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Phenotypic Diversity of Shea (*Vitellaria Paradoxa* C. F. Gaertn.) Populations across Four Agro-Ecological Zones of Cameroon

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Abstract

Vitellaria paradoxa commonly called shea is an important agro forestry and fruit-bearing species present in four agro-ecological zones of Cameroon. The goal of this work was the morphological characterization of certain populations of *V.* paradoxa which will serve as a necessary step for a subsequent genetic study of the species. Morphological observations related to 20 agronomic traits, studied on 8-13 trees selected from each of the eight shea populations across four different agro-ecological zones located in four provinces of Cameroon were studied. The study showed that there was a variation between the populations, related to the traits measured on the trunk, fruit, nut, and leaf. Three shapes of the tree (ball, broom, and trained), five shapes of the fruit (round, oblong, reversed pear, ovoid, and oblong), three colors of the nut (clear brown, dark brown, and blackish brown) were identified. The principal component analysis (PCA) carried out on the quantitative characters revealed 72% of the total variance expressed on the first and second main axis. This variation was essentially explained by the traits measured on the fruits and on the nuts. The analyses showed that only the traits of the fruits and the nuts were discriminative. The shea populations studied were structured into two distinct groups using these discriminative traits.

Key words: Cameroon, *Vitellaria paradoxa*, morphological traits, genetic variation

Introduction

Shea (*Vitellaria paradoxa* Gaertn.), is a multi-purpose tree with medicinal and pharmaceutical properties. The uses of shea butter obtained from shea fruits are numerous. For example, it is used in food, soap, cosmetics, and in chocolate formulations (Diarrassouba et al. 2005). The high interest in shea is linked to its multiple physical and chemical properties. Just like most shea-producing countries in the West African subregion, Cameroon is in the process of developing the shea butter production sector. To this effect, some studies have been carried out in Cameroon on the physical and properties processing aspects of shea butter (Tchiégang et al. 2003; Womeni et al. 2006; Kapseu et al. 2006; Kapseu et al. 2007). Irrespective of the studies that have been done, very few have been centered on the morpho-agronomic characterization of the shea trees in Cameroon, in order to put in place a strategy for identifying the different shea varieties that exist in this country. Diarrasouba et al. (2007) reported some discriminative traits of shea after a study carried in Tengrela (Côte d'Ivoire) shea parkland. Similar studies carried out in some West African countries have shown the existence of a high intra-specific variation (Chevalier 1948; Ruyssen 1957) among shea trees. A phenotypic variation of shea trees and a correlation between its different physical properties have been reported in Ghana (Lovett and Haq 2004), Mali (Sanou et al. 2005) and in Côte d'Ivoire (Diarrasouba et al. 2007). On the other hand, it has been reported that the physical and chemical properties of the butter vary greatly but few studies have been carried out to evaluate the relationship that exists between the physical properties of the fruits, nuts, and the tree itself and the different morphotypes. The work of (Maranz 2004) has shown that the physico-chemical properties of the butter from the West African region varied significantly from that of the Central Africa subregion. A preliminary step to a genetic identification

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of the various varieties of shea that may exist in Cameroon is a phenotypic study on the trees and its fruits and nuts. Such a study is absent in this country.

This study carried out in four agro-ecological zones of Cameroon was the first in the country. The investigation was concerned with the evaluation of the diversity of the shea trees in Cameroon. The objective of the study was to analyze certain morphological properties of shea in order to identify the traits that had a discriminative effect and then verify if these traits had the same effect on all samples irrespective of the environment.

Materials and Methods

Study areas

Cameroon is located between latitudes 2° and 13°N (Fig. 1). Consequently, it has a wide range of climatic types, from the wet southern regions near the equator to the dry northern ones around the Lake Tchad basin. This study was carried on shea trees populations from four agro-climatic zones of Cameroun: Sudano-Guinean (Adamawa), Sahelian (Far North), Sudano-Sahelian (North) and Afro-Montain (West). The climate of the Adamawa Plateau is classified as tropical of the Sudan type. It has the dry season (November-March) and rainy season (April-October). Rainfall here averages 900 to 1,500 mm per year and decreases further north. In the Sahelian zone (Far North), the climate is tropical and Sahelian, and rainfall is relatively small ranging from 400 to 900 mm per year, arriving within the months of July to October, while the remaining eight months are dry. In the Sudano-Sahelian zone (North), the climate is tropical and of the Sudan type. Average rainfall is between 900-1,500 mm per year, decreasing from south to north due to elevation. The Afro-Montain zone (West) is located on high elevations. The climate is of the equatorial type. Rainfall moderated by the mountains averages 1,000-2,000 mm per year.

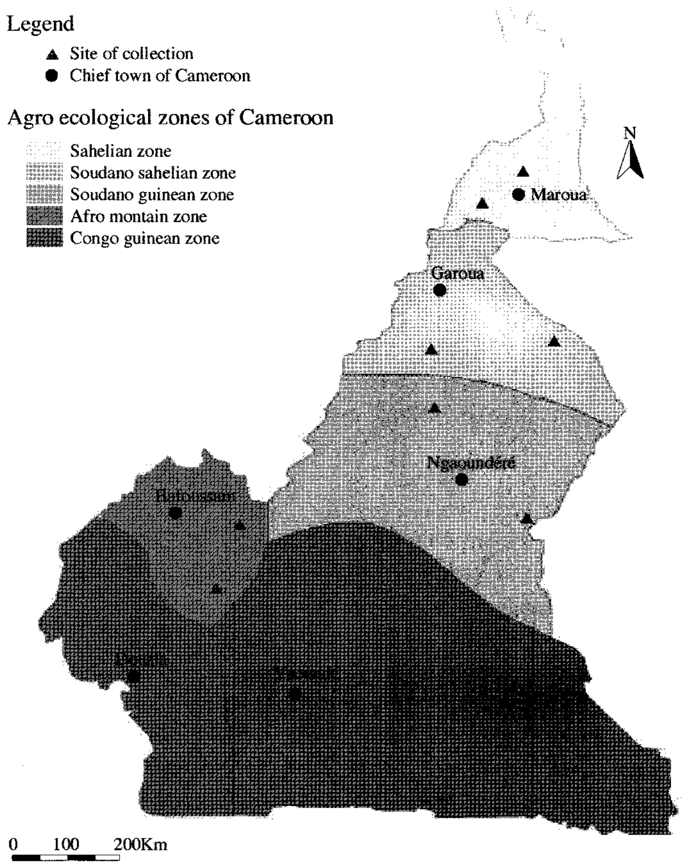

Fig. 1. Map showing data collecting sites and different agro ecological zones of Cameroon.

Sampling

According to Palmberg (1985), when the variation of the properties of a particular species over a given surface area is to be undertaken for the first time, the sampling sites should be chosen over a large grid as a function of the ecological gradient of the area in order to take into account differences that may be due to climate or ecology. In each zone, two localities located at least 50 km apart were chosen. In each locality, a single site containing a group of shea trees was randomly selected for sampling. A total of eight shea parklands, (two per agro-ecological zone) were sampled for this study. In each parkland, 8 to 13 shea trees separated by a distance of at least 25 m to avoid possible effects of inbreeding were sampled. The geographical coordinates of each parkland and tree were taken using a Geographical Positioning System apparatus. Seventy-five shea trees were sampled. Given the fact that the maturation season for shea fruits vary from one locality to the other (May-August), we arrived at some sites either just before or after the maturation season. Statistical analysis was therefore limited to 56 trees on which all the 20 parameters envisaged were actually measured.

Data collection

Twenty traits (three qualitative and 17 quantitative) were analyzed for each of the 56 trees considered for analysis.

Qualitative traits

Qualitative characters are more reliable and easy to use for the morphological variability studies on a large scale. It is worth noting that most qualitative parameters are evaluated in an empirical manner. The qualitative parameters measured were: the shape of the tree, the shape of the fruit and the color of the nuts. A phenotype for the tree was identified if its shape was related to one already described in the literature (Ruyssen 1957; Letouzey 1982). The predominant shape of the fruits and color of the nuts (just after depulping) for each tree were identified with reference to descriptions given by Chevalier (1946); Delolme (1947); Ruyssen (1957). Ten to 15 fruits/nuts from each tree were used to describe the shape of the fruits and color of the nuts.

Quantitative traits

According to Palmerg (1985), a minimum of 10 trees are required to describe the variation that may exist in a particular

Table 1. Quantitative parameters measured on the various parts of the shea tree.

Characters	Parameters measured (unity)	Abbreviation
Trunk	Circumference of the trunk (cm)	CIR
Leaves	Length of the limb (cm)	LLIM
	Length of the petiole (cm)	LPET
	Width of the limb (cm)	LALM
Fruits	Major diameter of the fruit (mm)	x_f
	Intermediate diameter of the fruit (mm)	y_f
	Minor diameter of the fruit (mm)	z_f
	Sphericity of the fruit	ω_f
	Area of the fruit (mm2)	A_f
Nuts	Major diameter of the nut (mm)	x_n
	Intermediate diameter of the nut (mm)	y_n
	Minor diameter of the nut (mm)	z_n
	Sphericity of the nut	ω_n
	Area of the nut (mm2)	A_n
Co-ordinates	Altitude	ALT
	Latitude	LAT
	Longitude	LONG

CIR : Circumference of the trunk (cm); LLIM: Length of limb; LALM: width of the limb; LPET: Length of the petiole (cm) AL: Altitude; x_f: Major diameter of the fruit (mm); x_n: Major diameter of the nut (mm); y_f: Intermediate diameter of the fruit (mm); y_n: Intermediate diameter of the nut (mm); z_f: Minor diameter of the nut (mm); z_n: Minor diameter of the nut (mm); ω_f: Sphericity of the fruit; ω_n: Sphericity of the nut; A_f: Area of the fruit (mm2); A_n: Area of the nut (mm2)

species growing within the same parkland. The quantitative traits were subdivided into three groups: traits related to the tree and leaves, traits related to the fruits and nuts, and those related to the geographical coordinates of each parkland (Table 1). The circumference of the trunk of each tree sampled was measured at a distance of about 2.5 m from the ground using a flexible meter rule. Ten to 15 leaves per tree were randomly harvested from the periphery of the tree branch while taking care to avoid border effect. Three traits were measured on the leaves: length of the limb (LLIM), width of the limb (LALM), and length of the leaf-stalk (LPT). All these values were measured based on 40 cm-long intervals and were expressed in centimeters. From each tree, 10-15 mature fruits that had fallen to the ground were sampled. The fruit linear dimensions namely major diameter (x, in mm), intermediate diameter (y, in mm), and the minor diameter (z, in mm) were measured with a digital vernier calliper (*Model SV-03-150*, Schlenker enterprises Ltd., Lombard, IL, USA) with an accuracy of 0.01 mm. The fruits were then depulped and the same measurements carried out on the nuts.

The geometric mean diameter D_e of the kernel was then calculated using the relationship:

$$D_e = (xyz)^{1/3} \quad [1]$$

The sphericity ω of the kernels was given by:

$$\omega = \frac{D_e}{x} \quad [2]$$

And the area was calculated from:

$$A = \pi D_e^2 \quad [3]$$

In the analysis x_f, y_f, z_f, D_{ef}, ω_f, and A_f refer to the major, intermediate, minor diameter, geometric mean diameter, sphericity, and surface area of the fruits. X_n, y_n, z_n, D_{en}, ω_n, and A_n are the corresponding values for the nuts. The altitude was expressed in meters; the longitude and the latitude in degrees, minutes, and seconds.

Descriptive statistics

Elementary statistics (mean, maximum, and minimum values) were evaluated on STATISTICA version 6.0 software. ANOVA was carried out using SPSS for Window V. 10.0 and significant differences between means were detected using Post-hoc pair-wise. Multiple comparisons were performed using Turkey's honest significant difference test (Gouet 1997). From a digital card, the map of Cameroon showing different ecological zones was conceived using Acview GIS 3.2 software. The sites of data collection have been positioned on the map according to their geographical coordinates.

Analysis of the variables by the Principal component analysis (PCA)

The data collected during this survey was subjected to Principal Component Analysis (PCA) on STATISTICA version 6.0 software. PCA is a multivariable descriptive analysis that allows for the construction of axes that maximize the variances of the individuals which participated in their construction in order to explain the observed variation (Phillippeau 1986; Escofier and Pagès 1998). PCA is a statistical technique that reduces the number of variables into a small number of synthetic variables by a linear combination of the original variables that explained most of the variation. All variables measured in this work were normalized (The data were centred and reduced) before being subjected to the PCA.

Correlation studies

Correlations studies were carried between pairs of some variables to verify if they were interrelated. For each pair of variables, the correlation coefficient (r) of Pearson was calculated. The Student (T) significance test was used to define the link between the variables. Bartlett's test with a significance of α = 0.05 and Student's T-test were then used to verify the absence on meaningful correlation between the variables hypothesis according to the following formula:

$$T = \frac{|r|\sqrt{n-2}}{\sqrt{1-r2}}$$

Structuring and typology of the shea trees populations

Hierarchical cluster analysis, using dissimilarity method of Pearson (dissimilarity in confident interval [0.1]). The Ward Method and squared Euclidean distance (HCA) were performed on discriminative phenotypic variables. The general principle for the construction of a hierarchical tree was based on middle tie criteria of aggregation. It consisted of classifying shea trees using discriminative traits into biologic or genetic entities. This method was based on the regrouping of all the trees into main groups and then progressively into subgroups.

Results

Vriability of the qualitative characters

From all the sites studied, three phenotypes for the shape of the tree (ball, broom, and trained or erected) were observed in variable proportions (Table 2). About 95% of the trees sampled had the ball or broom shape. Five forms (round, ovoid, reversed pear, fusiform, and ellipsoïd) of the fruits were identified. The ovoid form (54.38%) was predominant in all the sites studied. 63% of all the shea trees produced dark brown nuts. In was equally observed that the frequency of the different phenotypes varied from one site to another. In the North province (Sudano-Sahelian zone) 85% of the trees were ball shaped with 52% of it fruits ovoid. In the Far North province (Sahelian zone), 67% of the trees were broom in shape and the 66.66% ovoid fruits. In the Adamawa, there was an equal proportion of ball and broom shaped trees while 90% of the fruits were ovoid. In the West province (Afro-Montain), 80% of the trees were ball shaped and the proportion of ovoid and tapered fruits was equal (30%).

Table 2. Phenotypes observed and their frequencies of apparition on the set of the sites sampled.

Qualitative character	Phenotypes	Percentage %
FHOU	Ball	54.38
	Broom	40.35
	Erect	5.26
FFRU	Ovoid	54.38
	Rounded	10.52
	Fusiform	19.30
	Ellipsoïdale	7
	Pear reversed	8.77
CNOI	Brown clear	35.09
	Brown dark	63.16
	Brown blackish	1.75

Great variation was observed for the shape of the tree, shape of the fruit and the color of the nut. Three phenotypes were identified respectively for the color of nuts (Fig. 2) and for the shape of the tree (Fig. 3). Five phenotypes were observed for fruits shape (Fig. 4).

Descriptive statistics of the quantitative characters

Comparison of means between the four ecological zones in all the study areas showed that populations of the Sahelian and Sudano-Sahelian zones (low altitude) had significantly bigger circumferences of the trunk and significantly smaller diameters of the fruits and nuts compared to those of the Sudano-Guinean and Afro-Montain zones (high altitude) which had trees with smaller circumferences producing larger fruits with larger nuts. Generally for all the trees sampled, the circumference of the trunk ranged from 37 cm in the West (high altitude) to 420 cm in the Far North (low altitude) with an average value of (140.75 cm). The highest average values for the circumferences of the trunk were recorded in the Far North (Maroua) and North provinces (Garoua) with respective values of 182.33 cm and 259.14 cm. On the other hand, the major diameter of the fruit varied from 37.33 mm in the North (low altitude) to 82.47 mm in the West (high altitude) with an average value of 59.83 mm. The major diameter of the nuts varied from 29.57 mm in the Far North (low altitude) to 53.34 mm in the West province (high altitude) with an average value of 41.42 mm.

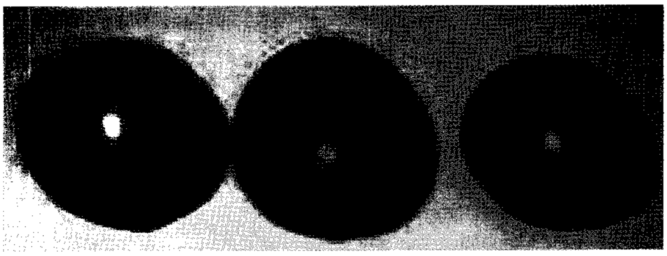

Fig. 2. Photo showing variability observed for the color of the nut (from left to right: brown clear, brown dark and brown blackish).

The assessment of morphological diversity distribution among shea population and agro-ecological zones was estimated by an Analysis of Variance (ANOVA) showed significant differences between traits measured on trunk, fruits, and altitude across agro-ecological zones (Table 3). However, no significant difference has been noted between the different ecological zones for leaves traits studied.

Structuring of the parameters

The results of the Principal Component Analysis (PCA) showed that only traits linked to the altitude, fruits, and nuts contributed significantly to explain the genetic diversity expressed. Each of these variables contributed significantly (more than 70%) in the constitution of the principal axes. The

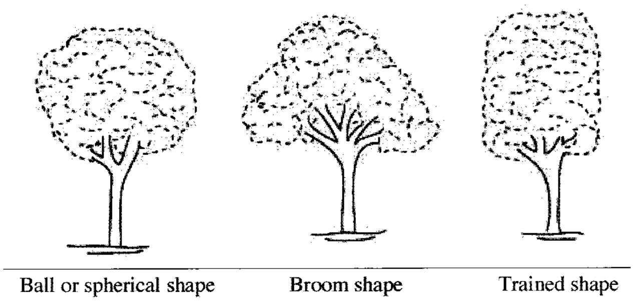

Fig. 3. Variability observed for the crown shape of the tree (according to IPGRI/INIA descriptors, 2006).

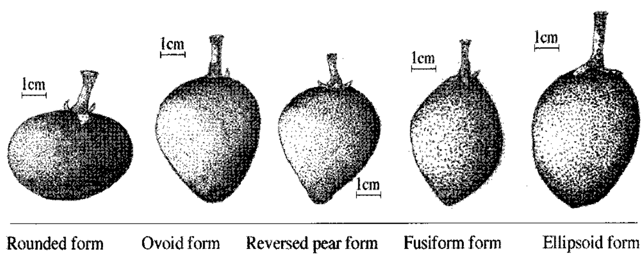

Fig. 4. Variability observed for the shape of the fruit.

Table 3. Analysis of the differences between agro ecological zones for quantitative traits studied with 99% confidence interval.

Source of variation	Squares mean	F Value	Signification
CIR	2.81	9.18	0.000
Xf	743.47	13.19	0.000
yf	312.12	16.76	0.000
zf	266.15	17.86	0.000
wf	0.01	3.09	0.017
xn	176.29	13.07	0.000
yn	116.404	20.02	0.000
zn	74.556	12.06	0.000
wn	0.005	3.56	0.08
ALT	2456522.32	2845.61	0.000
LPET	10.89	2.50	0.042
LLIM	21.00	1.92	0.107
LALIM	9.59	3.35	0.011

first two principal axes explained about 72% of the total variation observed. The variables measured on the fruits and the nuts were strongly correlated to the first axis and explained 55.43% of the total variation. It is the axis of the span of the fruits. Two variables, sphericity of the fruits and that of the nuts, as well as the altitude (ALT) were strongly correlated to the second axis and explained 16.56% of the total variation. It is the axis of the pace of the fruit. However, the quality of the representation of each variable in the correlation circles (Fig. 5) confirmed the performance of the variables measured on the fruits, nuts, and altitude. These results suggest that these variables are discriminative and can therefore be used to structure and classify the types of shea trees in Cameroon.

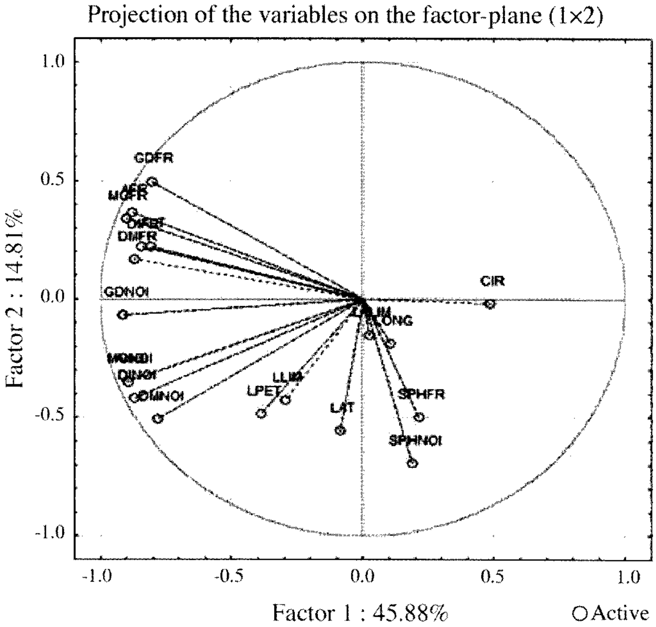

Fig. 5. Quality of the representation of the variables studied of the observations of the sample studied from the on correlation circles in the plan 1&2 of the MCA.

likely to contain larger fruits (36%). Positive and significant correlations observed between fruit variables and altitude varied between 0.68 to 0.77, indicating that there was a 68-77% chance of having larger fruits at high altitude (Table 4).

Correlations between variables

Bartlett's test applied on Pearson correlations with $\alpha = 0.05$ showed that correlations between the variables are meaningful. Negative and significant correlations were observed between the circumference of the trunk and the altitude on one hand, and between the circumference of the trunk and the major diameter of the fruit on the other. These values were -0.50 and -0.36, respectively. That is, at high altitude there was a 50% chance of having trees with a smaller trunk circumference which were likely to contain larger fruits (36%).

Structuring of the shea trees

Fig. 6 shows the dendrogram of the Euclidean distances calculated by applying the Ward algorithm to the sampled trees. From the phylogenetic tree based on discriminative variables, the truncation at 0.50 of dissimilarity coefficient also permitted to distinguish three phenotypic groups within the sample of investigated trees. Trees growing at low altitudes were characterized by their large trunks and small fruits while those growing at high altitudes were characterized by their smaller trunks and larger fruits.

Table 4. Matrix of correlations between quantitative traits with 95% confidence level.

Variables	CIR	LPET	LLIM	LALIM	GDFR	DIFR	DMFR	MGFR	SPHFR	AFR	GDNOI	DINOI	DMNOI	MGNOI	SPHNOI	ANOI	ALT
CIR	1	-0.24	-0.29	0.39	-0.36	-0.32	-0.31	-0.36	0.18	-0.36	-0.37	-0.39	-0.32	-0.38	0.02	-0.37	-0.50
LPET	-0.24	1	0.58	0.9	0.13	0.16	0.20	0.17	0.02	0.14	0.36	0.44	0.41	0.42	0.10	0.42	0.23
LLIM	-0.29	0.58	1	-0.08	0.08	0.13	0.16	0.13	0.07	0.11	0.24	0.30	0.32	0.30	0.11	0.30	0.12
LALIM	0.39	0.19	-0.08	1	-0.05	-0.03	0.02	-0.02	0.06	-0.04	0.01	0.04	0.00	0.02	0.00	0.02	-0.06
GDFR	-0.35	0.13	0.08	-0.05	1	0.71	0.71	0.89	-0.63	0.89	0.73	0.47	0.38	0.55	-0.55	0.54	0.68
DIFR	-0.38	0.16	0.13	-0.03	0.71	1	0.97	0.94	0.06	0.94	0.62	0.62	0.46	0.60	-0.17	0.59	0.73
DMFR	-0.30	0.20	0.16	0.02	0.71	0.97	1	0.95	0.06	0.93	0.65	0.65	0.53	0.64	-0.14	0.63	0.74
MGFR	-0.36	0.17	0.13	-0.02	0.89	0.95	0.95	1	-0.22	0.99	0.73	0.62	0.48	0.64	-0.34	0.63	0.77
SPHFR	0.18	0.02	0.07	0.06	-0.63	0.06	0.06	-0.22	1	-0.23	-0.35	0.00	-0.01	-0.12	0.61	-0.12	-0.18
AFR	-0.36	0.14	0.11	-0.04	0.86	0.94	0.93	0.99	-0.23	1	0.69	0.60	0.44	0.60	-0.33	0.60	0.73
GDNOI	-0.37	0.36	0.24	0.01	0.73	0.62	0.65	0.73	-0.35	0.69	1	0.84	0.80	0.93	-0.35	0.92	0.64
DINOI	-0.39	0.44	0.30	0.04	0.47	0.62	0.65	0.62	0.03	0.60	0.84	1	0.91	0.96	0.15	0.96	0.63
DMNOI	-0.32	0.41	0.32	0.00	0.38	0.46	0.53	0.48	-0.01	0.48	0.80	0.91	1	0.95	0.23	0.95	0.48
MGNOI	-0.38	0.43	0.30	0.02	0.55	0.60	0.64	0.64	-0.12	0.60	0.93	0.96	0.95	1	0.01	0.99	0.62
SPHNOI	0.02	0.10	0.11	0.00	-0.55	-0.17	-0.14	-0.33	0.61	-0.33	-0.35	0.15	0.23	0.01	1	0.01	-0.17
ANOI	-0.37	0.42	0.30	0.02	0.54	0.59	0.63	0.63	-0.12	0.60	0.92	0.96	0.95	0.99	0.01	1	0.60
ALT	-0.50	0.23	0.12	-0.06	0.68	0.73	0.73	0.77	-0.18	0.73	0.64	0.63	0.48	0.62	-0.17	0.60	1

Meaningful values of bilateral test are in greasiness (with 95% confidence level)

Discussion

A study of the variation and the discriminative nature of the parameters under consideration is a necessary step for characterizing shea resources. This study will therefore aid in the evaluation of the genetic diversity of shea in Cameroon. The originality of this work lies in the fact that it is the first that cuts across four ecological zones of Cameroon. The 20 parameters taken into account in this work were analyzed for each tree. Three phenotypes (ball, broom, and erected) have been observed for the shape of the trees. However, the existence of intermediate shapes made using this parameter to distinguish the various types of trees difficult. The existence of intermediate forms seems to have been influenced by the type of vegetation in which it grows. Indeed, the competition generated by the proximity of the other trees as well as the action of humans (for agriculture) on the environment can modify the shape of the tree. Similar results were reported in Côte d'Ivoire (Delome 1947) and in other shea-producing countries (Baker 1877; Heckel 1897; Ruyssen 1957). On the basis of the morphology of the fruits, five forms were identified (round, ovoid, reversed pear, fusiform, and oblong). These characteristics were very discriminative and easily observable on a large scale. The distinction of shea population using these characteristic is easy. The observed phenotypes seemed to have separated into two extreme sizes (large and small fruits). A similar observation was reported in Côte d'Ivoire (Diarrassouba et al. 2007). Before this work, four other shapes had already been described in different countries: in Côte d'Ivoire (Delolme 1947), West Africa (Chevalier 1946); and in Ghana (Greenwood 1929; Pennington 1991).

Three mains phenotypes were identified for the color of the nut in Cameroon. For a better appreciation of the color of the nuts, they should be analyzed immediately after depulping since the color varies significantly with the degree of drying of the cockle. All the qualitative variables considered in the study were observed at all the sampling sites. Though these parameters varied significantly between sampling sites, the qualitative parameters seemed to have been little influenced by environmental factors. The variations of the proportions of the different parameters observed between the sites could be attributable to anthropogenic activities given the fact that the species grows mostly in areas close to human settlements.

Variation of the quantitative variables

Statistical analysis carried out on the measured variables related to the shea trunk, leaves, fruits, and nuts showed a very high variation between sampling sites. The analysis equally revealed that each individual could be used to a certain degree to describe the types of shea trees that exist in Cameroon. Although similar results have been reported in the literature (Lovett and Haq 2004; Kelly *et al.* 2004), these results in their present form did not permit us to identify the most discrimina-

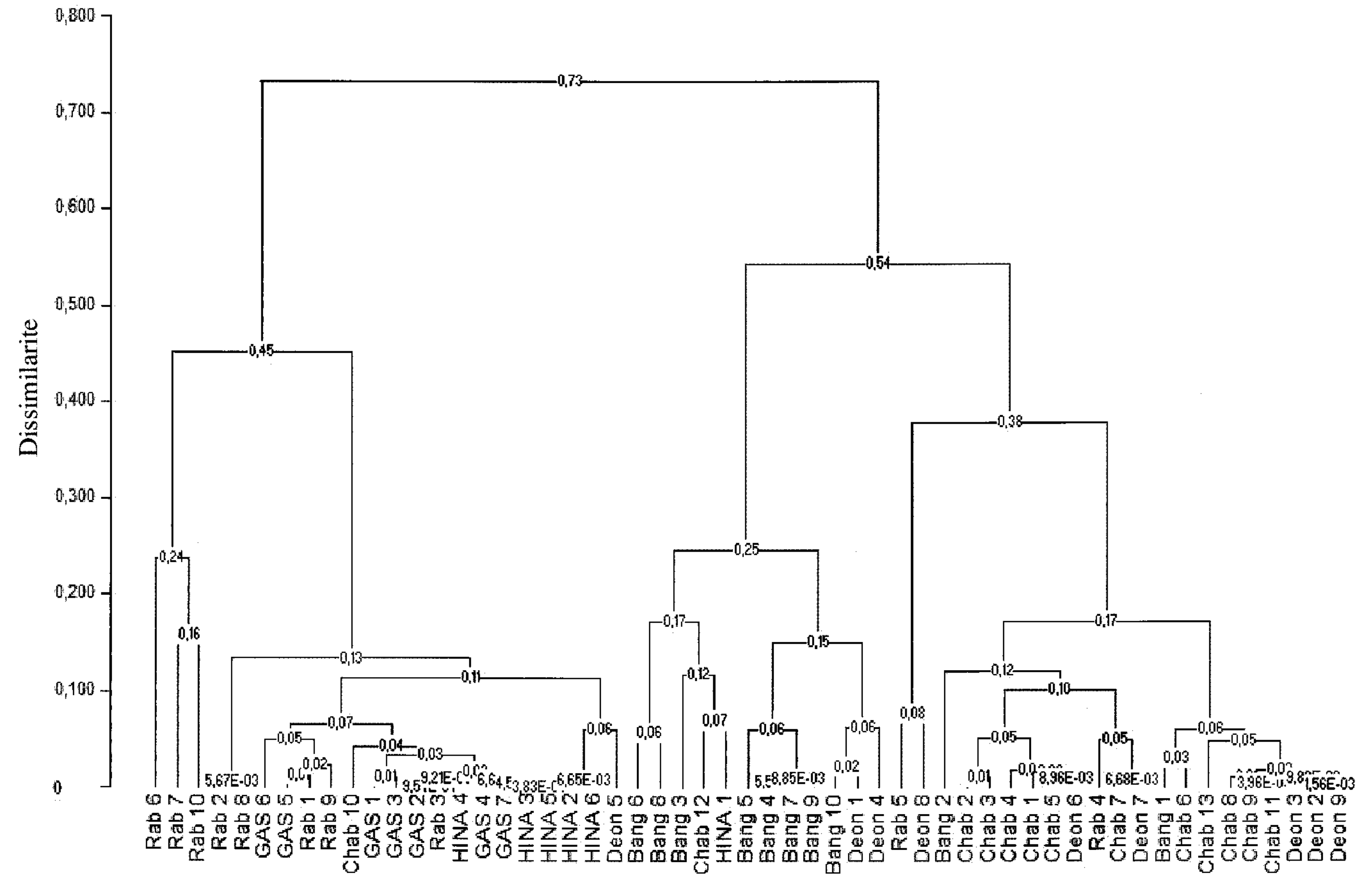

Fig. 6. Regrouping shea trees sampled using quantitative discriminative variables (Diagram descended of the CAH).

tive variables. To achieve this, it was necessary to carry out complementary factorial analysis. It was observed that the major diameter of the fruits was positively and highly correlated to the intermediate and minor diameters. Therefore, fruits with high values of the major diameters could be classified as large fruits. The fruits were regrouped into two phenotypes: large and small fruits. This simplification actually sheds a qualitative polymorphism that is not reflected in the quantitative measures. The morphological variables have already been used for the characterization other savannah species. Different phenotypes have been identified for the shapes and dimensions of the leaves and fruits of *Parkia biglobosa* (Ouédraogo 1995). The morphological characterization of dimensions of the trees and nuts of *Deutarium microcarpum* equally revealed a high existence of intra-population variation for these parameters (Amadou and Van Damme 2002). Studies on some morphological traits have shown a non-negligible, inter-population variation (Chevalier 1948; Ruyssen 1957). A phenotypic variation of shea trees and the correlation between different morphological properties has been demonstrated by other authors (Lovett and Haq 2004; Sanou et al. 2005).

Organization of the morphological variation

The principal component analysis was employed to structure the observed polymorphism using essentially the discriminative variables. Thus, two phenotypic classes were identified. All variables related to the fruits and nuts were discriminative. However, due to the high correlations that existed between these variables, three were retained to describe the shea trees. The major, intermediate, and minor diameters were retained since they can be easily measured. The sphericity was also retained since it describes the shape of the tree and was therefore considered the most descriptive qualitative parameter. A morphological distinction can also be done by associating the parameters retained for the fruits to those of the leaves and the nuts. For agronomic interests, it will be necessary to associate the quantitative with qualitative parameters in order to better distinguish morphotypes.

Significant correlations were established between some variables. These correlations suggested that larger fruits were produced at high altitudes and vice versa. It was also observed that the very first fruiting was faster for fruits growing at high altitude than those growing at lower altitudes. The high dependence of the quantitative parameters on the altitude raises the question of the possible rule played by environmental conditions. It is apparent that the environment plays a large part in determining the quantitative traits of mature shea trees, as distinct types were observed under different agro-ecological conditions. The use of these quantitative variables would have been more reliable if the study had been carried out in localities with homogenous environmental conditions. The extension of these results on a large scale should therefore be done with some precautions.

The hierarchical classification was used to classify the shea samples by employing the discriminative variables identified from the PCA into two phenotypic groups. In Côte d'Ivoire, three phenotypic classes have been distinguished using quantitative traits (Diarrassouba et al. 2007). In addition to these two main groups, many subgroups were identified with some degree of similarity. Since *Vitellaria paradoxa* is an allogame plant, it is possible that these subgroups are morphotypes resulting from cross pollination between trees. The existence of these subgroups can be used to explain the existence of many subspecies within *paradoxa*. These three groups formed are similar to those described by Chevalier (1946). This author had distinguished three varieties (*Poissoni*, *niloticum*, and *mangifolium*) within the *Vitellaria* species using a limited number of morphological characters. Some varieties (*viridis* and *rubifolia*) have also been reported for the subspecies *mangifolium* (Ruyssen 1957). In this work, a large variation was observed with respect to the shapes and sizes of the trees, fruits and leaves, and nuts fruits and leaves. The extreme variation of all the phenotypic variables put together makes it difficult to identify varieties. Some previous works had mentioned, using some qualitative characters, several varieties within the species at a time when all the parameters were not well mastered (Ruyssen 1957). The phenotypic variation observed in this work could as well be genetic although there is a high possibility that this variation could have been influenced by environmental factors. The dependence of the trunk circumference and the size of the fruit on the altitude was a perfect illustration.

Conclusion

A high morphological variation was observed within shea populations from four different agro-ecological zones of Cameroon. Three phenotypes were observed for the shape of the tree (ball, broom, and erected). For the morphology of the fruits, five phenotypes (round or globular reversed pear, ovoid, ellipsoid, and fusiform) were identified. Three phenotypes were identified for nut color (clear brown, dark brown, and blackish brown). For the quantitative variables, those related to the fruits and nuts were the moss discriminative. However, the circumference of the trunk of the tree and the size of the fruits were significantly influenced by altitude. The bigger trees were found at low altitudes (250-396 m) and the smaller trees at high altitudes (900-1471 m). On the other hand, larger fruits were found at high altitudes and the smaller fruits at low altitude. *V. paradoxa* populations have been structured into two distinct phenotypic groups.

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