

Morphological Diversity within *Pterocarpus erinaceus* Poir. (Fabaceae), an Overexploited Species in the Savannahs of Côte d'Ivoire

Koudougnon Alice Estère Goba*, Léonie Clémence Kouonon, Kouamé Guillaume Koffi,
Béket Sévérin Bony, Issoumaila Diomandé, Raoul Sylvère Sié

Laboratoire de Biologie et Amélioration des Plantes, UFR Sciences of Nature, Université Nangui Abrogoua, Abidjan, Côte d'Ivoire
Email: *aegoba3@yahoo.fr, lckouonon@yahoo.fr, koffiguillaume2005@yahoo.fr, bonybekets@yahoo.com,
ismaeldiemande051@gmail.com, sieraoul@yahoo.fr

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Abstract

Pterocarpus erinaceus is a high socio-economic tree of African savannahs. It is overexploited due to technological qualities of its wood, forage value and medicinal uses. The main objective of this study is the assessment of the morphological variability within this species in Côte d'Ivoire, in sight of rational management. Fourteen morphological traits were used to appraise the variability within 144 trees in production from six sites (Yalo, Moyenne Marahoué, Kahanso, Kouassi-Ndawa, Ouarigué and Téguidouo). The results indicate that the variability reaches 6.60 for the height of the fruit and 45.99 for the weight of the fruit. The results reveal also that there are three morphological groups of *P. erinaceus* in Côte d'Ivoire. Of the four traits that revealed a distinction among the three morphotypes, only the width of leaves and the number of leaflets enabled their complete distinction. Trees of group 1 have long leaves with a high number of leaflets and large fruits. Trees of group 2 have small leaves with a reduced number of leaflets and large fruits. Then trees of group 3 have intermediate value of width of leaves and number of leaflet and small fruits. The three morphological groups could be useful for varietal selection of *P. erinaceus* in Côte d'Ivoire.

Keywords

Morphological Traits, *Pterocarpus erinaceus*, Rational Management, Varietal Selection

1. Introduction

The implementation of trees sustainable management and conservation strategy cannot be achieved without a good knowledge of the phenotypic and genotypic variability of the species, enabling individuals' differentiation [1]. Morphological variability study is appropriate for overall genetic improvement and tree varietal selection activities. It enables the identification of attractive morphological descriptors, identification of traits linked to the origin of seeds sources [2] and possible genetic groups. In Côte d'Ivoire, the variability of woody savannah species is poorly studied, when ecosystems that support them are highly threatened and native species are lost with their gene pools. *P. erinaceus*, commonly known as African rosewood, Senegal rosewood, African teak, African kino tree, is a species widespread in the savannahs of Côte d'Ivoire. This species, endemic to Guineo-Sudanian and Sudano-Sahelian areas, is multipurpose for local populations [3]. Indeed, it is sought by craftsmen for the manufacture of various musical instruments (balafons, n'goni and djembés). It is one of the most widely used woody species in the savannah of Côte d'Ivoire by farmers as forage [4]. Likewise, the bark, leaves and roots of the tree are used in pharmacopoeia to treat several illnesses including anemia, cough, dysentery, malaria and infant fever [5] [6] [7]. This species is sought-after, exploited and threatened in West Africa [8] for timber and is exported to Asian countries, mainly China. African teak provides a high-value timber for export used in cabinetmaking, building and armaments. For these uses, the species is constantly mutilated and cut in its natural populations without any preservation measures. The high pressure exerted on the populations of *P. erinaceus* makes it one of the most threatened woody species in the savannahs of Côte d'Ivoire. In addition, studies carried out to date in west Africa on the species have only focused on structural variability and ethnobotany [9] [10] and those conducted especially in Côte d'Ivoire are only on germination tests [11]. Considering the threats on this species, it is appropriate to produce reliable data on its morphological variability, what is a prerequisite for detecting outstanding phenotypes and the development of optimal valorization plans and preservation of the species. The objective of the present study was to assess the genetic diversity among populations of *P. erinaceus* by morphological traits in Côte d'Ivoire. Specifically, this involves 1) identifying different morphological groups within *P. erinaceus* based on morphological traits and 2) determining the discriminating traits of morphological groups of *P. erinaceus* present in Côte d'Ivoire.

2. Material and Methods

2.1. Plant Materials

P. erinaceus is a leafy arborescent species about 20 m high in a straight shaft. Compound leaves, alternate and imparipinnate consist of 7 to 15 leaflets from oval to elliptical shapes [12]. The inflorescence is a panicle made up of golden yellow fragrant hermaphroditic flowers. The fruit is an indehiscent pods garlic at maturity, rounded and flat in shape. Straw-coloured fruits contain one or two

seeds. The seeds are kidney-shaped and dark brown in colour [12].

2.2. Description of the Study Areas

The study was carried out in the savannahs of Côte d'Ivoire (northern part of the country), the natural distribution area of *P. erinaceus*. According to variation in climatic factors and vegetations, Sudanian savannah, sub-Sudanian savannah and Guinean savannah can be distinguished [13]. In each of these savannahs, two sites were selected to characterize the morphological variability of natural populations of *P. erinaceus* (Figure 1).

In Sudanian savannah, the sampling sites are the Ouarigué protected area (58,000 ha) located between 9°61' and 9°65' North latitude and between 4°89' and 4°96' West longitude and the Téguidou site (village to 5 kms from Bouna) located between 9°25' and 9°28' North latitude and between 2°92' and 2°95' West longitude. The Téguidou site is subjected to many pressures including illegal grazing and bushfires. The Ouarigué protected area is under pressure from human activities such as uncontrolled land clearing and overgrazing. The climate in the area is Sudanese and typified by a long dry season (October to June) and a short rainy season (July to September). The annual rainfall varies from 700 to 1200 mm [14] with the intermittent presence of harmattan (fresh and dry wind) from December to February. Temperatures vary from 28°C to 32°C [13]. The vegetation consists of shrubby and grassy savannah with forest galleries along the water-courses [13]. The soils are of tropical ferralitic and ferruginous types [15].

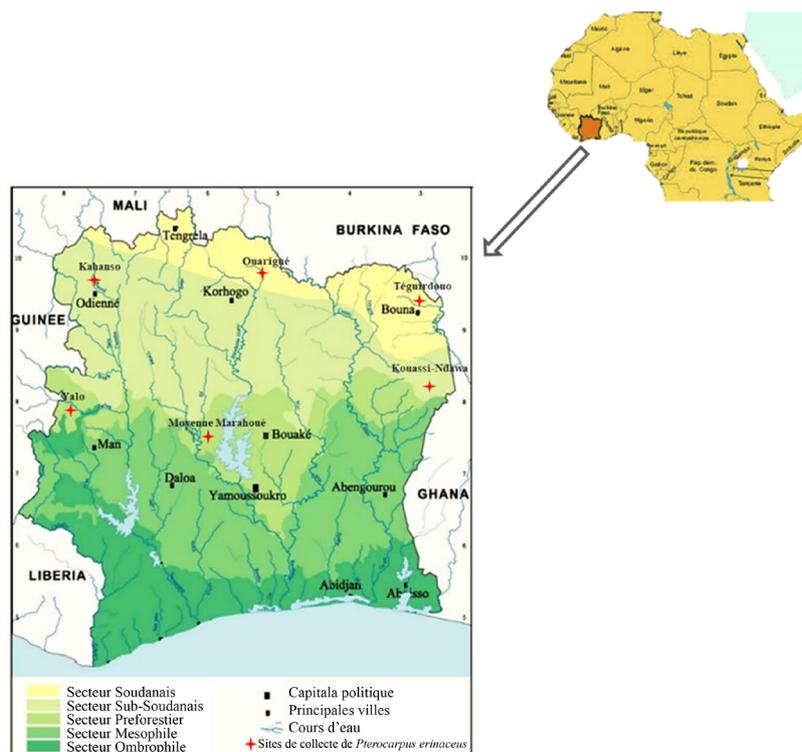


Figure 1. Morphological data collection sites of *Pterocarpus erinaceus* in the three types of savannahs of Côte d'Ivoire.

In sub-Sudanian savannah, the protected areas of Kahanso (7400 ha) located at latitude 9°17' North and longitude 7°37' West, and Kouassi-Ndawa located at latitude 8°13' North and longitude 2°90' West (300 ha), constitute the sampling sites. The Kahanso site, which is poorly preserved, is typified by the presence of grazing. On the other hand, Kouassi-Ndawa site deprived of all human activities is a well preserved site. These sites are characterized by open forests and wooded savannahs that stretch over ferralitic soils [15]. The climate is Sudano-Guinean, under the influence of the harmattan, with two seasons, a rainy (4 to 5 months) and a dry (7 to 8 months). Annual precipitation ranges from 1200 to 1600 mm [14] and occurs mostly during July to September. The temperature varies from 16°C to 36°C with an average of 27°C [16].

In Guinean savannah, the Yalo protected area (7°80' - 8°10' North latitude and 7°70' - 8°12' West longitude) with an area of 26,800 ha and the Moyenne Marahoué protected area in the department of Zuenoula (7°52' - 7°80' North latitude and 6°12' - 6°30' West longitude) with an area of 38,800 ha were investigated to this study. The protected area of Yalo is an open anthropized forest (Teak reforestation (*Tectona grandis*) and grazing). The Moyenne Marahoué site is also subject to pressures such as farming, illegal tree logging and carbonization which is the important activity practiced by the population in this area. The Guinean savannah is the area of the pre-forest sector made of mesophilic (or semi-deciduous) forests and savannahs. The climate is equatorial with a bimodal regime; it consists of two rainy seasons spaced by two dry seasons [13]. The average annual rainfall is 1200 mm with an average annual temperature of 27°C [17]. The soils are ferralitic type [18].

2.3. Sampling Methods

Individuals of *P. erinaceus* from the same site were considered as one population, provenance or origin. In each population, trees separate at least 100 m from each other, with a diameter of 1.30 m from the ground (dbh) greater than 30 cm [1] [19] were selected for organs collection. Each individual is numbered with paint to prevent it from being inventoried twice, then georeferenced using a GPS system (Geographical Positioning System). A total of 144 fruit-trees of *P. erinaceus* from the six sites following the climatic gradient were sampled in this study (Table 1).

Table 1. Geographical coordinates of the six stands of *P. erinaceus* and the number of trees sampled in Côte d'Ivoire.

Types of savannah	Sites	Number of samples	Longitude	Latitude	Altitude (m)
Guinean savannah	Yalo	28	7.904919	-7.840648	502
	Moyenne Marahoué	18	7.609717	-6.236031	282
Sub-Sudanian savannah	Kahanso	24	9.285753	-7.62309	426
	Kouassi-Ndawa	35	8.116282	-2.90282	361
Sudanian savannah	Ouarigué	13	9.614801	-4.974909	369
	Téguirdou	26	9.612379	-4.97574	373

2.4. Data Collection

Fourteen quantitative traits were measured on trees, leaves, fruits and seeds of *P. erinaceus* [1] [19] [20]. The parameters measured on the productive trees are the diameter at breast height (dbh), the height of the bole and the total height. The heights (total and bole) were measured using a graduated pole. The circumference of the trees was measured with a tape measure. The mensurations on leaves concerned ten leaves per tree. The variables evaluated on the leaves are the length and width of the leaf and the number of leaflets per leaf. On each leaf, three leaflets (basal, medial and apical) were collected for measuring the length and width of the leaflet. The mensurations on leaves and leaflets were made with a graduated ruler and an electronic caliper with an accuracy of 0.01 cm. Fruit characterization was performed on 150 fruits per tree. At the fruit level, height, width and weight were measured. The number of seeds per fruit was counted. For each seed, length, thickness and weight were measured. The length and width of the fruit and seed were measured using an electronic caliper with an accuracy of 0.01 cm. Fruits and seeds were weighed with a 0.1 mg electronic precision scale. The total traits which is using in this study are summarized in **Table 2**.

Table 2. Morphological descriptors used to characterize the six populations of *P. erinaceus* in Côte d'Ivoire.

Traits	Codes	Mensuration methods
Tree height	Th	Distance from the ground surface to the end of the tree top
Bole height	Bh	Distance from the ground surface to the first branch of the tree
Diameter at breast height	Dbh	Ratio of the circumference at breast height on π ($\pi = 3.14$)
Length of the leaf	Lle	Distance between the point of leaf insertion on the stem and the tip of the apex of the terminal leaflet
Width of the leaf	Wile	Lateral distance of the leaf
Number of leaflets	Nllt	Total number of leaflets observed on a leaf
Length of the leaflet	Lllt	Distance between the attachment point of the petiolule on the main rib and the end of the leaflet
Width of the leaflet	Willt	Lateral distance of the leaflet
Weight of the fruit	WFr	Weight of mature fruit
Height of the fruit	HFr	Distance between the point of insertion of the fruit on the pedicel and the end of the fruit
Width of the fruit	WiFr	Lateral distance from the fruit
Weight of the seed	WSe	Weight of the seed from the mature fruit
Length of the seed	LSe	Distance between the two tips of the seed
Thickness of the seed	TSe	Spread between the two faces of the seed

2.5. Data Analysis

Several statistical methods were used to evaluate and analyse the structure and

distribution of phenotypic variability of *P. erinaceus* from the collected data. The modalities of the different parameters have been codified for the statistical analyses. The coded data were analyzed using XLSTAT Ecology software version 2018.5, according to the six sites of the three types of savannah. A descriptive statistic was performed to analyze all the variables of the six sites in order to highlight the mean, standard deviation, coefficient of variation (CV), maximum and minimum. The relationships between the quantitative traits were analyzed by submitting a data at a matrix correlation in order to determine the coefficients of correlation. A transformation of the reduced centred variables was performed for multifactor analysis followed by hierarchical ascendant classification (HAC). The discriminant function analysis (DFA) was carried out to structure the *P. erinaceus* of the trees according to morphological traits. This analysis also revealed the most discriminating traits. A dendrogram from the HAC was constructed using the Unweighted Pair-Group Method with arithmetic Average (UPGMA). A multiple analysis of variance was performed to compare all discriminating morphological traits together then one way analysis of variance (ANOVA 1) were carried out using the means of the discriminating variables to compare the different groups constituted. Significant ANOVA tests were followed by the multiple pair comparison (LSD) Fisher test at the 5% significance threshold.

3. Results

3.1. Global Morphological Characteristics of *Pterocarpus erinaceus*

The results of the descriptive statistics carried out with all the morphological traits are in **Table 3**. Of the fourteen morphological traits, seven (diameter at breast height, bole height, leaf length and width, leaflet length and seed length) showed a fairly high variability with CV varying from 15% to 30%. The fruit weight is the most variable trait with CV upper than 45% whereas the fruit height and width are the less variable with CV lower than 10%. The number of leaflets per leaf and seed thickness showed moderate variability ($10 < CV < 15$).

3.2. Structuration of Morphological Variability in *Pterocarpus erinaceus*

3.2.1. Analysis of Correlations between Variables

The correlation matrix of the different variables analyzed is reported in **Table 4**. The presence of a link between the variables made it possible to retain those that were taken into account in the discriminant function analysis. The examination of the correlation matrix on the entire sample indicates the existence of some correlations strong, positive and very significant between different quantitative traits measured on *P. erinaceus*. There is a correlation between the leaf length and leaf width ($r = 0.762$), between leaf width and leaflet length ($r = 0.772$), between leaflet length and leaflet width ($r = 0.809$), between fruit width and seed weight ($r = 0.701$) and between seed weight and seed length ($r = 0.772$). The fruit

Table 3. Mean values, coefficients of variation (CV) and amplitudes of *Pterocarpus erinaceus* variables.

Variables	Average	Standard deviation	CV (%)	Minimum	Maximum
Th (m)	12.27	2.16	17.57	7	18
Bh (m)	4.23	1.27	29.97	2	8
Dbh (cm)	40.11	9.54	23.77	30.19	69.05
Lle (cm)	28.64	4.79	16.74	19.28	45.29
Wile (cm)	17.01	2.62	15.39	11.64	24.17
Nllt	9.75	1.23	12.63	6.80	12.50
Lllt (cm)	8.06	1.22	15.18	5.42	11.57
Willt (cm)	4.27	0.76	17.68	2.92	6.80
WFr (g)	0.41	0.19	45.99	0.21	0.76
HFr (mm)	66.29	4.38	6.60	55.85	77.58
WiFr (mm)	49.40	4.89	9.90	41.02	68.16
WSe (g)	0.06	0.02	33.86	0.03	0.14
LSe (mm)	8.66	1.428	16.50	5.86	10.50
TSe (mm)	2.16	0.25	11.60	1.31	2.67

Table 4. Correlation matrix between the fourteen morphological variables analyzed in the six populations of *Pterocarpus erinaceus*.

Variables	Dbh	Bh	Th	Lle	Wile	Nllt	Lllt	Willt	WFr	HFr	WiFr	WSe	LSe	TSe
Dbh	1.000													
Bh	-0.001	1.000												
Th	0.254	0.459	1.000											
Lle	-0.061	0.051	0.195	1.000										
Wile	-0.194	0.080	0.122	0.762*	1.000									
Nllt	-0.282	0.177	0.059	0.472	0.368	1.000								
Lllt	-0.108	0.125	0.121	0.603	0.747*	0.267	1.000							
Willt	-0.157	0.175	0.094	0.555	0.637	0.251	0.809*	1.000						
WFr	-0.037	-0.041	-0.044	0.298	0.302	0.176	0.418	0.376	1.000					
HFr	-0.131	0.007	-0.077	0.286	0.196	0.344	0.312	0.326	0.562	1.000				
WiFr	-0.024	-0.080	-0.054	0.277	0.271	0.106	0.347	0.305	0.827*	0.532	1.000			
WSe	0.012	-0.064	-0.067	0.157	0.116	0.029	0.262	0.197	0.863*	0.447	0.701*	1.000		
LSe	0.043	0.136	0.085	0.163	0.119	0.099	0.301	0.139	0.728*	0.427	0.578	0.772*	1.000	
TSe	0.047	-0.042	-0.121	0.102	0.022	0.050	0.232	0.195	0.423	0.385	0.329	0.372	0.438	1.000

*corrélations significatives et positives.

weight is correlated positively to three characters that are the fruit width ($r = 0.827$), the seed weight ($r = 0.63$) and seed length ($r = 0.728$). In this case, only one of the variables of these pairs was considered. To avoid redundancy, the number of variables was reduced and five variables (leaf length, leaflet length, fruit

width, seed weight and seed length) were removed.

3.2.2. Identification of *Pterocarpus erinaceus* Groups

The discriminant function analysis (DFA) was carried out using the mean values of the nine quantitative traits considered. The first factors (axes 1 and 2) of DFA represent the largest part of discrimination, accounting for 95.46% of the total variance (Table 5). These first two axes will therefore be used to describe the identified groups. The first axis accounts for 86.85% of the total variability. It is strongly correlated to fruit weight and fruit height. The second axis accounts for only 8.62% of the total diversity. The main contributions to this axis come from two traits: leaf width and the number of the leaflet. Of the fourteen traits studied, four enabled distinguishing three groups within population of *P. erinaceus* in Côte d'Ivoire.

Figure 2 shows, in the discriminating factorial plane, the three groups formed by canonical axis 1 and 2. In addition, the hierarchical ascendant classification (HAC) carried out made it possible to group populations of *P. erinaceus* into relatively homogeneous groups on the basis of their similarities.

The UPGMA dendrogram highlighted three groups (Figure 3). Groups can be distinguished from the truncation point of 117 Euclidean distance units. Based on discriminated traits, the characteristics of the different groups are:

- Group 1, located in the positive part of axes 1 and 2, consists of the Kouassi-Ndawa trees. This group represents 24.3% of all trees. The trees in this group have the best phenotypic characteristics compared to trees in other groups. Kouassi-Ndawa trees are characterized by large leaves (19.61 ± 2.14 cm) with a high number of leaflets (10.48 ± 0.90) and large fruits (0.65 ± 0.04 g; 69.48 ± 2.82 mm of height).

Table 5. Eigvalues, variance in discriminat function analysis axes 1 and 2 and factorial weights of quantitative variables.

Axes	1	2
Eigenvalues	21.862	2.169
Variance (%)	86.85	8.62
Cumulative variance (%)	86.85	95.46
Th	-0.065	0.213
Bh	-0.047	0.28
Dbh	-0.053	-0.232
Wile	0.309	0.721*
NlIt	0.198	0.724*
Willt	0.395	0.515
WFr	0.999*	-0.037
HFr	0.599*	0.55
TSe	0.423	0.104

*Significant values: variables that contribute most to the formation of axes.

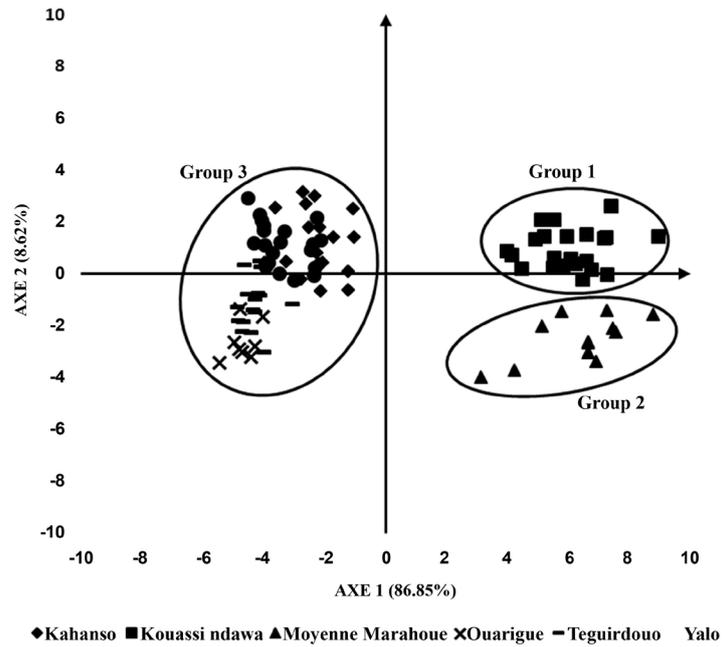


Figure 2. Representation of the three groups identified on *Pterocarpus erinaceus* populations in factorial plan 1 and 2.

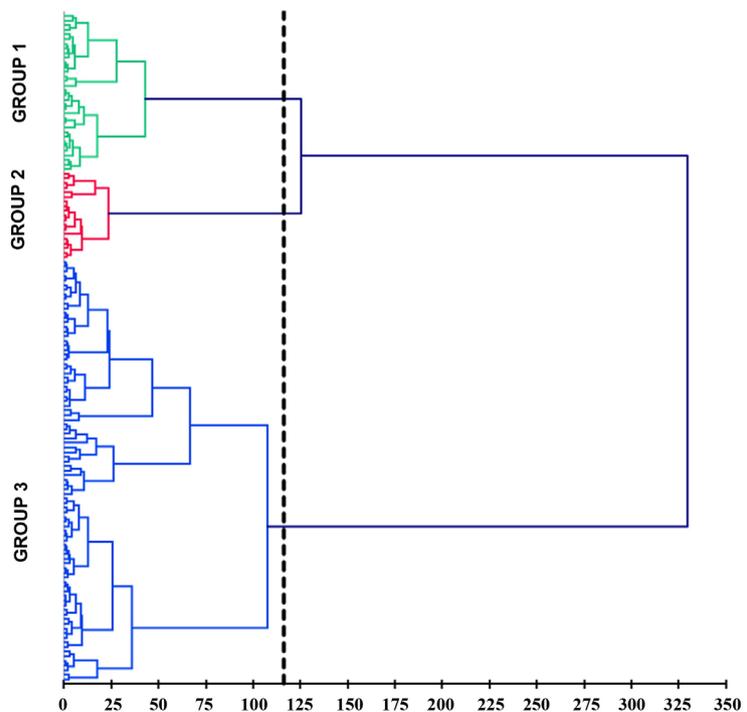


Figure 3. Dendrogram of the six populations of *P. erinaceus* based on Euclidean distances of morphological traits [G1: Group 1 (35 individuals), G2: Group 2 (18 individuals) and G3: Group 3 (91 individuals)].

- o Group 2, with 18 individuals (12.5% of total trees), includes trees of Moyenne Marahoué. This group is located in the negative part of axis 1 and positive part of axis 2. Individuals in this group have small leaves (14.87 ± 1.32 cm)

with a reduced number of leaflets (8.90 ± 0.94) and large fruits (0.65 ± 0.07 g; 68.44 ± 2.68 mm).

- o Group 3 placed in the negative part of axis 2 consist of trees from Yalo, Kahanso, Ouarigué and Téguidou. This group represents 63.2% of the total trees size. This group includes trees with intermediate leaves size (16.44 ± 2.23 cm of width; 9.64 ± 1.25 leaflets) and small fruits (0.27 ± 0.04 g).

3.3. Determination of Discriminating Traits of Morphological Groups of *Pterocarpus erinaceus*

The multivariate analysis of variance (MANOVA) for the parameters of the identified groups showed very highly significant difference ($F = 145.2$; $p = 0.038$). The results of the analysis of variance (ANOVA) for each of the four discriminating traits by factorial weight showed a very highly significant difference (Table 6). Of the four distinctive traits, two (leaf width and the number of leaflet per leaf) revealed a complete distinction among the three groups. Regarding leaf width, group 1 has wide leaves (19.61 ± 2.14 cm) than those in group 3 (16.44 ± 2.23 cm) which are wide than those in group 1 (14.87 ± 1.32 cm). In terms of the number of leaflets per leaf, trees in group 2 have a high number of leaflets (10.48 ± 0.90) than those in group 3 (9.64 ± 1.25) which in turn are smaller than those in group 2 (8.90 ± 0.94). Two characteristics (fruit weight and height) revealed a partial distinction among the three groups. Thus, trees in group 1 and 2 are larger (0.65 ± 0.04 g and 0.65 ± 0.07 g respectively) than those in group 3 (0.27 ± 0.04 g). For fruit height, Group 1 and 2 trees have big fruits (69.48 ± 2.82 mm; 68.44 ± 2.68 mm respectively) than those in group 3 (64.64 ± 4.29 mm).

Table 6. Mean values and standard errors of descriptors of the different groups formed by the discriminant factor analysis.

	Groups			Tests statistiques	
	Group 1 (N = 35)	Group 2 (N = 18)	Group 3 (N = 91)	F	P
Wile (cm)	19.61 ± 2.14^a	14.87 ± 1.32^c	16.44 ± 2.23^b	38.56	<0.001
Nllt	10.48 ± 0.90^a	8.90 ± 0.94^c	9.64 ± 1.25^b	12.61	<0.001
WFr (g)	0.65 ± 0.04^a	0.65 ± 0.07^a	0.27 ± 0.04^b	1059.2	<0.001
HFr (mm)	69.48 ± 2.82^a	68.44 ± 2.68^a	64.64 ± 4.29^b	23.54	<0.001

4. Discussion

4.1. Morphological Descriptors Variability and Sustainable Conservation of *Pterocarpus erinaceus*

Descriptive statistics made from the fourteen morphological traits of *P. erinaceus* from savannahs of Côte d'Ivoire revealed significant variability for some of the traits studied such as height of the drum, diameter at breast height, weight of the fruit and weight of the seed. This variability could be related mainly to genotypic factors and to a lesser extent to anthropogenic and environmental factors. There is a partial correlation between morphological variables and genetic data

in trees [19] [20] [21]. Indeed, morphological characters are markers that reveal important variations between individuals of the same trees population. Thus, they enable to highlight genetic variation related to geographical origin [22]. The variation in morphological traits should be taken into account in the implementation of conservation measures for trees species. Phenotypic variability is essential for the selection of attractive genotypes for domestication purposes [23]. Intra-specific genetic variation is needed for “plus-trees” based on a large gene pool, assurance of species’ ability to adapt to changes in the environment, to avoid the loss of interesting phenotypes for both local populations’ uses and for wood machining. No scientific large-scale reforestation studies with *P. erinaceus* have yet been undertaken in Côte d’Ivoire. Through present study, some *P. erinaceus* trees of attractive and contrasting phenotypes should be used as “plus-trees” for the production of seedlings for the implementation of the species in agroforestry systems for its conservation.

4.2. Morphological Variability Structure of *Pterocarpus erinaceus*

Discriminant factorial analysis and Ward’s ascending hierarchical classification grouped the *P. erinaceus* individuals sampled in the six studied sites into three morphological groups. Of the fourteen traits used for the distinction among the 144 samples, four were found to be discriminatory. Of the four, two (fruit weight and height) enabled partial distinction among the three groups and the other two (leaf width and number of the leaflet) enabled complete distinction among the three groups. These four morphological descriptors could be used as markers to identify phenotypic groups among individuals of *P. erinaceus*. This differentiation of *P. erinaceus* trees could be due to hereditary (genetic) and environmental (origin) factors. These results are consistent with those obtained by [24] on *P. santalinus* and [25] on *Adansonia digitata*. Apart from the probable effect of ecological factors on the differential vegetative development of the analyzed population of *P. erinaceus*, the spatial structuring of morphological diversity could be accentuated by the impact of human pressures (farms and pasture) [20]. In addition, leaf width and number of the leaflet traits can be used as a selection index for an improvement program to increase leaf size for forage production. Based on these results, it is preferable to make a selection from group 1 of *P. erinaceus* consisting of Kouassi-Ndawa trees for a valuation of the species. Also, individuals from the three contrasting phenotypic groups could be chosen as seed producers to produce plants of different origins and phenotypes for provenance tests in the three types of savannah for varietal selection adapted to each type of savannah for different uses for local populations and industrial exploitation.

4.3. Discriminating Phenotypic Traits in *Pterocarpus erinaceus*

The discriminant factorial analysis identified the most discriminating traits for the morphological characterization of the *P. erinaceus* populations studied. The

first component is defined by the fruit weight and height. Leaf width and number of leaflet contributed to the formation of the second component. The analysis of variance of morphological characteristics indicated a differentiation of the populations studied. It results from these comparative analyses that group 1 trees (Kouassi-Ndawa) in the sub-Sudanian savannah have the phenotypic characteristics of high modalities. However, group 2 trees (Moyenne Marahoué) have small leaves with a reduced number of leaflets and large fruits. Group 3 trees (Yalo, Kahanso, Ouarigué and Téguidouo) have the smallest morphological character values. These results could be explained in part by the difference in anthropogenic action on rural populations and to a lesser extent by climatic conditions [25] [26]. It should be noted that the most sought-after aspect of *P. erinaceus* in Côte d'Ivoire is its production of wood (construction and export) and leaves (livestock feed). The discriminating traits identified constitute selection markers for routine identification of phenotypes adapted to different savannah ecosystems in Côte d'Ivoire.

5. Conclusion

The study of the morphological variability of *P. erinaceus* populations carried out in Côte d'Ivoire showed the existence of three phenotypic groups based on tree, leaf, leaflet, fruit and seed traits. Leaf width and number of leaflets enabled a complete distinction of the three groups. The assessment of morphological variability is an essential link in varietal selection to identify individuals that are in the interests of rural populations and domestication of the species. As part of this study, three groups of trees were defined. *P. erinaceus* trees from Kouassi-Ndawa (group 1) showed the best morphological characteristics. However, for the preservation of the species evolutionary potential, the three morphological groups must be considered to capture a broader base of the species variability. Morphological traits are not sufficient to capture the maximum diversity for genebank development because most morphological traits are influenced by the environment. Molecular analyses are therefore necessary to better understand the diversity and genetic structure within the sampled populations. Molecular markers will provide a better understanding of the genetic diversity of *P. erinaceus*. Seeds from the three morphological groups should be used for provenance tests primarily at the Kouassi-Ndawa, Moyenne Marahoué and one Sudanian savannah site.

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Conflicts of Interest

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

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