable energy is determined by multiplying its content by its specific Atwater caloric factor, set respectively at 4 for proteins, 9 for lipids, and 4 for carbohydrates. The metabolizable energy of the produced flour was thus estimated in accordance with equation (9).

$$ME(\text{kcal}) = (\%CP \times 4) + (\%CF \times 9) + (\%TC \times 4) \quad (9)$$

Where ME is the metabolizable energy in kilocalories (kcal), $\%CP$ is the crude protein content (%), $\%CF$ is the crude fat content (%), and $\%TC$ is the total carbohydrate content (%).

2.3.8. Mineral Element Analysis

The mineral element content was determined by the AOAC (1990) method.

- *Sample Preparation (Digestion)*

The crude ash obtained after incineration of the sample was digested by the acid method. Approximately 5 ml of concentrated nitric acid (HNO_3) at 37% and 20 ml of distilled water were added to the ash in a beaker. The mixture was then heated on a hot plate to a temperature near boiling, about 95°C, for 15 minutes to ensure complete dissolution of the minerals. After cooling, the solution was quantitatively transferred to a 100 ml volumetric flask, which was then filled to the mark with distilled water and homogenized to obtain the stock solution for analysis.

- *Assay by Atomic Absorption Spectrometry*

The concentrations of Iron (Fe), Calcium (Ca), Copper (Cu), Manganese (Mn), Zinc (Zn), Potassium (K), Sodium (Na), and Magnesium (Mg) in the stock solution (or its appropriate dilutions) were determined by flame atomic absorption spectrometry (flame-AAS). Atomic Absorption Spectrometry (AAS) is a quantitative elemental analysis technique where a light source, typically a specific hollow-cathode lamp, emits radiation at a characteristic wavelength that can be absorbed by atoms of the target element in their ground state. The liquid sample is aspirated, nebulized into a fine aerosol, and introduced into an atomization source such as a flame (air-acetylene or N_2O-acetylene), where it undergoes solvent evaporation, salt decomposition, and conversion of elements into free atoms. These atoms absorb part of the light beam passing through them, and a monochromator then isolates the analytical line, and a detector measures the transmitted intensity to calculate the absorbance, which is directly proportional to the analyte concentration in the sample according to the Beer-Lambert law.

For each element, a calibration range was prepared by successive dilutions of a certified stock standard solution in an acid matrix similar to that of the samples. The absorbance of each standard solution was measured, allowing a calibration curve of *Absorbance = f(Concentration)* to be plotted. For the determination of Calcium (Ca) and Magnesium (Mg), a solution of a Lanthanum salt ($LaCl_3$), often prepared by dissolving La_2O_3 in HCl, was added in sufficient concentration to both standards and samples to act as a releasing agent, i.e., to suppress chemical interferences, notably from phosphates. For the determination of Sodium (Na) and Potassium (K), a solution of a Cesium salt (CsCl) was added in sufficient concentration to both standards and samples to act as an ionization buffer, i.e., to suppress ionization interferences in the flame.

The instrument was set to the optimal conditions for each element (wavelength, flame type, gas flow rates, burner height). The appropriate hollow-cathode lamp was installed and aligned. After ignition and stabilization of the flame, the solutions (blank, standards, samples) were aspirated successively. The instrument measures the absorbance and uses the calibration curve to calculate the element concentration in the analyzed solution. These concentrations were recorded. Samples whose absorbance fell outside the calibration range were appropriately diluted (noting the dilution factor, *DF*) and re-measured.

The content of mineral elements such as Iron, Calcium, Copper, Manganese, Zinc, Potassium, and Sodium in the initial sample was calculated using equation (10):

$$MEC(\%) = \frac{X \times DF \times V}{m_{CS}} \times 100 \qquad (10)$$

Where *MEC* is the content of the mineral element in the sample (mg/100g), X is the concentration of the element measured by AAS in the analyzed solution (read from the spectrometer screen, usually in mg/l), *DF* is the dilution factor, V is the final volume of the stock solution after digestion and adjustment to the mark in liters (l), and m_{CS} is the mass of the initial sample (g).

- *Phosphorus Assay by Colorimetric Method*

Phosphorus, generally in the form of phosphate PO_4^{3-} after digestion, was determined by UV-Visible molecular absorption spectrophotometry using a colorimetric method. The method is based on the formation of a colored complex between phosphate ions and a specific reagent (vanadomolybdate reagent), where the color intensity is proportional to the phosphorus concentration. The vanadomolybdate method was used in an acidic medium; phosphates react with vanadate and molybdate to form a stable yellow-colored phosphovanadomolybdate complex.

The absorbance or optical density of this colored complex was measured at a specific wavelength (430 nm) and was related to the concentration (*C*) by the Beer-Lambert law:

$$OD = \sigma.L.C \qquad (11)$$

Where OD is the optical density or absorbance, σ is the molar extinction coefficient of a given solute, L is the path length of the solution in cm, and C is the concentration of the solute or element to be determined.

A series of phosphorus standards, not exceeding 40 µg, was prepared from a stock solution. Then, 5 ml of the sample and 5 ml of the vanadomolybdate reagent were mixed and agitated. The mixture was left to stand for 10 minutes for full and stable development of the yellow color. The optical densities of each solution were measured at 430 nm against a reagent blank. A calibration curve *Absorbance = f(Concentration)* was established from the standards. The phosphorus concentration in the samples was determined by interpolation on this curve. The displayed figures were noted.

2.4. Calculation of Functional Nutritional Indices

In order to evaluate the potential metabolic impact of plantain flour, the following indices were calculated.

2.4.1. Calcium/Phosphorus Ratio (Ca/P)

This index, an indicator of mineral balance for bone health, was calculated as follows (Houdji *et al.,* 2018):

$$\text{Ratio } (\text{Ca/P}) = \frac{\%\,Ca}{\%\,P} \qquad (12)$$

Where *%Ca* is the calcium content (mg/100 g); *%P* is the phosphorus content (mg/100 g).

2.4.2. Sodium/Potassium Ratio (Na/K)

Considered a relevant marker of cardiovascular health, this ratio allows evaluating the balance between two major electrolytes in blood pressure regulation. A low Na/K ratio (less than 1) is recommended by health authorities to prevent the risk of hypertension, a condition often favored by modern diets rich in sodium and poor in potassium. The ratio was determined by the formula used by Houdji *et al.* (2018):

$$\text{Ratio } (\text{Na/K}) = \frac{\%\,Na}{\%\,K} \qquad (13)$$

Where *%Na* is the sodium content (mg/100 g); *%K* is the potassium content (mg/100 g).

2.4.3. Potential Renal Acid Load (PRAL)

This index estimates the acidifying or alkalizing effect of the food on the organism (Pamplona-Roger, 2016). It was calculated using the equation of Remer & Manz (1995), expressed in milliequivalents (mEq) per 100 g:

$$\begin{aligned} PRAL = {} & (0,49 \times \%CP) + (0,037 \times \%P) \\ & - (0,021 \times \%K) - (0,026 \times \%Mg) - (0,013 \times \%Ca) \end{aligned} \qquad (14)$$

Where *%CP* is the crude protein content (g/100 g); *%P* is the phosphorus content (mg/100 g); *%K* is the potassium content (mg/100 g); *%Mg* is the magnesium content (mg/100 g); *%Ca* is the calcium content (mg/100 g).

A positive result indicates that the food has an acidifying effect on the organism; whereas a negative result means that the food has an alkalizing effect on the organism.

III. Results and Discussion

The results obtained from the present study are summarized in Table I below.

The analysis of plantain flour harvested in Anivorano Nord reveals a distinct nutritional profile, the quantitative details of which are presented in Table I. The flour presents a low moisture content of 9.99%, which, associated with a high dry

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matter content (90.01%), as illustrated in Fig. 1, confers excellent stability and a long shelf life. These characteristics inhibit microbial proliferation and slow down degradation reactions, making this flour a product well-suited for storage. The composition of its dry matter, dominated by organic matter (86.95%) over ash (3.17%), is detailed in Fig. 2.

TABLE I. Information on Nutrient Elements of Plantain Flour

Parameters	Nutrient Content per 100 g of Flour
Metabolizable Energy (kcal/100 g)	324.34
Moisture (g/100 g)	9.99
Dry Matter (g/100 g)	90.01
Proteins (g/100 g)	3.06
Lipids (g/100 g)	2.61
Total Carbohydrates (g/100 g)	81.17
Crude Ash (g/100 g)	3.17
Organic Matter (g/100 g)	86.95
Potassium (mg/100 g)	2434.34
Calcium (mg/100 g)	9.86
Phosphorus (mg/100 g)	198.30
Magnesium (mg/100 g)	110.77
Sodium (mg/100 g)	3.97
Iron (mg/100 g)	4.36
Zinc (mg/100 g)	0.67
Manganese (mg/100 g)	0.90
Copper (mg/100 g)	0.24
Ca/P Ratio	0.0497
Na/K Ratio	0.0016
PRAL Index	– 45.2928

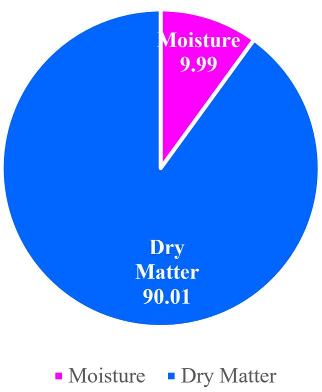

Fig 1. Moisture and dry matter rates determined from plantain flour

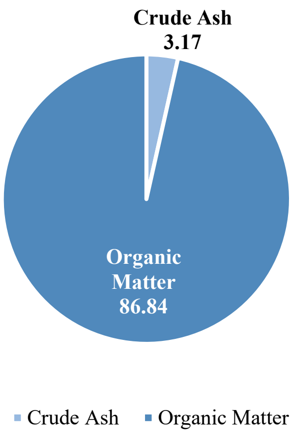

Fig 2. Crude ash and organic matter rates determined from dry matter of plantain flour

On the nutritional level, the flour constitutes a very important source of energy, providing 324.34 kcal per 100 g. As shown in Fig. 3, this energy value comes predominantly from its very high carbohydrate content (81.17 g/100 g), while protein (3.06 g/100 g) and lipid (2.61 g/100 g) contributions are more modest. This profile confirms its role as an ideal energy base, but also highlights the necessity of supplementing it with protein-rich foods to ensure a complete nutritional balance, particularly in the context of infant feeding.

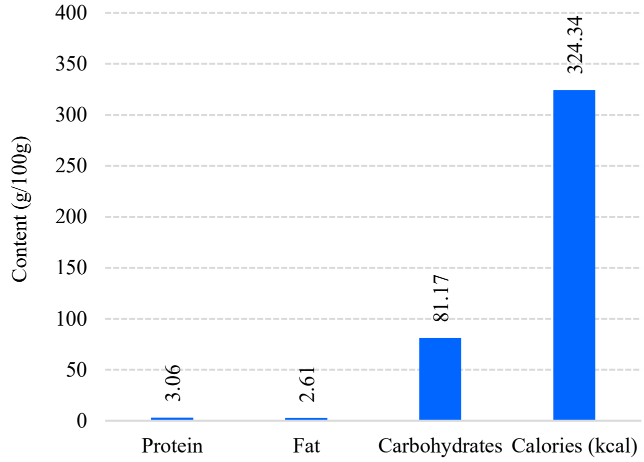

Fig.3. Energy value of plantain flour

The most remarkable characteristic of this flour lies in its unique mineral composition, visualized in Fig. 4. It is distinguished by an extraordinarily high content of potassium (2434.34 mg/100 g) and, conversely, very low sodium (3.97 mg/100 g).

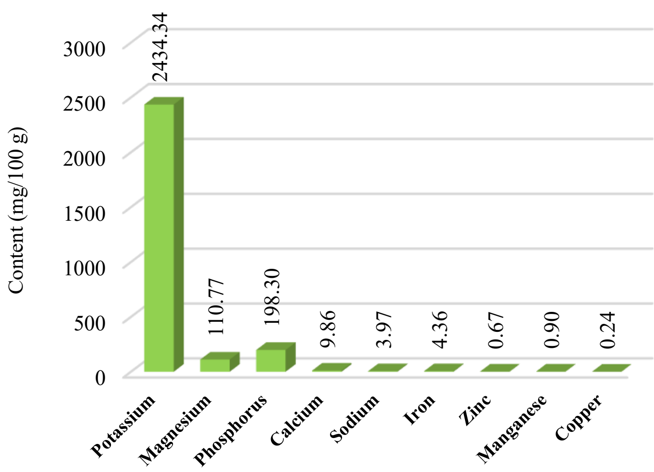

Fig. 4. Minerals in plantain flour

This combination results in an extremely low sodium/potassium ratio (0.0016), which is highly beneficial for cardiovascular health and blood pressure regulation. The flour is also an appreciable source of phosphorus (198.30 mg/100 g), magnesium (110.77 mg/100 g), and iron (4.36 mg/100 g). However, its low calcium content (9.86 mg/100 g) and unfavorable calcium/phosphorus ratio (0.0497), calculated from Table I data, indicate that it cannot constitute a primary source of calcium for bone health. Finally, its strongly negative

PRAL index (– 45.2928) demonstrates a powerful alkalizing effect on the organism, thus contributing to good acid-base balance.

The comparison of these results with other studies highlights the specificities of the Anivorano Nord product. As shown in Fig. 5, the energy value of 324.34 kcal/100 g, although significant, is more modest than levels reported in Bangladesh (Miah *et al.,* 2023) or Côte d'Ivoire (Badje *et al.,* 2019). This difference can be explained by the climate of the DIANA region, where the seasonal water deficit may limit photosynthesis and maximal starch accumulation, as well as by a moisture content (9.99%) slightly higher than certain industrial standards.

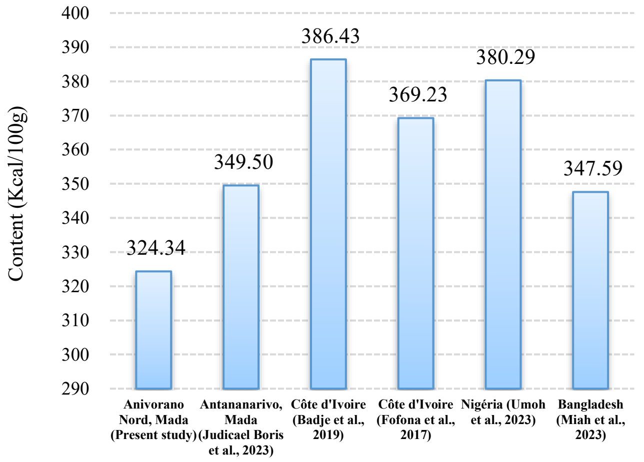

Fig. 5. Metabolizable energy of plantain flour compared to data from other studies

Regarding macronutrients, Fig. 6 illustrates that the protein content (3.06 g/100 g) falls within the average of observed values, higher than that of Antananarivo (Judicaël Boris *et al.,* 2023), but lower than that of Nigeria (Umoh *et al.,* 2023). The superiority over the Antananarivo results stems directly from the remarkable fertility of the Anivorano Nord soils; unlike the leached soils of the highlands, these brown soils derived from basaltic lavas offer better nutrient availability for protein synthesis.

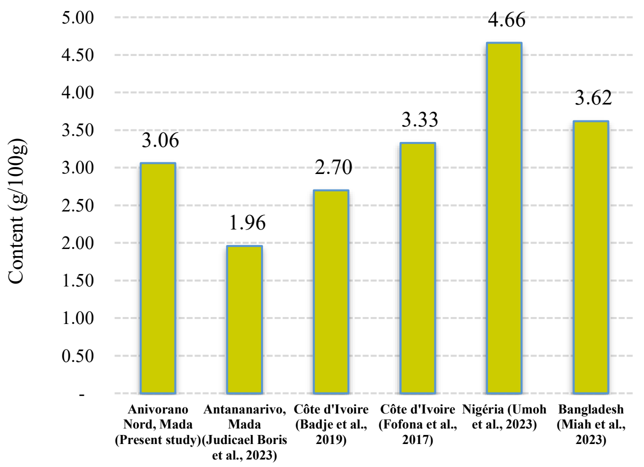

Fig. 6. Protein content of plantain flour compared to data from other studies

The lipid content (2.61 g/100 g), presented in Fig. 7, is clearly the highest of all compared studies (Fofona *et al.,* 2017; Umoh *et al.,* 2023). This exceptional peculiarity is likely linked to the combination of two factors: the genetics of the local variety and the specific processing method used in this study, notably the removal of the placental axis (central part of the fruit) which tends to concentrate lipids in the pulp processed into flour.

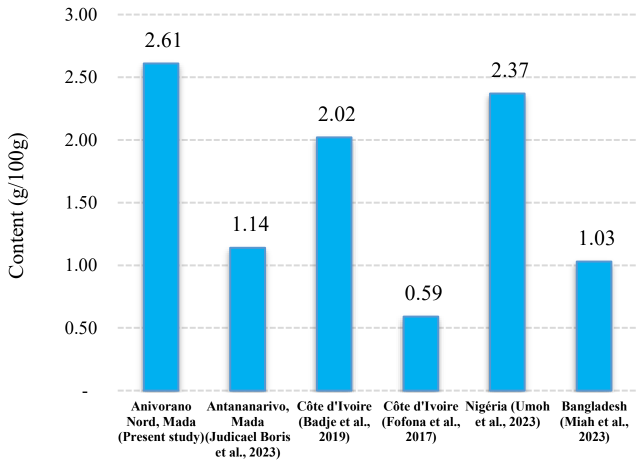

Fig. 7. Fat content of plantain flour compared to data from other studies

Finally, Fig. 8 shows that the carbohydrate content (81.17 g/100 g) remains comparable to that of other flours, although slightly lower than Ivorian samples. This slight difference is explained by a nutritional compensation effect: the exceptional richness of the volcanic soil of Anivorano Nord boosts mineral and lipid contents, which mechanically reduces the relative proportion of carbohydrates in the total dry matter of the product.

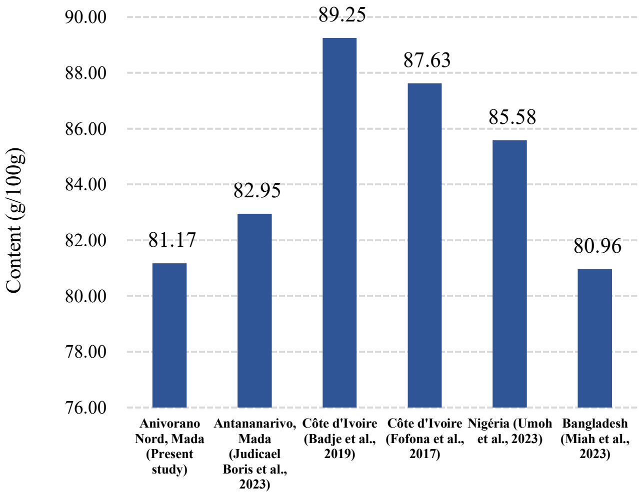

Fig. 8. Total carbohydrate content of plantain flour compared to data from other studies

It is at the level of mineral composition, detailed in Table II, that the differences between studies are the most spectacular. The potassium content of Anivorano Nord flour (2434.34 mg/100 g) is extraordinarily higher than those reported in Nigeria (Adegunwa *et al.,* 2017) and Bangladesh (Miah *et al.,* 2023). This concentration, sometimes more than thirty times higher, highlights a preponderant influence of the volcanic terroir of the DIANA Region, whose mineral richness is directly reflected in the plant. Indeed, unlike the older sedimentary or ferrallitic soils of certain West African regions, the soil of Anivorano Nord is derived from the alteration of recent basaltic lava flows, a magmatic rock naturally saturated in potassium.

Phosphorus and magnesium contents are also much higher than those reported in Nigeria. This exceptional accumulation is favored by the clay structure of the soil in stable aggregates, which ensures excellent water retention and increased bioavailability of minerals. This pedoclimatic synergy allows the plantain to draw more effectively from the soil's nutrient reserves.

Finally, the contents of trace elements (Iron, zinc, manganese) show significant geographic variability, being higher than those of Nigeria, but generally lower than those of Bangladesh, as synthesized in Table II. While the superiority over Nigerian results confirms the intrinsic richness of the Malagasy volcanic basement, the higher values from Bangladesh could be explained by the alluvial nature of their cultivation soils, often enriched by deposits of river sediments particularly dense in trace metals.

TABLE II. Mineral Composition of plantain flour compared in similar studies

	Study Location (Reference)		
Mineral Elements (mg/100 g)	**Anivorano Nord, Madagascar (Present study)**	**Abeokuta, Nigeria (Adegunwa *et al.*, 2017)**	**Bangladesh (Miah *et al.*, 2023)**
Potassium	2434.34	71.62	315.90
Calcium	9.86	6.92	176.29
Phosphorus	198.30	32.65	0.00
Magnesium	110.77	30.65	104.18
Sodium	3.97	0.00	21.06
Iron	4.36	0.25	19.14
Zinc c	0.67	0.00	13.20
Manganese	0.90	0.00	6.86
Copper	0.24	0.00	8.62

IV. CONCLUSION

The objective of this study was to nutritionally characterize the flour of plantains from Anivorano Nord in order to fill a gap in scientific data and to valorize this local resource. The results obtained fully meet this objective by demonstrating that this flour is an excellent source of energy, validating its traditional use in complementary feeding. However, its low protein content confirms the necessity of associating it with protein sources to formulate complete foods. The main conclusion of this study is the highlighting of the unique nutritional profile of this terroir product, characterized by an exceptional potassium content and strong alkalizing power. These properties confer upon it the status of a functional food, particularly interesting for the prevention of hypertension.

In conclusion, this study provides the scientific bases necessary to valorize the flour of plantains from Anivorano Nord. It can be considered not only as an energy food but also as a high-value-added ingredient for health. Its integration into dietary diversification strategies can contribute significantly to the fight against nutritional insecurity in the DIANA region.

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Conflicts of Interest
The authors declare no conflict of interest.

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