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Nutritional Characteristics of "Madame Rose" Rice Flour, a Fragrant Variety Cultivated in Anivorano Nord, District of Antsiranana II, Madagascar

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Abstract**—***"Madame Rose" rice, an aromatic variety cultivated in the DIANA region (Diégo-Suarez, Ambilobe, Nosy-Be, and Ambanja) of Madagascar, is experiencing growing popularity and is highly valued by consumers. However, scientific data justifying this preference remains scarce. The objective of this study was to characterize the nutritional profile of "Madame Rose" rice flour from Anivorano Nord, a Rural Commune within the District of Antsiranana II, to assess its value and provide a scientific basis for its popularity. Standard physicochemical and nutritional analyses were conducted to determine its macronutrient and mineral composition, and to calculate functional nutritional indices. The results revealed that the flour has a macronutrient profile typical of refined white rice, with 7.85 g/100 g of protein, 78.71 g/100 g of carbohydrates, a low lipid content (0.39 g/100 g), and an energy value of 349.75 kcal/100 g. Its major distinction lies in its mineral composition. It exhibits an exceptionally high iron content (5.34 mg/100 g) and a notable zinc content (1.52 mg/100 g), both of which are significantly higher than those found in most white rice varieties and even some whole grain rices. In conclusion, the popularity of "Madame Rose" rice is not solely based on its organoleptic qualities but also on a superior intrinsic nutritional value, linked to its remarkable richness in essential trace elements. This rice variety represents a local resource of great value for nutritional security.*

Keywords**—***"Madame Rose" Rice, Nutritional composition, Minerals, Energy value, Madagascar.*

I. INTRODUCTION

Rice (*Oryza spp.*) is a staple cereal that constitutes the basic food for more than half of the world's population, playing a central role in global food security (FAO, 2004a & 2004b; Conan, 2004; Nikiéma *et al*., 2022; Gouda *et al*., 2025). As the third most produced cereal after maize and wheat, rice provides approximately 27% of the global energy intake and 20% of the world's dietary protein (FAO, 2004a; Nikiéma *et al*., 2022). In Madagascar, a country with a rice-based diet, rice is ubiquitous and deeply embedded in daily and cultural life (Touzard, 2003), with an average annual per capita consumption exceeding 110 kg, and relies mainly on local varieties consumed up to three times a day (Raboin & Ramanantsoanirina, 2012; Radanielina, 2013; Rakotoson, 2019).

While over 150,000 rice varieties are recorded worldwide (Courtois, 2007), Madagascar possesses remarkable genetic diversity, with 4,000 accessions of traditional varieties and 2,000 improved accessions adapted to specific ecosystems (Ravaonoro *et al*., 1999; Raboin & Ramanantsoanirina, 2012; Radanielina, 2013; Rakotoson, 2019).

However, a large part of this richness remains scientifically under-documented and under-exploited. Among the multitude of local varieties, "Madame Rose" rice, a fragrant rice, has experienced growing popularity in recent years, particularly the one cultivated in the rural commune of Anivorano Nord (DIANA region), a renowned production area (Rakotosalama & Jaony, 2021).

This popularity raises a fundamental question: what specific characteristics, beyond its organoleptic qualities, justify consumer preference for this "Madame Rose" variety over the many other available options? Despite its high demand, scientific data on its nutritional profile, especially for crops from the DIANA region, are scarce. Bridging this gap is essential for fully valorizing this local resource.

Consequently, the objective of this study is to comprehensively analyze the nutritional characteristics (macronutrients, minerals, energy value) and functional indices of "Madame Rose" rice cultivated in the rural commune of Anivorano Nord. This research, the first of its kind for this variety in this specific region, aims to establish a scientific database to evaluate its nutritional value and help explain the reasons for its popularity.

II. MATERIALS AND METHODS

2.1. Description of Study Site

The rural commune of Anivorano Nord, located in the northern part of Madagascar (DIANA region, Antsiranana II district), served as the study and collection site for "Madame Rose" rice. Positioned at the geographical coordinates 12°44′00″ south latitude and 49°14′00″ east longitude, between the Analamerana forest reserve and the Ambre massif (Fig. 1), this area is characterized by a fertile volcanic landscape, shaped by recent basaltic lava flows (Tercinier, 1952; Zafitsara, 2019).

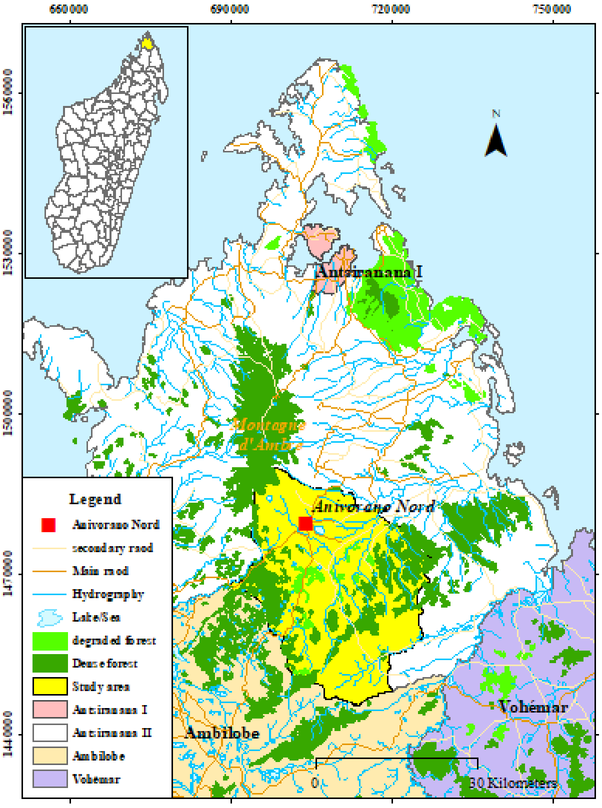

Fig. 1. Location of the study site

This unique terroir owes its richness to an intense weathering process of the parent rock, which has formed deep, non-stony brown soils. These soils possess exceptional qualities: a chemical composition naturally concentrated in iron and aluminum oxides, manganese, magnesium, and phosphorus, as well as a clayey physical structure with stable aggregates that ensures both excellent water retention and good permeability (Tercinier, 1952).

Supported by a dense hydrographic network including the Irodo River and Lake Antagnavo, this pedological potential makes agriculture the main economic activity for 90% of the population. Rice cultivation is predominant, but the soil's fertility also allows for great diversification with market garden crops, legumes (beans), maize, and cassava. Despite this strong potential, the region faces major challenges related to water management and a seasonal water deficit, exacerbated by climate change (Tercinier, 1952; Zafitsara, 2019).

2.2. Sample Collection and Preparation

A sample of paddy rice (*Oryza spp.*, cv. Madame Rose), collected from the rural commune of Anivorano Nord was used for this study. After transport to a processing facility in Antsiranana, the grains were manually screened to discard impurities and substandard grains. An initial mass of 4.094 kg of selected grains was recorded using an electronic balance (model SF-400). Dehulling was performed by manual pounding in a wooden mortar and subsequent winnowing. This process yielded 2.498 kg of white rice, representing a milling yield of approximately 61%.

Analysis of the nutritional characteristics of "Madame Rose" rice required its prior transformation into flour.

To produce the flour, the white rice grains obtained after pounding and winnowing were first washed with clean water to remove residual impurities. They were then soaked in clean water. After soaking, the grains were drained and fully air-dried for 30 minutes. At the end of this period, the grains were ground into a coarse flour in a wooden mortar using a wooden pestle. This coarse flour was then sifted through a very fine mesh sieve (<2 mm) to remove coarse particles and refine its texture. A final drying step was performed on the resulting flour to reduce its moisture content. Finally, the "Madame Rose" rice flour was packaged and stored in a clean, dark glass jar and kept in a dry place until analysis to ensure its preservation and quality.

2.3. Physicochemical Analyses

The analysis of "Madame Rose" rice was conducted at the National Center for Environmental Research (CNRE) in Antananarivo, Madagascar.

2.3.1. *Determination of Moisture and Dry Matter Content*

Moisture and dry matter content were determined by drying the samples in an oven at 130°C for 4 hours. According to the mass loss method, moisture corresponds to the percentage of mass lost during drying, while dry matter represents the percentage of residual mass relative to the initial sample mass. This practical approach aims to remove free water and volatile substances, in accordance with the theoretical definition of water content by Guilbot (1949, 1964).

For each measurement, approximately 5 g of the sample was accurately weighed into a pre-weighed crucible. The crucibles were then placed in an oven at 130°C for 4 hours to remove free water and volatile substances. After drying, the crucibles were cooled for 1 hour in a desiccator and then weighed again. The mass loss, corresponding to the evaporated water, was calculated by difference.

Using the mass of the empty crucibles, the initial sample mass, and the mass after drying, the moisture content was determined using equation (1), and the dry matter content of the sample was calculated using equation (2) (AOAC, 1989):

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

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

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*

The crude ash content was determined by calcination, based on the AOAC (1970) and Joslyn (1970) methods. The sample was subjected to incineration at 550°C for 4 hours in a muffle furnace. At this temperature, the organic matter is completely oxidized, leaving only an inorganic residue. This whitish residue, consisting of the mineral fraction of the sample, allowed for the determination of the ash content. The empty porcelain crucible was first weighed on a precision balance.

Then, after taring the balance, 5 g of the sample was placed in the crucible. The sample was incinerated at 550°C for 4 hours until white ash was obtained. It was then allowed to cool in a desiccator before being reweighed.

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).

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

Where *CB* 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 that constitute the total matter of a product. 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 calculated.

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

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 Fat Content*

The method of Wolf *et al.* (1991), based on Soxhlet extraction, was used for the determination of fat content. The sample was treated hot using a gravimetric method with an organic solvent, as lipids are soluble in this type of solvent. During this procedure, hexane was used as the extraction solvent. For each sample, approximately 5 g was accurately weighed, wrapped in filter paper, and placed in extraction thimbles. Concurrently, 120 ml of hexane was added to pre-weighed flasks. Each thimble was inserted into a different Soxhlet extractor. The flasks were heated for 6 hours. During this step, the fats from the sample migrate into the hexane. To determine the fat content, the solvent was evaporated at 80°C in a rotary evaporator. Then, the flasks were dried in an oven at 130°C for 30 minutes and cooled in a desiccator before being weighed on a precision balance.

The following formula allows for the calculation of the fat content of the sample (Wolf *et al.*, 1991).

$$CF(\%) = \frac{m_{FD} - m_{EF}}{m_{CS}} \times 100 \qquad (5)$$

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).

2.3.5. *Determination of Crude Protein Content*

Crude protein was determined using the Kjeldahl method. First, sample digestion was performed by placing a sample of about 5 g into a Kjeldahl flask with 20 ml of concentrated sulfuric acid (H_2SO_4) and catalysts (a mixture of $CuSO_4$/K_2SO_4 at a 1/10 p/p ratio). The mixture was then heated in a digestion block at approximately 340°C for 4 hours. During this hot digestion, the organic nitrogen in the sample is converted to ammonium sulfate ($(NH_4)_2SO_4$), and the end of this step is generally indicated when the solution becomes clear and turns a light green color.

After cooling the digestate, the ammonia production, distillation, and trapping steps were performed. A receiving flask containing 25 ml of a 40 g/l boric acid (H_3BO_3) solution and 3 to 5 drops of methyl red indicator, giving an initial pink color, was prepared. The flask containing the digested sample was connected to a distillation apparatus, and 50 ml of a 400 g/l sodium hydroxide (NaOH) solution was added to make the medium alkaline. This releases ammonia (NH_3) from the ammonium sulfate formed during the sulfuric acid digestion. The ammonia produced was then steam-distilled, condensed, and collected in the boric acid solution. As the ammonia is trapped, it reacts with the boric acid, causing the indicator's color to change to green.

The third step is titration, which quantifies the ammonia collected in the boric acid solution. The green solution in the receiving flask was titrated with a sulfuric acid (H_2SO_4) solution of a precisely known concentration (0.1 *N*), dispensed from a graduated burette. The sulfuric acid neutralizes the ammonia that reacted with the boric acid. The titration endpoint is reached when the solution returns to its initial pink color, indicating that all the ammonia has been neutralized. The volume of sulfuric acid used to reach this point was precisely recorded.

Using the recorded volume of sulfuric acid from the titration, its normality, and the initial mass of the rice flour sample, the total nitrogen content (%) of the sample was calculated using equation (6). This equation includes a calculation constant related to stoichiometry and units, which is 1.4 when the acid normality is 0.1 *N* and the result is expressed as a percentage. This nitrogen content was then converted to crude protein percentage by multiplying it by the nitrogen-to-protein conversion factor of 6.25, according to equation (7):

$$N_T(\%) = \frac{1.4 \times V \times n}{m_{CS}} \times 100 \qquad (6)$$

$$CP(\%) = N_T \times 6.25 \qquad (7)$$

Where N_T is the total nitrogen content (%), V is the volume (in milliliters) of 0.1 *N* sulfuric acid used for titration, n is the normality of the sulfuric acid which is 0.1 *N*, m_{CS} is the mass of the initial sample (g), and *CP* is the crude protein content (%).

2.3.6. *Determination of Total Carbohydrate Content*

The principle is to express the total carbohydrate content of a food product by the difference method. This method is based on the idea that the sum of the contents of water, protein, fat, ash, and carbohydrates in a food product equals 100%. By knowing the percentages of moisture, protein, fat, and crude ash, it is possible to calculate the total carbohydrate content. The total carbohydrate content was determined by the difference method used by Antia *et al.* (2006):

$$TC(\%) = 100 - \left[MC(\%) + CP(\%) + CF(\%) + CA(\%)\right] \qquad (8)$$

Where GT 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 Content*

The energy value was determined by applying the Atwater and Rosa (1899) thermal coefficients. The metabolizable energy (*ME*) of food products can be calculated by summing the metabolizable energies of carbohydrates, lipids, and proteins. The metabolizable energy of each component is obtained by multiplying its content by its specific Atwater caloric coefficient (*SCC*). The metabolizable energy of the produced flour was estimated using equation (9):

$$ME(\text{kcal/100g}) = \left(\%CP \times CCS_P\right) + \left(\%CF \times CCS_F\right) + \left(\%TC \times CCS_C\right) \quad (9)$$

Where ME is the metabolizable energy in kilocalories per hundred grams of product (kcal/100g), CP is the crude protein content (%), CF is the crude fat content (%), and TC is the total carbohydrate content (%). CCS_P, CCS_F and CCS_C are the respective specific ATWATER caloric coefficients (in kcal/g) for proteins, lipids, and carbohydrates, respectively.

2.3.8. *Determination of Mineral Elements*

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):

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

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:

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

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.

- *Determination of Starch Content by the Polarimetric Method*

This method allows for the determination of the content of starch and high molecular weight degradation products of starch in foods. It relies on a double determination of optical rotation.

The general principle of this method involves two distinct steps. In the first determination, which aims to measure the total optical rotation, the sample is subjected to a hot treatment with dilute hydrochloric acid. This treatment is followed by a clarification step, carried out using CARREZ I and CARREZ II solutions, then a filtration. Polarimetry is used to measure the optical rotation of the resultant solution after these procedures. The sample is initially extracted with 40% ethanol for the second determination, which measures the optical rotation of ethanol-soluble compounds. Following the acidification of the filtrate with hydrochloric acid, a clarification and a filtration are performed, and the optical rotation is measured under conditions identical to those of the first determination. Finally, the starch content of the sample is obtained by multiplying the difference between the two optical rotations by a known factor.

For the analysis, two test portions are prepared. The first test portion, of about 0.5 g, is used for the determination of the total optical rotation, while the second, of about 1 g, is used for the determination of the optical rotation of substances soluble in ethanol. These two test portions are treated separately following their respective procedures.

The protocol for the determination of total optical rotation begins with the addition of 10 ml of hydrochloric acid (HCl at 25%) into a 50 ml volumetric flask containing the first test portion. The flask is then immersed in a water bath and vigorously and regularly agitated for 15 minutes to prevent the formation of agglomerates. After these 15 minutes, the flask is removed from the water bath, distilled water is added to rinse the walls and recover all suspensions, and then the whole is left to cool. Once cooled, 2.5 ml of CARREZ I solution are added, and the solution is stirred for one minute. Subsequently, 2.5 ml of CARREZ II solution are also added, with further stirring for one minute. The volume is made up to the mark with distilled water, allowing for the recovery of all suspensions, and the solution is homogenized before being filtered. The filtrate is then introduced into the polarimeter tube for the reading of the polarization angle.

Regarding the protocol for determining the optical rotation of substances soluble in 40% ethanol, about 50 ml of 40% ethanol are poured into the flask containing the second test portion. The flask is vigorously agitated to ensure a good mixing of the test portion with the ethanol, then the solution is filtered. To 25 ml of this filtrate, 0.42 ml of hydrochloric acid are added, and the flask containing this mixture is vigorously agitated for about 5 minutes. This flask is then immersed in a boiling water bath for 15 minutes. After being removed from the bath and rinsed with distilled water, the flask is left to cool. After cooling, 2.5 ml of CARREZ I solution are added, followed by one minute of agitation. Then, 2.5 ml of CARREZ II solution are added, with another minute of agitation. The volume is made up to the appropriate volume (e.g., in a volumetric flask) with distilled water, then the solution is homogenized and filtered through filter paper. The filtrate is finally introduced into the polarimeter tube for the reading of the polarization angle.

For the calculation of starch content, the concentration from the total hydrolysis is obtained from the following equation (12):

$$C(\%) = \frac{P \times 13.58}{m_{CS}} \qquad (12)$$

Similarly, the concentration of substances soluble in 40% ethanol is determined using the equation (13) below:

$$C^{'}(\%) = \frac{P^{'} \times 27.17}{m_{CS}} \qquad (13)$$

Thus, the starch content is quantified based on the formula (14) below:

$$SC(\%) = C - C^{'} \qquad (14)$$

Where SC is the starch content (%), C is the total hydrolysis concentration (%), $C^{'}$ is the concentration of substances soluble in 40% ethanol expressed (%), P is the total optical rotation in degrees of arc, $P^{'}$ is the optical rotation in degrees of arc given by the substances soluble in 40% ethanol, and m_{CS} is the mass of the sample aliquot (g).

- *Assay of Reducing and Total Sugars*

The determination of reducing and total sugars was carried out by the Luff-Schoorl method. Reducing sugars, which contain a free aldehyde or ketone group, are important to be aware of. This method aims to determine the content of directly present reducing sugars and total sugars, the latter being obtained after hydrolysis of non-reducing sugars. The Luff-Schoorl method was applied after a clarification step, and the results were expressed as invert sugars.

The preparation of the extract and the clarification begin with weighing a quantity of 1 g of the sample, which is then dissolved in 40% ethanol. This solution is quantitatively introduced into a 250 ml volumetric flask. Subsequently, 2.5 ml of CARREZ I solution are added with a pipette, and the mixture is stirred for 1 minute. Then, 2.5 ml of CARREZ II solution are added, stirring again for one minute, before making up to the mark (with 40% ethanol or distilled water, according to the specific protocol) and filtering through a filter paper. To prepare the aliquot for analysis, the obtained filtrate is brought to evaporation to eliminate the ethanol, reducing its volume by about half.

A quantity of 10 ml of Luff-Schoorl reagent was added to 25 ml of the aliquot to be analyzed. The volume was then brought to 50 ml with distilled water. The mixture was then heated in a water bath for 1 minute until a color change to brown was observed. Finally, after this period, the titration was performed to determine the quantity of reducing sugars, noting the volume dispensed from the burette.

To determine the total sugar content, 25 ml of the aliquot were first placed in a 50 ml flask. Then, 2 to 3 drops of methyl red were added until an orange color was obtained. The solution thus obtained was acidified drop by drop (2 to 4 drops) with 3 *N* hydrochloric acid (HCl) until the indicator turned red. Subsequently, 7.5 ml of 0.1 *N* HCl were added. An acid hydrolysis was performed by heating the mixture in a water bath for 30 minutes to convert the non-reducing sugars. After cooling, the hydrochloric acid (HCl) was carefully neutralized with 3 to 5 drops of sodium hydroxide (NaOH) until the orange color returned. The final volume of the solution was adjusted to 50 ml with distilled water. Then, 10 ml of Luff-Schoorl reagent in an Erlenmeyer flask were drawn and added to 50 ml of the hydrolyzed and neutralized solution. This new mixture was heated in a water bath for 30 minutes, observing a color change to brown and pink. Finally, titration with a burette was performed to quantify the total sugar content.

The Luff-Schoorl table, whose reference must be specified, is consulted to find the mass of sugars (in mg) corresponding to the volume of 0.1 *N* thiosulfate used, for an initial volume of sugar solution defined by the table. The rate of reducing sugars, and by extension that of total sugars, is determined using formula (15) below, taking into account the initial mass of the sample and the dilutions applied.

$$RS(\%) = \frac{M \times V}{m_{CS}} \qquad (15)$$

Where RS is the rate of reducing sugars (%), M is the mass of sugar after inversion (mg), V is the volume of thiosulfate in (ml), and m_{CS} is the mass of the initial sample (g).

2.3.9. *Calculation of Functional Nutritional Indices*

To go beyond a simple description of the composition and to offer a more functional evaluation of the potential metabolic impact of "Madame Rose" rice, several key nutritional indices were calculated from the primary analytical data.

- *Calcium/Phosphorus (Ca/P) Ratio*

This ratio is an essential indicator of mineral balance for bone health. An adequate balance between these two minerals is fundamental, as a relative excess of phosphorus (a low Ca/P ratio) can impair intestinal calcium absorption and, in the long term, negatively affect skeletal mineralization. It is calculated from the following relationship (Houdji *et al*., 2018):

$$\text{Ca/P} = \frac{\%\,Ca}{\%\,P} \qquad (16)$$

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

- *Sodium/Potassium (Na/K) Ratio*

Considered a relevant marker of cardiovascular health, this ratio allows for the evaluation of the balance between two major electrolytes in the regulation of arterial blood pressure. 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 (Houdji *et al*., 2018):

$$\text{Na/K} = \frac{\%\,Na}{\%\,K} \qquad (17)$$

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

- *Potential Renal Acid Load (PRAL) Index*

The PRAL (Potential Renal Acid Load) index allows for estimating the effect of a food on the body's acid-base balance. It predicts the acid or alkaline load that the kidneys will have to handle after the metabolism of nutrients. A chronically acidic load (positive PRAL), often due to high intakes of protein and phosphorus, can tax the body's buffer systems and potentially affect renal and bone health. The calculation of this index is based on the magnesium, phosphorus, calcium, potassium, and protein contents of the food. Expressed in milliequivalents (mEq/100g), it evaluates the acid (or alkaline) load generated in the body per 100 g of food (Remer & Manz, 1995).

The PRAL index was calculated according to the following formula (Remer & Manz, 1995; Pamplona-Roger, 2016):

$$\begin{aligned} PRAL\ (\text{mEq/100g}) = {} & (0{,}49 \times \%CP) + (0{,}037 \times \%P) \\ & - (0{,}021 \times \%K) - (0{,}026 \times \%Mg) - (0{,}013 \times \%Ca) \end{aligned} \qquad (18)$$

Where $\%CP$ is the crude protein content (mg/100g); $\%P$ is the phosphorus content (mg/100g); $\%K$ is the potassium content (mg/100g); $\%Mg$ is the magnesium content (mg/100g); $\%Ca$ is the calcium content (mg/100g). A positive result indicates an acidifying effect on the body, while a negative result means it has an alkalizing effect.

- *Glycemic Load (GL)*

The Glycemic Load was estimated to provide a more precise view of the food's impact on blood glucose. Unlike the Glycemic Index (*GI*), which only measures the speed of carbohydrate absorption, the GL incorporates both the quality (*GI*) and the quantity of available carbohydrates in a portion, making it a better predictor of the insulin response. This parameter is particularly relevant for the management of diabetes and weight. The calculation was made considering the total sugar content determined in this study and a reference Glycemic Index for glutinous rice ($GI = 98$), a value commonly accepted in the scientific literature (Available at https://www.compagnie-des-sens.fr/indice-glycemique/). Thus, the Glycemic Load formula is given by the following equation (Salmeron *et al.,* 1997; Foster-Powell *et al.,* 2002):

$$GL = (GI \times TC)\ /100 \qquad (19)$$

Where GI is the Glycemic Index and TC is the total carbohydrate content (g/100g).

III. RESULTS AND DISCUSSION

The results of the nutritional analysis of "Madame Rose" rice flour are summarized in Table 1.

Regarding its general composition and energy value, the flour has a moisture content of 12.66 g/100 g, which complies with conservation standards. Its dry matter, which amounts to 87.34 g/100 g, is predominantly composed of carbohydrates. Fig. 2 illustrates this basic composition, showing the predominance of dry matter over moisture and the minimal share of ash (0.39%).

As detailed in Fig. 3, total carbohydrates (78.71 g/100 g) are the main energy contributor, far ahead of proteins (7.85 g/100

g) and fats (0.39 g/100 g). Starch, with 73.18 g/100 g, represents almost all of these carbohydrates, while simple sugars (reducing and total) are present only in very small quantities (0.06 and 0.14 g/100 g, respectively). The total energy value of this flour is 349.75 kcal/100 g.

The mineral profile, detailed in Fig. 4, reveals that the flour is a significant source of phosphorus (140.09 mg/100 g) and potassium (73.24 mg/100 g). Its most striking feature is its exceptionally high iron content, which reaches 5.34 mg/100 g. It also contains appreciable amounts of zinc (1.52 mg/100 g) and magnesium (22.40 mg/100 g), while the contents of calcium (5.21 mg/100 g) and sodium (7.75 mg/100 g) are more modest.

The PRAL index of 6.84 indicates a slightly acidifying effect. The Na/K ratio of 0.11 is low, which is very favorable for cardiovascular health.

Compared to the local red rice "Mamoriaka Mena" presented in Table 2 (Solofoniaina, 2019; Razafimahefa *et al.*, 2021), "Madame Rose" rice has a significantly higher protein content (7.85 g/100 g vs. 5.89 g/100 g). In contrast, "Mamoriaka Mena", being a whole grain rice, is richer in carbohydrates (86.04 g vs. 78.71 g) and slightly more energetic (372.72 kcal vs. 349.75 kcal). Its fat content is also slightly higher (0.57 g vs. 0.39 g), which is consistent with the presence of the germ and bran.

TABLE I. Nutritional Information for "Madame rose" Rice Flour.

Parameter (Unit)	Nutrient Amount per 100 g
Calories (kcal)	349.75
Moisture (g)	12.66
Dry Matter (g)	87.34
Protein (g)	7.85
Fat (g)	0.39
Carbohydrates (g)	78.71
Crude Ash (g)	0.39
Organic Matter (g)	86.95
Reducing Sugar	0.06
Total Sugars	0.14
Starch	73.18
Potassium [K] (mg)	73.24
Magnesium [Mg] (mg)	22.40
Phosphorus [P] (mg)	140.09
Calcium [Ca] (mg)	5.21
Sodium [Na] (mg)	7.75
Iron [Fe] (mg)	5.34
Zinc [Zn] (mg)	1.52
Manganese [Mn] (mg)	0.81
Copper [Cu] (mg)	0.20
Ca/P Ratio	0.04
Na/K Ratio	0.11
PRAL Index (mEq/100 g)	6.84
Glycemic Charge	0.14

The most spectacular difference lies in the mineral profile: The iron (Fe) content of "Madame Rose" rice (5.34 mg/100 g) is more than eight times higher than that of "Mamoriaka mena" (0.64 mg/100 g). It is also richer in phosphorus (P) (140.09 mg vs. 100 mg), potassium (K) (73.24 mg vs. 62.51 mg), and zinc (Zn) (1.52 mg vs. 1.16 mg). Conversely, "Mamoriaka mena" rice has higher contents of calcium (Ca) and magnesium (Mg), which is typical of whole grain rice.

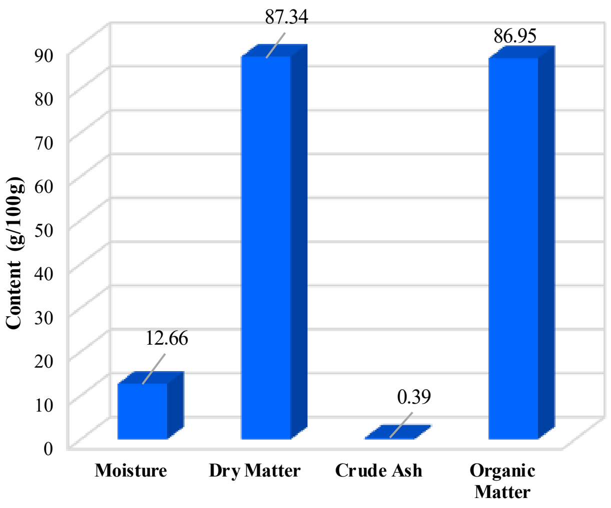

Fig. 2. General composition of "Madame Rose" rice

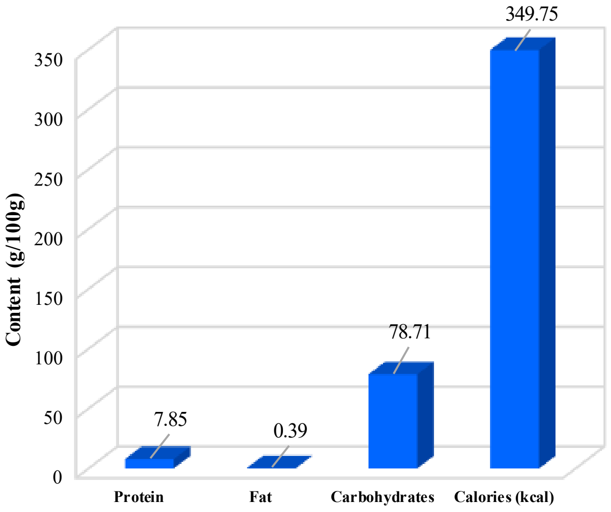

Fig. 3. Energy value of "Madame Rose" rice

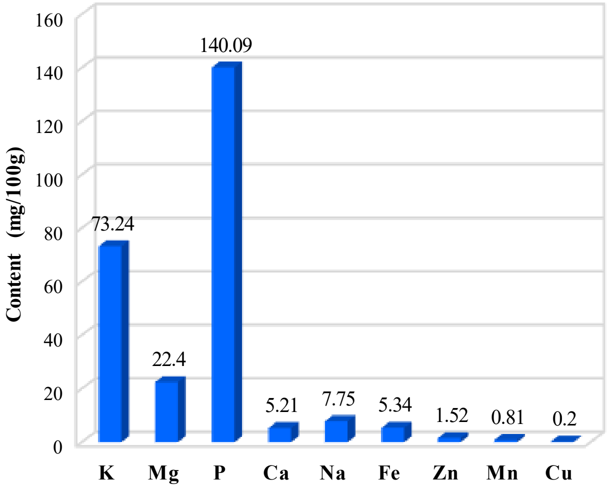

Fig. 4. Minerals of "Madame Rose" rice

When comparing "Madame Rose" rice with international varieties (Tables 2 and 3) from Ciqual tables (2020) and other sources (Zhao, 2025; Institute of Nutrition, Mahidol University, 2014), its atypical profile is confirmed.

TABLE III. General composition and energy value of "Madame Rose" rice compared to other rices from Madagascar and elsewhere.

Rice Variety	General composition and energy value (Unity)											References
	Energy (kcal/100 g)	Moisture (g/100 g)	Dry Matter (g/100 g)	Protein (g/100 g)	Fat (g/100 g)	Carbohydrates (g/100 g)	Crude Ash (g/100 g)	Organic Matter (g/100 g)	Reducing Sugar (g/100 g)	Total Sugars (g/100 g)	Starch (g/100 g)	
White rice "Madame Rose"	349.75	12.66	87.34	7.85	0.39	78.71	0.39	86.95	0.06	0.14	73.18	Present study
Red rice "Mamoriaka mena"	372.72	10.03	89.97	5.89	0.57	86.04	0.47	-	-	-	-	Solofoniain, 2019 Razafimahefa et al., 2021
Brown rice	12.6	350	-	7.38	2.8	71.4	1.2	-	-	0.66	70.7	Ciqual, 2020a
Basmati rice	12.4	353	-	8.06	0.84	77.8	0.34	-	-	0.17	-	Ciqual, 2020b
Red rice	12.4	352	-	8.38	3	70.6	1.5	-	-	< 0.5	58.4	Ciqual, 2020c
White rice	12.5	352	-	7.4	0.91	78	0.49	-	-	0.16	77.8	Ciqual, 2020d
Wild rice	11.5	344	-	11.7	0.94	69.2	1.3	-	-	2.5	64	Ciqual, 2020e
Black rice	-	-	-	-	-	-	-	-	-	-	-	Zhao, 2025
Black rice	347	12.7	-	8.5	2.6	69.9	1.4	-	-	-	-	Institute of Nutrition, Mahidol University, 2014
White rice	354	12.6	-	7.3	1.5	77.4	0.6	-	-	-	-	
Red rice	356	11.2	-	6.8	2.7	74.2	1.1	-	-	-	-	
White rice	354	11.7	-	6.8	0.7	79.7	0.5	-	-	-	-	
Jasmine rice	353	11.9	-	6.1	0.7	80.2	0.3	-	-	-	-	
Brown rice	353	11.9	-	7.9	2.1	74.1	1.2	-	-	-	-	

TABLE IIII. Mineral composition, PRAL index, and glycemic charge of "Madame Rose" rice compared to other rices from Madagascar and elsewhere.

Rice Variety	Mineral Composition (mg/100g)									Ca/P	Na/K	PRAL	GL	References
	K	Mg	P	Ca	Na	Fe	Zn	Mn	Cu					
White rice "Madame Rose"	73.24	22.4	140.09	5.21	7.75	5.34	1.52	0.81	0.2	0.04	0.11	6.84	0.14	Present study
Red rice "Mamoriaka mena"	62.51	30.13	100	11.24	5.12	0.64	1.16	0.56	0.15	0.11	0.08	4.34	-	Solofoniaina, 2019 Razafimahefa et al., 2021
Brown rice	219	118	163	11.1	4.1	< 1	2	2.2	0.27	0.07	0.02	1.84	0.65	Ciqual, 2020a
Basmati rice	-	-	-	-	-	-	-	-	-	-	-	-	0.17	Ciqual, 2020b
Red rice	288	130	372	13.5	11	< 1	2.1	2	< 1	0.04	0.04	8.27	-	Ciqual, 2020c
White rice	121	31.3	118	33	2.28	1.57	1.41	0.99	0.19	0.28	0.02	4.21	0.16	Ciqual, 2020d
Wild rice	298	90.1	317	6.95	2.7	< 1	3.7	1.1	< 1	0.02	0.01	8.77	2.45	Ciqual, 2020e
Black rice	256	147	356	12	7.1	1.6	3.8	1.72	-	0.03	0.03	-	-	Zhao, 2025
Black rice	82	-	215	21	2	3.5	-	-	-	0.10	0.02	-	-	Institute of Nutrition, Mahidol University, 2014
White rice	35	-	81	20	6	1.8	-	-	-	0.25	0.17	-	-	
Red rice	-	-	134	14	-	0.8	-	-	-	0.10	-	-	-	
White rice	71	-	105	19	27	1.2	0.5	-	0.1	0.18	0.38	-	-	
Jasmine rice	113	-	65	5	34	0.9	0.1	-	0.14	0.08	0.30	-	-	
Brown rice	193	-	244	32	33	2.2	0.5	-	0.1	0.13	0.17	-	-	

K: Potassium; Mg: Magnesium; P: Phosphore; Ca: Calcium; Na: Sodium; Fe: Fer; Zn: Zinc; Mn: Manganese; Cu: copper; Na/K: Ratio Na/K; Ca/P: Ratio Ca/P; PRAL: PRAL Index (mEq/100 g) et GL: Glycemic Load

Regarding proteins, its content of 7.85 g/100 g places "Madame Rose" rice in the upper range of white rice (6.8 to 7.4 g/100 g) (Ciqual, 2020d, Institute of Nutrition, Mahidol University, 2014) and makes it comparable to brown rices (7.9 g/100 g) (Institute of Nutrition, Mahidol University, 2014). Its very low-fat content (0.39 g/100 g) is characteristic of a refined and polished rice, markedly lower than that of whole grain rices like brown rice (2.1-2.8 g/100 g) (Ciqual, 2020a, Institute of Nutrition, Mahidol University, 2014) or red rice (3 g/100 g) (Ciqual, 2020c).

Its iron content of 5.34 mg/100 g is exceptional, far exceeding that of international white rice (1.2-1.8 mg/100 g) (Ciqual, 2020d, Institute of Nutrition, Mahidol University, 2014), brown rice (2.2 mg/100 g) (Institute of Nutrition, Mahidol University, 2014), and even black rice (3.5 mg/100 g) (Zhao, 2025). This value rivals that of red rice varieties. Similarly, its zinc content of 1.52 mg/100 g is markedly higher than that of international white and brown rices (around 0.5 mg/100 g) (Institute of Nutrition, Mahidol University, 2014) and approaches that of black rice (3.8 mg/100 g) (Zhao, 2025).

Its phosphorus (140.09 mg) and potassium (73.24 mg) contents are higher than those of a standard white rice (105 mg of P and 71 mg of K) (Institute of Nutrition, Mahidol University, 2014), although lower than those of whole grain rices (brown, wild, black) (Ciqual, 2020d; Zhao, 2025; Institute of Nutrition, Mahidol University, 2014) which retain their mineral-rich bran.

The exceptional richness in iron and zinc of "Madame Rose" constitutes a major nutritional asset. The origin of this richness is directly attributable to the exceptional terroir of Anivorano-Nord. The region's volcanic soil, offering high mineral availability, allows "Madame Rose" rice to bioaccumulate these trace elements in significant quantities. Thus, it is the alchemy between a specific genotype and a unique geological environment that confers this superior profile to the rice.

The PRAL index of 6.84 indicates a slightly acidifying effect, higher than that of brown rice (1.84) (Ciqual, 2020a) but lower than that of red or wild rice (Ciqual, 2020b & 2020d). The Na/K ratio of 0.11 is low, which is very favorable for cardiovascular health.

IV. CONCLUSION

This study aimed to elucidate the scientific foundations of the popularity of "Madame Rose" rice cultivated in Anivorano Nord. The results revealed that while its macronutrient profile is characteristic of a refined white rice (78.71% carbohydrates, 7.85% protein, and an energy value of 349.75 kcal/100 g), its distinctive value lies in an exceptional mineral composition. This profile, far from being fortuitous, is directly attributable to the unique volcanic terroir of the region, which promotes remarkable mineral bioaccumulation.

The quantitative analysis highlighted exceptionally high levels of iron (5.34 mg/100 g) and zinc (1.52 mg/100 g), surpassing most common rice varieties. Furthermore, the flour presents very significant concentrations of phosphorus (140.09 mg/100 g) and potassium (73.24 mg/100 g), complemented by notable amounts of magnesium (22.4 mg/100 g), calcium (5.21 mg/100 g), sodium (7.75 mg/100 g), manganese (0.81 mg/100 g), and copper (0.20 mg/100 g).

Thus, this research confirms that the preference for "Madame Rose" is based on an intrinsic nutritional superiority, and not solely on its organoleptic qualities. It establishes the first comprehensive database for this variety, constituting a fundamental reference for future studies in agronomy, in public health for the fight against deficiencies, and in varietal selection. This study positions the "Madame Rose" rice from the DIANA region as a local resource with high added value, essential for nutritional security and economic development.

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Conflicts of Interest

The authors declare no conflict of interest.

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