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Evaluation of Agromorphological Characters of Cassava Cultivars (*Manihot esculenta* Crantz) from Eight Agroecological Conditions in Côte d'Ivoire

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Abstract The objective of this study was to analyze the agromorphological variability within cassava cultivars from eight agroecological area conditions or Agro-poles in Côte d'Ivoire. One hundred and forty six (146) cassava cultivars were evaluated in a randomized complete block design with 10 discriminants quantitatives traits. Data were collected at six and twelve months after planting. High phenotypic variability was shown within the collection for all the traits evaluated. The principal component analysis (PCA) applied to the 146 accessions confirmed this variability of 71.01% revealed by the first two principal components (PCs). The ascending hierarchical clustering (AHC) revealed three groups based on by the height to first branching, the number of leaf lobes, the length of leaf lobe, the petiole length, the number of roots per plant, the fresh root weight and the tuber yield per plant. These three groups were constituted of cassava cultivras independently of the agroecological area from which they were collected. This study demonstrated that there is a considerable genetic variability among ivorian cassava cultivars which should improve food security and breeding potential.

Keywords: *Cassava, agro-poles, agromorphological, variability, Côte d'Ivoire*

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1. Introduction

Cassava (*Manihot esculenta Crantz*) is a tuberous crop, which provides more than half of the calories consumed by more than 900 million people in Sub-Saharan Africa, with annual production in this part of Africa estimated at 178 millions tons, which is 61% of global production [1]. The cassava tuberous roots is rich in starch [2,3] and its leaves are also rich in proteins, in minerals, in vitamins and in carotenoids [4]. Used for human consumption, animal feed and industrial applications [5], Cassava is a hardy plant that can grow in drought-prone environments, survives in poor soils with low nutrient content, relatively producing higher yields than other root and tuber crops [6]. However, the response of cassava accession to production is linked to environment (soil, climate) and biotic factors [7]. It is an important food security crop and poverty reduction, particularly to smallholder farmers in growing area [8]. In Côte d'Ivoire, cassava is the main food crop after yam with an annual production of around 7.44 million tonnes [1]. This crop is well integrated into all cropping systems [9]. The ivorian people have made it a staple food and the availability of several varieties in the country favors different types of local dishes (Attiéké, foutou, placali, etc.) [10]. Despite this socio-economic importance, production still remains low and the average crop yield in Côte d'Ivoire is still as low as 8 tonnes per hectare, compared with a potential yield of 40 t/ha under good agronomic management [11]. The low yield of the crop could be due to the use by farmers of low yielding varieties that are susceptible to pests and diseases, and the lack of good agronomic practices [10]. To this, we can add the give up of some cultivars by farmers witch leads to a genetic drift of cassava in the country [9]. Thus, there is the need to develop new improved varieties that are adapted to the environments and promote high yielding existing varieties. Develepment of improved varieties, depends on a better understanding of the genetic variability present in the population assembled [12]. Therefore, it is important to carry out studies to assess the genetic diversity within cassava accessions in order to provide breeding programs with divers known genotypes [11,13]. Many studies of characterization have been carried out on the genetic resources of cassava from Côte d'Ivoire [9,10,14,15], however, cassava accessions newly collected in farmers' fields in the eight Agro-poles of Côte d'Ivoire had not yet been characterized in terms of agromorphological evaluation. In traditional farming systems in Côte d'Ivoire, the coexistence of different cassava accessions in the same field is frequent leading to a high diversity of accessions due to the natural hybridization and the exchange of planting materials between farmers. Most of the time, different accessions may have the same name, while an accession could be given different names as vernacular names has given to the accessions according to ethnic groups. This leads to the presence of duplicates in the collection among accessions collected in different localities [9]. An assessment of cassava genetic diversity through agromorphological characterization and removing duplicates from a collected germplasm is very important for breeding activities and will provide breeding programs with unique genotypes. According to [9], cassava characterization through agromorphological parameters could reveal morphological variability and duplicates within current germplasm.

The objective of the present study were to assess the agromorphological diversity of cassava accessions newly collected in Côte d'Ivoire for conservation, further evaluation and utilization by breeders.

2. Material and Methods

2.1. Description of the Study Area

The study was conducted in Belier region of Côte d'Ivoire on the experimental site of Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS, Côte d'Ivoire) at Bringakro. The experimental site is located at 6°25'0'' N et 5°4'60'' W and the area of the study is a transition zone, located between forest and savanna. The soil of Belier region are ferralitic. The rainy season is from March to October and the dry season is from november to Febrary. The mean monthly air temperature ranges from 24°C to 28°C for the greater part of the day and night, especially during the rainy season The average annual rainfall is 1200 mm of rain spread over 5 to 8 months.

2.2. Plant Material and Experimental Design

The plant materials included stem cuttings of 146 cassava genotypes collected in eight agroecological conditions in Côte d'Ivoire grouped in Agro-poles according to Ivorian National Agricultural Investment Program 2 (PNIA2) (Table 1, Figure 1) [16]. The experiment was laid out in a completely randomized design with ten replications. The experimental plot measured 30 × 50 m and included 1460 plants, representing the 146 accessions. Each accession was represented by 10 plants. The planting distance was set at 1 m between and within rows, with 1 m edges. The planting density 10.000 plants/ha, with a spacing of 1 m (rows) x 1 m (plants) was adopted. The planting materials consisted of mature stem cuttings (stakes) of about 20 cm in length, containing between 10 and 12 nodes. The stem were horizontally planted on ploughed soil at a depth of less than 10 cm. Manual weeding was done when it was necessary. No fertilizer was applied and harvesting was done 12 month after planting.

Table 1. Agroecological area and number of collected cultivars

Agro-Pole	Agroecological area	Region	Number of cultivras collected
4	Centre	Gbèkè	3
		N'zi	5
		Bélier	9
6	Centre-West	Haut-sassandra	10
		Gôh	11
3	East	Indénié-djuablin	3
	South-East	Sud-comoé	16
2	North-East	Gontougo	2
8	North-West	Kabadougou	4
5	South	Abidjan	11
		La mé	5
		Agnéby-tiassa	4
		Grands ponts	14
		Loh-djiboua	2
7	South-West	Cavally	7
		San pedro	13
9	West	Guémon	8
		Tonkpi	19

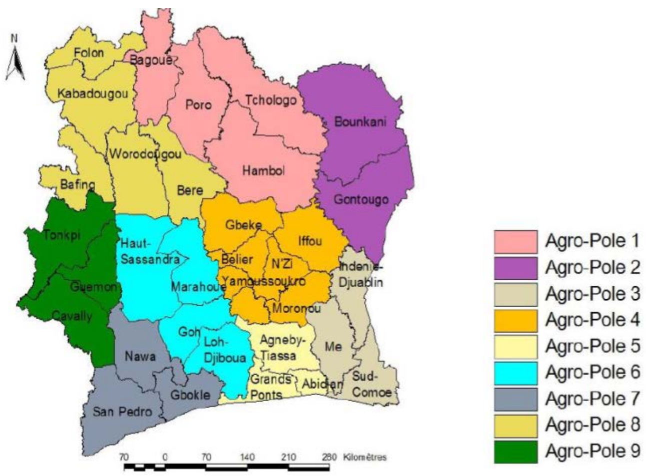

Figure 1. Agro-poles (2, 3, 4, 5, 6, 7, 8 and 9) where the cassava cultivras were collected (PNIA, 2017)

2.3. Data Collection

Agromorphological traits were evaluated based on the cassava descriptors developped by [17]. Ten (10) discriminants quantitatives traits were used to characterize agro morphological diversity. The data collected, the sampling periods and the codes are presented in Table 2.

Table 2. List of agromorphological descriptors used and collecting period

Period of data recording	Traits observed	Code	Techniques of measurement
6 months after planting	Number of leaf lobes	NDLO	Counted the leaves per plant with consideration of the predominant number of lobes (5 leaves/plant)
	Length of leaf lobe (cm)	LONLOC	Measure from the intersection of all lobes to the end of the middle lobe
	Width of leaf lobe (cm)	LARLOC	Measured from the widest part of the middle lobe.
	Ratio length/width lobe	RATIO L/W	Calculate the Ratio between length and width
	Petiole length (cm)	LPE	Measured on three leaves per plant
12 months after planting	Height to first branching (cm)	HRAM1	Measure vertical height from ground to first primary branch
	Plant height (cm)	HPL	Measured vertically from the ground to the top of the canopy
	Number of roots per plant	NTP	Record the number of roots from three plants with length greater than 20 cm.
	Weight of fresh root (kg)	PTP	Total root root shaving length greater than 20 cm are weighted
	Tuber yield per plant (t/ha)	RDT	Calculate using the formula: RDT= (Weight of fresh root/plant (kg) / (Plot area (m^2)) * (10 000 m^2 / 1 000)

Table 3. Descriptive statistics and results of the analysis of variance (ANOVA) of 146 cassava cultivars for the quantitative traits

Variables	Minimum	Maximum	Average	SD	CV (%)	F
HPL (cm)	100.00	347.00	236.27	53.96	22.84	***
HRAM1 (cm)	24.00	331.33	117.09	79.89	68.23	***
NDLO	4.000	10.00	7.19	1.48	20.54	***
LARLOC (cm)	1.80	6.00	3.79	1.25	32.83	***
LONLOC (cm)	8.00	20.00	14.01	2.599	18.55	***
RATIO L/W	1.62	8.05	4.12	1.57	38.18	***
LPE (cm)	11.67	29.00	18.89	3.32	17.56	***
NTP	1.00	10.00	6.58	2.19	33.36	***
PTP (kg)	0.10	4.00	2.08	0.89	42.50	***
RDT (t/ha)	1.00	40.00	20.79	8.84	42.50	***

HPL: Plant height; HRAM1: Height to first branching; NDLO: Number of leaf lobes; LARLOC: Width of leaf lobe; LONLOC: Length of leaf lobe; RATIO L/W: Ratio length/width lobe; LPE: Petiole length; NTP: Number of roots per plant; PTP: Weight of fresh root; RDT: Tuber yield per plant; SD: Standard Deviation; CV: Coefficient of Variation; F: Fisher's coefficient; *** = significant at $P < 0.001$.

2.4. Data Analysis

Descriptive statistics and correlation coefficients analysis were computed using XLSTAT-Pro software version 2019. Analysis of variance (ANOVA) was performed to identify significant traits, with a significance level of 5%. When the ANOVA was significant ($p < 0.05$), a Student Newman Keul (SNK) test was performed to differentiate the means. Multivariate analysis were also done. Thus, Principal Component Analysis (PCA) was used to examine the contribution of each trait to total genetic variation. The structure of the agromorphological variability was visualized using ascending hierarchical clustering (AHC) through a dendrogram. Groups formed by the Ascending Hierarchical Clustering (AHC) were characterized by the analysis of variance.

3. Results

3.1. Descriptive Analysis of Traits

The traits observed in this study were subjected to descriptive statistics analysis (minimum, maximum, average, standard deviation and coefficient of variation) to appreciate the variability of each trait among the cassava cultivars (Table 3). The results showed high variability for the agromorphological traits assessed. Highly significant differences ($p < 0.001$) was observed for all traits with coefficients of variation ranging from 17.56% in the petiole length (LPE) to 68.23% for the height to first branching (HRAM1. Based on the 10 quantitative characters, 8 had high coefficients of variation (CV>20%). Only the length of petiole (CV = 17.56%) and the length of leaf lobe (CV = 18.55%) have low variations. The range of values produced were 100 to 347 cm for plant height, 24 to 331.33 cm for the height to first branching, 4 to 10 for the number of leaf lobes, 1.80 to 6 cm for the width of leaf lobe, 8 to 20 cm for the length of leaf lobe, 1.62 to 8.05 for the ratio of lobe length to lobe width of central leaf lobe, 11.67 to 29 cm for the petiole length, 1 to 10 for number of roots per plant, 0.10 to 4 kg for the weight of fresh root and 1 to 40 t/ha for the tuber yield per plant (Table 3).

3.2. Correlation Between Traits

The Table 4 show the correlation matrice between quantitative traits and indicated that the height to first branching (HRAM1) is the trait significantly and positively correlated with the most traits. It is correlated to plant height (HPL), the number of leaf lobes (NDLO), the length of leaf lobe (LONLOC), the petiole length (LPE), the number of roots per plant (NTP), the weight of fresh root (PTP) and the tuber yield per plant (RDT) except the width of leaf lobe (LARLOC). Positive correlations were also observed between the plant height (HPL) and almost all traits. The number of leaf lobes (NDLO) is highly and positively correlated to the number of roots per plant (NTP, $r = 0.841$), the weight of fresh root (PTP, $r = 0.732$)

and the tuber yield per plant (RDT, r =0.732). Furthermore, the ratio length/width of lobe leaf (RATIO L/W) was negatively correlated to the number of roots per plant (NTP), the weight of fresh root (PTP) and the tuber yield per plant (RDT), meaning that as the tuber yield per plant is high, the lower is the ratio ratio length/width and plant had wider leaves. Finally, the tuber yield per plant (RDT) is positively correlated to plant height, the height to first branching, the number of leaf lobes, the width of leaf lobe, the petiole length, the number of roots per plant and the weight of fresh root.

3.3. Structuring Agro-Morphological Variability

The principal component analysis (PCA) of the 10 quantitative traits showed that the first two principal components (PCs) with eigenvalues greater than 1 unity were responsible for 71.01% of the total variation (Table 5). The first PC (PC1) axis with an eigen value of 4.57 accounted for 45.77% of the variation. The traits that contributed most of the variation were number of leaf lobes (0.778), width of leaf lobe (0.415), number of roots per plant (0.760), weight of fresh root (0.810) and Tuber yield per plant (0.810). The second PC (PC2) also contributed for 25.25% of the total variation and contained plant height (0.308), height to first branching (0.505), length of leaf lobe (0.765), ratio length/width of lobe leaf (0.464) and petiole length (0.310).

The Ascending Hierarchical Clustering (AHC) carried out on 10 quantitative traits revealed 3 cultivars groups (Figure 2). Groups 1, 2 and 3 have respectively 44, 80 and 22 cassava cultivaes (Table 6). Significant differences ($P < 0.05$ and $P < 0.001$) were observed between the groups for the characters such as the height to first branching, the number of leaf lobes, the length of leaf lobe, the petiole length, the number of roots per plant, the fresh root weight and the tuber yield per plant. These seven (7) traits allow differentiating the three groups. But among these traits, the height to first branching (HRAM1) and the petiole length (LPE) clearly distinguished the three groups. Individuals from group (G1) are characterised by high petiole length (LPE) and height to first branching (HRAM1) compared to individuals from the other two groups G2 and G3, which have medium and low LPE and HRAM1 respectively. Individuals from groups G1 and G2 have highest number of leaf lobes, number of roots per plant and tuber yield per plant compared to individuals from group G1. Cultivars to group 3 have the lowest values of the different traits. Also, the analysis of the dendrogram showed that, cultivars were grouped independently of the agroecological area from which they were collected (Table 7).

Table 4. Correlation matrix between quantitative traits

Variables	HPL	HRAM1	NDLO	LARLOC	LONLOC	RA L/W	LPE	NTP	PTP	RDT
HPL	**1**									
HRAM1	**0.555**	**1**								
NDLO	**0.353**	**0.298**	**1**							
LARLOC	0.100	0.080	**0.504**	**1**						
LONLOC	**0.490**	**0.598**	0.050	0.032	**1**					
RA L/W	0.048	**0.131**	**-0.459**	**-0.835**	**0.438**	**1**				
LPE	**0.300**	**0.497**	**0.386**	**0.187**	**0.541**	0.026	**1**			
NTP	**0.370**	**0.223**	**0.841**	**0.492**	-0.093	**-0.546**	**0.234**	**1**		
PTP	**0.375**	**0.241**	**0.732**	**0.447**	0.029	**-0.434**	**0.361**	**0.749**	**1**	
RDT	**0.375**	**0.241**	**0.732**	**0.447**	0.029	**-0.434**	**0.361**	**0.749**	**1.000**	**1**

HPL: Plant height; HRAM1: Height to first branching; NDLO: Number of leaf lobes; LARLOC: Width of leaf lobe; LONLOC: Length of leaf lobe; RATIO L/W: Ratio length/width lobe; LPE: Petiole length; NTP: Number of roots per plant; PTP: Weight of fresh root; RDT: Tuber yield per plant; Values in bold are significant at alpha = 0.05.

Table 5. Principal component (PC) analysis of 10 qualitative traits showing their contributions to the total variation among 146 cassava cultivars

Variable	PC1	PC2
Eigen value	4.577	2.525
% Variation expressed	45.769	25.246
Cumulative variation expressed (%)	45.769	71.016
HPL	0.256	0.308
HRAM1	0.172	0.505
NDLO	0.778	0.004
LARLOC	0.415	0.121
LONLOC	0.017	0.765
RATIO L/W	0.326	0.464
LPE	0.232	0.310
NTP	0.760	0.037
PTP	0.810	0.005
RDT	0.810	0.005

HPL: Plant height; HRAM1: Height to first branching; NDLO: Number of leaf lobes; LARLOC: Width of leaf lobe; LONLOC: Length of leaf lobe; RATIO L/W: Ratio length/width lobe; LPE: Petiole length; NTP: Number of roots per plant; PTP: Weight of fresh root; RDT: Tuber yield per plant; Values in bold are significant at alpha = 0.05.

Table 6. Characteristics of 3 cassava cultivars groups from ascending hierarchical clustering

Groups	1	2	3	P
Number of cultivars	44	80	22	
HPL	238.823a	238.498a	222.274a	ns
HRAM1	205.221a	88.878b	35.763c	***
NDLO	7.252a	7.454a	6.052b	***
LARLOC	3.949a	3.812a	3.421a	ns
LONLOC	15.988a	13.338b	12.319b	***
RATIO L/W	4.445a	3.900a	4.250a	ns
LPE	21.415a	18.439b	15.143c	***
NTP	6.488a	6.881a	5.625b	**
PTP	2.043a	2.245a	1.524b	***
RDT	20.427a	22.454a	15.244b	***

HPL: Plant height; HRAM1: Height to first branching; NDLO: Number of leaf lobes; LARLOC: Width of leaf lobe; LONLOC: Length of leaf lobe; RATIO L/W: Ratio length/width lobe; LPE: Petiole length; NTP: Number of roots per plant; PTP: Weight of fresh root; RDT: Tuber yield per plant. Values with same letters and in the same line are not significantly different according to the test of Student Newman- Keuls at 0.05.; *** = significant at P < 0.001.; ** = significant at P < 0.05

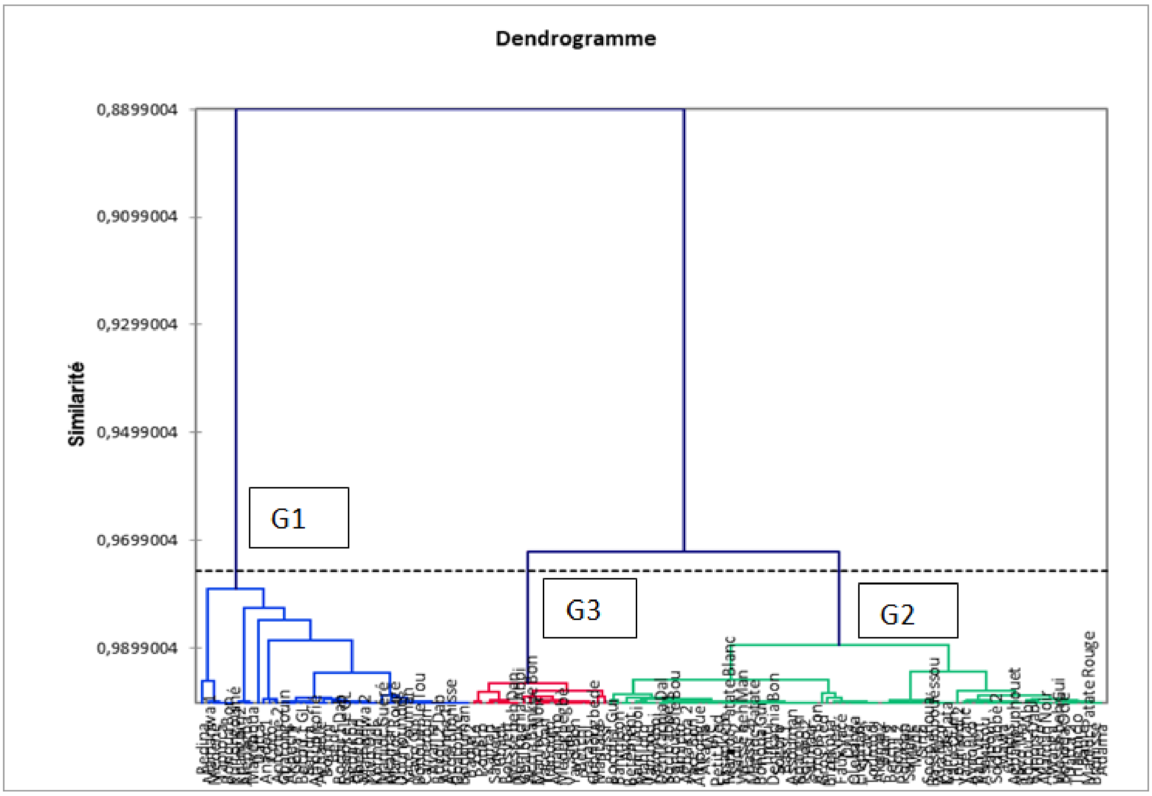

Figure 2. Cluster dendrogram (UPGMA) showing the genetic relationship between the 146 cassava cultivars based on the Ward's method

Table 7. (1) Distribution of the cassava cultivars in HAC groups by origin

Agroecological area	Center			Center-West		East	North-East	North-West	South	
Region / Groups	Gbèkè	N'zi	Bélier	Haut-sassandra	Gôh	Indénié-djuablin	Gontougo	Kabadougou	Abidjan	La mé
G1	1		2	2	3	1	1	2	6	2
G2	2	4	7	7	6	2	1	2	3	2
G3		1		1	2				2	1

Table 7. (2) Distribution of the cassava cultivars in HAC groups by origin

Agroecological area	South			South-East	South-West		West		
Region / Groups	Agnéby-tiassa	Grands ponts	Loh-djiboua	Sud-comoé	Cavally	San pedro	Guémon	Tonkpi	Number of accessions
G1		6	1	2	1	5	3	6	44
G2	4	7	1	10	5	4	4	9	80
G3		1		4	1	4	1	4	22

4. Discussion

In Côte d'Ivoire. cassava contributes enormously to food security and valorization of the diversity maintained by farmers are opportunities for improving national production. The agromorphological characterization of accessions is the preliminary phase for plant breeding especially in cassava [9,10,18,19,20]. This study permitted to evaluate the level of cassava variability newly collected in Côte d'Ivoire by using morphological and agronomic traits. The high coefficients of variation observed for most traits in our study can indicate the presence of a high heterogeneity within the collection characterized that can be exploited in breeding program. These results are similar to those reported respectively by [5,21] and [20] in India, in Ghana and in Côte d'Ivoire. The correlation between traits is an important tool in the choice of characters to be integrated in plant breeding programs. Several correlations have been highlighted between the traits in this study and corroborate those obtained on cassava in Benin [22], in Ghana [23], in Côte d'Ivoire [24] and in Colombia [25]. In our study, the principal component analysis (PCA) showed that the first two PCs, PC1 (45.77%) and PC2 (25.24%) accounted for a total of 71.01% of the total variation. This is similar to the work of [24] who reported the first two PCs of 81.81% with slightly higher value. This variability is much greater to the value of [10], which obtained 37.018% of the total variation with the first two PCs working on 200 cassava accessions collected in Côte d'Ivoire and [15] who obtained a morphological variability of 63.84% within 44 cassava accessions from the same country. The high variability within the cassava cultivars in Côte d'Ivoire could be explained by regular introductions of cassava varieties from other countries, by natural hybridization, by the presence of several cultivars in farmers field and continuous exchange of plant material between farmers [10,11]). The number of leaf lobes, the width of leaf lobe, the number of roots per plant, the fresh root weight and the tuber yield per plant are the major contributors to the variation explained by the first principal component which agrees with the findings of [22] and [26].

Based on Ascending Hierarchical Clustering (AHC), the 146 cassava cultivars were clustered into 3 groups. These results are similar to those of [9,10,15] and [20] who obtained again three clusters by assessing respectively the morphological diversity of 159, 44 and 200 and 47 cassava accessions collected in Côte d'Ivoire. These results means that cultivated cassava in Côte d'Ivoire consists of three distinct genetic clusters. The groups were differentiated by the height to first branching, the number of leaf lobes, the length of leaf lobe, the petiole length, the number of roots per plant, the fresh root weight and the tuber yield per plant. Our results are similar to those of [22,27] and [24] who through the same trait revealed diversity within cassava genotypes from respectively in Benin, in Chad and in Côte d'Ivoire. Also. cassava cultivars were grouped in the three groups independently of the agroecological area from which they were collected. Similar results on cassava accessions were obtained in Indonesia by [28] assessing the agromorphological diversity of 22 cassava accessions from several regions. The authors obtained tree classes and the 22 accessions were not grouped according to their origin. [10] obtained the some results with 200 accessions collected in five regions of Côte d'Ivoire. The distribution of cultivars in the three groups independently of their origin suggest the presence of duplicates within the 146 accessions collected. [9] also highlighted the presence of duplicates in the collection of 159 cassava accessions collected in the Centre-west. South-west and West of Côte d'Ivoire. The presence of duplicate in collection can be attributed to the vernacular names given to cassava accessions by the farmers. According to [29] different cassava cultivars could have the same name and several names could be assigned to one cultivar on the farm. A reliable detection of these duplicates can be possible by using molecular markers (SSR. RFLP. RAPD). These techniques have been successfully used to detect duplicate within cassava collections [26,30].

5. Conclusion

The objective of the present study were to assess the agromorphological diversity of 146 cassava cultivars newly collected in Côte d'Ivoire. The results reveals the existence of significant variability within the collection. Agromorphological relevant traits and three classes of performing cultivars were identified. These accessions were structured into three genetic groups differentiated by the height to first branching, the number of leaf lobes, the length of leaf lobe, the petiole length, the number of roots per plant, the fresh root weight and the tuber yield per plant. This high variabiliy is interesting for breeding and cassava varietal improvement. Complementary studies like molecular characterization is however necessary to define a unique set of germplasm for conservation and for breeders for breeding programs for the development of novel varieties with high yield.

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