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*Full Length Research Paper*

# **Morphological diversity patterns among selected elite Shea trees (*Vitellaria paradoxa* C.F. Gaertn.) from Tchologo and Bagoué districts in Northern Côte d'Ivoire**

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**Agromorphological diversity structure of the elite shea trees identified in village lands and conserved *in situ* in the districts of Bagoué and Tchologo by the shea breeding program of the University of Peleforo Gon Coulibaly (UPGC, Côte d'Ivoire), are not known. In the present study, we characterized the agromorphological parameters of 220 elite shea trees using a set of 12 quantitative traits. The results showed that elite shea trees population has been structured into three morphological clusters or genetic pools that do not overlap with the original geographic areas. Morphological Cluster I contain elite shea trees with small trunk diameters carrying large leaves and producing fewer fruits per tree. Morphological Cluster II consisted of elite shea trees with stronger trunks bearing small leaves and producing a high number of fruits per tree. Morphological Cluster III regrouped elite shea trees of medium trunk diameters carrying medium sized leaves; fruit production level is intermediate compare to preceding groups. The elite shea trees of morphological Clusters II, which are more interesting from an agronomic point of view, can be used as grafting trees for the production of high-yielding grafted plants for farmers in Côte d'Ivoire.**

**Key words:** elite shea trees, genetic improvement, phenotypic variability, Northern Côte d'Ivoire.

## **INTRODUCTION**

*Vitellaria paradoxa* C.F. Gaertn., commonly known as 'shea butter tree' or 'shea tree' in English and '*karité*' in French, is a plant species of the *Sapotaceae* family that grows naturally in Sudano-Sahelian belt of Africa (Hall et

al., 1996; Diarrassouba et al., 2007). The geographical distribution of shea tree extends from Senegal to Uganda at latitudes between 2° and 8° North in East Africa, 7° and 12° North in Central Africa and 9° and 14° North in

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West Africa (Naughton et al., 2015). The large distribution of shea doubled by practicing allogamy as a mode of reproduction suggests a high intra-specific diversity (Diarrassouba et al., 2007). It is already reported the existence of two subspecies within the species *V. paradoxa* that are *paradoxa* and *nilotica* (Gwali et al., 2014). Butter of the western subspecies *paradoxa*, present in Côte d'Ivoire, is rich in stearic acid and gives a solid oil calling butter at ambient temperature, while the oil from the eastern subspecies *nilotica* is especially rich in oleic acid with liquid oil at ambient temperature. The species is widely known for its oil from nut which is used in cooking, cosmetics and traditional medicine (Diarrassouba et al., 2009a; Soro et al., 2011). The marketing of almonds and butter on local markets provides substantial income for women who are involved in the sector (Diarrassouba et al., 2008).

Despite the economic importance of shea butter as a multipurpose product, the erosion of genetic diversity and density of shea trees in natural agroforestry park is increasing over time. The cumulative effects of violent wind uprooting trees, the cutting downs for household needs, plowing for the installation of fields and the systematic collecting of fruits in natural parks by rural populations limit natural regeneration of shea trees (Boussim, 1991; Senou, 2000; Diarrassouba et al., 2009a). To overcome these problems, progressive domestication and genetic improvement of the species are being considered. Previous research has focused on fruit production (Lamien, 2006; Aleza et al., 2018), vegetative propagation (Bonkoungou et al., 1988), molecular diversity of populations (Bouvet et al., 2004; Fontaine et al., 2004; Sanou et al., 2005; Gwali et al., 2014; Abdulai et al., 2016), the spatial structure of populations (Kelly et al., 2004; Sanou et al., 2006, Aleza et al., 2015), the parasitism of the shea trees (Bayala et al., 2009; Samaké et al., 2011), the variability of fruit yields (Lamien et al., 2007; Bondé et al., 2019), etc. In Côte d'Ivoire especially, researches on *V. paradoxa* by Salé et al. (1991) reported that some characters such as fruit number, leaf and fruit size, leaf density, flowering and fruit ripening times are related to nut and butter yields. Also, in an agroforestry park of shea trees only 26% of trees are good producers and 15% of them have stable production (Salé et al., 1991). Similarly, quantitative and qualitative traits have proved highly relevant for probing morphological diversity in park of shea trees in Tengrela in Northern Côte d'Ivoire (Diarrassouba et al., 2007; Diarrassouba et al., 2009b). Only from qualitative morphological traits related to fruits and leaves, five morphological varieties of shea tree have been identified in the shea tree park at Tengrela (Diarrassouba et al., 2009b). The research activities carried out in the context of vegetative propagation enable breeding program of the shea tree of Côte d'Ivoire to multiply grafted plant materials and disseminate selected elite shea trees in village lands (Yao et al., 2019).

However, in the light of previous researches, there are still questions about the best ways and means of conserving shea genetic resources and improving the productivity of this species. Until today, the agromorphological characteristics of elite shea trees, identified in village terroirs and preserved *in situ* in the Bagoué and Tchologo districts, are not known in Côte d'Ivoire. Such knowledge would make help to set up breeding program of shea tree in Côte d'Ivoire and to judiciously involve the identified elite individuals in the subsequent hybridization plans for the creation of improved plant material. This study aims to know phenotypic diversity patterns among selected elite plant from Tchologo and Bagoué districts constituting the *in situ* collection of shea trees in Northern Côte d'Ivoire, using quantitative agromorphological traits.

## MATERIALS AND METHODS

### Study area

The study was conducted in the administrative districts of Bagoué and Tchologo (Figure 1). The districts of Tchologo and Bagoué are located in Northern Côte d'Ivoire between 9° 31' and 9° 35' North latitude and 5° 11' and 6° 29' West longitude.

### Ecological zones of districts and departments selected for the study

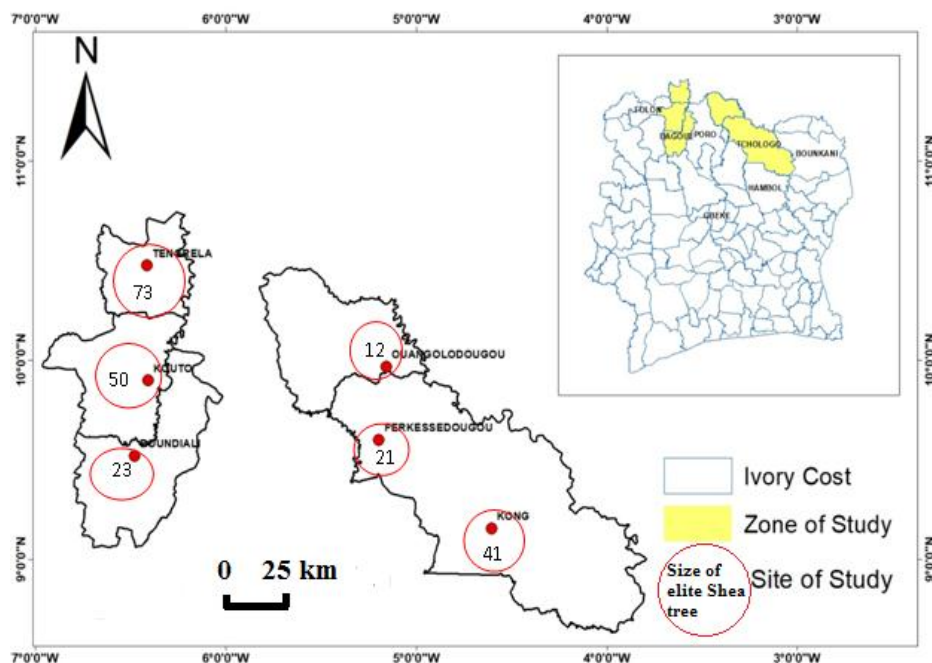
The Northern region of Côte d'Ivoire (Figure 1) has a Sudano Guinean climate characterized by two major seasons. The dry season runs from November to April and the rainy season covers the period from May to October. The rainy season has an annual rainfall of around 1, 200 mm per year (Brou, 2005). The vegetation is of Sudano Guinean type with gallery forests along the rivers and a predominance of wooded and grassy savannas (N'Guessan et al., 2015). The geological formations of the zone consist of a succession of bands of schistose rocks, magmatic rocks and plutonic rocks from which several types of soils are derived, namely Ferralsols, Cambisols, Fluvisols and Luvisols (Yace, 2002; Kone et al., 2009).

### Plant material

The study was conducted on 220 elite shea trees constituting the *in situ* collection of the University of Peleforo Gon Coulibaly (UPGC) (Figure 1). The elite shea tree is a natural tree presenting good agronomic characteristics in village lands and recognized by the farmers themselves basing on their knowledges about shea tree. Like that, the elite shea trees were identified according participatory method by the farmers from a survey based on criteria such as the high fruit yield of tree, the sweet taste of the fruit pulp, the high size of the fruit, the early flowering every year and the regularity of production of the tree. The survey was conducted by the shea breeding program of UPGC, Côte d'Ivoire in collaboration with *Agence Nationale d'Appui au Développement Rural* (ANADER, Côte d'Ivoire). The elite shea trees were selected in four localities that are Tengrela (73 trees), Kouto (50 trees), Boundiali (23 trees), Ferkéssédougou (21 trees), Ouangolodougou (12 trees) and Kong (41 trees).

### Morphological parameter measurements

The data was collected on elite shea trees during the period of



**Figure 1.** Study site maps showing Bagoué and Tchologo districts and sample size of observed elite shea trees.

Source: Shea breeding program of UPGC, Côte d'Ivoire, December (2019).

**Table 1.** Measured morphological traits, codes and unity.

Traits (SI Unity)	Code	Unity (SI)
Girth of trunk	GT	cm
Petiole length	PL	cm
Limb length	LL	cm
Limb width	LW	cm
Limb length/Limb width ratio	LL/LW	-
Fruit per tree	FT	Unit
Nut per fruit	NF	Unit
Nut length	NL	cm
Nut width	NW,	cm
Nut length/Nut width ratio	NL/NW	-
Nut volume	NV	cm <sup>3</sup>
Nut weight	NWG	g

fruiting (May to July 2017), to characterize both vegetative aspects (trunk and leaf) and some descriptors related to the fruits. A total of 12 agromorphological quantitative traits were evaluated (Table 1, Figure 2). Quantitative traits such as girth of trunk, petiole length, limb length, limb width, fruit per tree, nut per fruit, nut length, nut width and nut weight were measured directly on the tree. For nut per fruit, nut length, nut width and nut weight evaluations ten nuts were considered per tree and the average values were retained. Thus the nuts extracted per well-developed fruit (when they fall down) were count. The length and width of each extracted nuts were measured using a sliding caliper type tool. The weight of each extracted nuts was assessed using an electronic scale. The parameters such as Limb length/Limb width ratio, Nut length/Nut

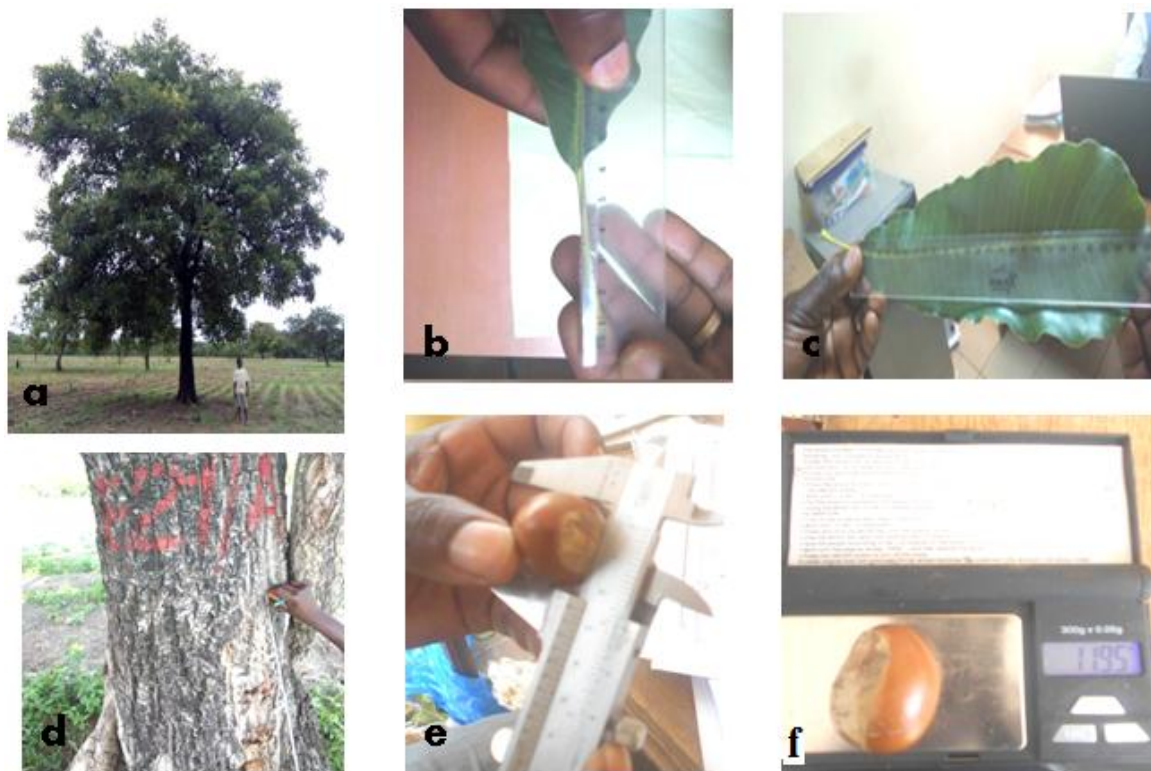
width ratio and nut volume were calculated. The shape of the shea nut has been assimilated to a cylinder and its volume (NV) has been determined according to the mathematical expression:

$$NV = \pi \times r^2 \times h$$

where  $r^2 = NW/2$ ,  $h = NL$  and  $\pi = 3.14$ .

#### Data analysis

First, data collected on elite shea trees have been submitted to a descriptive statistic analysis. The minimum, maximum and mean



**Figure 2.** Measures of morphological traits on the trunk, leaf and the seed of elite shea trees in the Bagoué and Tchologo districts, Northern Côte d'Ivoire. (a) Elite shea tree at the field, (b and c) Leaf size measures, (d) Measure of girth of trunk at 130 cm above the soil level (e and f). Measures of nut size and nut weight.

values, standard deviations and coefficients of variation have been determined for all quantitative traits. Then, a multiple analysis of variance (MANOVA) has been realized. This analysis was performed from all studied agromorphological traits and has been done in order to test the significance of all studied traits for elite shea trees discrimination when "district" or "department" was fixed as factor. Once the significance of the effect of the "district or department" factor is verified, the specific traits that contributed to the difference between localities (district or department) were identified from t-test when two districts (Bagoué vs. Tchologo) are compared and analysis of variance (ANOVA) when comparisons were done between six departments (Tengrela, Kouto, Boundiali, Ferkessedougou, Ouangolodougou and Kong) at the risk threshold of 5%. Any significant ANOVA ( $p < 0.05$ ) was followed a post-ANOVA test like Student Newman Keuls (SNK) test. Before MANOVA and ANOVA tests, the normality of each quantitative trait was verified from Shapiro-Wilk test at 5% of probability. Finally, the structure of the morphological diversity of elite shea trees was done from Principal Component Analysis (PCA), Hierarchical Classification Analysis (HCA) and Discriminant Analysis (DA). For PCA, the first four principal components were retained. Cluster analysis (Unweighted Pair Group Method Analysis, UPGMA) was performed using the matrix of average population values based on the elite shea tree's matrix of means. The clusters were then represented in a dendrogram. Also, the Pearson correlations between the morphological characters were revealed from Heat map using a quick and semi-automatic computational bio-statistical pipeline developed by Dago et al. (2019) in a simple programming language with R software. The other statistical analyzes were carried out using STATISTICA version 7.1 (StatSoft Inc., France) and SPSS version 20 (IBM Corp., USA) softwares.

## RESULTS

### Morphological variability of elite shea trees

The multiple analysis of variance (MANOVA) showed that all 12 variables made distinctions between the elite shea trees of two districts at the scale of the districts (Wilks'Lambda test;  $F = 4.100$ ;  $p < 0.001$ ) (Table 2). Likewise, at the scale the department, differences between six departments were observed with all studied traits (Wilks'Lambda test;  $F = 3.100$ ;  $p < 0.001$ ) (Table 2). Among the agromorphological traits that contributed to the structure of elite shea trees per district or department, the highly significant differences were observed in the expression of trunk girth (61 to 287 cm), the fruit number per tree (241 to 3903 fruits.tree<sup>-1</sup>) and the nut weight (1.05 to 17.92 g) (Table 2).

Principal Component Analysis (PCA) identified four factors accounting for 75.95% of the variability observed among elite shea trees. The first identified factor accounting for 30.48% of the total variability reflects the nut size. The second identified factor accumulates 18.02% of the variability and defines the trunk robustness and fruit yield per tree. The third factor captured 15.01% of the variability and essentially explains the nut shape. The fourth factor identified accounted for 12.38% of the

**Table 2.** Variations in the trait expression in elite Shea trees and associated MANOVA, Student and ANOVA tests from district and department factors in Northern Côte d'Ivoire.

Traits (SI Unity)	Mean	Range	t-test with factor district		ANOVA test with factor department	
			F	p-value	F	p-value
Girth of trunk (cm)	149.25	50.00-287.00	18.63	<0.001	18.69	<0.001
Petiole length (cm)	8.50	5.18-29.42	4.92	0.027	1.71	0.131
Limb length (cm)	14.84	9.34-21.58	4.28	0.039	2.77	0.018
Limb width (cm)	4.58	2.82-9.94	5.87	0.016	1.71	0.133
Limb length/Limb width ratio	3.28	1.10-4.83	1.57	0.211	1.76	0.120
Fruit per tree	1774.51	241.00-3903.00	18.63	<0.001	18.69	<0.001
Nut per fruit	1.02	1.00 – 2.00	3.51	0.062	1.89	0.097
Nut length (cm)	3.18	2.26-6.60	5.29	0.022	3.83	<0.01
Nut width (cm)	2.38	1.21-3.15	3.85	0.051	2.71	0.021
Nut length/Nut width ratio	1.34	1.06-2.94	1.26	0.260	1.15	0.335
Nut volume (cm <sup>3</sup> )	14.44	2.63-26.34	8.51	0.033	4.73	<0.01
Nut weight (g)	8.96	1.05-17.92	14.73	<0.001	6.17	<0.001
Wilks' Lambda test	-	-	4.10	<0.001	3.10	<0.001

**Table 3.** Factor loadings in the first four factor components.

Factor components	First	Second	Third	Fourth
Eigenvalues	3.65	2.17	1.80	1.48
Variance (%)	30.48	18.08	15.01	12.38
Cumulative variance (%)	30.48	48.56	63.57	75.95
Girth of trunk	-0.38	0.74	0.33	0.00
Petiole length	0.39	-0.36	0.13	0.31
Limb length	0.42	-0.52	0.26	0.28
Limb width	0.31	-0.47	0.37	-0.57
Limb length/Limb width ratio	0.05	0.04	-0.13	0.96
Fruit per tree	-0.38	0.75	0.33	0.00
Nut per fruit	0.38	0.03	0.48	-0.08
Nut length	0.70	0.32	-0.57	-0.14
Nut width	0.85	0.31	0.27	0.04
Nut length/Nut width ratio	0.07	0.07	-0.84	-0.19
Nut volume	0.92	0.34	-0.06	-0.04
Nut weight	0.86	0.30	0.09	0.04

total variability and reflected leaf shape (Table 3).

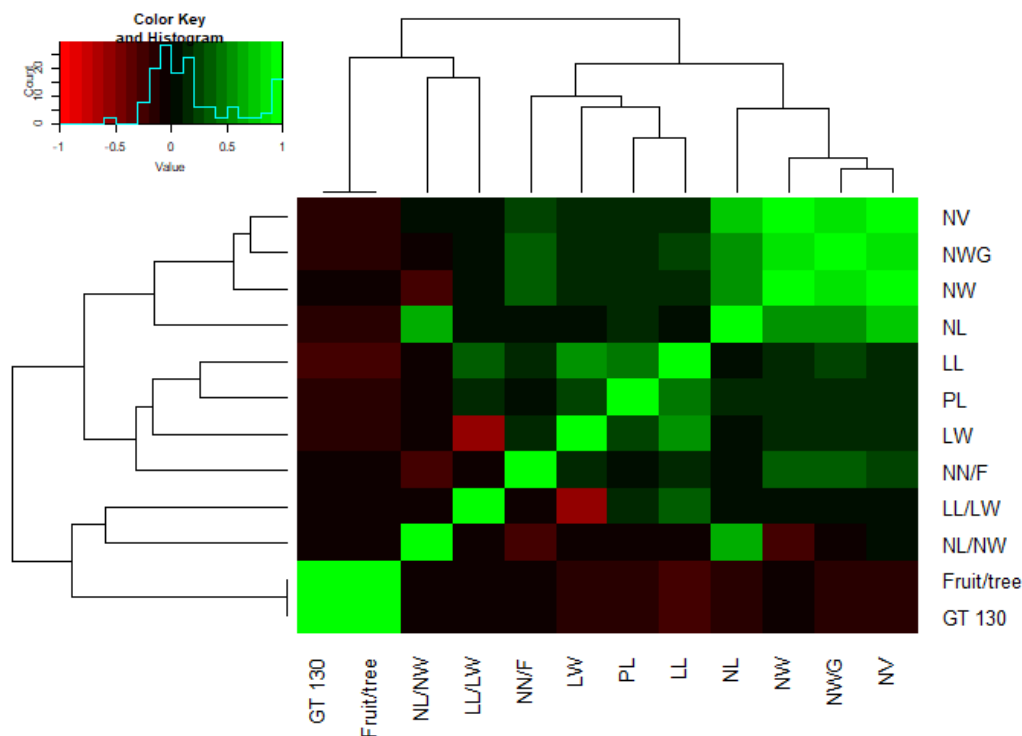
The analysis of the heat map revealed four categories of studied traits: (i) the trunk girth and the fruit number per tree, (ii) the nut length / nut width and limb length / limb width ratio, (iii) nut size (NV, NWG, NW and NL) and (iv) leaf size (LL, LW and LP) and nut number per fruit (see color key in Figure 3). Positive correlations were revealed within the descriptors of each identified category. In these categories, the strongest positive correlations were recorded in categories (i) and (iii). The highest correlation ( $r = 0.98$ ) was obtained between the trunk girth at 130 cm (GT 130) and the fruit number per tree (fruit / tree). Highly significant values ( $p < 0.001$ ) of

positive correlations were also observed between nut weight and nut width ( $r = 0.80$ ), between nut weight and nut length ( $r = 0.58$ ) and between nut weight and nut volume ( $r = 0.84$ ). For foliar characteristics, the longer leaf is wider ( $r = 0.56$ ,  $p = 0.01$ ) also (see color key in Figure 3).

### Morphological clusters of elite shea trees

The Hierarchical Classification Analysis (HCA) of the 220 elite of shea trees performed according to the Unweighted Pair Group Method Analysis (UPGMA)





**Figure 3.** Pearson correlation heat map showing relationships between morphological traits measured on elite shea trees in Bagoué and Tchologo districts in Northern Côte d'Ivoire. GT 130: Girth of trunk at 130 cm above the soil; PL: Petiole length; LL: Limb length; LW: Limb width; LL/LW: Limb length/Limb width ratio; FT: Fruit per tree; NF: Nut per fruit; NL: Nut length; NW: Nut width; NL/NW: Nut length/Nut width ratio; NV: Nut volume; NWG: Nut weight.

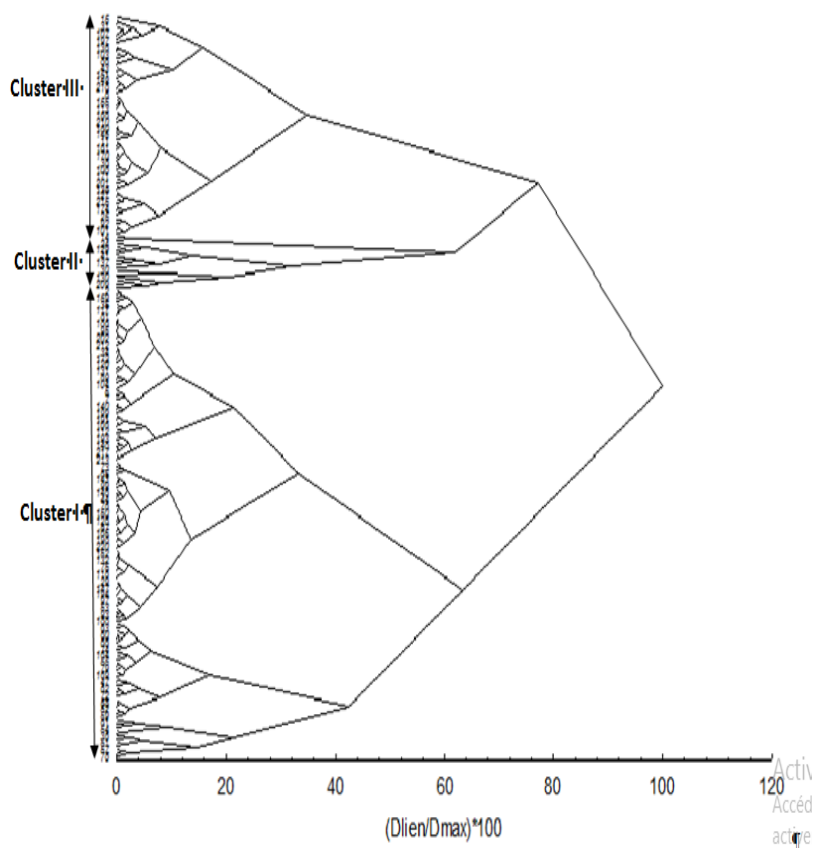
aggregation criterion from the Euclidean distances of the quantitative traits revealed three morphological clusters (Figure 4). The multiple analysis of variance (MANOVA) performed on these clusters from the set of 12 studied morphological traits showed a significant difference (Wilks'Lambda test;  $F = 20.22$ ;  $p < 0.001$ ) (Table 4). Morphological cluster I consisted of 139 elite shea trees, of which 83 were from the Bagoué district and 56 elite shea trees coming from Tchologo district. Elite shea trees of morphological cluster I have small trunk diameters ( $121.21 \pm 26.73$  cm) with large leaves ( $15.21 \pm 2.45$  cm limb length and  $4.69 \pm 0.73$  cm limb width) and producing less fresh fruits per tree ( $1341 \pm 413$  fruits per tree) (Table 4, and Figure 5). Morphological cluster II consisted of 16 elite shea trees that represent 7.27% of studied sample: 10 trees from Bagoué and 6 trees from Tchologo. Trees of morphological cluster II express high values of trunk diameter ( $244.56 \pm 20.98$  cm) carrying small leaves ( $13.66 \pm 1.68$  cm limb length and  $4.17 \pm 0.84$  cm limb width) and producing a high number of fresh fruits per tree ( $3247 \pm 324.26$  fruits per tree) (Table 4 and Figure 5). Morphological cluster III contains 65 elite shea trees or 29.54% of all studied elite shea trees with 53 and 12 from Bagoué and Tchologo districts respectively. Elite shea trees from morphological cluster III express medium values of trunk diameter ( $185.78 \pm 14.56$  cm) with

medium-sized leaves ( $14.34 \pm 2.15$  cm limb length and  $4.45 \pm 1.04$  cm limb width) and an intermediate fruit production ( $2339 \pm 225$  fresh fruits per tree) in relation to the two preceding morphological clusters (Table 4 and Figure 5).

## DISCUSSION

The agromorphological diversity study is important approach for the management of plant genetic resources. Likewise, Djekota (2014) reported that agromorphological approach constitutes the first step to start shea tree selection. For a long time, shea resources management has been mainly based on the classification of farmers for the conservation, domestication and selection (Lovett and Haq, 2000). However, these local knowledges retained for shea elite trees must necessarily be refined by scientifically proven knowledge in order to optimize improvement strategies for the species (Masters, 2002).

The agromorphological traits measured on the trunk, leaves and fruits showed significant variations between districts or even departments in Northern Côte d'Ivoire. These results suggest the significant influence of the environment on the expression of morphological characters in shea tree. These results can be explained



**Figure 4.** Dendrogram UPGMA of 220 elites shea trees in Bagoué and Tchologo districts, Northern Côte d'Ivoire.

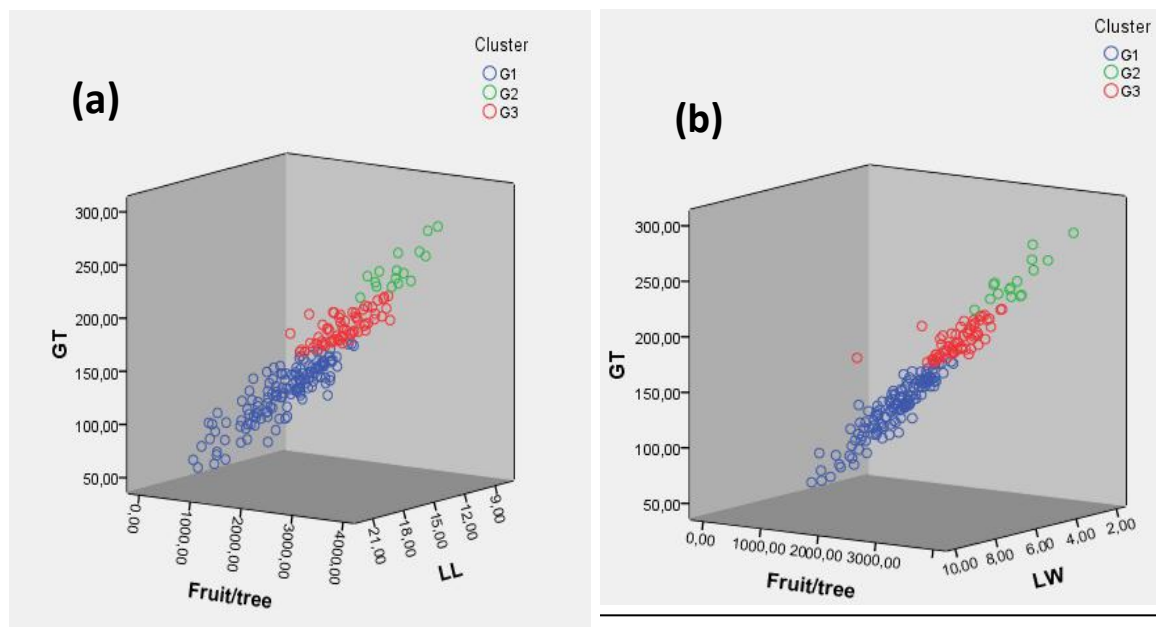
**Table 4.** Characteristics of three morphological clusters identified from Hierarchical Cluster Analysis within 220 elite shea trees in Northern Côte d'Ivoire.

Traits (SI Unity)	Means $\pm$ standart deviation			F	p-value
	Cluster I (N=139)	Cluster II (N=16)	Cluster III (N=65)		
Girth of trunk (cm)	121.21 $\pm$ 26.73 <sup>c</sup>	244.56 $\pm$ 20.98 <sup>a</sup>	185.78 $\pm$ 14.56 <sup>b</sup>	311.91	<0.001
Petiole length (cm)	8.73 $\pm$ 2.34 <sup>a</sup>	7.74 $\pm$ 1.08 <sup>a</sup>	8.21 $\pm$ 1.52 <sup>a</sup>	2.59	0.077
Limb length (cm)	15.21 $\pm$ 2.45 <sup>a</sup>	13.66 $\pm$ 1.68 <sup>b</sup>	14.34 $\pm$ 2.15 <sup>ab</sup>	5.41	0.005
Limb width (cm)	4.69 $\pm$ 0.73 <sup>a</sup>	4.17 $\pm$ 0.84 <sup>b</sup>	4.45 $\pm$ 1.04 <sup>ab</sup>	3.84	0.022
Limb length/Limb width ratio	3.26 $\pm$ 0.41 <sup>a</sup>	3.34 $\pm$ 0.44 <sup>a</sup>	3.30 $\pm$ 0.54 <sup>a</sup>	0.31	0.726
Fruit per tree	1341.00 $\pm$ 413.00 <sup>c</sup>	3247 $\pm$ 324.26 <sup>a</sup>	2339.00 $\pm$ 225.00 <sup>b</sup>	311.91	<0.001
Nut per fruit	1.02 $\pm$ 0.75 <sup>a</sup>	1.02 $\pm$ 0.42 <sup>a</sup>	1.02 $\pm$ 0.78 <sup>a</sup>	0.12	0.887
Nut length (cm)	3.22 $\pm$ 0.44 <sup>a</sup>	3.19 $\pm$ 0.22 <sup>a</sup>	3.10 $\pm$ 0.31 <sup>a</sup>	1.95	0.144
Nut width (cm)	2.39 $\pm$ 0.24 <sup>a</sup>	2.39 $\pm$ 0.14 <sup>a</sup>	2.36 $\pm$ 0.20 <sup>a</sup>	0.41	0.667
Nut length/Nut width ratio	1.35 $\pm$ 0.18 <sup>a</sup>	1.33 $\pm$ 0.06 <sup>a</sup>	1.31 $\pm$ 0.10 <sup>a</sup>	1.32	0.266
Nut volume (cm <sup>3</sup> )	14.74 $\pm$ 4.04 <sup>a</sup>	14.47 $\pm$ 2.43 <sup>a</sup>	13.80 $\pm$ 3.20 <sup>a</sup>	1.39	0.249
Nut weight (g)	9.11 $\pm$ 2.81 <sup>a</sup>	9.08 $\pm$ 1.74 <sup>a</sup>	8.62 $\pm$ 2.11 <sup>a</sup>	0.84	0.432
Wilks' Lambda test	-	-	-	19.22	<0.001

by a savannah gradient observed in the localities of study. In fact, on the ecological level, the Sudanese and Sudano-Guinean savannah are encountered in the study

area (Bagoué and Tchologo). The climatic characteristics of these two savannah types being not similar would be at the origin of the environmental effects observed in the





**Figure 5.** 3-D Scatter showing morphological diversity structure of the three clusters in the space formed from axes (X) Fruit per tree, (Y) Girth of trunk and (Z) Limb length or Limb width. GT: Girth of trunk at 130 cm; LL: Limb length; LW: Limb width; FT: Fruit per tree.

variation of the morphological characters expression as reported by McGowen et al. (2010). The impacts of climate on the expression of morphological characters have also been reported in Northern Equator (Maranz and Wiesman, 2003), Mali (Sanou et al., 2006; Tchabi and Adechi, 2014), Benin (Kouglénou et al., 2012; Kafilatou et al., 2015) and Uganda (Gwali et al., 2012). Moreover, in area of study the mineral composition of the soil, varying from one ecological zone to another, would have also influenced the expression of morphological characters as reported by Sanou et al. (2006), Moore (2008) and Bondé et al. (2019) respectively in studies on the vegetative characteristics of shea tree parks in Mali, Eastern Ghana and West Africa. The environmental effect significantly influencing the expression of agromorphological characters in shea tree can lead to a possible structuring of elite shea trees according to districts or departments. But, analysis of the diversity of all the elite shea trees without prior fixing of the district or department factors gave three morphological clusters. These morphological clusters do not correspond to the geographical structuring of the identified elite shea trees. These results would indicate that the geographic zone factor alone cannot constitute the basic factor in the structuring of identified elite shea trees. Indeed, the natural and human selections could be at the origin of these groupings. The selection of elite trees based on farmers' preferences would have led to the selection of trees with identical performances from one locality to another (Gwali et al., 2012; Karambiri et al., 2016). Similarly, the allogamous nature of shea tree has been

found to cause important gene flow between populations (Vaughan et al., 2007; Abasse et al., 2011). This would have led to similar morphological characteristics of shea trees from one locality to another.

The results show that the variability factors reflecting the dimensions of the nut, although more important in explaining the variability in the shea tree, did not make it possible to differentiate the three morphological clusters of elite trees identified in the Bagoué and Tchologo districts. The three morphological clusters differed mainly in the girth of trunk and the number of fruits per tree and secondarily in the size of the leaves. These results demonstrate that girth of trunk could be a good indicator for selection of producing trees, especially since a higher correlation ( $r = 0.99$ ) was obtained between trunk girth and fruit number per tree. In the study areas, elite shea trees are spared and maintained by the farmers during agricultural practices according to preference criteria such as the taste of the pulp, the fruit size and the oil content. This way of phenotypic selection made by farmers in village lands would have led to retaining elite trees or semi-domesticated trees with similar performances depending on the characteristics of the nut.

The results reveal four categories of studied traits presenting significant positive interrelationships between them: (i) the trunk girth and the fruit number per tree, (ii) the nut length / nut width and limb length / limb width ratio, (iii) nut size (NV, NWG, NW and NL) and (iv) leaf size (LL, LW and LP) and nut number per fruit. This result indicates that the use of a single pomological descriptor such as the nut width is sufficient to characterize the

shea nut. For example there are 80% odds to make a good estimate of the nut weight by referring to its width. Also, a single foliar descriptor such as the leaf length can be retained to discriminate populations of shea trees. Similarly, there is a significant correlation between trunk girth and fruit number per tree. This positive correlation indicates that fruit yield increases with the tree robustness. Meanwhile the increase of the fruit production is not linear with the age of the shea tree. Indeed, Nouvellet et al. (2006) showed that old shea tree individuals with big diameter are less or not productive compare to young ones with medium diameter in shea trees park of Ténéfina, Mali. Thus, the correlations found in the categories of characters highlighted in the present study in shea tree have already been mostly reported in the earlier works of Diarrassouba et al. (2007). Taking correlations into account may reduce the number of descriptors as the biological information provided by two positively correlated descriptors is similar as reported by Yao et al. (2015) concerning the coconut trees.

## Conclusion

This study was conducted with a view to characterize the morphological diversity of selected elite shea trees identified in the Bagoué and Tchologo districts of Côte d'Ivoire. The results revealed three morphological clusters of elite shea trees from Bagoué and Tchologo districts in Northern Côte d'Ivoire. While waiting to use these three gene pools for hybrid creation, individuals of morphological cluster II showing attractive agronomic performances, can serve as graft-producing trees for the production of high-yielding grafted plants in Côte d'Ivoire.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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