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# Agromorphological Characterization of Ginger (*Zingiber officinale* Rosc., Zingiberaceae) Accessions Grown in Côte d'Ivoire

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## Abstract

In Côte d'Ivoire, ginger (*Zingiber officinale* Rosc.), generally used to make a drink called "Gnamankoudji", has become an important source of agricultural income diversification. In order to assess the agromorphological diversity of a ginger collection from different regions of Côte d'Ivoire, a survey collection of accessions was carried out in the different production zones of the country. One hundred and eighty-eight ginger accessions were collected in 15 regions and one autonomous district of Côte d'Ivoire. Analysis of variance revealed that all the variables used in this study discriminated between the ginger accessions collected. Principal component analysis revealed morphological variability of 45.931% for the first two components. Ascending Hierarchical Classification was used to classify these accessions into three groups based on fourteen quantitative characters. These three groups were formed independently of collection areas and are characterized by moderate morphological variability. This variability has been structured into three distinct agromorphological groups, with thallus (rhizome) length and width, finger width, secondary finger length and yield in tons per hectare as distinctive characters. This revealed genetic diversity could be exploited in ginger breeding and improvement programs in Côte d'Ivoire.

## Keywords

Sustainable Management, Plant Genetic Resources, Genetic Diversity, Côte d'Ivoire

## 1. Introduction

The species, *Zingiber officinale* Roscoe, commonly known as ginger, is a tropical plant, a perennial herb that grows in sunny, humid regions [1]. This plant belongs to the Zingiberaceae family, which is native to Southeast Asia [2] and includes approximately 50 genera and more than 1300 species [3] distributed throughout Asia, the Pacific Islands, and Africa [4] [5]. The tuberous roots of ginger are particularly rich in starch (60%), proteins, fats (10%) and oleoresin (4% to 8%) [6]. Compounds such as shogaol, paradol, gingerol, gingerone and zingerone give ginger anti-inflammatory, antioxidant, analgesic, antipyretic, antiemetic, antibacterial and aphrodisiac properties [7] [8] [9]. As a result, ginger is valued not only for its food uses, but also for its medicinal and industrial applications. It is one of the oldest and most widely consumed spices in the world [10], and is used in the manufacture of medicines to treat gastrointestinal (constipation, flatulence), pulmonary (asthma), cancer (breast, colon, ovary…), nervous, dental, inflammatory diseases, and diabetes [11] [12] [13]. This justifies its massive use in food and alternative medicine around the world. As a result, it holds an important place in the cuisine of various communities, where it is used in a variety of ways to add flavor, spice, and depth to dishes. In Côte d'Ivoire, in particular, it is used to make a highly prized drink called "Gnamankoudji", which is widely consumed by the local population [14]. Originally cultivated in forested areas, ginger is now increasingly widespread throughout the country. Ginger rhizomes can be found in every market, stimulating trade between rural and urban areas. In 2021, the price of fresh rhizomes on urban markets was 700 CFA francs (around 1 euro/kg), five times that of cashew nuts currently on Ivorian markets. This species is therefore an important source of agricultural income diversification and the raw material for a category of food industries. In addition, the essential oils extracted supply an important export network between Côte d'Ivoire and Europe [15].

Despite its importance as a food, therapeutic and industrial crop, and despite the fact that it occupies an important place in people's socio-economic activities, ginger cultivation faces a number of factors that limit its development. Underdeveloped and unsustainable farming practices include the use of rudimentary technical itineraries and a preference for industrial crops with improved, profitable varieties, to the detriment of neglected food crops in a country where overcoming poverty remains a real challenge.

In this context, an approach based on the introduction of improved varieties becomes an absolute necessity. Unfortunately, knowledge of this resource is sorely lacking among local breeders or improvers who can propose new varieties, introduce seeds, and meet the needs of local communities. Research into the characterization of biodiversity is of paramount importance. Agromorphological characterization therefore plays a critical role in the study and development of crop genetic resources, as well as in the selection and improvement of crops to meet the agricultural and food needs of populations. As raw material for plant breeding, it is essential that these resources are correctly characterized. Numerous genetic diversity studies have been conducted for ginger management and breeding [16] [17] [18]. However, in Côte d'Ivoire, apart from the work on the genetic diversity of ginger carried out by [15], no study has yet been carried out on the distribution and agronomic characterization of this plant. Therefore, analysis of the genetic diversity of ginger based on agronomic traits is essential for understanding its performance and designing breeding programs [17]. The aim of the present study is therefore to assess the agromorphological diversity of a ginger collection from different regions of Côte d'Ivoire. This revealed genetic diversity could be exploited in ginger breeding and genetic improvement programs.

## 2. Materials and Methods

### 2.1. Study Site

The study was conducted out at the NANGUI ABROGOUA University experimental farm in Abidjan, southern Côte d'Ivoire, between 5˚17' and 5˚31' north latitude and between 3˚45' and 4˚22' west longitude. The region's climate is "Atrean". Vegetation is of the dense tropical forest type. The area is characterized by an average rainfall of around 2000 mm/year, divided into two rainy seasons and two dry seasons. The dry seasons are mild, tempered by the sea breeze. Temperatures in southern Côte d'Ivoire vary little over the year (25˚C and 29˚C). The experimental study site is characterized by a deep sandy-clay soil [19].

### 2.2. Plant Material

The plant material used consisted of rhizomes from 188 ginger accessions collected in 15 administrative regions (Agneby-Tiassa, Goh, Lôh-Djiboua, Nawa, Gontougo, Moronou, Iffou, Haut-Sassandra, Tonkpi, Marahoué, Béré, Bagoué, Poro, Kabadougou and Guémon) and one autonomous district (District of Lacs) of Côte d'Ivoire. These accessions were referenced by codes listed in **Table 1**.

### 2.3. Experimental Design

The characterization tests were carried out on an area of 1867.5 $m^2$, corresponding to the 45 m length and 41.5 m width of the experimental plot. The experimental setup used is a completely randomized block design with three replicates. The 15 cm × 41.5 cm unit plot is made up of 7 lines of 27 ridges (with the exception of the last line, which is made up of 26 ridges), 188 ridges and each ridge bears a ginger accession. After clearing the plot, ridges 1 m wide, 1.5 m long and 30 cm high were made. These ridges were spaced 50 cm apart. Afterwards, the soil was turned over with chicken droppings (5 kg per ridge). The rhizome pieces, 3 to 5 cm long and bearing 1 to 3 buds, were planted in 5 cm deep pots during the rainy season in June 2021. The plots were spaced 30 × 30 cm in rows and between rows. Each plot (each ridge) carried 2 rows of 5 plants. After sowing, the ridges were mulched with dry Panicum maximum grass.

Table 1. Distribution of 188 ginger accessions according to collection area.

| Collection zones | Number of accessions | Accessions |
|---|---|---|
| Agnéby-Tiassa | 6 | G001, G002, G009, G046, G047, MG01 |
| Goh | 1 | G041 |
| Gontougo | 13 | G073, G074, G075, G076, G077, G078, G079, G080, G081, G082, G086, G084, G085 |
| Iffou | 7 | G062, G063, G064, G065, G067, G068, G069 |
| Lôh-Djiboua | 12 | G045, G007, G008, G011, G012, G013, G015, G017, G018, G019, G042, G043 |
| Moronou | 12 | G048, G049, G050, G051, G052, G053, G057, G058, G059, G070, G072, G089 |
| Nawa | 17 | G022, G024, G026, G027, G028, G032, G033, G034, G036, G037, G038, G039, G040, G044, G021, G025, G035 |
| Haut-Sassandra | 18 | GK1, GK2, GK3, GK4, GK5 GK6, GK31, GK35, GK38, GK39, GK58, GK81, GK83, GK90, GK94, GK121, GK130, GK134 |
| Tonkpi | 8 | GK16, GK19, GK20, GK21, GK32, GK33, GK46, GK128 |
| Marahoué | 24 | GK34, GK37, GK44, GK45, GK47, GK49, GK50, GK52, GK59, GK65, GK66, GK69, GK71, GK74, GK75, GK93, GK99, GK100, GK102, GK105, GK126, GK127, GK129, GK125 |
| Béré | 21 | GK41, GK51, GK55, GK56, GK57, GK61, GK63, GK64, GK70, GK73, GK84, GK86, GK98, GK101, GK104, GK132, GK117, GK118, GK120, GK18, GK138 |
| Bagoué | 5 | GK109, GK112, GK124, GK135, GK91 |
| Poro | 13 | GK48, GK72, GK76, GK78, GK79, GK80, GK95, GK96, GK133, GK107, GK108, GK110, GK111 |
| Kabadougou | 10 | GK53, GK60, GK67, GK68, GK92, GK97, GK113, GK114, GK115, GK116 |
| Guémon | 10 | GK11, GK14, GK15, GK30, GK36, GK43, GK62, GK87, GK89, GK123 |
| District of Lacs | 11 | GK40, GK77, GK82, GK85, GK88, GK106, GK119, GK122, GK131, GK137, GK138 |

## 2.4. Data Collection and Analysis

### 2.4.1. Data Collection

We examined eighteen quantitative descriptors (Table 2) from the list of descriptors used by [16] [17] [20] to assess the agromorphological diversity of 188 ginger accessions in the collection.

### 2.4.2. Data Analysis

The data collected were subjected to several analyses. First, univariate analysis of variance was used. The ANOVA using individual characters highlighted the discriminating characteristics of the ginger accessions. Multivariate analyses were

Table 2. List of quantitative variables used to characterize 188 ginger accessions.

| Quantitative variables | Codes | Methods |
|---|---|---|
| Mean germination time (days) | **GeTi** | Notation of rhizome germination date at two-day intervals |
| **Data taken at 5ème months of maximum growth** | | |
| Number of leaves per plant | **NuLe** | Counting the number of leaves on a plant |
| Plant height (cm) | **PlHe** | Height from ground surface to V formed by last two leaves |
| Leaf length (cm) | **LeLe** | Measured from leaf tip to leaf base |
| Leaf width (cm) | **LeWi** | Measurement made at point of maximum width |
| Diameter at collar (mm) | **DiCo** | Measurement taken at the base of the stem |
| Number of rejet per plant | **NuRe** | Count all daughter plants that have emerged from the soil, |
| **After harvesting** | | |
| Length of thallus or rhizome (cm) | **LeTh** | Measurement taken from the tip of the rhizome to the base of the rhizome after harvesting. |
| Thallus or rhizome width (cm) | **ThWi** | Measured at the point of maximum rhizome width |
| Thallus or rhizome thickness (mm) | **ThTh** | Measurement taken at the thickest point of the rhizome |
| Rhizome finger length (cm) | **FiLe** | Measured from attachment point to base of rhizome |
| Rhizome finger width (cm) | **FiWi** | Measured at the point of maximum finger width |
| Rhizome finger thickness (mm) | **FiTh** | Measurement taken at the thickest point of the fingers |
| Length of secondary rhizome fingers (cm) | **LsFi** | Measured from point of attachment to base of rhizome |
| Yield (t/ha) | **Yild** | Rhizome mass gain |
| Yield per plant (g) | **YiPl** | Mass measurement of rhizomes from each harvested plant |
| Number of ramifications | **NuRa** | Counting the number of branches from the finger insertion point |
| Number of nodes | **NuNo** | Counting the number of knots per finger |

then performed. Principal component analysis (PCA) was used to identify the variables that contributed most to the formation of the axes or components. PCA was preceded by Pearson's correlation. This was used to assess the relationship between variables taken in pairs. Individual groupings were then obtained by hierarchical ascending classification (HAC) using the most discriminating variables. HAC was based on the Euclidean distance model according to [21] aggregation criterion. Finally, a discriminant factor analysis (DFA) was carried out to determine the most discriminating traits and give the characteristics of the groups obtained by CAH. All analyses were performed using XLSTAT 2019 version 21.2.59614 statistical analysis software.

## 3. Results

### 3.1. Comparative Study of Accessions Using Analysis of Variance (ANOVA)

Analyses of variance indicate the traits that differentiate accessions. ANOVA results are presented in Table 3. The ANOVA using individual characters enabled us to highlight the characters that discriminate between ginger accessions. Thus, all the variables used in this study were able to discriminate the ginger accessions collected.

### 3.2. Analysis of Correlations between Quantitative Variables

The correlation matrix for the various traits analyzed is reported in Table 4.

**Table 3.** Minimum, maximum, mean and standard deviation values of quantitative characters analyzed for 188 ginger accessions collected in Côte d'Ivoire.

| Variables | Minimum | Maximum | Mean ± standard deviation | F | p |
|---|---|---|---|---|---|
| GeTi | 9.00 | 22.75 | 14.45 ± 2.51 | 1.97 | <0.001 |
| NuRe | 4.00 | 58.33 | 19.98 ± 6.61 | 4.95 | <0.001 |
| NuLe | 19.00 | 28.67 | 22.80 ± 1.60 | 2.7 | <0.001 |
| PlHe | 31.00 | 72.00 | 49.36 ± 7.21 | 4.71 | <0.001 |
| LeWi | 1.88 | 3.16 | 2.49 ± 0.22 | 4.4 | <0.001 |
| LeLe | 14.04 | 24.11 | 19.14 ± 1.79 | 4.4 | <0.001 |
| DiCo | 5.20 | 10.66 | 7.77 ± 0.99 | 1.57 | <0.001 |
| LeTh | 9.00 | 29.4 | 19.59 ± 2.77 | 1.44 | <0.001 |
| ThWi | 6.00 | 15.65 | 9.54 ± 1.81 | 1.59 | <0.001 |
| ThTh | 14.36 | 78.15 | 39.14 ± 9.91 | 1.52 | <0.001 |
| NuRa | 2.00 | 4.00 | 2.91 ± 0.34 | 1.36 | <0.001 |
| FiLe | 6.5. | 36.93 | 10.79 ± 2.42 | 1.40 | 0.005 |
| FiTh | 3.25 | 8.00 | 5.71 ± 0.99 | 1.37 | 0.003 |
| FiWi | 14.6 | 35.44 | 20.72 ± 3.16 | 1.58 | 0.004 |
| LsFi | 4.35 | 11.25 | 7.82 ± 1.23 | 1.43 | <0.001 |
| NuNo | 3.25 | 5.50 | 4.22 ± 0.38 | 1.57 | <0.001 |
| Yild | 7.82 | 27.67 | 15.54 ± 3.76 | 2.35 | <0.001 |
| YiPl | 117.33 | 947.50 | 236.12 ± 75.85 | 48.72 | <0.001 |

**GeTi**: Mean germination time; **NuLe**: Number of leaves per plant; **PlHe**: Plant height; **LeLe**: Leaf length; **LeWi**: Leaf width; **DiCo**: Diameter at collar; **NuRe**: Number of rejet per plant; **ThLe**: Length of thallus or rhizome; **ThWi**: Thallus or rhizome width; **ThTh**: Thallus or rhizome thickness; **FiLe**: Rhizome finger length; **FiWi**: Rhizome finger width; **FiTh**: Rhizome finger thickness; **LsFi**: Length of secondary rhizome fingers; **Yild**: Yield in tonnes per hectare; **YiPl**: Yield per plant; **NuRa**: Number of ramifications; **NuNo**: Number of nodes.

**Table 4.** Correlation matrix between quantitative variables for 188 ginger accessions in Côte d'Ivoire.

| Variables | GeTi | NuRe | NuLe | PlHe | LeWi | LeLe | DiCo | LeTh | ThWi | ThTh | NuRa | FiLe | FiWi | FiTh | LsFi | NuNo | Yild | YiPl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GeTi** | 1 | | | | | | | | | | | | | | | | | |
| **NuRe** | 0.03 | 1 | | | | | | | | | | | | | | | | |
| **NuLe** | 0.01 | 0.13 | 1 | | | | | | | | | | | | | | | |
| **PlHe** | −0.04 | 0.03 | **0.72** | 1 | | | | | | | | | | | | | | |
| **LeWi** | −0.08 | −0.15 | 0.48 | 0.63 | 1 | | | | | | | | | | | | | |
| **LeLe** | 0.01 | −0.01 | 0.58 | **0.74** | **0.83** | 1 | | | | | | | | | | | | |
| **DiCo** | −0.08 | −0.07 | 0.55 | 0.62 | 0.51 | 0.57 | 1 | | | | | | | | | | | |
| **LeTh** | 0.10 | 0.04 | 0.23 | 0.26 | 0.21 | 0.29 | 0.27 | 1 | | | | | | | | | | |
| **ThWi** | 0.04 | 0.12 | 0.23 | 0.31 | 0.26 | 0.30 | 0.24 | 0.42 | 1 | | | | | | | | | |
| **ThTh** | −0.16 | 0.06 | 0.32 | 0.28 | 0.27 | 0.29 | 0.35 | 0.44 | 0.43 | 1 | | | | | | | | |
| **NuRa** | −0.06 | 0.09 | 0.02 | 0.06 | 0.07 | 0.02 | 0.01 | 0.15 | 0.12 | 0.14 | 1 | | | | | | | |
| **FiLe** | 0.11 | 0.09 | 0.29 | 0.29 | 0.27 | 0.32 | 0.31 | 0.62 | 0.47 | 0.42 | 0.20 | 1 | | | | | | |
| **FiWi** | 0.14 | 0.08 | 0.21 | 0.22 | 0.20 | 0.26 | 0.19 | 0.50 | 0.52 | 0.32 | 0.01 | 0.55 | 1 | | | | | |
| **FiTh** | 0.01 | −0.06 | 0.25 | 0.25 | 0.29 | 0.31 | 0.34 | 0.36 | 0.28 | 0.56 | −0.05 | 0.39 | 0.26 | 1 | | | | |
| **LsFi** | 0.08 | 0.09 | 0.40 | 0.35 | 0.29 | 0.37 | 0.25 | 0.59 | 0.55 | 0.55 | 0.15 | **0.71** | 0.56 | 0.36 | 1 | | | |
| **NuNo** | 0.13 | 0.19 | 0.23 | 0.19 | 0.14 | 0.26 | 0.26 | 0.59 | 0.38 | 0.41 | 0.2 | 0.66 | 0.39 | 0.34 | 0.59 | 1 | | |
| **Yild** | 0.04 | 0.40 | 0.46 | 0.52 | 0.32 | 0.45 | 0.41 | 0.42 | 0.31 | 0.36 | 0.17 | 0.41 | 0.30 | 0.22 | 0.39 | 41 | 1 | |
| **YiPl** | 0.04 | 0.40 | 0.45 | 0.52 | 0.33 | 0.46 | 0.40 | 0.39 | 0.32 | 0.37 | 0.17 | 0.4 | 0.30 | 0.20 | 0.39 | 0.41 | **0.98** | 1 |

**GeTi**: Mean germination time; **NuLe**: Number of leaves per plant; **PlHe**: Plant height; **LeLe**: Leaf length; **LeWi**: Leaf width; **DiCo**: Diameter at collar; **NuRe**: Number of rejet per plant; **ThLe**: Length of thallus or rhizome; **ThWi**: Thallus or rhizome width; **ThTh**: Thallus or rhizome thickness; **FiLe**: Rhizome finger length; **FiWi**: Rhizome finger width; **FiTh**: Rhizome finger thickness; **LsFi**: Length of secondary rhizome fingers; **Yild**: Yield in tonnes per hectare; **YiPl**: Yield per plant; **NuRa**: Number of ramifications; **NuNo**: Number of nodes.

Pearson's correlation was significant (≥0.70) and positive for five pairs of variables. Pearson's correlation was significant (≥0.70) and positive for five pairs of variables. Plant height (PlHe) was significantly correlated with the number of leaves (NuLe) per plant ($p < 0.0001$; $r = 0.72$) and leaf length (LeLe) ($p < 0.0001$; $r = 0.74$). Correlation analysis also showed a positive and significant relationship between leaf length (LoFe) and leaf width (LeWi) ($p < 0.0001$; $r = 0.83$), and between rhizome finger length (FiLe) and rhizome secondary finger length (LsFi) ($p < 0.0001$; $r = 0.71$). A significant positive correlation was also observed between yield per plant (YiPl) and yield in tons per hectare (Yild) ($p < 0.0001$; $r = 0.98$). In the pairs of variables listed, one of the variables in each pair was eliminated to avoid redundancy in the subsequent analyses. Thus, the variables number of leaves per plant, leaf length, rhizome finger length and yield per plant were eliminated. The remaining variables were used for further analysis.

## 3.3. Principal Component Analysis (PCA)

The results of the Principal Component Analysis variability plot are shown in Table 5. The first four components with eigenvalues greater than 1 were selected

Table 5. Eigenvalue matrix and correlations between variables and PCA principal components for the 188 ginger accessions collected.

| | Components | | | |
|---|---|---|---|---|
| **Variables** | F1 | F2 | F3 | F4 |
| **GeTi** | 0.047 | −0.393 | 0.1 | **−0.642** |
| **NuRe** | 0.23 | −0.322 | **0.73** | −0.133 |
| **PlHe** | 0.607 | **0.619** | 0.219 | −0.119 |
| **LeWi** | 0.525 | **0.645** | 0.043 | −0.002 |
| **DiCo** | 0.577 | **0.603** | 0.002 | −0.175 |
| **ThLe** | **0.662** | −0.303 | −0.136 | 0.059 |
| **ThWi** | **0.681** | −0.142 | −0.131 | 0.122 |
| **ThTh** | **0.672** | −0.042 | −0.263 | 0.136 |
| **NuRa** | 0.205 | −0.095 | 0.306 | **0.741** |
| **FiWi** | **0.631** | −0.319 | −0.192 | −0.11 |
| **FiTh** | **0.58** | 0.055 | −0.346 | −0.132 |
| **LsFi** | **0.788** | −0.255 | −0.175 | 0.017 |
| **NuNo** | **0.658** | −0.369 | 0.075 | 0.087 |
| **Yild** | **0.643** | 0.02 | 0.582 | −0.086 |
| **Eigenvalue** | **4.634** | **1.796** | **1.322** | **1.105** |
| **Variability (%)** | **33.103** | **12.828** | **9.446** | **7.896** |
| **Cumulative** | **33.103** | **45.931** | **55.377** | **63.273** |

for analysis [22]. They explain the variability within the 188 ginger accessions. The eigenvalue matrix showed that all 14 descriptors contributed significantly (threshold 0.5) to the formation of the first four components. The cumulative variance values of the first four principal components (F1, F2, F3, and F4) for the 14 quantitative traits are 63.273%. The F1 and F2 principal components contribute 33.103% and 12.828%, respectively, to the total variability. The main component (F1) is positively correlated with the variables length (ThLe), width (ThWi) and thickness (ThTh) of thalli, width (FiWi) and thickness (FiTh) of fingers, length of secondary fingers of rhizomes (LsFi), number of nodes (NuNo) and yield in tons per hectare (Yild) of ginger rhizomes. Component (F2) is positively correlated with leaf width (LeWi), height (PiHe) and crown diameter (DiCo) of the main plant. Component (F3) is also positively correlated with the variable number of rejections (NuRe) per plant. Finally, component (F4) is positively correlated with the variable number ramifications (NuRa) and negatively correlated with the mean germination time (GeTi) of rhizomes. The F1 main component therefore describes rhizome-related parameters, while the F2 axis highlights growth-related parameters. The F3 and F4 components provide complementary information to the F1 and F2 components. Principal component analysis revealed variability among ginger accessions grown in Côte d'Ivoire.

### 3.4. Grouping Accessions According to Classification Criteria

CAH was used to group the accessions in the collection into relatively homogeneous groups on the basis of their similarities. The CAH dendrogram is truncated at inertia level 178.42 (**Figure 1**). Typological analysis based on Euclidean distance-weighted means revealed three groups of ginger accessions. Groups 1, 2 and 3 represent 18.62%, 57.98% and 23.40% of the individuals in the collection, respectively (**Table 6**). Group 1 includes 35 accessions collected from 13 surveyed areas. Group 2 includes 56 accessions from 15 collection areas. Finally, Group 3 includes 44 accessions from 15 areas.

### 3.5. Discriminant Factor Analysis (DFA)

The three groups identified by hierarchical ascending classification (HAC) were subjected to discriminant factor analysis (DFA). The first two factors (Factors 1 and 2) of the DFA explained 100% of the total variation (**Table 7**). Factor 1 explains 97.826% of the total variation and Factor 2 expresses 2.174% of this variability. It strongly discriminates between the variables thallus (rhizome) length and width, rhizome finger width, secondary finger length and yield in tons per hectare. All these variables are positively correlated with Axis 1.

**Figure 2** shows, in the discriminant factorial plane, the three groups formed by the canonical Axes 1 and 2. Group 1, represented on the positive side of Axis 1,

**Table 6.** Distribution of the number of accessions according to collection areas after ascending hierarchical classification (AHC).

| Administrative regions/district | Group 1 | Group 2 | Group 3 |
|---|---|---|---|
| Agneby-Tiassa | 3 | 2 | 1 |
| Loh-Djiboua | 3 | 5 | 4 |
| Nawa | 5 | 9 | 3 |
| Goh | 0 | 0 | 1 |
| Moronou | 3 | 5 | 5 |
| Gontougo | 2 | 4 | 6 |
| Iffou | 0 | 3 | 4 |
| Haut-Sassandra | 4 | 11 | 3 |
| Tonkpi | 1 | 4 | 3 |
| Marahoué | 3 | 18 | 3 |
| Béré | 7 | 12 | 2 |
| Bagoué | 1 | 4 | 0 |
| Poro | 1 | 10 | 2 |
| Kabadougou | 0 | 8 | 2 |
| Guémon | 1 | 5 | 4 |
| District of Lacs | 1 | 9 | 1 |
| **Total** | **35 (18.62%)** | **109 (57.98%)** | **44 (23.40%)** |

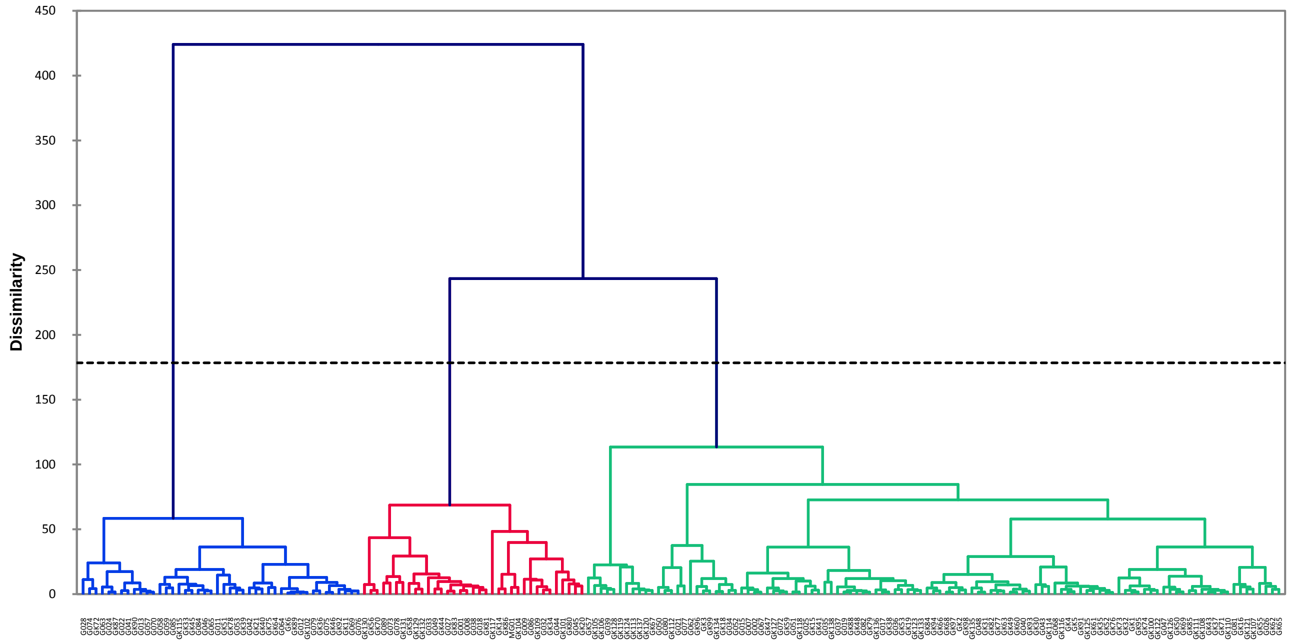

Figure 1. Dendrogram of the 188 ginger accessions from the CAH, showing the three groups based on Euclidean distances.

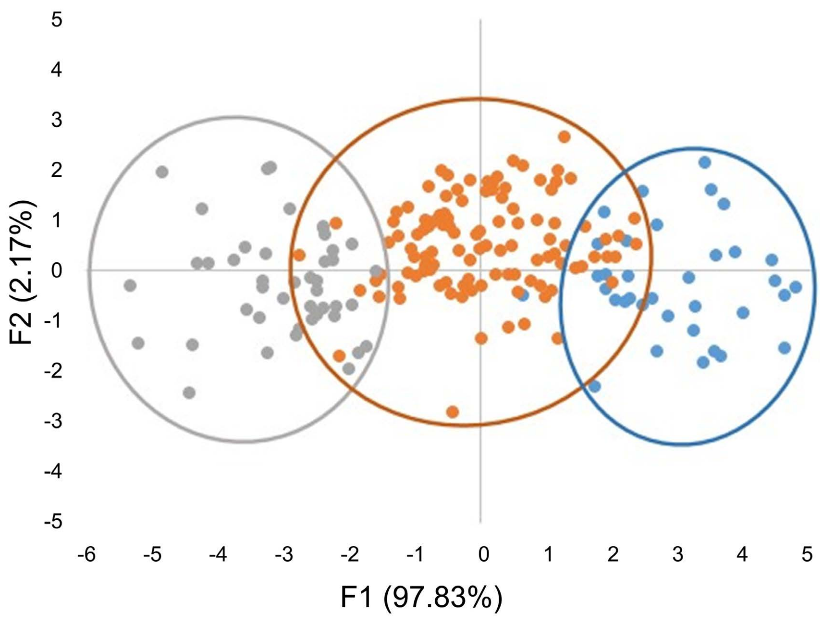


Figure 2. Representation of ginger accession groups in the discriminant factorial plane formed by canonical Axes 1 and 2.

Table 7. Eigenvalue matrix from discriminant factor analysis of 188 ginger accessions.

| | Components | |
|---|---|---|
| Variables | F1 | F2 |
| GeTi | 0.116 | −0.325 |
| NuRe | 0.314 | −0.187 |
| PlHe | 0.639 | 0.136 |

**Continued**

| | | |
|---|---|---|
| **LeWi** | 0.570 | 0.509 |
| **DiCo** | 0.561 | 0.276 |
| **ThLe** | **0.768** | 0.001 |
| **ThWi** | **0.732** | −0.113 |
| **ThTh** | 0.626 | −0.312 |
| **NuRa** | 0.188 | −0.306 |
| **FiWi** | **0.820** | 0.032 |
| **FiTh** | 0.549 | −0.279 |
| **NuNo** | 0.657 | 0.024 |
| **LsFi** | **0.817** | −0.233 |
| **Yild** | **0.745** | −0.105 |
| **Eigenvalue** | **5.997** | **0.133** |
| **Discrimination (%)** | **97.826** | **2.174** |
| **Cumulative** | **97.826** | **100** |

brings together large individuals with longer, wider rhizomes and high yields. These accessions come from the zones of Agneby-Tiassa (3), Loh-Djiboua (3), Nawa (5), Moronou (3), Gontougo (2), Haut-Sassandra (4), Tonpki (1), Guémon (1), Marahoué (5), Lacs (1), Béré (7), Poro (1) and Bagoué (1).

Group 3, represented on the negative side of Axis 1, features smaller individuals, smaller and less wide rhizomes and low yields. These accessions come from Agneby-Tiassa (2), Loh-Djiboua (5), Nawa (9), Iffou (3), the Moronou (5), Gontougo (4), Haut-Sassandra (11), Tonpki (4), Guémon (5), Marahoué (18), District des Lacs (9), Béré (12), Poro (10), Kabadougou (8) and Bagoué (4).

Finally, Group 2, in the middle of the benchmark, is intermediate between the other two groups. This group has medium-sized individuals, rhizomes of average length and width, and average yields. Accessions in this group come from the zones of Agneby-Tiassa (1), Loh-Djiboua (5), Nawa (3), Iffou (4), Moronou (5) and Gontougo (6), Haut-Sassandra (3), Tonpki (3), Guémon (4), Marahoué (3), District des Lacs (1), Béré (2), Poro (2), Kabadougou (2) and Goh (1).

An analysis of variance carried out on the different groups resulting from the ascending hierarchical classification revealed the main distinguishing characteristics (**Table 8**). This table shows that, except for the mean germination time and the number of rhizome branches, all other parameters were able to distinguish the three groups. The analysis of the results in this table shows that, on average, Group 1 has the highest values for all the parameters studied: number of shoots (23.25 ± 9.36a), height (54.58 ± 6.16a) and diameter at plant collar (8.34 ± 1.01a), leaf width (2.60 ± 0.16a), length (22. 36 ± 2.13a), width (11.39 ± 1.87a) and thallus thickness (49.03 ± 12.41a), finger width (6.75 ± 0.71a) and thickness (23.42 ± 4.17a), secondary finger length (9.31 ± 0.89a), number of nodes (4.53 ± 0.36a) and yield in tons per hectare (19.27 ± 2.93a).

**Table 8.** Characteristics of the groups resulting from the ascending hierarchical classification.

| Variables | Group 1 | Group 2 | Group 3 | P | F |
|---|---|---|---|---|---|
| GeTi | 15.12 ± 2.27a | 14.22 ± 2.56a | 14.47 ±2.5a | 0.181 | 1.727 |
| NuRe | 23.25 ± 9.36a | 19.71 ± 5.61b | 18.06 ± 5.38b | 0.002 | 6.622 |
| PlHe | 54.58 ± 6.16a | 49.97 ± 6.61b | 43.70 ± 5.51c | <0.001 | 30.383 |
| LeWi | 2.60 ± 0.16a | 2.54 ± 0.19a | 2.31 ± 0.21b | <0.001 | 28.486 |
| DiCo | 8.34 ± 1.01a | 7.90 ± 0.90b | 7.02 ± 0.73c | <0.001 | 23.913 |
| ThLe | **22.36 ± 2.13a** | **19.74 ± 2.16b** | **17.03 ± 2.23c** | **<0.001** | 59.087 |
| ThWi | **11.39 ± 1.87a** | **9.56 ± 1.41b** | **8.02 ± 1.17c** | **<0.001** | 52.427 |
| ThTh | 49.03 ± 12.41a | 38.50 ± 7.21b | 32.86 ± 7.32c | <0.001 | 36.608 |
| NuRa | 3.03 ± 0.42a | 2.87 ± 0.33a | 2.87 ± 0.29a | 0.059 | 2.883 |
| FiWi | **6.75 ± 0.71a** | **5.78 ± 0.80b** | **4.72 ± 0.64c** | **<0.001** | 72.612 |
| FiTh | 23.42 ± 4.17a | 20.54 ± 2.59b | 19.02 ± 1.99c | <0.001 | 24.022 |
| NuNo | 4.53 ± 0.36a | 4.23 ± 0.33b | 3.92 ± 0.30c | <0.001 | 34.435 |
| LsFi | **9.31 ± 0.89a** | **7.79 ± 0.861b** | **6.70 ±1.01c** | **<0.001** | **81.582** |
| Yild | **19.27 ± 2.93a** | **15.60 ± 3.24b** | **12.42 ± 2.67c** | **<0.001** | **48.719** |

Column averages marked with the same letter do not differ significantly at the 5% threshold (HSD Tukey).

Furthermore, except for the number of shoots, where the means of Groups 2 and 3 are statistically identical, Group 3 has the lowest means: plant height (43.70 ± 5.51c), leaf width (2.31 ± 0.21b), length (17.03 ± 2.23c), width (8.02 ± 1.17c) and thallus thickness (32.86 ± 7.32c), width (4.72 ± 0.64c) and thickness (19.02 ± 1.99c) of fingers, length of secondary fingers (6.70 ± 1.01c), number of nodes (3.92 ± 0.30c) and yield in tons per hectare (12.42 ± 2.67c).

Finally, Group 3 had mean values intermediate between those of the other two groups: plant height (49.97 ± 6.61b) and diameter at collar (7.90 ± 0.90b), length (19.74 ± 2.16b), width (9.56 ± 1.41b) and thickness of thallus (38.50 ± 7.21b), width (5.78 ± 0.80b) and thickness (20.54 ± 2.59b) of fingers, length of secondary fingers (7.79 ± 0.861b), number of nodes (4.23 ± 0.33b) and yield in tons per hectare (15.60 ± 3.24b).

## 4. Discussion

Varietal selection relies on the genetic variability of species. Assessing the genetic diversity of ginger based on agronomic traits is essential for understanding its performance and designing breeding programs [17]. Morphological markers also form the basis for the identification and classification of plant species [23]. These morphological markers continue to be used successfully in numerous characterization and agronomic evaluation studies, enabling easier and faster differentiation of phenotypes. In order to assess the agromorphological diversity of a ginger collection from different regions of Côte d'Ivoire, 18 variables related to plant growth, thallus (rhizome) characteristics and yield were used to characterize a collection of 188 accessions. The analysis of variance carried out on these morphological traits revealed significant variability for all the traits studied. This variability could be linked mainly to genotypic factors. Good variability for various morphological and yield traits has been reported in ginger cultivars [24] [25] [26].

The association between different traits is an important and useful feature that allows the identification of different traits that can potentially be targeted for further consideration in crop improvement [27]. This study showed a strong positive and significant correlation between yield per plant and yield in tons per hectare, between leaf length and leaf width, between plant height and leaf length, and between plant height and number of leaves. These positive correlations can therefore be easily used as an indicator of rhizome yield, which is an important trait in ginger breeding. Correlations have the advantage of facilitating indirect improvement of the different variables involved in yield. Thus, improvement in one trait leads to improvement in the others. Such correlations between variables were also reported by [16] who showed that rhizome yield had strong correlations with rhizome weight per plant, followed by leaf length, plant height and number of leaves per plant.

Principal component analysis (PCA) showed moderate variability (45.931%) within accessions. Fourteen of the 18 descriptors mainly contributed to the overall variability. Furthermore, the diversity recorded between ginger accessions is probably due to the diversity of the collection areas and the dispersion of the sites where the accessions were collected. This diversity reflects the genotypic heterogeneity of the plant material used in this work. The moderate variability of accessions collected in different areas of Côte d'Ivoire could be explained, on the one hand, by cultivation practices based on the use of several cultivars in the same field and, on the other, by the continual exchange of plant material with interesting agronomic traits between growers in different localities [28]. These are the same reasons that justify the existence of genetic variability for yield and associated traits ranging from moderate to high variability in the species in India as reported [29] [30]. In neighboring Burkina Faso, [16] observed a high variability (69.938%) for the first three axes combined, with a partial contribution from 6 out of 13 descriptors. This observed difference could be explained by the different origins of the plant material and the number of accessions used for characterization.

Hierarchical ascending classification structured the accessions, on the basis of fourteen characters, into three distinct groups. Group 1 is characterized by larger accessions, longer and wider rhizomes and high yields. Group 3 consists of small accessions with smaller, less wide rhizomes and low yields. These results indicate that ginger grown in Côte d'Ivoire is made up of three distinct genetic groups based on plant stature, rhizome and yield. These three groups bring together accessions from diverse origins. The fact that the groups are distributed independently of origin could indicate the presence of duplicates within the 188 accessions collected. The presence of duplicates within the pool could be explained by the method used to obtain planting material. In fact, most growers obtain planting material for their plots either by purchase on local markets or by donation [15]. The same genetic structuring was observed in Benin, where ginger accessions were grouped into three groups independently of their collection area on the basis of characters such as rhizome length, width, thickness and weight, skin and flesh color, finger length, streak arrangement and fiber density for 29 ginger accessions [18]. [31] also obtained a structuring of their collection based on rhizome yield, number of thalli per plant and plant height with ginger ecotypes grown in Japan. The relevance of the morphological similarities derived from the ascending hierarchical classification was assessed using discriminant factor analysis. The high representativeness of the first two axes of the DFA (97.826% for Axis 1 and 2.174% for Axis 2) testifies to a strong phenotypic organization based essentially on five variables. Thus, the variables that discriminated the three groups were the length and width of the thalli (rhizomes), the width of the fingers, the length of the secondary fingers and the yield in tons per hectare of rhizomes. The genetic resources available from this study can therefore be used to define strategies for the selection and improvement of ginger by characterizing its diversity.

## 5. Conclusions

This study was carried out to assess the diversity of 188 ginger accessions collected in fifteen administrative regions and one autonomous district of Côte d'Ivoire on the basis of 18 quantitative variables. All 18 variables were found to be discriminant in assessing the variability of the collection.

The study also showed the existence of three phenotypic groups, independent of the geographical origin. Five parameters (rhizome length and width, finger width, secondary finger length and yield in tons per hectare) allow us to distinguish the three morphological groups identified in this study.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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