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Morphological Diversity and Distribution of *Garcinia kola* Heckel (Clusiaceae) in Two Agro-Ecological Areas of Côte d'Ivoire

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Abstract

The purpose of this study is to determine the morphological diversity and distribution of *Garcinia kola* Heckel (Clusiaceae) in two preferential agro-ecological growth areas in Côte d'Ivoire, for the sustainable management of the species. Ninety-four (94) trees of *G. kola* were sampled in Affery (south) and Biankouma (west) and characterized on the basis of 13 quantitative characteristics of the fruit, the general appearance of a plant, leaves and seeds. This study revealed the existence of very significant variability and differences within the trees sampled for most characteristics. Very strong correlations were found among the characteristics of the fruits. On the basis of these characteristics, it emerged that the fruits of the Biankouma area are larger than those of Affery. Ascending hierarchical classification (AHC) structured the trees into three distinct phenotypic groups based on the following discriminating characteristics: fruit height (Hfr), seed mass (Mgr), trunk diameter (Dm), leaf width (largF), Height of first branch (HtF) and width of the petiole (larP). These parameters can be used as a basis for selecting and maintaining the high variability of *G. kola*. Analysis of the geographical distribution of trees, based on the nearest neighbour model, revealed an aggregate distribution in both areas.

Keywords

Garcinia kola Heckel, Morphological Variability, Geographical Distribution, Discriminating Characteristics

1. Introduction

Garcinia kola Heckel (Clusiaceae), known as "petit kola" in Côte d'Ivoire, is one of the most important non-timber forest product (NTFP) generators. Indeed, seeds are sought for their stimulating effects, aphrodisiacs, bad cholesterol cleaners and liver protectors [1]. Seeds are also used in drugs to treat multiple gastrointestinal and pulmonary conditions [2] [3]. Thus *G. kola* is used as a remedy for the treatment of diseases such as diarrhoea, laryngitis, gonorrhoea, headaches and gastritis: *Garcinia kola* bark is also used as a purgative [4]. The pulp is also consumed. The supply of minerals, vitamins and amino acids contained in these fruits makes them complementary foods, sometimes essential, during the lean season for local forest populations [1] [5]. About this species, all parts (from the top to the root) are used by man. It, therefore, provides many services to a large part of the rural population and provides an additional source of income. *G. kola* is one of the forest species of socio-economic interest much appreciated by local populations [6] because the plant has a good market value in Côte d'Ivoire; the economic value of seeds per kilogram is between 1. 70 and 4. 25 USD on average [7].

As a result, there is strong anthropogenic pressure on this species. In Côte d'Ivoire, Ahoussou *et al.* [8] have compiled a list of 35 useful but endangered wildlife species. Among these is *G. kola* (Heckel) which is under permanent human pressure because it is multi-purpose. The threats to forest resources in Côte d'Ivoire are worrying and linked to the expansion of agriculture but also to the development of forestry [9]. In addition, the reforestation policy is aimed at species with a high growth rate and major economic interest [8], such as teak (*Tectona grandis* L. F), framiré (*Terminalia ivoirensis* A. Chev.), azobé (*Lofira alata* Van Tiegh.), makoré (*Tieghemella africana* P.), etc. This has led to the disappearance and scarcity of a significant number of forest trees, thus relieving Côte d'Ivoire of its most beautiful species [9]. Thus, more scientific research studies have recently been carried out in Côte d'Ivoire on this forest resource (*G. kola*). The work mainly concerns technologies for the regeneration of the species [10] and socio-economic interest [6]. Despite this work, several questions remain unanswered, particularly regarding the structuring, distribution and variability of *G. kola* Heckel. 1) *Is there a morphological variability of certain characteristics within the species*? 2) *What is the distribution of G. kola*? *The* main objective of this study is to characterize *Garcinia kola* in two agro-ecological areas of Côte d'Ivoire. The specific objectives are 1) to determine the most discriminating morphological parameters; 2) to group all individuals in the populations on the basis of these parameters; and 3) to assess the distribution status of the two natural populations.

2. Materials and Methods

2.1. Study Environment

This study was carried out in two agro-ecological areas of Côte d'Ivoire for three

years, from 2015 to 2018. One is in the west (Biankouma) and the other in the south (Affery). The choice of these areas was made after several prospecting studies with wholesale and field merchants. The surveys revealed that most of their supply of "petit kola" grains originated in these two areas. Biankouma is a department in the west of Côte d'Ivoire and is part of the Tonpki region. This locality is located 635 km from Abidjan between 7˚44'00'' North and 7˚37'00'' West. The villages in which the work was carried out are Kanta, Kabakouma and Blagouin. Like the entire region, our study area is characterized by mountainous relief, ferralitic and hydromorphic soils. During the year the temperature generally varies from 17˚C to 33˚C with an average of 24˚C. The rainfall varies between 1300 and 2400 mm per year and the vegetation consists mainly of humid forest. Cocoa, rubber and oil palm are the main agricultural export resources, including coffee from the region, which is very popular.

Affery, the second study area, is located in the south of Côte d'Ivoire in the department of Adzopé, 101 km from Abidjan between 6˚18'54'' North and 3˚57'37'' West. The villages in which the work was carried out are Daguikoi, Npokoi, Agbokia and Kossoa. They are located between 4 and 10 Km from Affery. Like the whole region, Affery is located in a humid tropical climate zone, of the Attiéen type. This climate gives it a relatively constant temperature which oscillates around 27.5˚C with four seasons of uneven lengths. The annual rainfall is 1300 mm on average. The town of Affery is characterised by the presence of many hills whose average altitude does not exceed 100 metres. They are separated by long valleys that look like precipices from which several marigots and rivers sometimes leave. The vegetation is dominated by tropical rainforest. This vegetation is composed of two types of forests: primary forest, which is similar to classified forests, and secondary forest, which merges with the vast expanses of fallow land resulting from shifting cultivation and intense logging. The soils are mixed, sandy-clayey and suitable for growing coffee, cocoa, rubber and oil palm. Humid hydromorphic soils suitable for the cultivation of plantain bananas, sweet bananas, rice, etc. are also found there.

2.2. Device for Morphological Characterization

Morphological characterization was conducted on 94 adult trees in all two study areas. These trees have produced fruit at least once. They are considered as adults and therefore make it possible to record all the parameters of the study. These trees were monitored throughout their breeding season, from flowering to fruit harvesting, from April to November, to take into account all phenological stages. From the remarkable flowering stage to the next flowering stage for two cycles. 13 parameters were selected based on a work of Leakey *et al.* [11] [12] Fofana *et al.* [13] and Towanou *et al.* [14]. It is about:

- Fruit parameters: Fruit height (HFr), fruit diameter (DiF), fruit mass (maF), pericarp thickness (EpP), seed box cavity (CLG), seed mass (Mgr), number of seeds per fruit (Ngr);
- The parameters of the shaft port: shaft diameter (Dm), height of the first fork

(HtF);

- Leaf parameters: length (LgF) and width (largF) of the leaf, length (LgP) and width (largP) of the petiole.

On each tree, a minimum of thirty fruits were collected. Given the importance that owners attach to the tree, fruit is usually picked at the base of the trees. Thus, to ensure that the fruits are actually from the collected tree, the selected individuals are separated from each other by at least 25 m. All leaves were collected at the end of the first branch, from the ground, from all trees. Measurements were made on a minimum of thirty leaves per tree.

For data processing, EXCEL and R software were used. The means and analysis of variance made it possible to assess the difference between the parameters studied. The most discriminating variables and related species were identified. The statistical tools that are the PCA (Principal Component Analysis) and AHC (Ascending Hierarchical Classification) make it possible to achieve this objective. The classification carried out is a hierarchical bottom-up classification on the principal component and covers all the parameters studied. This classification was carried out according to the Ward method taking into account the Euclidean distance matrix. The relationships between the different parameters were studied on the basis of total correlations.

2.3. Methods for the Study of Distribution

Transects were constructed and an inventory of *Garcinia kola* trees was carried out using GPS, in projected coordinate systems (x; y) and UTM (Universal Tranvers Mercator). It consisted in noting the geographical coordinates of each individual. Mobile sampling was conducted because the density per hectare of the tree is low; less than three trees per hectare on average. It consisted of walking through the environment in all directions, noting all the trees. This inventory made it possible to create a database.

Data analysis was performed using ArcGIS software. The Average Nearest Neighbor (ANN) tool was used to study the distribution [15]. The ANN measures the distance between each tree and the location of the nearest neighbouring tree. He then averages all these distances from the nearest neighbour. If the average distance is less than the average calculated for a hypothetical random distribution, the distribution of the entities analyzed is considered aggregated. If the average distance is greater than the hypothetical random distribution, the entities are considered dispersed. The average of the nearest neighbour is equal to the observed average distance divided by the expected average distance (the expected average distance is based on a hypothetical random distribution with the same number of entities covering the same total area).

The nearest average neighbor, Average Nearest Neighbor, is given by the following relationship:

$$ANN = \frac{\bar{D}o}{\bar{D}E}$$

where $\bar{D}o$ is the average distance observed between each tree and its nearest

neighbor

$$\bar{D}o = \frac{\sum_{i=1}^{n} d_i}{n}$$

And $\bar{D}E$ is the expected mean distance for the characteristics given in a random way

$$\bar{D}E = \frac{0.5}{\sqrt{n/A}}$$

In the above equations, ***di*** is equal to the distance between entity ***i*** and the nearest neighbouring entity; ***n*** is the total number of individuals and ***A*** is the area of the minimum rectangle encompassing all entities, or an area value specified by the user

The z-score of the nearest average neighbour for the statistics is calculated as follows:

$$SE = \frac{0.26136}{\sqrt{n^2/A}}$$

3. Study of Morphological Variability

3.1. Characteristics of Tree Fruits

Tables 1-3 present the mean values of the fruit parameters and the result of the analysis of variance (ANOVA) for all trees sampled respectively within the population and between the two sites.

3.1.1. Fruit Height (HFr) and Mass and Fruit (maF)

The variables fruit height ***Hfr*** and fruit mass ***maF*** show a significant difference for all trees in the two sites (Table 1). However, the ***maF*** does not show any variation between sites (Table 3). This parameter has a coefficient of variation of 62.14%. The average weight of fruit in Affery is 146.18 g while in Biankouma it is 307.71 g. The ***HFr*** is significantly different from one site to another. The average height of the fruit is 68.36 mm. The coefficient of variation between the sites for fruit height is 20 for Affery and 20.48 for Biankouma.

Table 1. Mean tree performance for fruit dimensions and analysis of variance results (F).

Parameters	Min	Max	Average	Standard deviation	CV (%)	F
HFr (mm)	3.68	106.00	68.36	14.37	21.03	**
maF (g)	5.00	625.00	206.32	128.21	62.14	**
DiF (mm)	36.1	88.94	67.51	10.36	15.35	**
EpP (mm)	7.21	37.16	20.05	5.35	26.72	**
CLG (mm)	25.93	64.00	47.46	8.57	18.06	**
Mgr (g)	2.80	85.81	9.34	8.41	90.06	**
Ngr	1.00	4.00	2.08	0.89	43.01	NS

: significant at the 5% threshold; NS: not significant at the 5% level. **NB: **Hfr**: height of the fruit; **maF**: mass of the fruit; **DiF**: diameter of the fruit; **CLG**: cavity of the seed box; **Mgr**: mass of seeds; **Ngr**: number of seeds per fruit; **EpP**: thickness of the pericarp, **CV:** coefficient of variation.

Table 2. Mean tree performance for leaf size, tree size, and variance analysis results (F).

Parameters	Min	Max	Average	Standard deviation	CV (%)	F
Dm (cm)	15.28	76.43	44.91	12.75	28.39	**
HtF (m)	1.13	14.00	5.27	2.64	50.24	**
LgF (cm)	6.81	17.42	11.84	2.35	19.89	**
largF (cm)	2.43	15.86	5.04	1.71	33.92	**
LgP (cm)	0.78	3.70	1.38	0.34	24.70	NS
larP (cm)	0.16	0.59	0.22	0.06	26.50	**

: significant difference at the 5% level; NS: not significant at the 5% level. **NB: **Dm:** diameter of the trunk; **HtF**: height of the first branch; **LgF**: leaf length; **largF**: leaf width; **LgP**: petiole length; **lgP**: width of the petiole.

Table 3. Average performance of variables for each site and analysis of variance.

	AFFERY		BIANKOUMA		
Variables	Average	CV(%)	Average	CV %	P
Dm (cm)	48.56	25.35	38.76	28.75	0.07
HtF (m)	5.92	46.37	4.16	49.79	0.11
LgF (cm)	11.22	20.15	12.90	16.70	0.04
largF (cm)	4.60	24.50	5.79	38.28	0.07
LgP (cm)	1.34	15.95	1.45	33.12	0.03
larP (cm)	0.22	27.70	0.24	23.56	0.04
HFr (mm)	65.17	20.00	73.75	20.48	0.04
maF (g)	146.18	62.74	307.71	38.12	0.22
DiF (mm)	64.61	16.01	72.41	11.75	0.04
EpP (mm)	19.12	29.23	21.63	21.29	0.04
CLG (mm)	45.50	18.67	50.78	15.24	0.04
Mgr (g)	9.20	113.87	9.62	28.01	0.02
Ngr	2.03	40.50	2.17	46.75	0.02

NB: The underlined probability values are not significant at the 5% level.

3.1.2. The Thickness of the Pericarp (EpP) and the Diameter of the Fruit (DiF)

The diameter of the fruit ***DiF*** and the thickness of the pericarp ***EpP*** are significantly different at the 5% threshold for all trees and between sites (Table 1 and Table 3). The average diameter of fruits ***DiF*** for both populations is 67.51 mm. The coefficient of variation for this parameter is lower for the Biankouma zone, 11.75%, while that of Affery is closer to the general average of 16.01%. There is a high variability for ***EpP*** between sites and for all trees (Table 1 and Table 3).

3.1.3. The Cavity of the Seed Box (CLG)

The results of the analysis of variance indicate that there is a significant difference in the seed housing cavity between fruits from the same area and between areas (Table 1). This character varies from 25.93 to 64 mm for the sites combined. The average determined on all trees is 47.47 mm with a coefficient of var-

iation of 8.57 for Affery and 18.06% for Biankouma respectively. Between the sites (Table 3) the cavity of the seed box varies from 45.50 (Affery) to 50.78 mm (Biankouma). The coefficient of variation between the sites is from 15.24% (Affery) to 18.67% (Biankouma).

3.1.4. Seed Mass (Mgr)

The mass character of the seeds (Mgr) differs significantly between sites and within the entire sample (Table 1). It varies from 2.8 to 85.81 g for the two study areas combined with an average of 9.34 g. The overall coefficient of variation of 90.06% is high. However, according to Table 3, the coefficient of variation is higher in Affery (113.87%) than in Biankouma (28.01%).

3.1.5. The Number of Seeds per Fruit (Ngr)

Analysis of the variance analysis of the number of seeds per fruit (Ngr) for all trees shows that there are no significant differences (Table 1). The number of seeds varies from 1 to 4 per fruit for all trees. The average is 2.08 with a high coefficient of variation of 43.01. The inter-site analysis (Table 3) of the variance for this characteristic indicates a significant difference. The intersite averages are between 2.03 (Affery) and 2.17 (Biankouma) with respective coefficients of variation of 40.50% and 46.75%.

3.2. Characteristics Tree Architecture

Table 2 presents the performance of the leaf and tree wearing variables and the results of the analysis of variance. Table 3 presents the results of the descriptive statistics and the analysis of inter-site variance.

3.2.1. The Diameter of the Trees (Dm)

For the trunk diameter characteristic measured at 1.30 m from the ground, the analysis of variance shows that there is a significant difference for the entire sample (Table 2). The diameter of the trunk is between 15.28 and 76.43 cm. The overall average is 44.91 cm. However, the analysis of variance for each site (Table 3) shows that there is no significant difference for this characteristic. The coefficients of variation are close (Affery, 25.35% and for Biankouma 28.75%).

3.2.2. The Height of the First Branch (HtF)

The height of the first branch varies from 1.13 to 14 m with an average of 5.27 m and a high coefficient of variation of 50.24%. The results of the analysis of variance (Table 2) show that there is a significant difference for this characteristic between trees while there is no difference between sites (Table 3). The coefficients of variation for the two sites are close (46.37% for Affery and 49.79% for Biankouma).

3.3. Leaf Characteristics

3.3.1. Leaf Length (LgF) and Leaf Width (largF)

The analysis of variance (Table 2) for all trees shows that there is a significant

difference for leaf length (LgF) and leaf width (largF). The length of the sheet varies from 6.81 to 17.42 mm. The leaf width varies from 2.43 to 15.86 mm for all trees and a high coefficient of variation of 33.92%. However, there is no significant difference between the sites in terms of leaf width (widthF). For this characteristic, the values of the coefficient of variation are 24.50% for the minimum and 38.2% for the maximum. The length of the inter-site sheets (Table 3) varies slightly from 11.22 to 12.90 mm with a coefficient of variation between 16.70% and 20.15%.

3.3.2. Petiole Length (LgP) and Petiole Width (largP)

The data in Table 2 show that the average petiole length (LgP) is 1.38 cm and a coefficient of variation of 24.7%. The values for this characteristic range from 0.78 to 3.7 cm for all trees. There is no significant difference on the length of the leaf petiole among all trees, unlike the width of the petiole (largP). In addition, there is a difference between sites for petiole length (LgP). However, the width of the inter-site petiole (largP) (Table 3) does not differ significantly. The coefficient of variation for petiole width (largP) is high for both zones combined (26.5%) and inter-site (23.56% for Biankouma and 27.70% for Affery).

3.4. Structuring Morphological Variability

Correlations between parameters

The correlation matrix between the parameters studied (Table 4) shows that there are many positive and significant correlations between the fruit parameters. Some correlations between the fruit parameters are as follows:

Table 4. Correlation matrix on all variables studied in *Garcinia kola* H.

Variables	Dm	HtF	LgF	largF	LgP	larP	HFr	maF	DiF	EpP	CLG	Mgr	Ngr
Dm	1												
HtF	0.04	1											
LgF	−0.23	−0.08**	1										
largF	−0.04	−0.08	0.57****	1									
LgP	−0.06	−0,05*	0.30**	0.27**	1								
larP	−0.14	−0.16*	0.35***	0.33**	0.07	1							
HFr	−0.02	−0.13*	0.22*	0.27**	0.06	0.27**	1						
maF	−0.07	−0.15	0.29**	0.25*	0.13	0.13	0.50****	1					
DiF	−0.03	−0.14	0.25*	0.25*	0.09	0.14	0.55****	0.74****	1				
EpP	0.03	−0.08*	0.19	0.23*	0.10	0.01	0.39***	0.39***	0.56****	1			
CLG	−0.05	−0.12	0.19	0.16	0.05	0.17	0.42****	0.65****	0.86****	0.06	1		
Mgr	−0.01	0.04	0.01	0.08	0.04	0.01	0.03	0.05	0.09	0.03	0.09	1	
Ngr	−0.11	−0.16	0.01	−0.09	−0.08	0.03	0.07	0.30	0.34	0.06	0.38	0.06	1

NB: Underlined values indicate variables between which there is a strong correlation, $p < 0.0001$ "****", $p < 0.001$ "***", $p < 0.01$ "**", $p < 0.05$ "*", r value without "*" are not significative.

- Diameter of the fruit (DiF) and the mass of the fruit (maF), with a correlation coefficient r = 0.74 and p value < 0.0001;
- Seed compartment cavity (CLG) and fruit mass (maF) with a correlation coefficient r = 0.65 and p value < 0.0001;
- Diameter of the fruit (DiF) and the cavity of the seed box (CLG) with a correlation coefficient r = 0.86 and p value < 0.0001;
- Fruit diameter (DiF) and pericarp thickness (EpP) with a correlation coefficient r = 0.56 and p value < 0.0001;
- Diameter of the fruit (DiF) and height of the fruit (HFr) with a correlation coefficient r = 0.55 p value < 0.0001;
- Fruit height (HFr) and fruit mass (maF) with a correlation coefficient r = 0.50 p value < 0.0001;
- Fruit height (HFr) and cavity of seed box (CLG) with a correlation coefficient r = 0.42 and p value < 0.0001.

The only correlation between the morphological parameters of the leaves is that between the width (largF) and length (LgF) of the leaf with a correlation coefficient r = 0.57 with p < 0.0001. No significant correlations are established between tree parameters, fruit parameters, seed parameters and leaf parameters.

3.5. Multivariate Analyses

***Principal Component Analysis* (*PCA*)**

The principal component analysis (PCA) covers 08 parameters. Indeed, given the correlations between the parameters, 5 variables were eliminated to avoid redundancy. Table 5 presents the main axes of the PCA with their own value. The results of the principal component analysis (PCA) showed that three axes have eigenvalues greater than 1. Axis 1 (23.56% of the total variation) is largely explained by leaf width (0.70), petiole width (0.64) and fruit diameter (0.62). These parameters are all positively correlated with axis 1. This axis can be defined as the growth axis of leaves and fruits. It makes it possible to distinguish trees with strong foliar growth and producing large fruits. Axis 2 expresses 15.59% of the total change. The parameters that contribute to the formation of this axis are the number of grains per fruit (0.66). This axis can be defined as the axis of grain growth. This axis is used to determine which trees have low and high production. The third axis expresses 12.80% of the total variability. The mass of the grains is the only parameter that contributes strongly to the formation of this axis (0.84). Axis 3 can be defined as the axis of seed performance.

The first two components explain most of the variability revealed by the quantitative variables studied. The two principal axes express 38.34% of the total variation.

3.6. Phylogenetic Relationships between Trees

The study of phylogenetic relationships between trees was carried out by means of ascendant hierarchical classification (AHC). The principle of AHC is to group

together individuals that have a sufficient degree of similarity in the same set. The dendrogram resulting from the ascendant hierarchical classification (AHC) obtained by Ward's method allowed the identification of two large sets (A and B) with 25 and 69 trees respectively. These sets are composed of trees from both populations. A truncation at resemblance level 50 gives a finer classification with three groups (I, II and III). Group I is identified with set A and groups II and III are included in set B (Figure 1). Group I contains 25 trees with 16 from Affery and 9 from Biankouma. Group II is composed of 23 trees including 20 trees from Affery and 3 trees from Biankouma. Group III was the largest, composed of 46 trees including 23 trees of each population (Table 6).

Table 5. Eigenvalues, and percentage of variation expressed by the first three axes from the 08 variables.

Variables	Axis 1	Axis 2	Axis 3
Dm	0.27	−0.55	−0.12
HtF	−0.56	0.06	0.31
largF	0.70	0.25	0.10
LgP	0.42	0.51	−0.22
larP	0.64	−0.23	0.20
DiF	0.62	−0.12	0.05
Mgr	0.08	0.28	0.84
Ngr	−0.01	0.66	−0.28
Eigenvalues	1.89	1.25	1.02
% Expressed variance	23.56	15.59	12.80
% Cumulative variance	23.56	39.16	51.95

NB: The underlined values indicate the variables that contribute the most to the formation of the axes.

Table 6. Composition of the three groups (I, II and III) from the Ascending Hierarchical Classification (AHC).

Groups	Staff	Trees
I	**25**	A1; A26; A33; A40; A42; A48; A51; A54; A66; A68; A82; **A84**; A86; A91; A103; A110; BK25; BK27; BK29; BK41; BK44; BK52; BK58; BK59; BK71
II	**23**	A5; A8; A12; **A16**; A22; A27; A34; A35; A36; A41; A43; A45; A50; A78; A99; A106; A108; A109; A111; A112; BK19; BK39; BK45
III	**46**	A6; A10; A11; A13; A17; A28; **A32**; A37; A46; A65; A70; A74; A77; A79; A80; A83; A85; A93; A96; A101; A104; A105; A107; BK4; BK5; BK7; BK10; BK11; BK12; BK13; BK18; BK34; BK40; BK46; BK47; BK48; BK49; BK56; BK57; BK61; BK62; BK66; BK68; BK70; BK72; BK74

Values in bold indicate the most representative trees in each group.

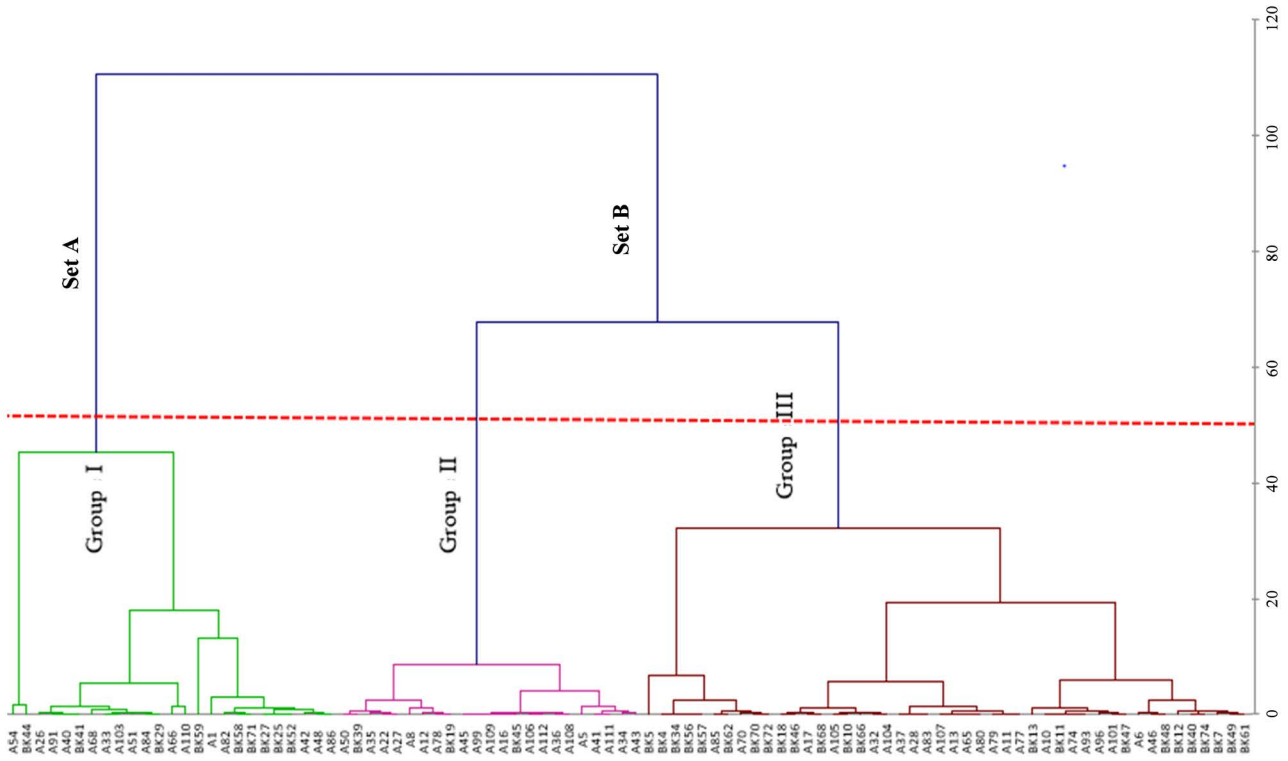

Figure 1. Dendrogram of the ascendant hierarchical classification (AHC) of trees according to the Ward method; Group I (25 trees), Group II (23 trees) and Group III (46 trees).

The differentiation between the three phenotypic groups resulting from AHC was refined by the analysis of variance to a classification criterion (ANOVA) of all the variables analysed. The results indicate significant differences ($P < 0.05$) for all variables except petiole length (LgP) and number of seeds per fruit (Ngr) (Table 7). Among the six variables that revealed a differentiation between the three groups, three (Dm, Hfr and Mgr) allowed a complete distinction. The three (3) other variables (largF, largP and HtF) allowed a partial differentiation.

Group I is characterised by trees with low average values for trunk diameter (34.65 cm) and fruit height (53.27 mm). Individuals in this group showed intermediate mean values for the height of the first branch (6.09 m), leaf width (widthF) and petiole width (0.21 mm). For this group, the seed mass is relatively high (7.14 g).

Group II had the highest mean values for trunk diameter (60.47 cm), height of first branch (6.09 m) and seed mass (8.17 g). No low mean values of the variables were recorded in this group. However, relatively high values were recorded for leaf width (4.51 mm), petiole width (0.20 mm) and fruit height (67.69 mm).

In Group III, leaf width (5.55 mm), petiole width (0.24 mm) and fruit height (76.90 mm) were the variables with the highest average values. On the other hand, seed mass recorded a low average value (4.49 g). For the individuals in this group, the height of the first branch is relatively high (4.56 m).

Table 7. Mean values and standard deviations of the morphological variables analysed in the 3 groups of phenotypic diversity derived from AHC and analyses of variance (ANOVA).

Variables	Group I (N = 25)	Group II (N = 23)	Group III (N = 46)	*F*	*P*
Trunk diameter (Dm) cm	34.65 ± 9.53^{c}	60.47 ± 6.29^{a}	42.17 ± 9.44^{b}	51.92	<0.001***
Height of first branch (HtF) m	6.09 ± 7.31^{ab}	7.34 ± 3.08^{a}	4.56 ± 2.23^{b}	3.32	0.041*
Sheet width (largF) mm	4.59 ± 1.09^{ab}	4.51 ± 0.95^{b}	5.55 ± 2.11^{a}	4.34	0.016*
Petiole length (LgP) mm	1.36 ± 0.23^{a}	1.30 ± 0.19^{a}	1.43 ± 0.43^{a}	1.20	0.306^{ns}
Width of the petiole (larP) mm	0.21 ± 0.04^{ab}	0.20 ± 0.03^{b}	0.24 ± 0.07^{a}	4.01	0.020 *
Fruit height (HFr) mm	53.27 ± 15.25^{c}	67.69 ± 6.26^{b}	76.90 ± 9.10^{a}	40.51	<0.001***
Seed mass (Mgr) g	7.14 ± 2.57^{b}	8.17 ± 2.99^{a}	4.49 ± 2.24^{c}	7.28	<0.001***
Number of seeds per fruit (Ngr)	2.05 ± 0.89^{a}	1.81 ± 0.66^{a}	2.23 ± 0.98^{a}	1.63	0.202^{ns}

For each parameter, the means with the same letters are statistically identical to the threshold P<0.05, according to the ppds test; ns: not significant; ** and *** indicate highly significant and very highly significant respectively.

3.7. Study of the Distribution of Trees

The analysis of the distribution of *Garcinia kola* Heckel trees in Affery is shown in Figure 2, which shows the geographical distribution (A1) of the trees and a distribution curve according to the Average Nearest Neighbor model. The curve (A2) indicates an aggregate distribution of trees. According to Table 8, the observed distance between trees in this zone is 84.28 m while the expected distance is 333.91 m; the ratio of the nearest neighbour is 0.25 with a z-score value of −14.79. Thus the observed distance less than the expected distance the z-score less than 0 indicates that the distribution is aggregated. The same is true for Biankouma (Figure 3 and Table 8) because the observed distance (157.46 m) is less than the expected distance (320.35 m) and the z-score (−8.42) is less than 0. For these two zones, there is less than a 1% probability that these models are the result of chance.

Table 8. Average distances and nearest neighbor values (ANN) by site.

Site	DO (m)	DE (m)	ANN	*z*-score	p	Area (m^2)
Biankouma	157.46	320.35	0.49	−8.42	0.01	30,788,879.98
Affery	84.28	333.91	0.25	−14.79	0.01	47,720,769.21

DO: Distance observed; DE: Expected distance; P: probability; ANN: Average Nearest Neighbor.

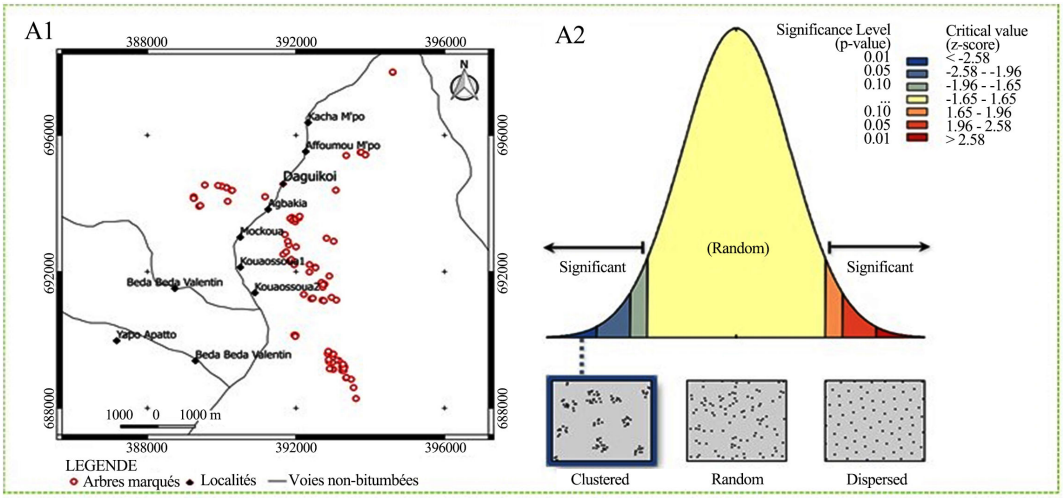

Figure 2. Cartography and curve of the distribution of *Garcinia kola* trees in Affery.

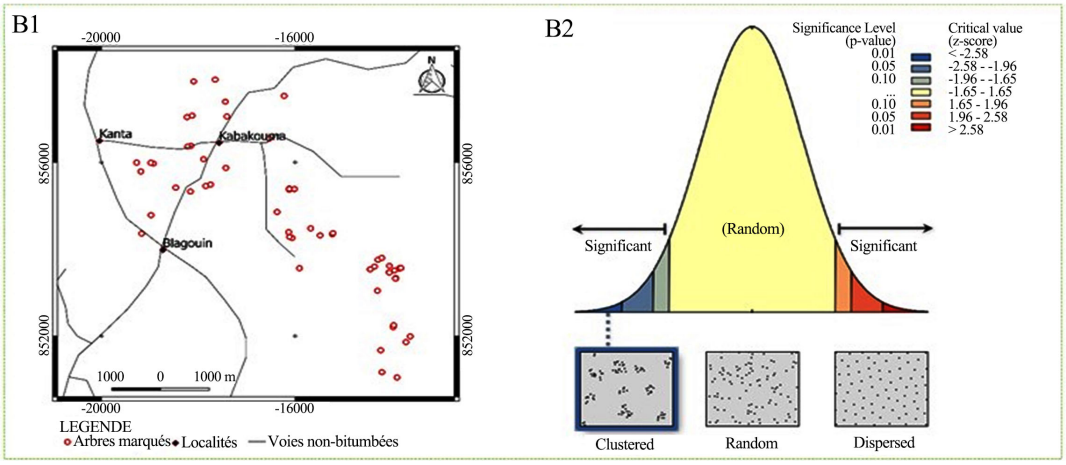

Figure 3. Cartography and distribution curve of *Garcinia kola* trees in Biankouma.

4. Discussion

This study was initiated as part of a program for the sustainable management of non-timber forest products other than timber. More specifically, it is a programme aimed at the domestication of the *Garcinia kola* (Heckel) species, which is widely exploited in Côte d'Ivoire for its therapeutic values. This study aimed to assess the morphological diversity of *Garcinia kola* H. (Clusiaceae) in two preferential agro-ecological areas for tree growth in Côte d'Ivoire.

All the characteristics studied revealed a significant difference between the individuals sampled at the two sites combined. There is great heterogeneity between *Garcinia kola* H trees. These results are similar to those of Bationo [16] on *Sclerocarya birrea* in Burkina Faso. Similarly, in South Africa and Namibia, [11] [12]) on *Sclerocarya birrea,* subsp *caffra* yielded similar results. Only the length of the petiole (LgP) and the number of grains per fruit (Ngr) do not differ significantly.

The study of intra-population variability revealed high variability for fruit

diameter (DiF), fruit height (Hfr), leaf width (largF), fruit mass (maF), grain mass (Mgr) and number of grains per fruit (Ngr). The high coefficient of variation at Affery for fruit mass (maF) and grain mass (Mgr) indicates greater variability between fruits in the Affery area. However, in Biankouman, these two characters have larger average masses, which suggests larger fruits and seeds than in Affery. This could be explained by the fact that the trees of *Garcinia kola* Heckel in Biankouma are found in a much more preserved forest environment, in a forest that is difficult to access. The number of seeds per fruit (Ngr) on the scale of all samples does not show any significant difference. However, this characteristic makes it possible to make the difference on a smaller scale, in a study area. Some seeds are larger, egg-shaped and elongated; this is believed to be due either to the influence of the microclimate on seed formation or to the existence of several *Garcinia* species. Thus, the mass of seeds and the number of seeds, the mass of fruits and the number of seeds per fruit would make it possible to gather as many divergent individuals as possible within the natural populations of *G. kola.* These parameters were highlighted by Nafan [17] in Vitellaria paradoxa (Shea) as the most variable. The same was true for *Detarium microcarpum* [18].

The study of inter-population variability reveals a significant difference between most traits, except Dm, HtF, largF and maF. Thus, these four characteristics do not allow the study of diversity between populations. These results are similar in *J. curcas* [19]. Indeed, the results of these authors show that the variability of morphological descriptors is generally greater at the level of individuals or between individuals in the same population than between populations.

According to the PCA, the highest variabilities in this study are recorded for grain mass (Mgr), number of grains per fruit (Ngr), leaf width (largF), petiole width (largP) and trunk diameter (Dm). Concerning fruits, similar results were obtained in Santalum austrocaledonicum (Santalaceae) [20] and V. paradoxa [17]. These authors have shown that the size and shape of the fruits make it possible to identify different phenotypes of these trees. One other author obtained similar results in Andansonia *digitata* [18]. Moreover, since fruiting is an important step in the development cycle, it remains influenced by various factors that would be responsible for variability. These factors can be of environmental, nutritional or even anthropogenic origin. It is also assumed that the months of July and August mark the beginning of the fruiting period of *Garcinia kola*. However, the rainfall in August is relatively low and could induce a variation in water absorption and nutrients depending on the location of the trees. Similar results on baobab (*Andansonia digitata*) have shown that the width of the leaves is part of the morphological descriptors that discriminate trees according to their origin [18].

The ascending hierarchical classification (AHC) revealed three groups of phenotypic diversity. Furthermore, the independent distribution of trees of different origins (Affery and Biankouma) in the three groups suggests that genetic diversity was not related to geographical origin. This result would indicate a phyletic link between the different trees. Six traits were the most relevant to dif-

ferentiate the AHC derived groups. These were, according to their discriminatory power, trunk diameter, fruit height, seed mass, leaf width, petiole width and height of the first branch. Thus, these characteristics would make it possible to characterise *Garcinia kola* in a large-scale study.

The study of the distribution of trees within the two populations (Affery and Biankouma) revealed an aggregate distribution of trees. The average distance observed between trees is smaller at Affery (84.28 m) than at Biankouma (157.46 m). These results are similar to those obtained in Strombosia *sheffleria* [21]. The aggregate spatial distributions of some tree species can be interpreted as reflecting variations in environmental characteristics [22] [23]. These species will aggregate in areas where environmental conditions are favourable for their development [24]. On the other hand, the mode of dispersion may also explain the aggregation. The limitation of dispersion also results in an aggregate geographical distribution [25] often observable for tropical tree species [26]. The aggregate distribution of *Garcinia kola* H. would be due either to sarcochores, *i.e.* totally or partially fleshy diasporas, or ballochores, *i.e.* expelled by the plant itself during the spread. Indeed these types of diasporas, which cannot ensure long-distance dispersal, can give species an aggregated spatial structure made by rodents [21].

5. Conclusion

This work has enabled us to gather information on the level and structure of the morphological diversity of *Garcinia kola* Heckel in two agro-ecological zones in Côte d'Ivoire. The geographical distribution of the trees of the two populations revealed an aggregated structure. The evaluation of the morphological diversity of *G. kola made it* possible to highlight the most discriminating descriptors. Indeed, at the fruit level, it is the height of the fruit and the mass of the grains that are the most discriminating. At the foliar organ and tree level, it was the width of the leaves and trunk respectively that revealed greater variability in the trees. The ascending hierarchical classification (AHC) has given details on the approximation of trees by structuring them into three groups of phenotypic diversity. The differentiation of these groups is based on six most discriminating parameters. These can be classified according to their order of discriminating power. These are trunk diameter, fruit height, seed mass, leaf width, petiole width and height of the first branch. In this way, the representatives of the three groups can be used to set up a wood yard to bring together most of the diversity of *G. kola* in Côte d'Ivoire. But since morphological markers are subject to variations related to the tree growing environment, we intend to extend this study to molecular analysis. Microsatellite primers have been selected to conduct this step. The combined results will make it possible to propose a strategy for the sustainable conservation of the resource.

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Conflicts of Interest

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

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