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AMELIORATION OF THE NUTRITIONAL QUALITIES OF PLANTAIN (*MUSA PARADISIACA* L.) USING AN ORGANIC FERTILIZER

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ABSTRACT: *The increase in world population has caused banana and plantain farmers to use excessive amounts of fertilizers to improve agricultural production. However, this excessive use of fertilizers has negative effects on the nutritional quality and shelf life of the fruit. This study aims to improve the nutritional quality of plantain using an organic fertilizer. Eleven treatments were applied to plantain plants in an experimental design consisting of randomized blocks with 3 replications. Three plantain fingers from the second hand of each bunch were peeled, dried, processed into flour and analyzed for biochemical parameters following fertilizer application. The results showed that treatment T4-1 (15 t/ha of Tithonia diversifolia) significantly improved the protein contents in plantain pulp (5.50%). Similarly, treatment T3-1 (10 t/ha of Tithonia diversifolia) improved the concentrations of potassium (8675 mg/kg), magnesium (900 mg/kg), iron (264.97 mg/kg) and sodium (587.99 mg/kg). Principal component analysis revealed that T3-1 (10 t/ha of Tithonia diversifolia) promotes a better transfer of mineral elements into plantain pulp. This study showed that Tithonia diversifolia-based fertilization significantly improves the nutritional quality of plantain.*

KEYWORDS: *Tithonia diversifolia*, fertilization, nutritional qualities, plantain.

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INTRODUCTION

Plantain (*Musa paradisiaca* L.) belongs to the plantain subgroup of the AAB group and has more than 200 species cultivated worldwide (CNRA, 2016; Lassois *et al*., 2009). It plays an important role in global food security. Banana fruits rank fourth among the world's most important foodstuffs after rice, wheat and milk (FAO, 2010). Global plantain production in 2016 was estimated at 35 063 802 tons (FAOstat, 2017) with Central Africa, producing 10,155,803.51 tons (FAOstat, 2022). In Cameroon, plantain production is estimated at 4,660 386.86 tons (FAOstat, 2022). Plantain is an important starchy crop that contributes significantly to subsistence economies in West and Central Africa (Ortiz and Vuylsteke, 1996). It generates considerable income for smallholder farmers who produce the fruit on compound farms. Plantain is a rich source of dietary energy, vitamins (A, B6 and C) and minerals such as calcium, potassium, phosphorus, iron and zinc (Tenkouano *et al*., 2002). The proximate analysis of plantain has been elucidated previously by Yomeni *et al*. (2004), Adeniji *et al*. (2007) and Baiyeri *et al*. (2009). Currently, agricultural research is focusing on breeding food crops to improve the content and quality of macro and micro-nutrients (Aluru *et al*., 2008; Hillocks, 2011; Welch and Graham, 2004). These nutrients enrich food crops and meet the nutritional needs of humans and livestock. Crops with higher micronutrient content have been successfully bred by scientists through a process called biofortification (Ball, 2008). The ability of the crop to absorb nutrients from the soil plays a major role in its nutrient composition. Plantain requires higher amounts of nitrogen, phosphorus, and potassium, and lower amounts of micronutrients. Nitrogen is most important in the first 4–6 months for vigorous plant growth and later for improved yield (Bhalerao *et al*., 2009). Phosphorus is important for fluorescence fixation and healthy rhizome growth, and potassium for fruit quality (Bhalerao *et al*., 2009). Climatic conditions, particularly temperature and light intensity, have a significant effect on the nutritional quality of fruits (Mozafar, 1994). All soils are deficient in nitrogen, 80-90% in phosphorus (Memon *et al*., 1992; Anon, 2001) and 25-30% in potassium (Akhtar *et al*., 2003).

Soil nutrients can be supplied in organic form (crop residues, green manures, kitchen waste, municipal waste, livestock manure, compost, faecal sludge, among others) or inorganic form (chemical fertilizers and lime), as well as in combinations. However, the continuous use of chemical fertilizers alone is not sufficient to maintain crop yields on highly weathered soils in the tropics (Kang and Balasubramanian, 1990). Mineral fertilizers are used to meet the majority of the nutritional requirements of plantain mainly potassium, phosphorus and nitrogen. In addition to their negative impact on the soil, mineral fertilizers have a detrimental influence on fruit quality (Dutta *et al*., 2010). However, the application of organic and mineral sources of nutrients has the advantage of releasing nutrients gradually and consistently while maintaining the optimum C/N ratio, improving the water storage capacity of the soil profile and increasing microbial biomass (Yadav *et al*., 2010). Therefore, organic amendments are required to replenish lost nutrients and improve physicochemical and biological properties for sustainable crop production. Soil amendments using both organic and inorganic sources have been shown to promote better crop performance (Shiyam *et al*., 2011; Osundare *et al*., 2015). Furthermore, there is an increasing preference for organic foods in the global market due to the anticipated health and environmental benefits (Lundegardh and Martensson, 2003). The combined application of manure and mineral fertilizers promotes the rapid release of applied nutrients to meet the nutrient demand of the crops (Mohammed, 2002). Furthermore, the quality of any agricultural product is predetermined by the prevailing growing environment of which soil fertility variables are major determinants (Wills *et al*., 1998; Lundegardh and Martensson,

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2003). The use of *Tithonia diversifolia* as a green manure improves soil fertility (Mucheru-Muna *et al*., 2014; Susanti *et al*., 2017; Kaboneka *et al*., 2021) thereby increasing the growth and yield of agricultural products. Organic nutrient management, including organic manure and biofertilizers, is economically attractive and environmentally friendly. Thus, *Tithonia diversifolia* promotes soil health by increasing organic matter content, enhancing aeration, and enhancing microbial abundance and diversity, while improving the nutritional quality and shelf life of fruits. Among factors such as cultivar type, prevailing climate, growing or harvesting season, and physiological stage of the fruit at harvest, plant nutrition is a critical element for fruit quality at harvest (Ani and Baiyeri, 2008; Benkeblia *et al*., 2011; Mészáros *et al*., 2021; Bacelar *et al*., 2024). The objective of this study was to improve the nutritional quality of plantain using organic fertilizer (*Tithonia diversifolia*).

MATERIALS AND METHODS

Site description

The study was conducted at the Ivoloina station of the FOFIFA-East Regional Research Center, located in the Rural Commune of Antetezambaro, Fokontany Andakolosy, 12 km from Toamasina (Madagascar) on the left bank of the lower Ivoloina River. The study site is located at a latitude -18°03’00 South, longitude of 49°21’00 and an altitude of 20 m. The climate is characterized by a high average rainfall of 3071 mm/year, and a high average annual temperature of 23.8°C, although some months are relatively cool and high annual insolation. The climate of this locality is tropical and has two climatic periods: the wet season from November to March and the dry season from April to October, but it can be cold during the winter generally located between June and August.

Plant material

The plant material consists of green plantain bunches (Figure 1) from the experimental plot of the Ivoloina station of the FOFIFA-East Regional Research Center.

Figure 1: Plantain bunches

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METHODS

Experimental design and fertilizers application to plantain plants

The study was carried out on an area of 1590 m^2 (53 m x 30 m). The land was prepared by manual ploughing to bury varying quantities (5 t/ha, 10 t/ha and 15 t/ha) of green biomass of *Tithonia diversifolia* at a depth of 15 to 20 cm in order to improve the physicochemical properties of the soil. One month after growing *T. diversifolia*, a 40 x 40 x 40 cm hole was dug in the soil for planting young plantain plants (Sebuwufu *et al*., 2005).

The experimental design consists of randomized blocks with 3 repetitions and each block includes 11 treatments (Table 1). The planting density was 3 m between rows and 2 m between plantain plants on the same row. The distance between the two plot units was 2 m and 6 m between blocks.

The application of organic and inorganic fertilizers was adapted according to the fertilization program of Kwa and Temple (2019). The spreading of zebu dung was carried out by mixing it with the surface soil when planting the plants and then every two months within a radius of 15 to 40 cm around the foot depending on the age of the plant. The inorganic fertilizer was applied in a crown of around 8 plantain plants constituting the elementary plot one day after planting and then every two months.

Table 1: Different treatments and their doses of fertilizers used

Treatments	Fertilizer doses
T0	Without fertilizer
T1	100 g/plant of NPK 11-22-16
T2-1	5 t/ha of *T. diversifolia*
T2-2	5 t/ha of *T. diversifolia* + 75 g/plant of NPK
T2-3	5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung
T3-1	10 t/ha of *T. diversifolia*
T3-2	10 t/ha of *T. diversifolia* + 75 g/plant of NPK
T3-3	10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung
T4-1	15 t/ha of *T. diversifolia*
T4-2	15 t/ha of *T. diversifolia* + 75 g/plant of NPK
T4-3	15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung

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Sampling

Three plantain fingers from each treatment were collected from the second hand of each bunch. After peeling, the fingers were dried in a Memmert oven at 65°C for 24 h. The samples were then ground using a Retsch GM 200 electric grinder and prepared in triplicate (representing the three field blocks) for laboratory analysis to determine the pH, proteins, ash and micronutrients concentrations (P, K, Na, Ca, Mg, Zn and Fe).

Physicochemical and biochemical analysis of plantain flour from each treatment

Determination of pH

The pH determination was carried out according to the AOAC method (2005). Ten grams of flour sample were weighed and then placed in a 50 mL plastic beaker. Then, 25 mL of distilled water was added and stirred using a wooden stick. The mixture was left to stand for 1 min before taking the pH meter reading.

Determination of ash content

The total ash contents of the flours were determined according to the AOAC method (2005). First, the porcelain crucibles were weighed using a Fisher Scientific precision balance to determine their masses (m_0). A mass of flour (1 g) was introduced into each porcelain crucible and weighed (m_1), the whole was introduced into a Nabertherm muffle furnace at a temperature of 550°C for 5 h. Finally, the crucibles were removed from the furnace and introduced into a desiccator for 24 h before being weighed (m_2). The ash contents (%) were therefore obtained by the following formula:

$$\text{Ash content (\%)} = \frac{m_2 - m_0}{m_1 - m_0} \times 100$$

m_0 = crucible mass (g)

m_1 = mass of the crucible containing the sample (g)

m_2 = mass of the crucible containing the residue remaining after removal from the furnace (g)

Determination of total protein contents

Protein contents were determined by the Kjeldahl method (1976). First, a mass quantity (1 g) of flour (m) was weighed using a Fisher Scientific precision balance; 2.7 g of K_2SO_4 and 0.3 g of $CuSO_4$ were also weighed and added as catalysts. The whole was introduced into a mineralization flask and then introduced into a 450°C oven for 2 h to obtain a liquid solution (mineralized). The mineralized obtained was diluted with distilled water until a 50 mL solution was obtained. Then, 10 mL of each sample was taken and introduced into a Kjeldahl distiller, then 10 mL of NaOH was added. Twenty (20) mL of boric acid (4%) were taken using a pipette and then introduced into a beaker. The beaker was fixed on the Kjeldahl distiller for 10 min so that the acid captured all the nitrogen contained in the sample. The titration was then carried out with a sulfuric acid solution (0.01 N). During this process, a quantity of volume V allowed a change in the color of the previous solution to be observed in the presence of a colored indicator. The nitrogen contents were calculated using the following formula:

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$$N\,(\%) = \frac{0.01\ x\ V\ x\ 5}{m}\ X\ \frac{14\ x\ 100}{1000}$$

N (%) = nitrogen contents

m= sample mass (g)

V= titration volume (mL)

Protein contents were determined using the following formula:

PN (%) = N (%) x 6.25

PN (%) = protein contents

N (%) = nitrogen contents

6,25 = conversion factor

Determination of mineral content

The determination of P, K, Na, Ca, Mg, Zn and Fe concentrations was carried out according to the method described by AOAC (2005). The flour samples were calcined using a muffle furnace at a temperature of 550°C for 5 h. Then, 10 mL of 20% HCl was added to the ashes contained in each crucible, the mixture was heated for 20 min on a hot plate. After cooling the mixture, 5 mL of HNO3 (2 N) was added to each crucible and then filtered into a 50 mL graduated flask using filter paper. Hot distilled water was added to the filter paper to facilitate the washing of the residues. The filtrate obtained was completed with distilled water up to the gauge mark. The 1/10 dilution consisted of taking 5 mL of the solution obtained introducing it into a 50 mL graduated flask and then filling it with distilled water up to the gauge mark. Potassium and sodium were determined using a flame photometer. Iron, calcium, zinc and magnesium were determined using an atomic absorption spectrophotometer. The values obtained were expressed in mg/kg. Phosphorus was determined by the vanado-molybdate method. This method consisted of introducing 2 mL of molybdate into a test tube containing the solution diluted 1/10, 6 mL of distilled water was then added and the mixture was stirred for 1 min. Finally, 1 mL of $SnCl_2$ was added to each tube and the reading was taken using a spectrophotometer.

Principal component analysis was performed to determine the treatment that promotes better nutrient export in plantain pulp.

Statistical analysis

The data from the collection of the physicochemical and biochemical analysis of plantain flour from each treatment were entered into the Excel 2019 table and then subjected to an analysis of variance (ANOVA) using the Xlstat 2019 statistical analysis software. The Duncan test at the 5% threshold was used to compare the means of all the parameters studied in order to determine if there was a significant difference. The principal component analysis was carried out with the R.4.4.0 statistical analysis software and made it possible to identify the treatment that promoted a better nutritional quality of the plantain.

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RESULTS

Physicochemical and biochemical analysis of plantain flour from each treatment

Influence of treatment on the proteins, pH and ash content of the flour

Table 2 presents the physicochemical and biochemical composition of plantain flour from each treatment. The flours obtained from plantains from each treatment showed a significant difference ($p<0.05$) in proteins, pH and ash content.

The pH of plantain flours ranged from 5.14 for treatment T1 (100 g/plant of NPK) to 5.87 for treatment T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung). With treatments T1 (100 g/plant of NPK) and T2-1 (5 t/ha of *T. diversifolia*), the pH was lower compared to that of the control T0 (without fertilizer). The contribution of chemical fertilizers influences not only the physicochemical composition of the soil but also that of the plantain pulp. The pH of flours from treatments T4-1 (15 t/ha of *T. diversifolia*) and T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) of 5.80 and 5.87 respectively were significantly higher compared to the other treatments. The dose of *T. diversifolia* used as organic manure influences the pH value of flours.

The ash contents of the flours varied from 1.93% for treatment T4-1 (15 t/ha of *T. diversifolia*) to 2.91% for treatment T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK). The flours from treatments T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant of NPK), T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK) and T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant of NPK) recorded the highest ash contents which were respectively 2.87%, 2.91% and 2.74%. On the other hand, that obtained from treatment T4-1 (15 t/ha of *T. diversifolia*) contained a lower quantity of ash. The combination of organic and mineral fertilizer increased the ash contents in plantain pulp.

Protein contents of flours ranged from 2.21% for treatment T3-1 (10 t/ha of *T. diversifolia*) to 5.50% for treatment T4-1 (15 t/ha of *T. diversifolia*). Protein contents of flours from treatments T0 (without fertilizer) and T3-1 (10 t/ha of *T. diversifolia*) were the lowest, 2.71% and 2.21%, respectively, but they were not significantly different. However, flour from treatment T4-1 (15 t/ha of *T. diversifolia*) had the highest protein content reaching up to 5.50%, compared to those from other treatments. Thus, the application of a high dose of *T. diversifolia* (15 t/ha) to the crop significantly increased the nitrogen and consequently protein contents in plantain pulp.

Table 2: Physicochemical and biochemical composition of flours from plantain of each treatment

Treatments	pH	Ash (%)	Proteins (%)
T0	5.49±0.02 [ab]	2.33±0.19 [ab]	2.71±0.70 [a]
T1	5.14±0.24 [a]	2.60±0.20 [ab]	3.19±0.47 [ab]
T2-1	5.17±0.14 [a]	2.48±0.16 [ab]	3.35±0.38 [ab]
T2-2	5.55±0.42 [ab]	2.87±0.42 [b]	3.96±0.80 [b]
T2-3	5.55±0.46 [ab]	2.50±0.58 [ab]	3.03±0.67 [ab]
T3-1	5.26±0.29 [ab]	2.56±0.10 [ab]	2.21±0.30 [a]
T3-2	5.28±0.13 [ab]	2.91±0.62 [b]	3.18±0.30 [ab]
T3-3	5.87±0.22 [b]	2.62±0.18 [ab]	3.31±0.92 [ab]
T4-1	5.80±0.08 [b]	1.93±0.002 [a]	5.50±0.06 [c]
T4-2	5.27±0.42 [ab]	2.74±0.16 [b]	2.85±0.44 [ab]
T4-3	5.28±0.05 [ab]	2.55±0.43 [ab]	3.25±0.19 [ab]

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*Means with similar letters in the same column indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: no fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the calcium content of plantain flour

Figure 2 depicts effects of fertilizers on calcium concentrations in flours. It can be deduced that the calcium level ranged from 26.66 mg/kg (T2-2) (5 t/ha of *T. diversifolia* + 75 g/plant of NPK) to 110 mg/kg (T4-3) (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung). The lowest calcium concentrations (26.667 mg/kg; 30 mg/kg) in the flours were observed with the respective treatments T2-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK) and T2-1 (5 t/ha of *T. diversifolia*). In addition, there were also significant differences between these concentrations and those of flours from the other treatments. Treatments T4-1 (15 t/ha of *T. diversifolia*) and T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant of NPK) are moderately effective in enriching plantain flour with calcium. With fertilization consisting of 15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung (T4-3), the best result was obtained, corresponding to the maximum calcium concentration (110 mg/kg) recorded in the flour. This indicates that these fertilizers are favorable for increasing the calcium concentration in the plantain pulp.

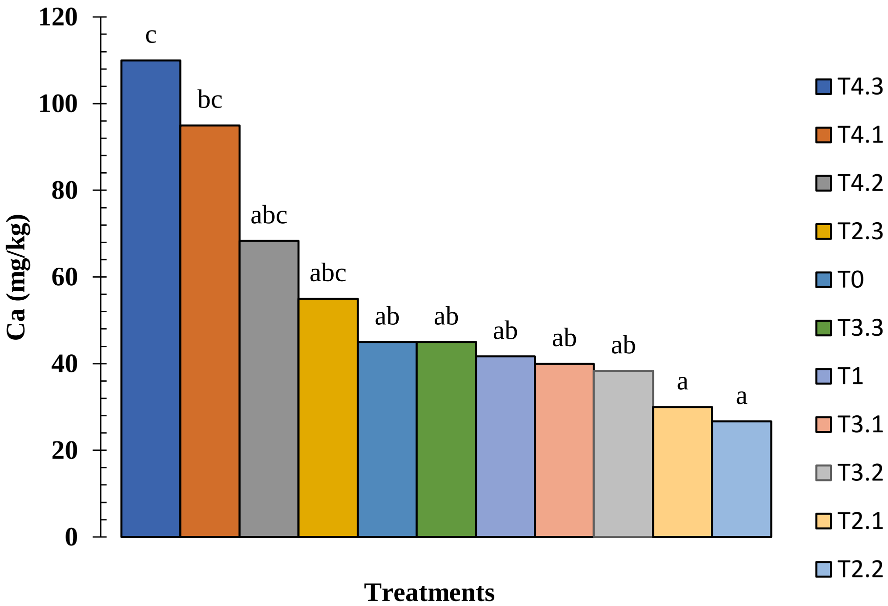

Figure 2: Effects of fertilizers on calcium concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia;* T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1:

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10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the magnesium content of plantain flour

Figure 3 highlights effects of fertilizers on magnesium concentrations in flours. It appears that magnesium concentrations varied from 625 mg/kg for treatment T4-1 (15 t/ha of *T. diversifolia*) to 1050 mg/kg for treatment T0 (without fertilizer). Magnesium concentrations in flours from treatments T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK), T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) and T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) were identical (700 mg/kg). Furthermore, these concentrations showed significant differences with the other treatments.

Indeed, the contribution of fertilization seems to lead to a reduction in the absorption of magnesium by the plant, thus decreasing its concentration in the pulp of the plantain.

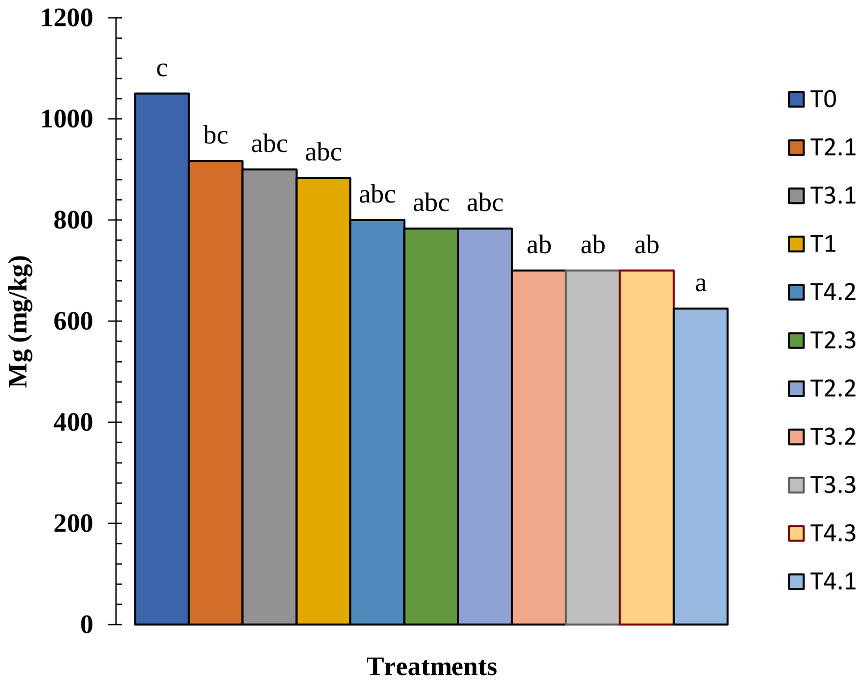

Figure 3: Effects of fertilizers on magnesium concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

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Influence of treatments on the sodium content of plantain flour

Figure 4 shows effects of fertilizers on sodium concentrations in flours. Sodium concentrations ranged from 277.75 mg/kg for treatment T0 (without fertilizer) to 585 mg/kg for treatment T3-1 (10 t/ha of *T. diversifolia*). Furthermore, the sodium concentrations of flours from treatments T2-2 (5 t/ha *T. diversifolia* +75 g/plant NPK), T2-1 (5 t/ha *T. diversifolia*), T1 (100 g/plant NPK) were 310.66 mg/kg, 299 mg/kg and 291.66 mg/kg, respectively. These treatments showed significant differences with treatments T3-1 (10 t/ha of *T. diversifolia*), T4-2 (15 t/ha *T. diversifolia* + 75 g/plant NPK), T4-1 (15 t/ha of *T. diversifolia*) and T2-3 (5 t/ha *T. diversifolia* + 3 kg/plant of zebu dung) with respective sodium concentrations of 585 mg/kg, 580 mg/kg, 525 mg/kg and 521.50 mg/kg. Thus, treatments T3-1 (10 t/ha of *T. diversifolia*) and T4-2 (15 t/ha *T. diversifolia* + 75 g/plant NPK) are the most effective in increasing sodium concentration in plantain pulp. These treatments stimulate sodium uptake by modifying its availability in the soil or by reducing competition with other nutrients.

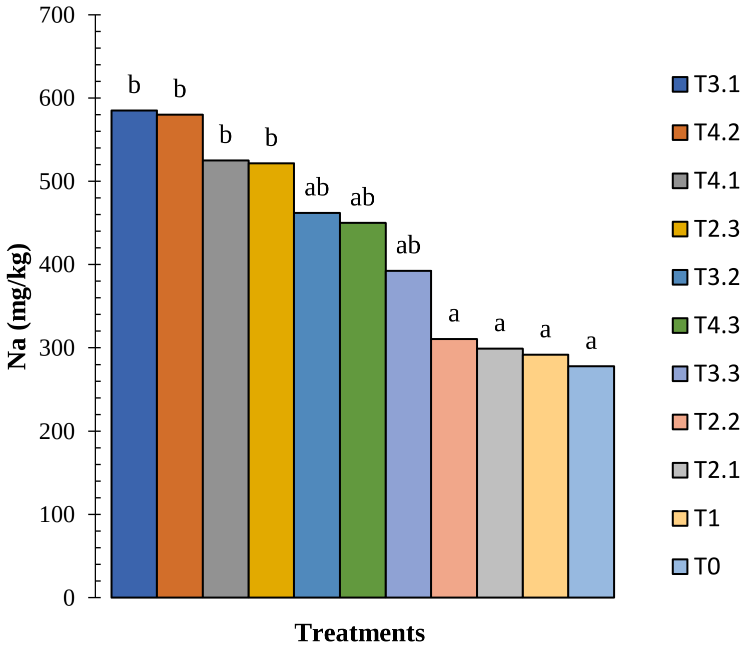

Figure 4: Effects of fertilizers on sodium concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the potassium content of plantain flour

Figure 5 presents effects of fertilizers on potassium concentrations in flours. It appears that potassium concentrations ranged from 5400 mg/kg for treatment T4-1 (15 t/ha of *T.*

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diversifolia) to 8783.33 mg/kg for treatment T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK). Potassium concentrations were average with treatments T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant of NPK), T2-1 (5 t/ha of *T. diversifolia*), T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant of NPK), T1 (100 g/plant of NPK), T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) and T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), which are respectively 8083.33 mg/kg, 7683.33 mg/kg, 7650 mg/kg, 7516.66 mg/kg, 740 mg/kg and 6850 mg/kg.

Flours from treatments T0 (without fertilizer), T3-1 (10 t/ha of *T. diversifolia*) and T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK) had the highest potassium concentrations of 8775 mg/kg, 8675 mg/kg and 8783.33 mg/kg, respectively. This suggests an efficient absorption of potassium both under these conditions and under the normal crop condition without fertilization.

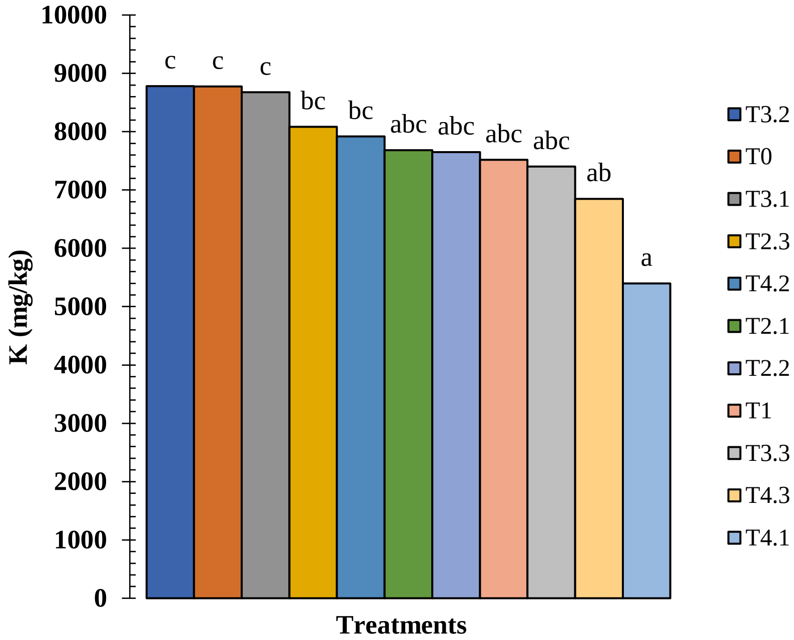

Figure 5: Effects of fertilizers on potassium concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the phosphorus content of plantain flour

Figure 6 shows effects of fertilizers on phosphorus concentrations in flours. Phosphorus concentrations ranged from 2.06 mg/kg for treatment T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant of NPK) to 18.07 mg/kg for treatment T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of

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zebu dung). Indeed, the lowest phosphorus concentration (2.06 mg/kg) was obtained with the flour from the T4-2 treatment (15 t/ha of *T. diversifolia* + 75 g/plant of NPK). Also, no significant difference was observed between the phosphorus concentration of the flour from this treatment and the flours from the T3-1 (10 t/ha of *T. diversifolia*) and T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) treatments, which had identical phosphorus concentrations (2.43 mg/kg). In addition, the phosphorus concentrations of flours from treatments T2-1 (5 t/ha *T. diversifolia*), T3-2 (10 t/ha *T. diversifolia* + 75 g/plant of NPK), T0 (without fertilizer), T3-3 (10 t/ha *T. diversifolia* + 3 kg/plant of zebu dung) and T2-2 (10 t/ha *T. diversifolia* + 75 g/plant of NPK) were 6.75 mg/kg, 5.92 mg/kg, 5.59 mg/kg, 3.94 mg/kg and 3.33 mg/kg, respectively. Significant differences were observed between these treatments and the others. Furthermore, the maximum phosphorus concentration (18.07 mg/kg) was noted with the flour from treatment T2-3 (5 t/ha *T. diversifolia* + 3 kg/plant of zebu dung), followed by those from treatments T4-1 (15 t/ha of *T. diversifolia*) and T1 (100 g/plant of NPK) were respectively 13.75 mg/kg and 10.08 mg/kg. This suggests that these treatments promote the absorption and assimilation of bioavailable phosphorus for the plant, thus increasing the phosphorus concentration in the plantain pulp.

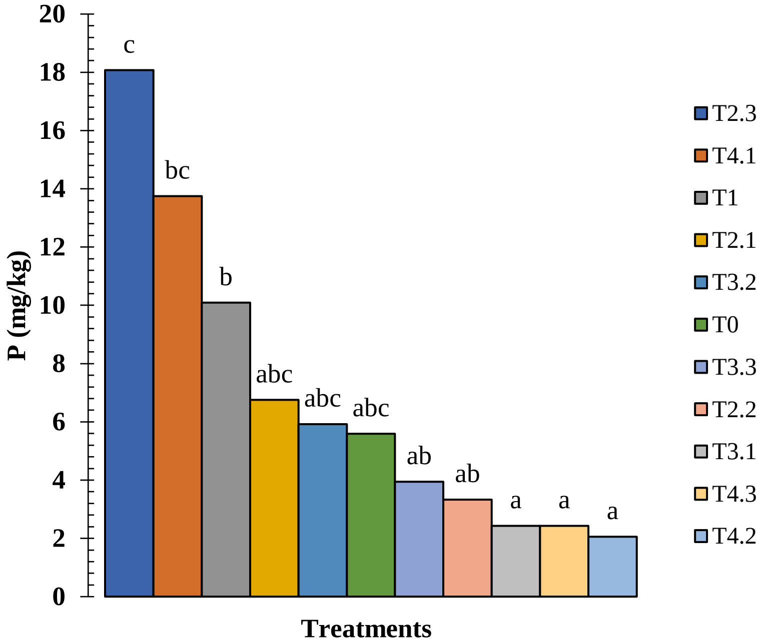

Figure 6: Effects of fertilizers on phosphorus concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the iron content of plantain flour

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Figure 7 depicts effects of fertilizers on iron concentrations in flours. Iron concentrations ranged from 22.01 mg/kg for treatment T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant of NPK) to 264.97 mg/kg for treatment T3-1 (10 t/ha of *T. diversifolia*). Iron concentrations in flours from treatment T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) (59.27 mg/kg) were significantly higher than those from treatment T4-1 (15 t/ha of *T. diversifolia*) (247.48 mg/kg).

Treatment T3-1 (10 t/ha of *T. diversifolia*) was the most effective in increasing iron content, suggesting that it promotes maximum absorption of this nutrient. It could be used to enrich flours with iron in nutritional applications.

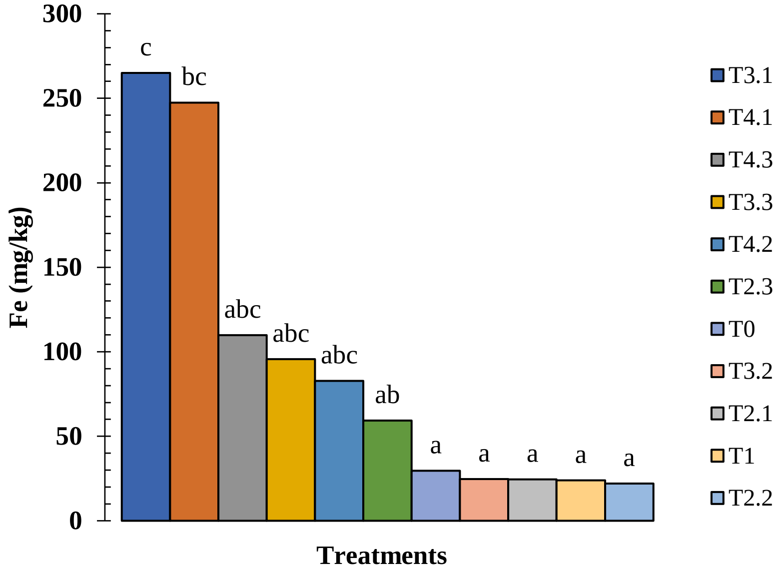

Figure 7: Effects of fertilizers on iron concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Influence of treatments on the zinc content of plantain flour

Figure 8 presents effects of fertilizers on zinc concentrations in flours. Zinc concentrations ranged from 5.53 mg/kg for treatment T3-1 (10 t/ha of *T. diversifolia*) to 7.57 mg/kg for treatment T0 (without fertilizer). While low zinc concentrations were observed with flours from treatments T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant of NPK), T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T4-1 (15 t/ha of *T. diversifolia*) and T3-1 (10 t/ha of *T. diversifolia*) correspond to 5.89 mg/kg, 5.78 mg/kg, 5.75 mg/kg, 5.73 mg/kg and 5.53 mg/kg respectively; The highest zinc concentrations were found in flours from treatments T0 (without fertilizer) and T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant of NPK), which were 7.57 mg/kg and 7.54 mg/kg, respectively.

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These treatments showed significant differences with the zinc concentrations of flours from other treatments. This suggests that the addition of chemical or organic fertilizer could influence the bioavailability of zinc in the soil. Furthermore, the mean zinc concentrations of the flours from treatments T1 (100 g/plant of NPK), T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T2-1 (5 t/ha of *T. diversifolia*) and T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant of NPK), which were respectively 7.20 mg/kg, 7.03 mg/kg, 6.68 mg/kg and 6.66 mg/kg.

In summary, the zinc concentration in plantain pulp depends not only on the management of organic and mineral fertilizers, but also on the complex interactions between nutrients and biomass in the soil.

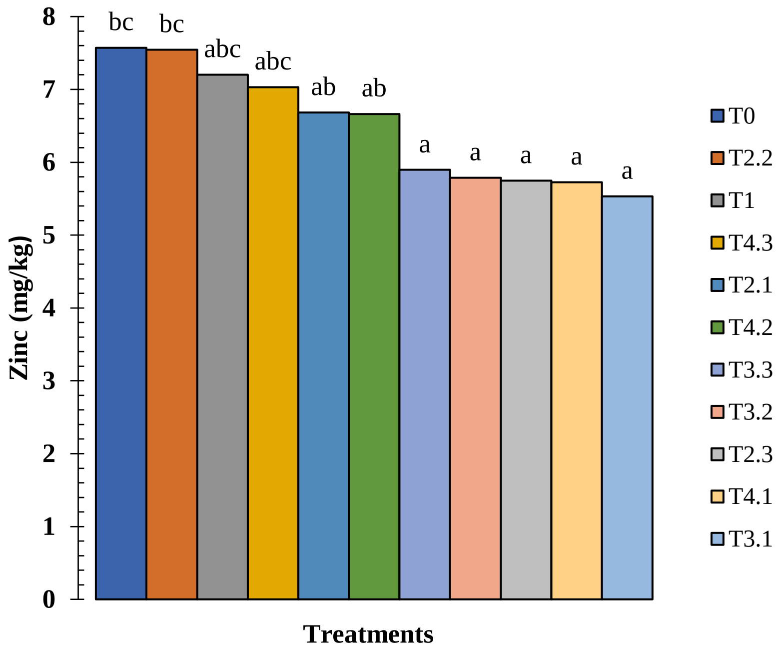

Figure 8: Effects of fertilizers on zinc concentrations in flours

*Histograms topped with similar letters indicate that there are no significant differences between treatments according to Duncan multiple comparison test ($p < 0.05$). T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung.

Selection of the best treatment

The principal component revealed that axes 1 and 2 characterized the treatments evaluated and it contributed 56.2% to the variation observed in the pulp. Principal component analysis, performed using data on proteins and minerals (calcium, magnesium, phosphorus, potassium, zinc, iron and sodium) showed that axes 1 and 2 were sufficient to show the effect of the

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fertilizers applied. Calcium, sodium and iron were positively correlated with axis 1, while those proteins were negatively correlated with axis 2. Magnesium and potassium were positively correlated with axis 2 (Figure 9). Thus, axis 1 made it possible to detect that treatment T3-1 (10 t/ha of *Tithonia diversifolia*) promoted a better transfer of mineral elements into the plantain pulp.

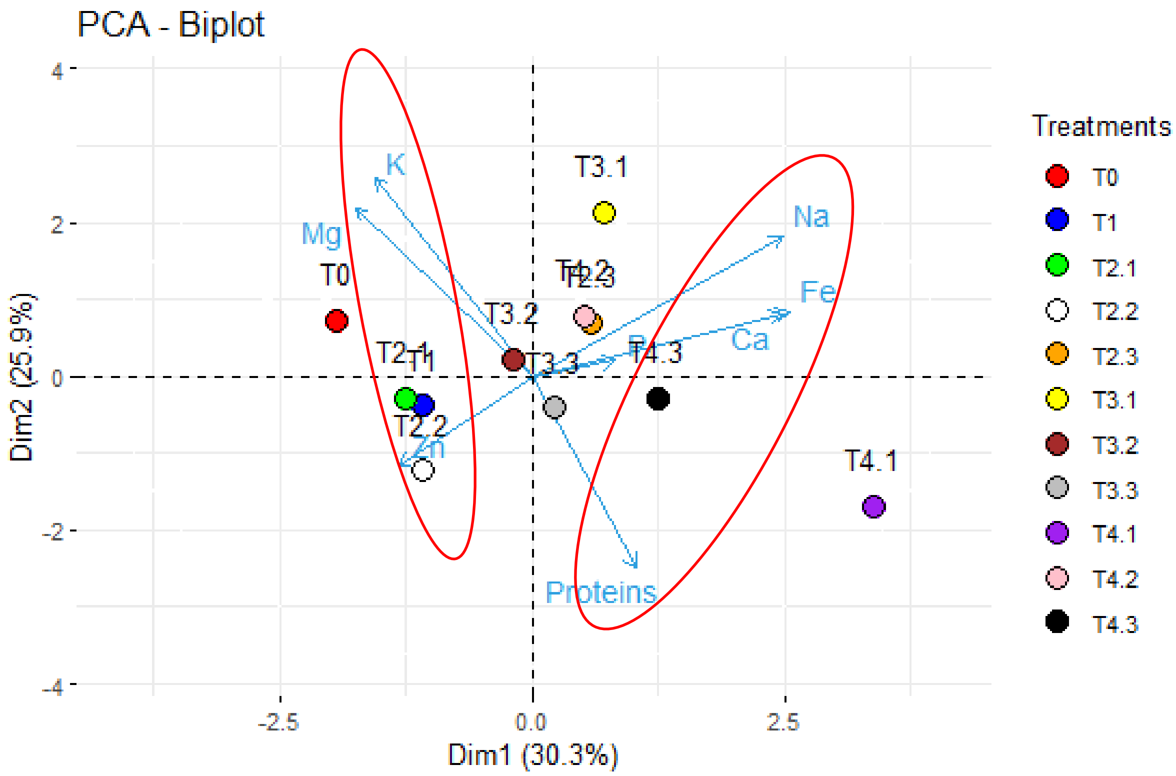

Figure 9: Distribution of treatments according to mineral components in plantain pulp along axes 1 and 2 of principal component analysis

T0: without fertilizer; T1: 100 g/plant of NPK; T2-1: 5 t/ha *Tithonia diversifolia*; T2-2: 5 t/ha *Tithonia diversifolia* +75 g/plant NPK; T2-3: 5 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T3-1: 10 t/ha *Tithonia diversifolia*; T3-2: 10 t/ha *Tithonia diversifolia* +75 g/plant NPK; T3-3: 10 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung; T4-1: 15 t/ha *Tithonia diversifolia*; T4-2: 15 t/ha *Tithonia diversifolia* +75 g/plant NPK and T4-3: 15 t/ha *Tithonia diversifolia* +3 kg/plant zebu dung. Na: sodium; K: potassium; Mg: magnesium; P: phosphorus; Fe: Iron; Zn: zinc; Ca: calcium

DISCUSSION

Physicochemical and biochemical analysis of flours from plantain pulp from each treatment

The pH of all flours from plantain pulps from each treatment was acidic. This result could be due to the acidity of the soil of the plot. According to Soro *et al*. (2013), flours with an acidic

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pH are better preserved against attacks by microorganisms. Thus, flours from the different treatments could be stored for a long time without risk of microbial alterations.

Fertilization significantly improved the nitrogen and therefore protein contents present in the plantain pulp. The protein content of flours from treatment T0 (2.70%) was slightly lower than those obtained by Aba *et al*. (2020) on a plot without fertilizer (2.86%). On the other hand, the protein content of flours from treatment T1 (100 g/plant of NPK) (3.19%) is higher than that of flours from a plot that received chemical fertilizer (2.90%). However, the protein content of flours from the T4-2 treatment (15 t/ha of *T. diversifolia* + 75 g/plant of NPK) was identical to that of flours from a plot with a combination of chemical and organic fertilizer (2.84%). These results could be explained by the fact that the application of chemical fertilizers increases the nitrogen content and consequently the protein content in the plantain pulp. Similarly, the application of chemical fertilizer increased the ash content of flours from each treatment. These results are in agreement with the work of Adewale et al. (2018) who showed that the application of NPK on maize plants improves the protein (7.24%) and ash (1.09%) content of its flour. Fertilization of plantain plants with 15 t/ha of *T. diversifolia* improved the protein content (5.55%) in the plantain pulp. The concentrations of Ca, Mg, K and P in flours from treatment T0 (without fertilizer) and T1 (100 g/plant of NPK) were higher than those obtained by Aba et al. (2020) which are respectively 40.73 mg/kg and 40.30 mg/kg for calcium; 12.76 mg/kg and 8.63 mg/kg for magnesium; 66.77 mg/kg and 64.60 mg/kg for potassium; 3.26 mg/kg and 3.51 mg/kg for phosphorus. On the other hand, the calcium concentrations of flours from treatments T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant NPK) and T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant NPK) were lower than those of flours from the combination of organic and chemical fertilizer (39.60 mg/kg) found by the same authors. This result could be explained by the fact that plants from these treatments largely used calcium to stimulate root development. In addition, plantain from these treatments has a low phosphorus concentration, this result could be due to the high photosynthetic activity of the plants because the phosphorus concentrations in the soil after harvest were zero. The low sodium concentrations in flour from treatment T0 (without fertilizer) (274.32 mg/kg) could be due to high potassium concentrations. Phosphorus concentrations in flour from T4-2 treatment (15 t/ha of *T. diversifolia* + 75 g/plant NPK) (2 mg/kg) were lower than those in flour from a treatment composed of organic and chemical fertilizer (3.07 mg/kg) (Aba *et al*., 2020). This result could be explained by the fact that acidic pH reduces the availability of this element. The low phosphorus concentrations in plantain pulp from treatments T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant NPK), T3-1 (10 t/ha of *T. diversifolia*), T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant NPK) show that they were used by the plant to carry out photosynthesis.

Plant fertilization with 5 t/ha of *T. diversifolia* (T2-1) improved phosphorus, potassium and magnesium concentrations in plantain pulp. These results are similar to the work of Flores-Mangual and González-Vélez (2019), who reported that chicken manure significantly increased the amount of NO_3^-, available P, K^+ and Mg^{2+} in the fruit compared to plots where chicken manure was not applied. The high magnesium concentrations in flours from the no-fertilizer treatment (T0) can be explained by a better natural availability of magnesium in the soil, the absence of competitive interactions with other nutrients and the possible absence of dilution due to lower biomass. A study by Alla *et al*. (2021) showed that the application of 30 g of NPK 10-18-18+10 g of urea+20 g of potassium sulfate significantly improves the concentrations of phosphorus, potassium and sodium in eggplant. Indeed, potassium

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participates in many metabolic processes determining for the yield and quality of fruits. It improves water regulation in the plant, assimilation and fruiting performance (Mpika *et al*., 2015). However, the high potassium concentrations observed in flours from the T0 treatment (without fertilizer) are probably due to the absence of competition with other nutrients. In addition, the absence of fertilizer helps maintain a natural balance of nutrients, promoting better absorption of potassium. Iron concentrations in flours from treatments T0 (without fertilizer), T1 (100 g/plant of NPK), T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) and T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) were higher compared to the results found by Ndukwe et al. (2012) which were respectively 18.71 mg/kg for flour from a plot without fertilizer, 18.08 mg/kg with chemical fertilizer and 19.55 mg/kg with organic fertilizer. This result could be due to a difference in the study site which is feralitic in nature. Similarly, zinc concentrations in flour from these treatments are higher than those found by the same authors, which are 0.821 mg/kg for flour from a plot without fertiliser, 0.93 mg/kg for flour from a plot treated with chemical fertiliser and 0.80 mg/kg with organic fertiliser. This difference could be due to the physicochemical nature of the soil and the type of fertiliser used. A similar study conducted by Ambrin *et al*. (2017) showed that the interaction between organic and inorganic sources significantly increases the iron and zinc concentrations of plantain pulp.

Selection of the best treatment

Organic fertilization alone or combined with low doses of inorganic fertilizers (NPK) decreased magnesium and potassium concentrations in plantain pulps from the treatments T2-1 (5 t/ha of *T. diversifolia*), T1 (100 g/plant of NPK), T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant NPK), T2-2 (5 t/ha of *T. diversifolia* + 75 g/plant NPK), T3-3 (10 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T4-3 (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) and T4-1 (15 t/ha of *T. diversifolia*). According to the main interactions in the absorption of nutrients, the high calcium concentrations due to the T4-3 treatment (15 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) disrupt the assimilation of magnesium and iron by the plant, hence their low content in plantain pulps (Anonyms, 2021). The high potassium concentrations recorded in the flours from treatments T3-1 (10 t/ha of *T. diversifolia*) and T3-2 (10 t/ha of *T. diversifolia* + 75 g/plant NPK) led to a decrease in calcium and magnesium concentrations. The high magnesium concentrations in the flours from treatment T0 (without fertilizer) disrupted the assimilation of calcium by the plant. The high sodium concentrations in the flours from treatments T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung), T3-1 (10 t/ha of *T. diversifolia*) and T4-2 (15 t/ha of *T. diversifolia* + 75 g/plant NPK) disrupted calcium assimilation and treatment T2-3 (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) promoted calcium assimilation. average phosphorus. Finally, the phosphorus concentration of the flour from the T2-3 treatment (5 t/ha of *T. diversifolia* + 3 kg/plant of zebu dung) significantly reduced the iron and calcium concentrations in the plantain flour. The application of *T. diversifolia* at a dose of 10 t/ha on the plants improves the export capacity of potassium, magnesium, iron and sodium in the plantain pulp

CONCLUSION

Fertilization plays an important role in improving the nutritional quality of a fruit. The specific case of plantain showed that the different treatments used in this study contributed significantly

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to the nutritional quality. This study shows that fertilization based on *Tithonia diversifolia* increases the protein contents, calcium, magnesium, potassium, phosphorus, iron and sodium concentrations in plantain pulp. A rational plant fertilization system helps to preserve the physicochemical properties of the soil and improve the nutritional quality of the fruits.

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