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Genetic Diversity of Taro Landraces from Côte d'Ivoire Based on Qualitative Traits of Leaves

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Abstract

Taro is an important crop species in Côte d'Ivoire. It is cultivated for its tubers and leaves. But its knowledge and genetic diversity and differentiation are very weakly documented. Several morphological types are found in rural area, but their identification is not very clear, and their agronomic potentiality is underexploited. In this context we initiated a survey and collected 213 accessions from 14 growing regions of Côte d'Ivoire. The diversity was evaluated based on seven qualitative traits of leaves (Shape of the base of the leaf, Predominant position (shape) of the leaf blade surface, Margin of the leaf blade, Leaf blade variegation, Profile of the petiolar junction, Shape of the leaf sheath, Shape of the appendix) during an experimentation conducted in rural area. The objective of this study was to characterize the collection of taros collected in different geographical zones of Côte d'Ivoire and identify the genera cultivated. Results of our study indicated that excepted margin of the leaf blade all traits are very discriminant. Several variants were observed for each of traits. According to observations and statistics analysis accessions were separated into two main groups. The characteristics of these groups indicate that taro cultivated in Côte d'Ivoire could belong to two genera: *Xanthosoma* and *Colocasia.*

Keywords

Côte d'Ivoire, Colocasia, Diversity, Taro, Xanthosoma

1. Introduction

Overcoming food and nutritional insecurity with the ever-growing population size remains a real challenge for African countries, mainly in sub-Saharan Africa, despite the fact that the continent abounds in a rich agricultural and nutritional diversity that can significantly contribute to the reduction of poverty and hunger in this region of the world. In Africa most food plants are cultivated and consumed locally. For many years, crop, food nutrition and technology sciences in Africa have focused on major crops such as maize [1], cassava, rice and yam leaving behind hundreds of crops and species relevant for the local economy and the nutrition of millions of rural and urban populations [2].

Although major crops feed 60% of the African population, they represent just 1% of the huge diversity used by farmers to adapt to climate hazards and ensure food and nutrition security of their households. For instance, more than 7000 species, frequently referred to as orphan crops, minor crops, or underutilized species, are used by rural and urban dwellers to alleviate hunger and promote healthy and balanced diets [3]. Unfortunately, most of those plant resources are by-and-large overlooked and very limited research programs focus on them. Moreover, very few researchers are trained for processing and promoting those locally adapted crops like leafy vegetables, indigenous fruits, old cereals, and pulses.

Among these crops we find a tuber plant called "Taro". It is an important crop species widely consumed in Côte d'Ivoire. It is cultivated in various agro-ecological areas for its tubers or leaves [4]. Despite its importance, taro is still marginal and few documented. The cropping system is not developed and sustainable, mainly due to the crops' natural characteristics and to current human practices. To enhance plant breeders' capacity to respond to climate challenges, it is acknowledged that they need to be able to access and use as much genetic diversity as they can get. In Côte d'Ivoire, knowledge of taro cultivated, its genetic diversity and differentiation are very weakly documented. In order to fill up this gap, it is crucial to collect the genetic resource available at country level and to characterize the genetic diversity of the collected accessions on the basis of several markers. In this context we initiated a survey and collection of taro accessions in various agroecological zones of Côte d'Ivoire to evaluate the diversity level and genetic structuration.

This survey allowed us to make a first regrouping of these accessions collected in seven morphotypes based on peasant knowledge [4]. But the name taro describes several genera and confusion exists among scientists. In this study we focused our analysis on the leaf's shapes to extent the knowledge of taro diversity cultivated in Côte d'Ivoire. Diversity in leaf characteristic and shape is considered to be most important as it is the primary criteria frequently used to characterize each of the diverse taro genera and to distinguish them visually [5].

The objective of this study was to characterize the collection of taros from different geographical zones available and identify the genera of taro cultivated. They could provide insights into the patterns of species divergence within taro cultivated in Côte d'Ivoire.

2. Material and Methods

2.1. Study Site

The experiment took place in rural area to Soubre from June 2020 to March

2021. Soubre is a city in southwestern Ivory Coast. It is the seat of Nawa Region in Bas-Sassandra District. Soubre is located between 5˚47'08"N and 6˚36'30"W. The climate is humid equatorial. The temperature varies between 29˚C and 32˚C. The annual variations in rainfall and temperature make it possible to determine four main seasons: two rainy seasons and two dry seasons, a long dry season from December to March. A long rainy season begins in April and end in mid-July. This is followed by a short dry season from mid-July to mid-September and a short rainy season from mid-September to November. Soubre is characterised by dense humid forest [6] [7] [8]. The soil is predominantly deep ferralitic with a sandy-clay texture and a lumpy structure [9].

2.2. Plant Material and Experiment Design

The field layout was a completely randomized design with five replications. Conception was a 42 m × 30 m plot containing 1065 plants (*i.e.*, the 213 accessions), each accession being represented by 5 plants. The planting distance was 1 m between and within rows with 1 m of edges. Manual weeding was carried out during plant development.

2.3. Data Collection and Analysis

Seven qualitative traits were selected in standard descriptors for Taro [10] to characterize morphological diversity (**Table 1**).

Multiple Correspondence Analysis (MCA) was performed to investigate the relationships between the qualitative traits. It was applied to further describe morphological variation among accessions. MCA is particularly relevant to describe dataset by combining correlated variables into factors. Hierarchical Ascending Classification (HAC) was applied to obtain homogeneous groups of accessions. Finally, discriminant factor analysis (DFA) was performed to determine the most discriminating traits and to give the characteristics of the groups obtained by the HAC. All these analyses were conducted using the statistical software R version 4.1.0 (2021-05-18) [11].

Table 1. List of descriptors used for characterization of "taro" germplasm.

Traits observed	Code	Variants
Shape of the base of the leaf	ShBL	1. peltate 2. sagittal 3. hastate
Predominant position (shape) of the leaf blade surface	PrPL	1. drooping 2. horizontal 3. cup-shaped 4. erect apex down (EAD) 5. oriented apex down (OAD)
Margin of the leaf blade	MaLB	1. whole 2. corrugated
Leaf blade variegation	LeBV	0. absent 1. present
Profile of the petiolar junction	PrPJ	0. absent 1. small 2. large
Shape of the leaf sheath	ShLS	1. closed 2. open
Shape of the appendix	ShAp	1. thin 2. thick 3. hook

3. Results

3.1. Traits Observed and Variants Distribution and Frequencies

A total of 213 accessions were collected throughout 14 regions of Côte d'Ivoire. As indicated in Table 2, the shape of the base of the leaf (ShBL) presented three variants. Leaves peltate and sagittal was the most abundant with 44.13% and 45.54% respectively. The third variant consisted of leaves hastate (10.33%). Five variants were observed for the trait, predominance position of the leaf blade surface (PrPL). The most abundant was cup-shaped which was observed on 45.54% of accessions. For Margin of the leaf blade (MaLB), two variants were observed, whole (0.94%) and corrugated (99.06%). Leaf blade variegation (LeBV) was present in 94 accessions (44.13%) and absent in 119 accessions (55.87%). Profile of the petiolar junction had three variants, small, large, or absent. Among the 213 accessions it was small in 11.27%, large in 19.25% and absent in the most of accessions (69.48%). For the whole of accessions, the shape of the leaf sheath was closed (44.13%) or open (55.87%). The shape of the appendix presented three variants. The most abundant was thin with 55.87% and the weak was

Table 2. Frequency of traits variants of the 213 accessions.

Traits observed	Variants	Numbers	Percents (%)
Shape of the base of the leaf (ShBL)	Peltate	94	44.13
	Sagittal	97	45.54
	Hastate	22	10.33
Predominant position (shape) of the leaf blade surface (PrPL)	Drooping	20	9.39
	Horizontale	2	0.94
	Cup-shaped	97	45.54
	Erect apex down (EAD)	53	24.88
	Oriented apex down (OAD)	41	19.25
Margin of the leaf blade (MaLB)	Whole	2	0.94
	Corrugated	211	99.06
Leaf blade variegation (LeBV)	Absent	119	55.87
	Present	94	44.13
Profile of the petiolar junction (PrPJ)	Absent	148	69.48
	Small	24	11.27
	Large	41	19.25
Shape of the leaf sheath (ShLS)	Close	94	44.13
	Open	119	55.87
Shape of the appendix (ShAp)	Thin	119	55.87
	Thick	62	29.11
	Hook	32	15.02

hook-shaped with 15.02%. The variants of the discriminants traits are present in Figure 1.

3.2. Morphological Variation and Accessions Structuration

Multiple Correspondence Analysis (MCA) performed revealed that the cumulative contribution of the first (PC1) to six (PC6) component was 100% of the total variability among the 213 accessions, with 43.2%, 19.6%, 17.4%, 13.2%, 5.4% and 1.2% for PC1, PC2, PC3, PC4, PC5 and PC6 respectively. For the following of this study, we focused our analysis in the first two principal components accounted for 62.8% of the total variability. Excepted the Margin of the leaf blade all the parameters analyzed contributes highly to the differentiation of accessions. All traits considered in this study were responsible for the separation of accessions. They were correlated strongly and positively with the two axes (r > 0.8).

1 2 3

Shape of the base of the leaf (1. peltate 2. sagittal 3. hastate)

1 2 3

Shape of the appendix (1. thin 2. thick 3. hook)

1 2 3

Profile of the petiolar junction (0. absent 1. small 2. large)

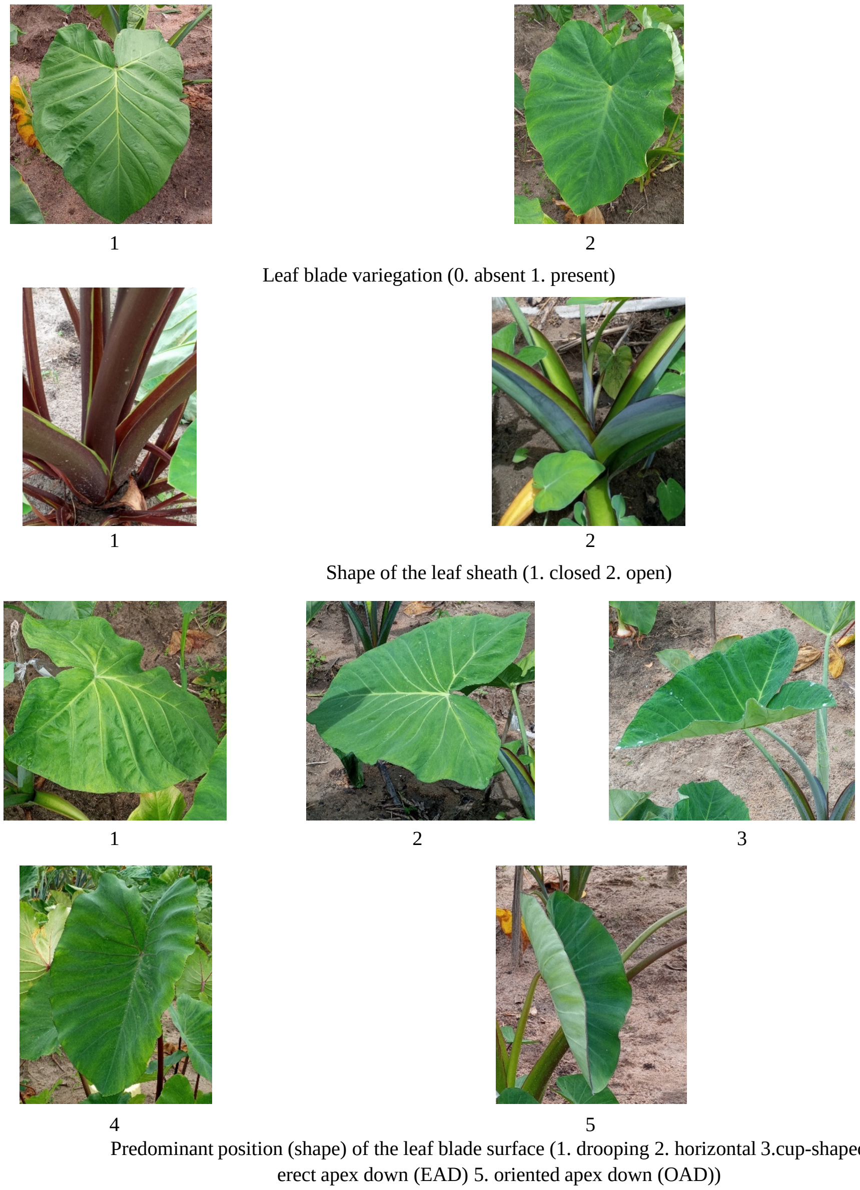

Figure 1. Variants of six discriminant traits on the taro accessions collected in Côte d'Ivoire.

Shape of the base of the leaf, Leaf blade variegation, Shape of the leaf sheath, Shape of the appendix were correlated with the first component. The axis 1 described the shape of leaf. Profile of the petiolar junction was correlated to the second component. One only parameter, predominant position of the leaf blade surface was correlated to the two components at the same time (**Table 3**).

Based on their average linkage to axes, the 213 accessions analyzed were grouped into six aggregates clearly separate (**Figure 2**). The group I brings together accessions with the same shape of the leaf sheath and appendix. The position of the leaf blade surface was predominant. Accessions of group III is characterized by the shape of the base of the leaf, the leaf blade variegation, and the

Table 3. Eigenvalues, correlations between traits and the first two factorial axis.

	PC1	PC2
Eigenvalues	0.8	0.36
% of variance	43.21	19.55
% of cumulative variance	43.21	62.76
Shape of the base of the leaf (ShBL)	0.99	0
Predominant position of the leaf blade surface (PrPL)	1	0.81
Margin of the leaf blade (MaLB)	0.02	0
Leaf blade variegation (LeBV)	0.99	0
Profile of the petiolar junction (PrPJ)	0.64	0.94
Shape of the leaf sheath (ShLS)	0.99	0
Shape of the appendix (ShAp)	0.99	0.79

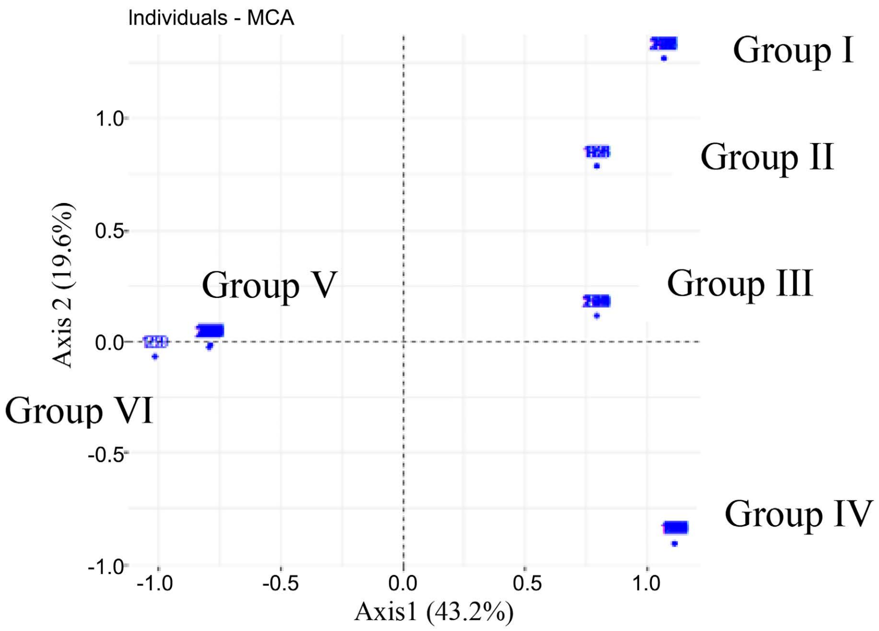

Figure 2. Scattered diagram of 213 accessions for the first two PCs.

shape of the sheath. The group II was intermediate between group I and III, it was characterized by the profile of petiolar junction which was different variants. Group IV was opposite to group I. The accessions of group V and VI were very nearly. They were opposite to group I, II, III and IV.

The phenogram (Figure 3), was obtained by the HCPC (Hierarchical Clustering on Principal Components) function with FactoMineR package. HCPC combines the classification methods (HAC and k-Means) and applies them on the results of Multiple Correspondence Analysis. The six aggregates clearly separate obtained by MCA have been grouped together in two large groups (Group I and Group II). Group II is composed of two subgroups.

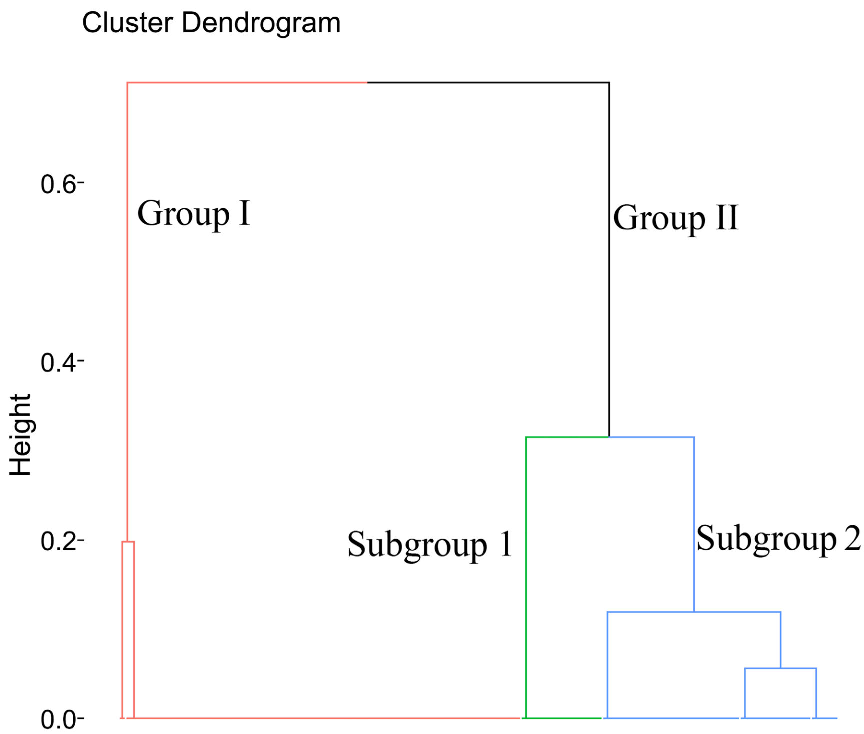

Figure 3. Dendrogram of 213 accessions constructed using HCPC (Hierarchical Clustering on Principal Components) function.

Factorial discriminant analysis was performed (FDA) using the groups highlighted by Hierarchical Ascending Classification (HAC) as a classification criterion. The first two factors (Factor 1 and 2) of FDA explained 78.5% of the total variation. Factor 1 account for 52.1% of the total variation and the factor 2 account for 26.4%. The main contributions of these factors ($P < 0.001$) came from six out of the seven traits analyzed: shape of the appendix (ShAp), predominant position (shape) of the leaf blade surface (PrPL), profile of the petiolar junction (PrPJ), leaf blade variegation (LeBV), shape of the leaf sheath (ShLS) and shape of the base of the leaf (ShBL). The scattered diagram of accessions in the plane describes by these two factors showed three main clusters (Group I, Subgroup 1 and Subgroup 2 of Group II) (**Figure 4**). Based on indicators of class/modality describing the percentage of all accessions presenting the modality found in a class and modality/class showing the percentage of all accessions of a class presenting the modality, the characteristic of each cluster was pointed out. As indicated in **Table 4**, six traits and 20 variants significantly contribute to the formation of clusters.

Cluster 1 brings together accessions with a thin appendix with the leaf sheath open, the leaf blade is without variegation. They have a leaf blade surface that has a predominant position in cup-shaped and drooping. Shape of the base of the leaf is sagittal, hastate without profile at the petiolar junction level. This cluster represents 55.87% *i.e.*, 119 out the 213 of analyzed accessions.

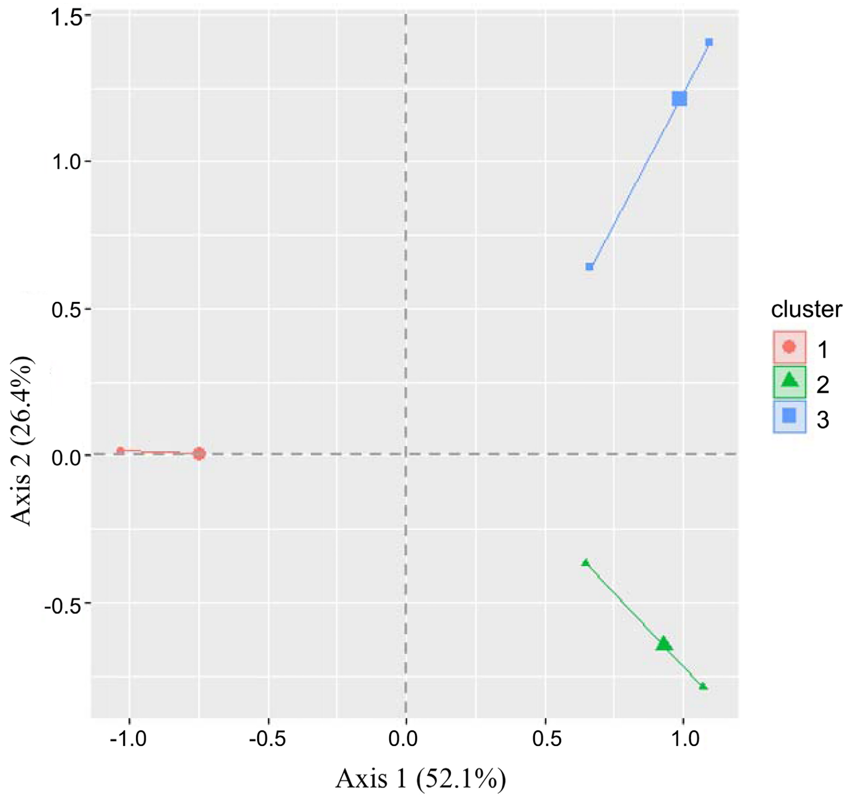

Figure 4. Clusters from the hierarchical classification of principal components made using the first two axes of the factorial analysis.

Table 4. Recapitulation of variables characterizing the three clusters obtained from the hierarchical classification on principle components.

Clusters	Variants	Class/Modality	Modality/Class	Global (%)	P
Cluster 1	ShAp = Thin	100	100	55.87	<0.001
	ShLS = Open	100	100	55.87	<0.001
	LeBV = Absent	100	100	55.87	<0.001
	PrPL = Cup-shaped	100	81.51	45.54	<0.001
	ShBL = Sagittal	100	81.51	45.54	<0.001
	PrPJ = Absent	80.41	100	69.48	<0.001
	ShBL = Hastate	100	18.49	10.33	<0.001
	PrPL = Drooping	100	16.81	9.39	<0.001
Cluster 2	ShAp = Thick	100	100	29.11	<0.001
	ShLS = Closed	65.96	100	44.13	<0.001
	LeBV = Present	65.96	100	44.13	<0.001
	ShBL = Peltate	65.96	100	44.13	<0.001
	PrPJ = Large	100	66.13	19.25	<0.001
	PrPL = OAD	100	66.13	19.25	<0.001
	PrPJ = Absent	14.19	33.87	69.48	<0.001
	PrPL = EAD	14.19	33.87	69.48	<0.001

Continued

	ShAp = Hook	100	100	15.02	<0.001
	PrPJ = Small	100	75	11.27	<0.001
	PrPL = EAD	60.38	100	24.88	<0.001
Cluster 3	ShLS = Closed	34.04	100	44.13	<0.001
	LeBV = Present	34.04	100	44.13	<0.001
	ShBL = Peltate	34.04	100	44.13	<0.001
	PrPJ = Absent	5.41	25	69.48	<0.001

Cluster 2 consists of accessions with thick appendix, with the leaf sheath closed and leaf blade is variegation. Shape of the base of the leaf is peltate with a profile petiolar junction large or absent. The leaf blade surface is erected apex down (EAD) and oriented apex down (OAD). This cluster represents 29.11% *i.e.*, 62 out the 213 of analyzed accessions.

Cluster 3 is characterized by accessions with hook-shaped appendix, with a profile petiolar junction small or absent. The leaf sheath closed and shape of the base of the leaf is peltate. The leaf blade surface is erected apex down (EAD). This cluster brings together 32 (15.02%) accessions.

4. Discussion

According to FAO [12], sustainable use of plant genetic resources is fundamental for a progressive realization of the right to food. This human right is realized when every man, woman, and child, alone or in community with others, always has physical and economic access to adequate food or means for its procurement. To face this challenge, it is important to rely on local resources. The access to quantitatively and qualitatively adequate and sufficient food focused to the cultural traditions of the people to which the consumer belongs is necessary for African countries. Today, 150 species are under cultivation in the world but only 12 of them provide 80 percent of our food needs. Hence the term neglected or orphan plant or still underutilized. The lack of adequate policies of promotion or conservation leads to the continued extinction of some crops. The goal of conservation genetics is to maintain genetic diversity at many levels and to provide tools for population monitoring and assessment that can be used for conservation planning.

To guarantee the full success for sustainable management of plant resources it's necessary to knowledge genetic diversity. In fact, the importance of plant genetic diversity (PGD) is now being recognized as a specific area since exploding population with urbanization and decreasing cultivable lands are the critical factors contributing to food insecurity in developing world [13]. Diversity in plant genetic resources (PGR) provides opportunity for plant breeders to develop new and improved cultivars with desirable characteristics, which include both farmer-preferred traits and breeders preferred traits.

Genetic diversity of crop plants is the foundation for the sustainable development of new varieties. So, there is a need to characterize the diverse genetic resources using different markers and utilize them in the breeding programme. Morphological data in conjunction with molecular data are used for precise characterisation of germplasm resources [14]. A first approach to evaluate genetic diversity is morphological characterization based on phenotypic data. Two main parameters are analyzed, the quantitative and the qualitative data. They allow highlighting the divergence intra and inter accessions or population collected. These tools were successfully used in germplasm characterization of several crops [15] [16]

Despite the importance of taro in Côte d'Ivoire, it is weak documented. A recent study realized by [4] revealed 7 morphological types. But a study on plant genetic resources in Côte d'Ivoire [17] revealed that two genera of taro were cultivated. The conservation and characterization of taro genotype are crucial to fulfil the needs of breeders for both present and future generations. In this study, the morphological characteristics of genotypes were determined using *Colocasia esculenta* descriptors for leaf structure and shape. These characteristics could assist breeders in genotype selection dependent on phenotype, as well as in genetic improvement program.

Traits used in this study to evaluate our germplasm diversity have been very discriminants. Six of the seven parameters studied strongly contributed to the formation of the first two axes of the MCA. A total of 63% of variability was described by these axes. This result showed a significant contribution of leaf related characters to morphological variability of taro.

In the first time, the accessions analyzed were grouped into six groups. According to axe 1, four groups (I, II, III, IV) are very close while group V is closer to group VI. This result suggested that the 213 accessions could belong to two distinct genetic groups. Combination of Hierarchical Ascending Classification (HAC) and Factorial discriminant Analysis (FDA) confirmed the existence of two major groups. Main group 2 is subdivided into two subgroups that are very close.

The morphological traits analyzed highlighted an important variability and allowed a clear distinction of the accessions studied. A total of 20 variants were observed on seven traits analyzed. Several authors have reported similar results for the same traits or others [18] [19]. These results indicate that a high phenotypical diversity exists within the taro cultivated in Côte d'Ivoire. The similar result was found by [18] to taro in Burkina Faso. The qualitative traits used in evaluation of diversity were carried out by some author too. Taking into account modalities of the variants three clusters were highlighted. Cluster 2 and cluster 3 have more variants in common compared to cluster 1. This result shows that both clusters would be very close. This conclusion is supported by result of Hierarchical Ascending Classification (HAC). Hereby, the shape of the base of the leaf more frequent is peltate [19] [20] and sagittal [21] which could indicate that at least two genera of Araceae are cultivated in Côte d'Ivoire and called "taro". It could be *Colocasia* and *Xanthosoma*. Characteristics of each cluster allow us to suggest that main group 1 could belong to genus *Xanthosoma*, main group 2 could belong to genus *Colocasia*. Separation of individuals of group 2 into two subgroups could indicate existence of various varieties or species into genus *Colocasia* [22]. In a study conducted on a species of taro, *Colocasia esculenta* in Côte d'Ivoire, authors revealed presence of cinq varieties. These results show the diversity of taro cultivated in Côte d'Ivoire. A high diversity in the position of the leaf blade surface was observed among accessions collected. Such a variation has been described by [19]. According to these authors drooping leaves are characteristic of *Colocasia* and hastate leaves to *Xanthosoma.* Based on these observations our study showed that the most cultivated genus in Côte d'Ivoire would be *Xanthosoma*.

5. Conclusion

The observable characteristics or traits of leaves have been used to describe the accessions of taro collected in various agro-ecological areas in Côte d'Ivoire. Our study showed the existence of more variants of each trait of taro. Two major groups have been highlighted based on traits analyzed. Result allows us to suggest that two genera of taro are cultivated in Côte d'Ivoire. The large group consisted of accessions presenting the characteristic to the genus *Xanthosoma*. But the highest diversity seems to be observed with accessions describing *Colocasia*. The genetic characterization by SSR markers in progress could help us with the identification of clones and the establishment of a breeding program of taro in Côte d'Ivoire.

Conflicts of Interest

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

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