



## Research Article

# Morphological and Agronomic Variability of Edible Tiger Nut (*Cyperus esculentus* L.) Accessions Cultivated in Côte d'Ivoire

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## Abstract

In Côte d'Ivoire, the cultivation of edible nutgrass (*Cyperus esculentus* L.) is mainly carried out by Senufo, Djimini, and Lobi women using traditional techniques. Given its importance in terms of food, medicine, and economics, promoting this sector is a major asset in reducing nutritional insecurity. However, the diversity of this crop remains poorly researched. This study aimed to characterize the agromorphological diversity of 27 tigernut accessions from four major production areas (Korhogo, Sinématiali, Dabakala, and Doropo) in a randomized experimental design with three replicates, set up in Bouaflé. Twenty-one morphological and agronomic traits related to growth, flowering, production, and yield were measured. High coefficients of variation (CV > 30%) revealed significant variability between accessions. Hierarchical classification analysis (HCA) structured the accessions into two distinct genetic groups. Group I was characterized by vegetative parameters and formed from accessions from the four study locations. Group II consisted of accessions from Korhogo and Doropo and was characterized by production parameters. Discriminant factor analysis (DFA) identified the number of mature tubers (NMT) and the total number of leaves (TNL) as the most discriminating traits. The results of this study will contribute to the implementation of a genetic improvement program for edible tiger nuts in Côte d'Ivoire.

## Keywords

*Cyperus esculentus*, Diversity, Morphology, Tiger Nut, Production

## 1. Introduction

Senufo, Djimini, and Lobi women are the main producers of edible tiger nuts in Côte d'Ivoire. [1-5]. This plant provides important food and financial support for this vulnerable segment of the Ivorian population. Nutritionally, edible tiger nut

tubers are rich in carbohydrates, lipids, proteins, trace elements, and essential amino acids [6, 7]. They are also prized for their high content of bioactive compounds and antioxidants, which makes them increasingly attractive to the agri-

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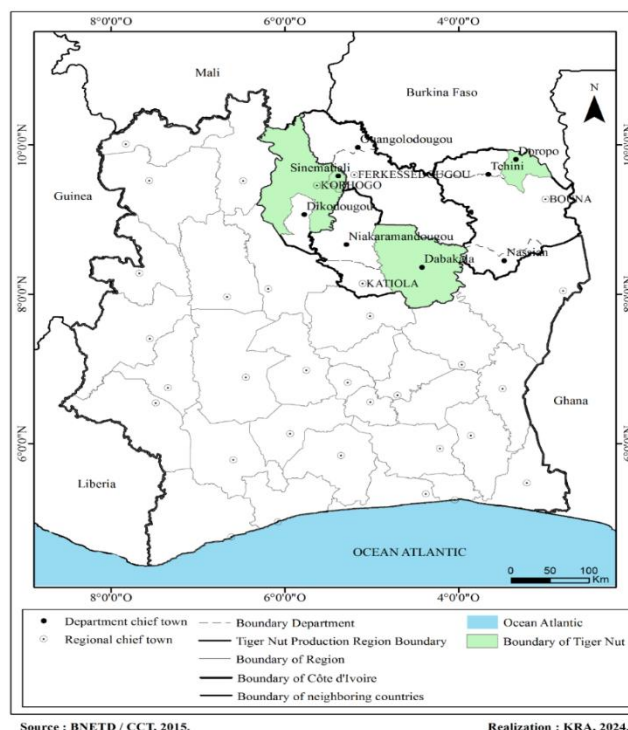
food industry and for human nutrition [8, 9]. In local and urban markets in Côte d'Ivoire, the price of edible tiger nuts varies from 700 to 1,200 CFA francs, reflecting high demand and continued expansion of the sector [10]. The technical approach to this crop of interest remains traditional and is characterized by the widespread use of non-improved seeds on farms run by women producers. The result of this approach is low production of edible tiger nuts in farmers' fields [11]. In this context, there is an urgent need to implement a genetic improvement program. The first step and the key to the success of this vision is knowledge of the diversity of edible tiger nut accessions available in Côte d'Ivoire. The second step is to identify improved varieties that are adapted to different agro-ecological zones. Genetic diversity is the foundation of sustainable varietal improvement [12, 13]. It allows for the selection of genotypes that perform well agronomically, are tolerant to biotic and abiotic stress, and meet consumer needs. In this context, studying the agromorphological diversity of edible tiger nut accessions appears to be a key step in identifying discriminating traits and guiding selection work [14]. The technical approach to this crop of interest remains traditional, and three types of genetic markers are generally used to identify genetic diversity, namely phenotypic, biochemical, and molecular. The first strategy is the most widespread, certainly because of its low cost and ease of use [15]. This group includes quantitative and qualitative agronomic parameters, which are essential for the classification and selection of agronomic elites. Principal component analysis (PCA) is one of the most relevant statistical tools for this type of study, as it facilitates the grouping of genotypes according to their similarity by highlighting the most discriminating traits [16]. However, although similar work has been carried out in Nigeria, Ghana, and Spain [17, 18], scientific data on the agromorphological diversity of edible tiger nuts in Côte d'Ivoire is virtually non-existent. It is therefore necessary to undertake in-depth studies to better characterize local accessions, identify potential breeding stock, and propose varieties adapted to agricultural and industrial needs. The long-term aim of this study is to contribute to strengthening the productivity of edible tiger nuts in Côte d'Ivoire, promoting the economic empowerment of local producers, and supporting the sustainable development of this strategic crop. Thus, the overall objective of this study is to improve the production of edible tiger nuts in Côte d'Ivoire. Specifically, this involves determining the agromorphological diversity of edible tiger nut accessions and identifying the best varieties.

## 2. Materials and Methods

### 2.1. Collection Areas and Study Site

Edible tiger nuts are found in the northern Sudanese part of Côte d'Ivoire, but samples were collected in three main regions: the Poro region (Korogo and Sinementiali), the Hambol region (Dabakala), and the Bounkani region (Doropo). These

regions are considered traditional areas for the cultivation of edible tiger nuts, and the reasons why these populations are interested in producing this crop are generally cultural and economic (Figure 1).



**Figure 1.** Geographic location of collection areas (Korogo, Sinementiali, Dabakala, and Doropo) for edible tiger nut samples on a map of Côte d'Ivoire [19].

The trials were set up on an experimental plot in the town of Bouafle (6°59'00"North; 5°45'00" West), the capital of the Marahoue region, located in the central-western part of Côte d'Ivoire. This study site was chosen because of its similarity to traditional tiger nut growing areas and the economic importance of its tubers for certain female traders in Marahoue.

The Bouafle department is a transition zone between forest and savanna with gallery forests and fallow land in places [20]. Rainfall varies between 800 and 1,800 mm per year. The terrain is generally composed of ferrallitic and hydromorphic soils [21, 22]. The climate is tropical humid with two rainy seasons and two dry seasons [23].

### 2.2. Plant Material

The study of the diversity of edible tiger nuts in Côte d'Ivoire involved identifying the different production areas and collecting samples by production area, locality, and variety, then sowing them at the cultivation site. A total of 972 tiger nut plants from 27 tuber accessions collected in 19 villages in northern Côte d'Ivoire were included in this study. These different accessions were coded and each was assigned a number based on its area of origin (Table 1).

**Table 1.** Characterization of edible tigernut accessions according to their origin and the size of the different varieties.

| Accessions   | Origin       | Locality         | Varieties     | Codes |
|--------------|--------------|------------------|---------------|-------|
| Accession 1  | Sinementiali | Fononkaha        | Large tuber   | AC1   |
| Accession 2  | Sinementiali | Nabegnikaha      | Large tuber   | AC2   |
| Accession 3  | Sinementiali | Fononkaha        | Large tuber   | AC3   |
| Accession 4  | Sinementiali | Meguekaha        | Large tuber   | AC4   |
| Accession 5  | Sinementiali | Zimekaha         | Large tuber   | AC5   |
| Accession 6  | Sinementiali | Nahouokaha       | Large tuber   | AC6   |
| Accession 7  | Sinementiali | Nogotienekaha    | Large tuber   | AC7   |
| Accession 8  | Korhogo      | Toulekaha        | Large tuber   | AC8   |
| Accession 9  | Korhogo      | Oleokaha         | Large tuber   | AC9   |
| Accession 10 | Korhogo      | Toulekaha        | Large tuber   | AC10  |
| Accession 11 | Korhogo      | Toulekaha        | Large tuber   | AC11  |
| Accession 12 | Korhogo      | Latiene          | Large tuber   | AC12  |
| Accession 13 | Korhogo      | Kafonnonkaha     | Large tuber   | AC13  |
| Accession 14 | Korhogo      | Pederikaha       | Small tuber   | AC14  |
| Accession 15 | Korhogo      | Toulekaha        | Small tuber   | AC15  |
| Accession 16 | Dabakala     | Kongo-Banadougou | Large tuber   | AC16  |
| Accession 17 | Dabakala     | Sokala-Sobara    | Large tuber   | AC17  |
| Accession 18 | Dabakala     | Kafoudougou      | Large tuber   | AC18  |
| Accession 19 | Dabakala     | Dienagana        | Large tuber   | AC19  |
| Accession 20 | Dabakala     | Tagbonon         | Large tuber   | AC20  |
| Accession 21 | Dabakala     | Kafoudougou      | Large tuber   | AC21  |
| Accession 22 | Dabakala     | Kafoudougou      | Small tuber   | AC22  |
| Accession 23 | Dabakala     | Kafoudougou      | Large tuber   | AC23  |
| Accession 24 | Doropo       | Nougbara         | Large tuber   | AC24  |
| Accession 25 | Doropo       | Olara 1          | Large tuber   | AC25  |
| Accession 26 | Doropo       | Youtedouo        | Large tuber   | AC26  |
| Accession 27 | Doropo       | Olara 1          | Large tuber s | AC27  |

### 2.3. Experimental Setup and Treatment

The tubers from the 27 accessions were sown on elementary plots comprising 36 sowing points with three replicates in a randomized experimental design on a large plot covering an area of 1,540 m<sup>2</sup> (67 m x 23 m). The three blocks were separated from each other by 1 m. Each block (23 m x 21 m) comprised 36 elementary plots (6.6 m x 1.2 m), each constituting one accession. The distance between two consecutive elementary plots was 0.6 m. Each elementary plot contained 36 pits

arranged in 3 rows and 12 columns. The elementary plots and pits were spaced evenly at a distance of 0.6 m. A 1 m border was created around the blocks.

### 2.4. Cultivation and Maintenance of the Plot

Before sowing, the tubers from each accession were soaked in pots containing water for 48 hours to promote turgidity and facilitate germination. In the system designed at each experimental site, the tubers were sown at a depth of 2 cm. Each planting hole contained two tubers. Thinning was carried out

one week after sowing and consisted of removing one plant and keeping only one vigorous tiger nut plant per planting hole. After sowing, the plots were watered regularly in the absence of rain. They were constantly weeded to avoid competition with weeds. The crop takes about three months to grow, and harvesting takes place when the tubers reach full maturity, which is indicated by the yellowing of the leaves.

## 2.5. Data Collection

The parameters involved in this experiment were vegetative parameters, growth parameters, production parameters, yield parameters, and flowering parameters. The vegetative parameters concerned the total number of leaves (TNL); the number of dry leaves (NDL), the number of yellow leaves (YL), the number of partially yellow leaves (PYL), the number of leaves on the mother plant (NMPL), the number of last leaves (NLL); leaf biomass (LBB) and root biomass (RBB). Growth parameters related to the length of mature plants (LPLT), diameter at the collar (DIACO); distance between the mother plant and the tillers (DISP); root length (LORA); and number of tillers per clump (NTAL). Flowering referred to floral branches (FLO) and number of spikelets (NEPI). For production and yield, the parameters considered were: tuber mass per clump (MTP); tuber length (LOT); tuber width (LAT); number of mature tubers (NTM), mass of 100 tubers (M100), and yield (RED). These agromorphological parameters from each accession will be measured and subjected to statistical analysis. Evaluating the different accessions using these agromorphological parameters will provide information on the diversity of edible tiger nuts.

## 2.6. Statistical Data Analysis

The measured parameters were subjected to four statistical analyses: Analyses of variance (ANOVA1), preceded by multiple comparison tests of means using Fischer's Least Significant Difference test, to assess the difference between accessions. De-

scriptive analyses including PCA (Principal Component Analysis), HCA (Hierarchical Cluster Analysis), and DFA (Discriminant Factor Analysis) were performed to identify homogeneous groups among accessions based on the variables and determine the discriminating parameters. All these analyses were performed using two software programs: Statistica version 7.1 and R [24].

## 3. Results

### 3.1. Variability Among Collected Accessions of Edible Tiger Nut

The results of the descriptive statistical analysis show that edible tiger nut accessions are highly diverse across Côte d'Ivoire. They vary from one growing area to another and within the same growing area. The results of the coefficient of variation show that the parameters are organized into two groups. Group 1, which has the smallest number of samples (06), has low coefficients of variation ( $CV < 30\%$ ). This group includes root length (14.32%), plant length (15.53%), number of leaves on the mother plant (16.49%), tuber length (21.08%), number of last leaves (26.42%), and tuber width (27.69%). Group 2, which has the largest number of parameters (15), has very high coefficients of variation ( $CV > 30\%$ ). It consists of the mass of 100 tubers (32.60%), the total number of leaves (32.92%), the distance between the mother plant and the tillers (36.92%), the number of dry leaves (38.63%), the number of partially yellow leaves (39.25%), the number of yellow leaves (41.61%), root biomass (44.29%), the number of mature tubers (44.40%), leaf biomass (44.79%), yield (57.22%), tuber mass per clump (57.28%) and collar diameter (64.56%), number of spikelets (77.51%) and floral branching (81.42%). The coefficient of variation for certain characteristics therefore varies very little, whereas a high degree of variation is observed for others. The very large differences between the minimum and maximum values confirm this high degree of diversity (Table 2).

**Table 2.** Results of the descriptive statistical analysis of the agronomic and morphological parameters of edible tigernut.

| Parameters | Average | Median | Minimum | Maximum | SD    | CV (%) |
|------------|---------|--------|---------|---------|-------|--------|
| NFS        | 76,23   | 70,50  | 20,00   | 218,00  | 29,45 | 38,63  |
| NFJ        | 42,34   | 39,00  | 8,00    | 110,00  | 17,62 | 41,61  |
| NFPJ       | 41,45   | 40,00  | 4,00    | 96,00   | 16,27 | 39,25  |
| NTF        | 159,58  | 153,00 | 11,00   | 371,00  | 52,59 | 32,96  |
| NTAL       | 18,10   | 16,00  | 3,00    | 60,00   | 8,57  | 47,35  |
| NFPM       | 16,69   | 16,00  | 9,00    | 32,00   | 2,75  | 16,49  |
| RAFLO      | 1,71    | 0,00   | 0,00    | 20,00   | 3,94  | 81,42  |
| NEPI       | 32,27   | 0,00   | 0,00    | 398,00  | 73,42 | 77,51  |

| Parameters | Average | Median | Minimum | Maximum | SD    | CV (%) |
|------------|---------|--------|---------|---------|-------|--------|
| NDF        | 4,44    | 4,00   | 4,00    | 12,00   | 1,17  | 26,42  |
| LPLT       | 85,68   | 85,00  | 40,00   | 131,00  | 13,30 | 15,53  |
| DIACO      | 1,17    | 1,00   | 0,40    | 14,00   | 0,75  | 64,56  |
| DISP       | 9,72    | 10,00  | 4,00    | 82,00   | 3,59  | 36,92  |
| LORA       | 61,03   | 62,00  | 11,00   | 93,00   | 8,74  | 14,32  |
| NTM        | 74,33   | 67,00  | 28,00   | 265,00  | 33,00 | 44,40  |
| LOT        | 2,36    | 2,38   | 1,10    | 4,38    | 0,50  | 21,08  |
| LAT        | 1,40    | 1,41   | 0,81    | 11,31   | 0,39  | 27,69  |
| MTP        | 51,79   | 44,25  | 10,06   | 176,27  | 29,67 | 57,28  |
| BIOFO      | 29,32   | 26,13  | 8,63    | 97,76   | 13,14 | 44,79  |
| BIORA      | 10,75   | 9,88   | 2,50    | 69,23   | 4,75  | 44,22  |
| RED        | 18,29   | 15,64  | 3,56    | 62,37   | 10,47 | 57,22  |
| M100       | 68,90   | 67,35  | 20,38   | 151,54  | 22,46 | 32,60  |

NFS: Number of dry leaves; NFJ: Number of yellow leaves; NFPJ: Number of partially yellow leaves; NTF: Total number of leaves; NTAL: Number of tillers; NFPM: Number of leaves of the mother plant; RAFLO: Number of flowering branches; NEPI: Number of spikelets; NDF: Number of last leaves; LPLT: Plant height; DIACO: Collar diameter; DISP: Distance between mother plant and tillers; LORA: Root length; NTM: Number of mature tubers; LOT: Tuber length; LAT: Tuber width; MTP: Tuber mass per planting hole; BIOFO: Leaf biomass; BIORA: Root biomass; RED: Yield per hectare; M100: Mass of 100 tubers; SD: Standard deviation; CV: Coefficient of variation

### 3.2. Correlation of Variables

The degree of association between the different variables studied was estimated using Pearson's correlation coefficient  $r$ . Some strong correlations were observed between the variables measured (Table 3). It was noted that most of the correlation coefficients were weak. Only 28 pairs showed positive and strong values. These pairs are: NTF-NFS (0.76); NTAL-NFS (0.77); NTF-NTAL (0.90); DIACO-NTAL (0.70); RAFLO-NEPI (0.99); RAFLO-NDF (0.97); NEPI-NDF (0.99); LPLT-NTM (0.71); LPLT-BIOFO (0.83); NTM-BIOFO (0.78); BIOFO-NTAL (0.76); BIORA-NTAL (0.76); NTF-BIORA (0.70); BIORA-MTP (0.79); LAT-DISP (0.70); MTP-NPFJ (0.76); MTP-NTM (0.74); MTP-LOT (0.76); BIOFO-DIACO (0.70); RED-NPFJ (0.76); RED-NTM (0.74); RED-MTP (1); NTM-M100 (0.76); RED-LAT (0.77); M100-LOT (0.80); M100-LAT (0.78) and M100-RED (0.78). This means that there is a correlation between these variables. Thus, the higher the number of shoots (NTAL), the higher the total number of leaves (NTF) and dry leaves (NFS), as well as the leaf biomass (BIOFO) and root biomass (BIORA). The diameter at breast height (DIBAH) varies according to the number of shoots (NTAL) and leaf biomass. In fact, the higher the diameter at breast height, the greater the number of shoots and leaf biomass. The number of spikelets (NEPI) and last spikelets (NDF) are also linked to the number of floral branches (RAFLO). In addition, the greater the number of floral branches (RAFLO),

the greater the number of final leaves (NDF) and spikelets (NEPI). Leaf biomass (BIOFO) and the number of mature tubers (NTM) change together depending on the length of the nutgrass plants (LPLT). Consequently, leaf biomass (BIOFO) and the number of mature tubers (NTM) are significant when the length of the nutgrass plants (LPLT) is high. The greater the leaf biomass (BIOFO), the higher the number of mature tubers (NTM). Root biomass (BIORA), total number of leaves (NTF), and mature tuber mass (MTP) are also related. The total number of leaves influences root biomass formation and tuber mass. The distance between the mother plant and the suckers influences tuber width (LAT). When the distance between the mother plant and the suckers is large, the tubers are very wide. In addition, the mass of tubers per clump (MTPC) varies according to the number of young partial leaves (NPYL), the number of mature tubers (NMT) and the length of the tubers (LOT). Consequently, the Slow yellowing of many leaves promotes an increase in the size, number, and mass of tubers. The number of partially yellow leaves (NFPY), the number of mature tubers (NMT), the mass of tubers per clump (MTPC), the width of tubers (LAT), the mass of 100 tubers (M100), and the yield (RED) are closely related. The higher the number of leaves that yellow slowly, the higher the number, diameter, mass of tubers, and yield. Finally, tuber length (LOT), tuber width (LAT), weight of 100 tubers (M100), and yield (RED) are also related. Indeed, tuber length, width, and weight have a positive influence on yield (Table 3).

**Table 3.** Correlation matrix between the twenty-one variables measured in twenty-seven accessions of tiger nut at the Bouafle site.

| Characters | NFS   | NFJ   | NFPJ  | NTF  | NTAL  | NFPM  | RAFLO | NEPI  | NDF  | LPLT |
|------------|-------|-------|-------|------|-------|-------|-------|-------|------|------|
| NFS        | 1     |       |       |      |       |       |       |       |      |      |
| NFJ        | 0,26  | 1     |       |      |       |       |       |       |      |      |
| NFPJ       | -0,14 | 0,05  | 1     |      |       |       |       |       |      |      |
| NTF        | 0,75  | 0,67  | 0,37  | 1    |       |       |       |       |      |      |
| NTAL       | 0,77  | 0,62  | 0,27  | 0,9  | 1     |       |       |       |      |      |
| NFPM       | 0,35  | -0,05 | -0,21 | 0,1  | 0,11  | 1     |       |       |      |      |
| RAFLO      | -0,39 | -0,41 | 0,04  | -0,4 | -0,44 | -0,28 | 1     |       |      |      |
| NEPI       | -0,39 | -0,44 | 0,05  | -0,5 | -0,46 | -0,24 | 0,99  | 1     |      |      |
| NDF        | -0,31 | -0,48 | -0,08 | -0,5 | -0,47 | -0,22 | 0,97  | 0,98  | 1    |      |
| LPLT       | 0,23  | 0,06  | 0,38  | 0,4  | 0,48  | 0,27  | -0,12 | -0,13 | -0,2 | 1    |
| DIACO      | 0,42  | 0,51  | 0,18  | 0,6  | 0,7   | 0,24  | -0,37 | -0,4  | -0,4 | 0,59 |
| DISP       | 0,17  | -0,27 | -0,06 | -0   | 0,04  | 0,03  | 0,16  | 0,15  | 0,16 | 0,26 |
| LORA       | -0,38 | -0,57 | 0,49  | -0,3 | -0,28 | 0,1   | 0,16  | 0,19  | 0,13 | 0,42 |
| NTM        | 0,37  | 0,26  | 0,51  | 0,6  | 0,64  | 0,22  | -0,24 | -0,25 | -0,3 | 0,71 |
| LOT        | -0,35 | -0,56 | 0,44  | -0,3 | -0,37 | -0,08 | 0,52  | 0,54  | 0,5  | 0,17 |
| LAT        | -0,24 | -0,43 | 0,58  | -0,1 | -0,08 | -0,12 | 0,07  | 0,09  | 0,03 | 0,48 |
| MTP        | 0,04  | -0,1  | 0,76  | 0,3  | 0,28  | 0,07  | 0,05  | 0,06  | -0   | 0,65 |
| BIOFO      | 0,52  | 0,32  | 0,39  | 0,7  | 0,76  | 0,31  | -0,24 | -0,25 | -0,3 | 0,83 |
| BIORA      | 0,54  | 0,42  | 0,37  | 0,7  | 0,75  | 0,34  | -0,3  | -0,3  | -0,3 | 0,52 |
| RED        | 0,05  | -0,1  | 0,76  | 0,3  | 0,28  | 0,07  | 0,05  | 0,05  | -0   | 0,65 |
| M100       | -0,29 | -0,38 | 0,68  | -0,1 | -0,16 | -0,19 | 0,35  | 0,37  | 0,29 | 0,35 |

| Characters | DIACO | DISP | LORA | NTM | LOT | LAT | MTP | BIOFO | BIORA | RED | M100 |
|------------|-------|------|------|-----|-----|-----|-----|-------|-------|-----|------|
| NFS        |       |      |      |     |     |     |     |       |       |     |      |
| NFJ        |       |      |      |     |     |     |     |       |       |     |      |
| NFPJ       |       |      |      |     |     |     |     |       |       |     |      |
| NTF        |       |      |      |     |     |     |     |       |       |     |      |
| NTAL       |       |      |      |     |     |     |     |       |       |     |      |
| NFPM       |       |      |      |     |     |     |     |       |       |     |      |
| RAFLO      |       |      |      |     |     |     |     |       |       |     |      |
| NEPI       |       |      |      |     |     |     |     |       |       |     |      |
| NDF        |       |      |      |     |     |     |     |       |       |     |      |
| LPLT       |       |      |      |     |     |     |     |       |       |     |      |
| DIACO      | 1     |      |      |     |     |     |     |       |       |     |      |
| DISP       | 0,17  | 1    |      |     |     |     |     |       |       |     |      |
| LORA       | -0,04 | 0,21 | 1    |     |     |     |     |       |       |     |      |
| NTM        | 0,48  | 0,27 | 0,14 | 1   |     |     |     |       |       |     |      |

| Characters | DIACO | DISP  | LORA | NTM   | LOT   | LAT   | MTP  | BIOFO | BIORA | RED  | M100 |
|------------|-------|-------|------|-------|-------|-------|------|-------|-------|------|------|
| LOT        | -0,17 | -0,06 | 0,63 | -0,14 | 1     |       |      |       |       |      |      |
| LAT        | 0,13  | 0,23  | 0,7  | 0,41  | 0,48  | 1     |      |       |       |      |      |
| MTP        | 0,29  | 0,15  | 0,45 | 0,74  | 0,42  | 0,76  | 1    |       |       | 1    |      |
| BIOFO      | 0,7   | 0,24  | 0,15 | 0,78  | -0,09 | 0,2   | 0,57 | 1     |       |      |      |
| BIORA      | 0,57  | 0,19  | 0    | 0,66  | -0,22 | -0,02 | 0,33 | 0,79  | 1     |      |      |
| RED        | 0,29  | 0,15  | 0,46 | 0,74  | 0,42  | 0,77  | 1    | 0,57  | 0,33  | 1    |      |
| M100       | 0,01  | 0,09  | 0,59 | 0,21  | 0,76  | 0,8   | 0,78 | 0,12  | -0,13 | 0,78 | 1    |

NFS: Number of dry leaves; NFJ: Number of yellow leaves; NFPJ: Number of partially yellow leaves; NTF: Total number of leaves; NTAL: Number of tillers; NFPM: Number of leaves of the mother plant; RAFLO: Number of flowering branches; NEPI: Number of spikelets; NDF: Number of last leaves; LPLT: Plant height; DIACO: Collar diameter; DISP: Distance between mother plant and tillers; LORA: Root length; NTM: Number of mature tubers; LOT: Tuber length; LAT: Tuber width; MTP: Tuber mass per planting hole; BIOFO: Leaf biomass; BIORA: Root biomass; RED: Yield per hectare; M100: Mass of 100 tubers

### 3.3. Genetic Structures

#### 3.3.1. Contribution of Characters to the Structuring of the Two Main Axes of PCA

The matrix of eigenvalues and percentages of variation are explained by the first principal components of PCA and the correlation coefficients of the 21 characteristics analyzed for 27 accessions of edible tiger nut. The first component accounts for 34.90% of the variability. It is defined by the total number of leaves (NTF), the number of shoots (NTAL), the length of mature plants (LPLT), the diameter at the collar (DIACO), the number of mature tubers (NTM), the leaf biomass (BIOFO), and the root biomass (BIORA). These seven (07) parameters are negatively correlated with axis 1. This axis indicates that an increase in the number of mature tubers (NTM)

is favored by a high number of tillers (NTAL), total number of leaves (NTF), and collar diameter (DIACO), as well as a large amount of leaf and root biomass. Axis 2, which expresses only 25.38% of the variability, is defined by root length (LORA), tuber length (LOT), tuber width (LAT), tuber mass per clump (MTP), mass of 100 tubers (M100), and yield (RED). Root length (LORA), tuber width (LAT) and tuber mass per cluster (MTP) are negatively correlated with axis 2, while tuber length (LOT), mass of 100 tubers (M100) and yield (RED) are positively correlated with axis 2. These latter traits contribute significantly to the formation of axis 2. This axis indicates that tuber weight is favored by long roots (LORA) and wide tubers (LAT). In addition, increased yield (RED) is favored when tuber length (LOT) and 100-tuber weight (M100) are high (Table 4).

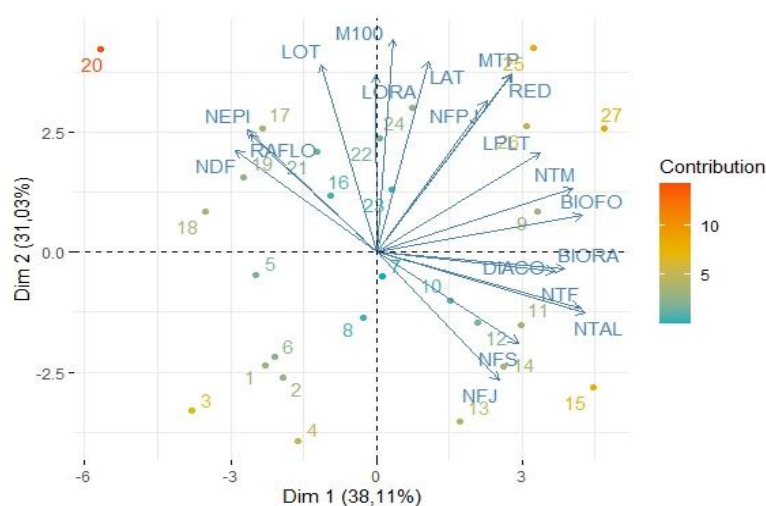
**Table 4.** Eigenvalues and percentage of variation explained by the PCA axes for 21 traits in 27 edible tiger nut accessions.

| Principal Component           | Axis 1 | Axis 2 |
|-------------------------------|--------|--------|
| Eigenvalue                    | 7.33   | 5.94   |
| Total variance (%)            | 34.90  | 28.29  |
| Cumulative variance           | 7.33   | 13.27  |
| Cumulative total variance (%) | 34.90  | 63.19  |
| NTF                           | -0.85* | -0.23  |
| NFS                           | -0.61  | -0.38  |
| NFJ                           | 0.50   | 0.55   |
| NFPJ                          | -0.45  | 0.65   |
| RAFLO                         | 0.54   | -0.51  |
| NEPI                          | 0.55   | 0.53   |

| Principal Component | Axis 1 | Axis 2 |
|---------------------|--------|--------|
| NDF                 | 0.60   | -0.44  |
| NPFM                | -0.30  | -0.13  |
| NTAL                | -0.88* | -0.25  |
| LPLT                | -0.70* | 0.43   |
| DIACO               | -0.76* | -0.08  |
| DISP                | -0.13  | 0.22   |
| NTM                 | -0.83* | 0.28   |
| BIOFO               | -0.88* | 0.16   |
| BIORA               | -0.81  | -0.07  |
| LORA                | -0.006 | -0.76* |
| LOT                 | 0.24   | 0.79   |
| LAT                 | -0.22  | -0.82* |
| MTP                 | -0.57  | -0.76* |
| RED                 | -0.57  | 0.76*  |
| M100                | -0.07  | 0.91*  |

NFS: Number of dry leaves; NFPJ: Number of partially yellow leaves; NTF: Total number of leaves; NTAL: Number of tillers; RAFLO: Number of floral branches; NEPI: Number of spikelets; NDF: Number of last leaves; LPLT: Length of mature plants; DIACO: Collar diameter; NFJ: Number of yellow leaves; NPFM: Number of leaves on the mother plant; DISP: Distance between mother plant and tillers; LORA: Root length; NTM: Number of mature tubers; LAT: Width of mature tubers; MTP: Tuber mass per clump; BIOFO: Leaf biomass; BIORA: Root biomass; RED: Yield; M100: Mass of 100 tubers. (Significant values): variables that contribute the most to the formation of the axes.

### 3.3.2. Characterization of Accessions by Region Based on Measured Variables



**Figure 2.** Distribution of the collected accessions based on the measured variables.

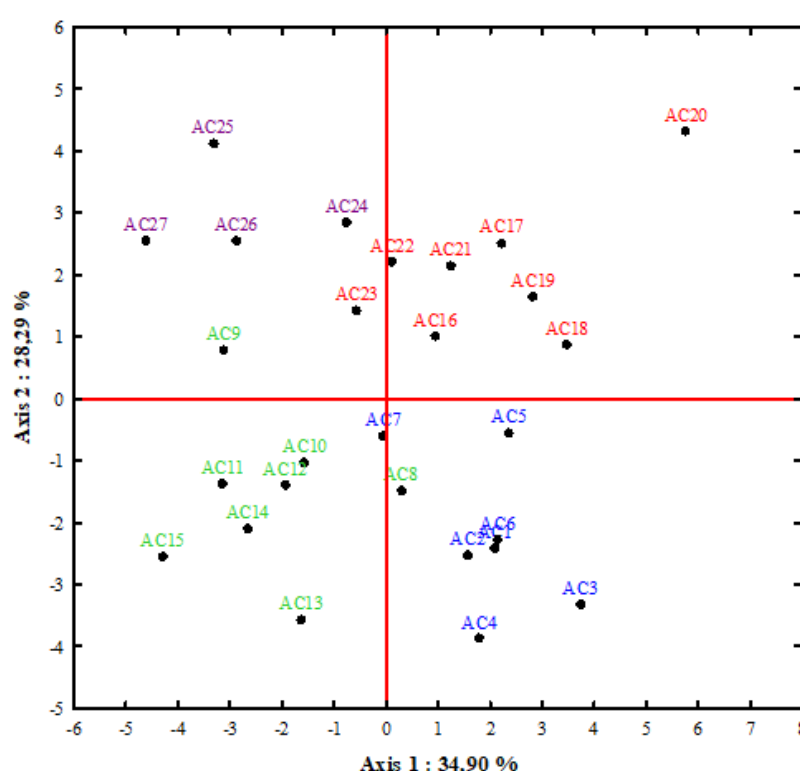
NFS: Number of dry leaves; NFJ: Number of yellow leaves; NFPJ: Number of partially yellow leaves; NTF: Total number of leaves; NTAL: Number of tillers; NPFM: Number of mother plant leaves; RAFLO: Number of floral branches; NEPI: Number of spikelets; NDF: Number of lower leaves; LPLT: Plant length; DIACO: Collar diameter; DISP: Distance between mother plant and tillers; LORA: Root length; NTM: Number of mature tubers; LOT: Tuber length; LAT: Tuber width; MTP: Tuber mass per hill; BIOFO: Leaf biomass; BIORA: Root biomass; RED: Yield per hectare; M100: Mass of 100 tubers.

The different accessions of edible tiger nuts collected in four locations in Côte d'Ivoire, namely Doropo, Korhogo, Dabakala, and Sinementiali, were grouped according to variables measured in the field (Figure 2). The accessions (AC24, AC25, AC26, and AC27) from the first locality (Doropo) are grouped around the variables LORA, LAT, NFPI, MTP, RED, LPLT, and NTM. They are characterized by production and yield parameters. For the second city (Korhogo), the accessions (AC8, AC9, AC10, AC11, AC12, AC13, AC14, and AC15) are identified through the parameters: DIACO, BIORA, NTF, NFS, NTAL, NFJ, and BIOFO. The Dabakala accessions (AC16, AC17, AC18, AC19, AC20, AC21, AC22, and AC23) were structured according to the variables NEPI, NDF,

RAFLO, LOT, and M100. The last locality, i.e., the Sinementiali accessions (AC1, AC2, AC3, AC4, AC5, AC6, and AC7), are based on parameters from both the Dabakala and Korhogo accessions. The accessions from these last three localities are distinguished by their vegetative parameters (Figure 2).

### 3.3.3. ACP of Accessions

The Sinementiali accessions (AC1–A7) and the Dabakala accessions (AC16–AC23) are mainly located on axis 1. In contrast, the Korhogo accessions (AC8–AC15) and the Doropo accessions (AC24–AC27) are mainly located on axis 2 (Figure 3).



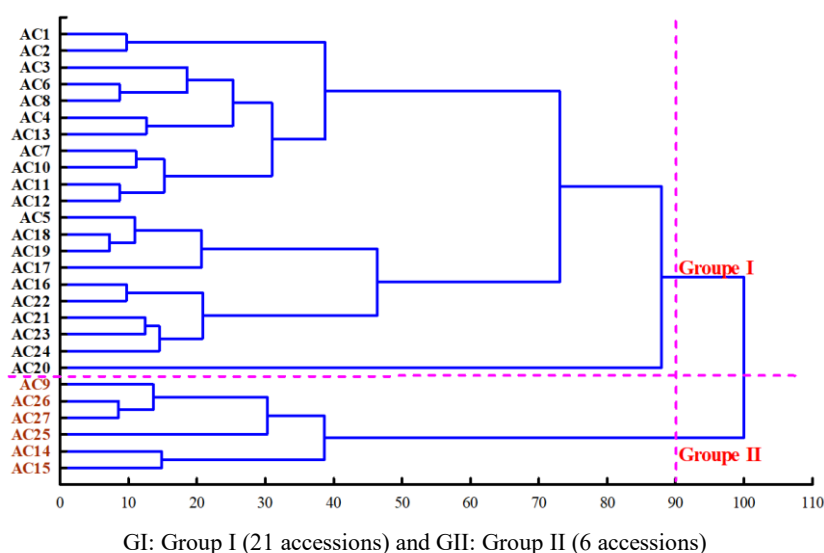
**Figure 3.** Distribution of the 27 edible tiger nut accessions along the PCA axes.

Sinementiali: PCA1-PCA2-PCA3-PCA4-PCA5-PCA6-PCA7  
 Korhogo: AC8-AC9-AC10-AC11-AC12-AC13-AC14-AC15  
 Dabakala: AC16-AC17-AC18-AC19-AC20-AC21-AC22-AC23  
 Doropo: AC24-AC25-AC26-AC27

### 3.3.4. Adjustment of Accession Classification

For the structuring of the 27 accessions of edible Ivory Coast edible nuts, the truncation line was set at 90. The resulting dendrogram showed significant heterogeneity between

them. Two genetic groups were recorded. Group 1 is highly diverse and variable in terms of the number of accessions from the four survey locations. The second group contains an equal number of accessions from Doropo and Korhogo. (Figure 4).



**Figure 4.** Dendrogram of the 27 tiger nut accessions based on Euclidean distances.

### 3.3.5. Characterization of CAH Groups Using Student's T-test

The two groups differed by 90 Euclidean distance units. MANOVA analysis of these groups showed a significant difference ( $F = 6.62$ ;  $p < 0.02$ ). Examination of the data indicated that the two groups differed on the basis of ten (10) characteristics of the 27 accessions analyzed. These characteristics are

the number of dry leaves (NFS), the number of partially yellow leaves (NFPJ), the total number of leaves (NTF), the number of tillers (NTAL), plant length (PLL), number of tubers (NT), tuber mass (TM), leaf biomass (LBB), root biomass (RBB), and yield (Y). Individuals in group I had the lowest values and those in group II had the highest values. Individuals in group II have on average the highest number of dry leaves, partially yellow leaves, tillers, and tubers. They also have on average the largest plants and very high tuber masses, leaf and root biomass, and yields (Table 5).

**Table 5.** Average values of the characteristics used to distinguish the 27 accessions into two clearly differentiated groups.

| Group-CAH     | NFS         | NFPJ       | NTF          | NTAL       | LPLT       |
|---------------|-------------|------------|--------------|------------|------------|
| GroupI (N=21) | 71,07±17,24 | 38,58±9,46 | 144,18±16,55 | 14,81±2,34 | 83,61±9,76 |
| GoupII (N=6)  | 94,29±13,38 | 51,52±8,08 | 185,77±19,04 | 23,71±3,24 | 92,93±8,66 |
| t             | -3,03       | -3,04      | -4,86        | -4,86      | -2,11      |
| p             | 0,006       | 0,005      | < 0,001      | < 0,001    | < 0,045    |

| Group-CAH     | NTM         | MTP         | BIOFO      | BIORA      | RED        |
|---------------|-------------|-------------|------------|------------|------------|
| GroupI (N=21) | 67,60±12,27 | 44,95±14,99 | 26,50±6,74 | 10,01±1,97 | 15,86±5,53 |
| GoupII (N=6)  | 97,86±12,26 | 75,72±18,91 | 39,22±6,52 | 13,32±1,63 | 26,78±1,53 |
| t             | -5,18       | -4,20       | -4,10      | -3,74      | -4,21      |
| p             | < 0,001     | < 0,001     | < 0,001    | < 0,001    | < 0,001    |

N: number of individuals; significant:  $p \leq 0.05$ ; very significant:  $p \leq 0.01$ ; highly significant:  $p \leq 0.001$ ; p: % probability; t: Student's t-test; NFS: number of dry leaves; NFPJ: number of partially yellow leaves; NTF: total number of leaves; NTAL: number of shoots; LPLT: length of mature plants; NTM: number of mature tubers; MTP: mass of tubers per clump; BIOFO: leaf biomass; BIORA: root biomass; RED: yield.

Analysis of the data also showed that eleven characteristics did not allow the 27 accessions to be differentiated. These characteristics are the number of yellow leaves (NFJ), the number of mother plants (NFPM), the number of floral branches (RAFLO), the number of spikelets (NEPI), the number of last leaves (NDF), the diameter at the collar (DIACO),

the distance between the mother plant and the tillers (DISP), the length of the roots (LORA), the length of the tubers (LOT), the width of the tubers (LAT), and the weight of 100 tubers (M100) (Table 6).

**Table 6.** Average values of characteristics that do not allow the 27 accessions to be divided into two clearly differentiated groups.

| Group-CAH     | NFJ         | NFPM       | RAFLO     | NEPI        | NDF       |
|---------------|-------------|------------|-----------|-------------|-----------|
| GroupI (N=21) | 40,77±12,00 | 16,69±0,77 | 1,87±2,44 | 35,21±42,68 | 4,49±0,61 |
| GoupII (N=6)  | 47,86±12,21 | 16,69±0,72 | 1,76±1,53 | 21,97±26,86 | 4,25±0,35 |
| <i>t</i>      | -1,27       | 0,02       | 0,67      | 0,71        | 0,93      |
| <i>p</i>      | 0,22        | 0,99       | 0,51      | 0,48        | 0,36      |

| Group-CAH     | DIACO     | DISP      | LORA       | LOT       | LAT       | M100        |
|---------------|-----------|-----------|------------|-----------|-----------|-------------|
| GroupI (N=21) | 1,13±0,22 | 9,60±0,97 | 61,30±6,72 | 2,38±0,34 | 1,38±5,53 | 66,31±18,06 |
| GoupII (N=6)  | 1,29±0,1  | 10,16±1,1 | 60,10±6,57 | 2,28±0,50 | 1,50±1,12 | 77,98±19,93 |
| <i>t</i>      | -1,73     | -1,22     | 0,39       | 0,55      | -1,31     | -1,37       |
| <i>p</i>      | 0,1       | 0,23      | 0,7        | 0,58      | 0,20      | 0,18        |

N: number of individuals; significant:  $p \leq 0.05$ ; very significant:  $p \leq 0.01$ ; highly significant:  $p \leq 0.001$ ; *p*: % probability; *t*: Student's t-test; NFJ: number of yellow leaves; NFPM: number of leaves on the mother plant; RAFLO: floral branches; NEPI: number of spikelets; NDF: number of last leaves; DIACO: diameter at the collar; DISP: distance between mother plant and tillers; LORA: root length; LOT: tuber length; LAT: tuber width; M100: mass of 100 tubers.

### 3.3.6. Determination of Discriminant Parameters

The discriminant function derived from the variables used to classify the units formed in the different groups was presented. The second function (axis 2) alone has the highest magnitude (1) and accounts for 63.19% of the total variability. It discriminates between the number of mature tubers (NTM) and the total number of leaves (NTF). These are inversely correlated with this axis. Axis 2 allows group II to be classified as a group characterized by individuals with numerous mature tubers (NTM) and numerous leaves (NTF). In contrast, the accessions in group I include individuals with fewer tubers and fewer leaves. The number of mature tubers (NMT) and the total number of leaves are the discriminating parameters for edible tiger nut accessions grown in Côte d'Ivoire (Table 7).

**Table 7.** Percentage of inertia and definition of axes in DFA.

| Axis       | 2    |
|------------|------|
| Eigenvalue | 1.71 |

| Axis                    | 2       |
|-------------------------|---------|
| Prop-Cum                | 1       |
| R                       | 0.79    |
| Wilks' Lambda           | 0.37    |
| Chi <sup>2</sup>        | 23.88   |
| dl                      | 2       |
| p-value                 | < 0.001 |
| Variance explained (%)  | 100     |
| Cumulative variance (%) | 100     |
| NTM                     | -0.70*  |
| NTF                     | -0.62*  |

NTM: Number of mature tubers; NTF: Total number of leaves

## 4. Discussion

The success of any genetic improvement program depends

on a study evaluating the genetic diversity of cultivated species. The results of this study would provide breeders with good starting material or seed [25, 26]. In general, diversity studies rely on phenotypic, biochemical, and molecular markers. The present study on the diversity of *Cyperus esculentus* cultivated in Ivorian farming communities used highly malleable and inexpensive phenotypic markers. The results of statistical tests showed that more than half of the variables analyzed had very high coefficients of variation, i.e.,  $CV > 30\%$ . This trend reflects the existence of genetic diversity among the accessions collected in the surveyed localities. This result could be explained by the way farmers acquire seeds during the growing season for this crop. The lack of an approved structure for the distribution of improved edible nutgrass seeds in Côte d'Ivoire forces farmers to turn to their counterparts in the same village or those in surrounding villages (regions) [5]. This dynamic process therefore promotes the flow of genes that contribute to genetic variability. However, our results corroborate the work of certain authors on edible nutgrass (*Cyperus esculentus* L.) accessions in Burkina Faso [27], Senegal [28], and Ghana [29]. In addition, strong correlations observed between certain vegetative parameters and some production parameters clearly show that the vegetative vigor of edible nutgrass plants inevitably influences the production and yield of this crop. Several production parameters, such as the number of mature tubers (NMT), the mass of tubers per clump (MTP), and the yield (RED), are influenced by vegetative growth. Thus, yield (RED) is influenced by the number of mature tubers (NTM) and tuber mass per clump (MTP), which are closely related to plant length (LPLT) and leaf biomass (BIOFO) and root biomass (BIORA). This study therefore demonstrates the cause-and-effect relationship between vegetative vigor and yield. This result is similar to that of [28], who, working on edible tiger nut ecotypes from several countries (Mali, Burkina Faso, Niger, Benin, and Senegal), found strong correlations between vegetative and yield parameters. Vegetative vigor generally influences the yield of tiger nut ecotypes regardless of their origin. Furthermore, the diversity of edible tiger nut accessions revealed in this study was structured into two large, contrasting genetic groups. The first group is highly heterogeneous with a very broad base involving accessions from the four areas surveyed. This structure is distinguished by vegetative parameters. The second group was structured on the basis of production parameters and consisted of accessions from Doropo and Korhogo. The contrast observed between these two groups could be explained by climatic and pedological causes. Certainly, the plants in each group were strongly influenced by ecological changes in the study environment. Furthermore, several researchers have clearly established that phenotypic markers are conditioned by the environment. Our results, compared to those of other researchers who have worked on the same species, found a higher number of genetic groups, notably five groups in Burkina Faso [27] and seven groups in Ghana [30]. There are several possible explanations for the difference between these results. On the one hand, the

number or size of accessions collected for this study is significantly different from the sample sizes used by other researchers, i.e., 27 accessions compared to 44 and 42 in Burkina Faso and Ghana, respectively. It should be noted that in Côte d'Ivoire, only the variety of edible tiger nut with yellow tubers is cultivated and consumed. Consequently, the current study focused on this group. This is not the case with the two researchers who included black and brown varieties. A third argument would be the definition of the dendrogram truncation line. This value is often left to the discretion of the researcher, who also defines the number of groups of individuals that share the same similarities. Statistically, discriminant factor analysis (DFA) specifies that the two genetic groups formed are justified by the variables, the number of mature tubers and the total number of leaves. These parameters could be accepted as morphological markers for the structuring and expression of agromorphological diversity. These results confirm the observations of [31] on the predominance of vegetative and productive parameters in the variability of cultivated plants. However, they differ from the work of [32] and [29], which favored tuber size, shape, and color as differentiation criteria. These differences illustrate the complementarity of vegetative, productive, and morphological criteria for the overall assessment of edible tiger nut diversity.

## 5. Conclusion

Varietal selection or the introduction of improved seeds for edible tiger nuts in Côte d'Ivoire depends on knowledge of the existing diversity of this useful plant. To this end, a study of the phenotypic diversity of Ivorian *Cyperus esculentus* accessions revealed two genetic groups. The first group is characterized by vegetative parameters and the second by production variables. The existence of these two genetic structures is due to two discriminating variables, namely the number of mature tubers (NMT) and the total number of leaves (TNL). Seed exchanges between producers and ecological factors justified the results obtained in this study. However, further studies, such as the use of molecular markers, are needed to confirm or refute these results.

## Abbreviations

|       |                                      |
|-------|--------------------------------------|
| AC    | Accessions                           |
| NFS   | Number of Dry Leaves                 |
| NFJ   | Number of Yellow Leaves              |
| NFPJ  | Number of Partially Yellow Leaves    |
| NTF   | Total Number of Leaves               |
| NTAL  | Number of Tillers                    |
| NFPM  | Number of Leaves of the Mother Plant |
| RAFLO | Number of Flowering Branches         |
| NEPI  | Number of Spikelets                  |
| NDF   | Number of Last Leaves                |
| LPLT  | Plant Height                         |

|       |                                           |
|-------|-------------------------------------------|
| DIACO | Collar Diameter                           |
| DISP  | Distance Between Mother Plant and Tillers |
| LORA  | Root Length                               |
| NTM   | Number of Mature Tubers                   |
| LOT   | Tuber Length                              |
| LAT   | Tuber Width                               |
| MTP   | Tuber Mass per Planting Hole              |
| BIOFO | Leaf Biomass                              |
| BIORA | Root Biomass                              |
| RED   | Yield per Hectare                         |
| M100  | Mass of 100 Tubers                        |
| SD    | Standard Deviation                        |
| CV    | Coefficient of Variation                  |

## Author Contributions

**Ehui Kirioua Jean-Baptiste:** Conceptualization, Resources, Writing – original draft, data curation, Investigation

**Gore Bi Boh Nestor:** Methodology, supervision, Formal analysis, Writing – review & editing

**Adjahossou Videdji Nasse:** Software

**Dago Lydia Karmelle Ornella:** Visualization

**Yao Kouakou Abessika Georges:** Visualization

**Coulibaly Belehonni François:** Data curation

**Akaffou Doffou Selastique:** Validation, project administration

## Conflicts of Interest

The authors declare no conflicts of interest.

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