Original article

Participatory identification and characterisation of shea butter tree (*Vitellaria paradoxa* C.F. Gaertn.) ethnovarieties in Burkina Faso

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Summary

Introduction – ***Vitellaria paradoxa*** **(shea) is an economically important edible oil-producing tree for local populations in African savannahs. However, domesticating these trees requires that scientific information is fully exploited. The objective of this study is to identify and characterize the different morphotypes of shea in three areas of Burkina Faso, assuming that the different varieties of shea are morphotypes for which the local populations hold the key to their description and their denomination.** *Materials and methods* – **This study used a participatory approach involving local communities in data collection, thus combining local knowledge with biometric measurements of shea fruit and leaves. The different variants of shea, classified according to local criteria, received the denomination of 'ethnovarieties' (EV). Data were collected over two years in three villages: Yarci, Yantenga and You.** *Results and discussion* – **Local communities use the characteristics of fruits and leaves to identify and describe EV. In the three study sites 13 EV were identified and classified in four groups: (i) Pulp/flesh fruits; (ii) Fruits with a high yield of almond butter; (iii) Pulp and butter fruits; (iv) Pulp fruits unfit for human consumption.** *Conclusion* – **Local people have a strong knowledge of shea morphotypes significant in the management of natural resources. Further study using molecular analysis of microsatellites would contribute to better understand the observed morphological variability.**

Keywords
African savannah, shea, *Vitellaria paradoxa*, genetic diversity, morphological traits, traditional knowledge, underutilized species

Résumé

Identification et caractérisation participative des ethnovariétés de karité (*Vitellaria paradoxa* C.F. Gaertn.) au Burkina Faso.

Introduction – ***Vitellaria paradoxa*** **(le karité) est un arbre producteur d'huile comestible d'importance économique pour les populations des savanes africaines. Cependant, la domestication de ces arbres nécessite que l'information scientifique soit pleinement exploitée. L'objectif de cette étude est d'identifier et de caractériser les différents morphotypes du karité dans trois villages (Yarci, Yantenga et You) du Burkina Faso, en supposant que les différentes variétés de karité sont des morphotypes pour lesquels les populations locales détiennent la clé de description et de dénomination.** *Matériel et méthodes* – **L'approche participative utilisée consiste à impliquer les communautés locales de chaque village dans la collecte des données. Elle combine ainsi les connaissances endogènes de chaque communauté avec les mesures biométriques des fruits et des feuilles de karité. Les différentes variantes du karité classées selon les critères locaux, ont reçu la dénomination d' 'ethno-variétés'**

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Significance of this study

What is already known on this subject?
- Shea tree is an oilseed endemic to Africa that grows naturally in African savannahs.
- There are two subspecies of *Vitellaria paradoxa* namely: (i) subsp. *paradoxa* in Western and central Africa, (ii) and subsp. *nilotica* in Eastern Africa.
- Within these two subspecies, there is a multitude of morphotypes.

What are the new findings?
- This study established a varietal typology of shea trees based on endogenous knowledge.
- There is a strong phenotypic variability of the fruit observed in the park systems, despite the empirical selection made by the farmers.
- Local and scientific knowledge are complementary in the description of ethno-varieties.
- It is possible to go from the concept of ecotypes to the notion of varieties in the shea butter tree which is only at the beginning of domestication.

What is the expected impact on horticulture?
- A total domestication of the shea tree is onwards, with assignment of ethno-varieties according to production objectives in food technology (butter, jam, beverage, syrup, *etc.*).
- Thanks to the knowledge of the nutritional values of each ethno-variety, the establishment of production plantations is currently underway in some localities.

(EV). *Résultats et discussion* **– En utilisant les caractéristiques des fruits et des feuilles les communautés locales ont identifié, dans les trois sites d'étude, 13 EV qu'ils ont classées en quatre groupes: (i) Fruits à pulpe charnue; (ii) Fruits avec des amandes à fort rendement en beurre; (iii) Fruits à pulpe et à beurre; (iv) Fruits à pulpe impropres à la consommation humaine.** *Conclusion* **– Les communautés locales détiennent des clés de reconnaissance des morphotypes du karité. Celles-ci sont significatives pour la gestion des peuplements naturels. Une étude complémentaire basée sur une analyse moléculaire par microsatellites permettrait de mieux comprendre l'organisation de cette variabilité morphologique.**

Mots-clés
savanes africaines, karité, *Vitellaria paradoxa*, diversité génétique, caractères morphologiques, savoirs traditionnels, espèce sous-utilisée

Introduction

The edible oil-producing shea butter tree grows naturally in the African savannahs. Its fruit is a valuable food source and the kernels are an important commodity for producing butter as cosmetics, such that the shea tree is a significant income source for all those involved in the sector (Lamien, 2006; Parkouda *et al*., 2007). It is a semi-domesticated species, the fruit of which is harvested by simple collection of the fallen fruits. In fact, producers use to harvest the fruits wherever they find them. Clearly, such a method is not conducive to a quality harvest nor can they constitute a long-term method of managing the resource. To improve the yield in kernels and the quality of shea butter, it would be necessary to set up progressively plantations with individuals which are genetically most suited to a fruit production of quality. For such an objective, it would be necessary to assess the potential of the various morphotypes and/or ethnovarieties (EV) and subsequently classify them according to their productive potential. This idea of evaluating and classifying the morphotypes is not new. It has long been known that such a classification is indispensable for defining any strategy for conservation and use of phytogenetic resources (Weber *et al*., 2008).

According to the botanists who first described the species (Chevalier, 1943; Ruyssen, 1957), there exist two sub-species: *Vitellaria paradoxa* subsp. *paradoxa* in Western Africa and subsp. *nilotica* in Eastern Africa. Within each sub-species there is a multitude of ecotypes. And within each ecotype there is again a profusion of morphological variants according to the tree's architecture, the morphology of the leaves or the characteristics of the fruit. Faced with this enormous phenotype variability, Vuillet (1911), Delolme (1947) and Chevalier (1948) produced a 'varietal' typology within the *Vitellaria paradoxa* species. The various descriptions gave rise to a 'botanical variety' definition, the use of which for managing the productive varieties proved to be hampered by the instability of the naming system. However, it appears from these studies that it would be necessary to have a different approach for describing the morphological diversity found in the field. Thus started the use of morpho-adaptive features as a means of assessing the various ecotypes in order to understand the organisation of the phenotype variability both within agroforestry plantations and in the natural wild habitat (Guira, 1997; Sanou *et al*., 2005; Diarrassouba *et al*., 2008; Compaoré, 2008). Subsequently, from the descriptors of the fruit, Diarassouba *et al*. (2009) in Ivory Coast, Djekota *et al*. (2014) in Chad, Gwali *et al*. (2012) in Ouganda, Compaoré (2010) and Karambiri *et al*. (2017) in Burkina Faso have described the different forms found in agroforest parklands.

With the discovery of more powerful molecular markers for differentiating biological material, other workers have focused on the genetic diversity both intra- and inter-population, using such biochemical markers as isoenzymes (Lovett and Haq, 2000), near infra-red spectrometry (NIRS) (Davrieux *et al*., 2010), DNA markers using RAPD (random amplified polymorphism DNA (Bouvet *et al*., 2004; Fontaine *et al*., 2004) or microsatellites (Kelly *et al*., 2004). In addition, the studies carried out in the past 20 years focusing on the Shea butter have produced numerous results concerning butter yielding, as a function of the geographic source of the kernels (Maranz *et al*., 2004), butter acidity factors (Jacobsberg, 1977), and the storage and preservation techniques of the kernels (Vind, 2011; Odongo *et al*., 2011). All these studies have shown a considerable morphological, genetic and biochemical variability both between and within populations. However, none of them has been able to translate all this variability into a clear varietal differentiation. This can be attributed to the absence of stable and easily identifiable descriptors that can be used both on field and in laboratory and be accepted by all the various players operating in the shea tree sector. Despite the scientific value of all the information gathered, the first studies taking into account the knowledge of the local population on the varietal differentiation of shea in Burkina Faso are those of Compaoré (2010) and Karambiri *et al*. (2017) on subsp. *paradoxa* but these studies have not incorporated the biometric parameters. Similar works have been done in Uganda by Gwali *et al*. (2011, 2015) on subsp. *nilotica*. And among the works having integrated the knowledge of the local populations, only the works of Gwali *et al*. (2012) incorporated the biometric parameters. Indeed, it is clear that throughout Africa, local environmental knowledge is absolutely essential for the management of plant genetic resources. During the international conference held in Ouagadougou in November 2011 on the theme "Science for better shea", the key players in the sector pointed out that there was no correlation between the scientific data and any notion of varietal differentiation. The main objective of this study was to give an ethno-varietal typology to well-established phenotypical characteristics. Three specific objectives were identified: (i) Identify the key descriptors used by the local population to differentiate and characterise the EV of shea tree; (ii) Take a census of the EV in three ecological areas in Burkina Faso; and (iii) Compare these EV characteristics emanating from the indigenous knowledge of rural communities with those resulting from biometric measurements of leaves and fruit. We hypothesized that the various EV of the shea tree are morphotypes for which the local populations hold the key to their differentiation.

Materials and methods

Identification and characterisation of the various EV in the field were carried out in a participative manner. The team was composed of field technicians comprising development officers, research technicians, research scientists and students, plus men and women designated by the local communities on each site.

TABLE 1. Pedoclimatic characteristics for the study sites in Burkina Faso.

Sites: village name (department)	GPS coordinates and altitude	Climate and annual rainfall (R in mm)	Topography	Type of soil*
You (Titao)	02°09'24W, 13°41'51N 320 m	South Sahelian 300 ≤ R ≤ 600	Flat terrain with two topo-sequences (medium slope and low slope)	Tropical ferruginous brown soil
Yarsi (Arbolé)	02°03'07W, 12°52'25N 389 m	North Sudanian 600 ≤ R ≤ 900	Flat terrain with two topo-sequences (medium slope and low slope)	Leached ferruginous soil with stains and concretions
Yantenga (Diabo)	01°01'36W, 12°02'04N 298 m	North Sudanian 600 ≤ R ≤ 900	Flat terrain with two topo-sequences (medium slope and low slope)	Compacted leached shallow tropical ferruginous soil

* Using the French classification system.

Study sites

The study covered three villages divided into three distinct administrative zones: (i) Yarci, in the department of Arbolé; (ii) You, in the Titao Department; and (iii) Yantenga, in the department of Diabo. Each village is inhabited by several ethnic groups but with linguistic dominance of one of them. The language commonly spoken in You, Yarsi and Yantenga is *Mooré*. The management of shea resources in the different zones of the study is structured as follows: generally, shea trees that grow in the bush are freely accessible, while those growing in fallows or on agricultural land (fields) belong to the landowner. Shea parkland belongs to men (field owners) while the collection of fruit, nuts and shea fines is vested in women and children. The three villages are among the sites defined in the ADA project (Austrian Agency for Development) according to three different agro-ecological zones of Burkina Faso (Figure 1). The geo-climatic characteristics of the study sites are presented in Table 1.

Plant material

The three populations were first mapped and all trees geo-referenced in medium and low slope topography. For identification by the local inhabitants, 35 individual fruit-bearing trees among those geo-referenced were sampled per site, giving a total of 105 individuals, across the three sites. The spatial layout of the trees in the agroforestry plantations differs from one site to another.

Experimental protocol

Field data collection

The sampling of individual fruiting trees has been done randomly in each agroforest parkland. Except the fruits of V8, almost all other EV fruits were free from any parasitism. The data collection was recorded during two shea nut production campaigns in the three study sites. The approach used to identify EVs consisted to visiting each site, accompanied by the local producers (5 men and 5 women) involved in the marketing of shea tree products and designated by their local community based on their knowledge of shea trees. The trees from which samples were taken were geo-referenced (longitude, latitude and altitude, see Table 1) using a GPS device and marked with a painted sign. From each tree 20 fruit samples and 20 leaves were taken and placed in plastic bags to avoid any drying out on site. A label with the tree's reference number was added to each bag. Each bag was labelled with the following: the site name, the EV number, the harvesting date, the tree number and its geographic coordinates (altitude, latitude and longitude) plus its trunk circumference at a height of 1.3 m.

Focus group data collection

Identification and characterisation of the EV were carried out in 'focus groups'. Two such groups were formed, one comprising 10 men, the other 10 women, all designated by their local community on the basis of their knowledge of the trees and their involvement in the shea tree value chain. Each focus group provided information concerning: (i) Criteria used by the producers in the identification and characterisation of each ethnovariety; (ii) Census of the EV present in the field; (iii) Characterisation of the various fruit types (size, form, taste, colour of the flesh and the Shea nut); (iv) characteristic identifiers for each EV; (v) the name given to each EV in the *Mooré* language. Characterisation by the local team of the trees in each EV was based largely on the shape (size and shape of tree crown), architecture (branch structure) and morphology of the leaves (size and degree of shade offered).

Biometric measurements of leaves and fruit

The collected samples were taken to the laboratory for biometric measurements (Figure 2). Measurements of the leaves and fruit were done with a 20-cm ruler and a set of callipers. The sample contained 20 healthy leaves and 20 fruits. The parameters measured for leaves were the length and width of the blade, the length of the stalk and the number of secondary veins. For fruit, the measurements were the weight when fresh and the large diameter (Ld) and small diameter (Sd) corresponding to the length and thickness of the fruit. Fruit weight was established using an electronic scale. Similar descriptors have already been used in the work of Gwali *et al.* (2012) to study the biometric variations between ethno-varieties of shea in Uganda.

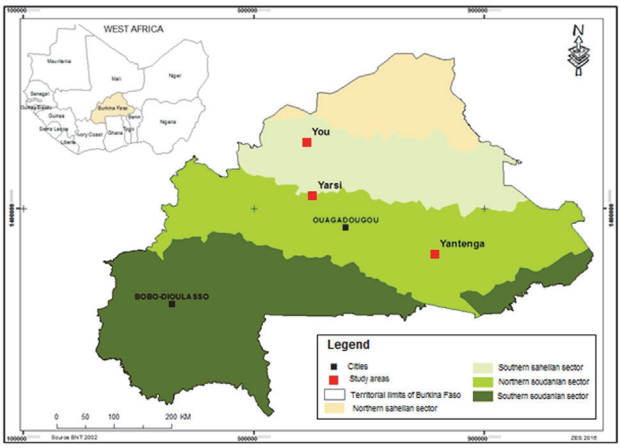


FIGURE 1. Geographic location of the study sites in Burkina Faso.

Measure of leaves | Measure of fruit | Fruit weight measurement

FIGURE 2. Figures illustrating some biometric measurements on fruits and leaves.

Data analysis

The local population's characterisation of each EV was transcribed into a contingency table, on which was performed a correspondence analysis (CA). The analysis of the biometric data was based on:

(i) The analysis of variance (ANOVA) performed per variable and per site which made it possible to test the EV effect on each variable according to the mathematical model:

$$Y_{ei} = M + P_i + E_i$$

where Y_{ei} is the observed value of EV_i, M the overall mean, P_i the effect of EV_i and E_i is the residue unexplained by the model;

(ii) A principal component analysis (PCA) that enabled a simultaneous analysis of all the variables from all sites. As a result of this analysis, specimens were positioned relative to the variables and a correlation table between variables was generated;

(iii) A hierarchical cluster analysis (HCA) was carried out on all the measured variables to construct a dendrogram from the similarity indices. This enabled forming sub-groups of individuals with similar characteristics. A multiple discriminant analysis (MDA) was used to demonstrate to which group each specimen belonged.

Results and discussion

Identification and characterisation of the various ethnovarieties by local populations

The local population's criteria for identification and characterisation

The differentiation between the various varieties, and the naming in local language, both in the field and in the focus groups, were done exclusively based on the characteristics of the fruit and not on the characteristics of the tree or on the morphology of the leaves. Thus, at the level of each site, the identification of ethnovarieties was done visually through the characteristics of the fruits (size and shape) in the *Mooré* language. The ethnovariety name is based on the shape of the fruit, the taste of its flesh/pulp or on the morphological characteristics of the nuts (Figure 3). However, the description of those EV identified referred to: (i) The characteristics of the fruit such as the taste, the nature of the flesh, the color of the nuts and the butter content of the kernels; (ii) The characteristics of the mother tree such as the structure of the branches, the density of leaf formation and the crowns pan; (iii) The phenology of the fruiting cycle based exclusively on the period when the fruit is ripe.

Identification of ethnovarieties by site

On the basis of the identification criteria used, 10 ethnovarieties (EV) were identified in Yarsi and You, and 7 in Yantenga. The ethnovariety V7 (*Taam guissé*) is characterized by a consistency of pulp at maturity giving it the characteristics of an immature fruit. Consequently, its pulp is pleasant to eat only after exposure of the fruit to the sun. Depending on the fruit ripening period, local communities identify three types of EV. This criterion was used in the western region of Burkina Faso in the work of Karambiri *et al.* (2017), but was not considered as a criterion in this study.

The ethnovariety V5 (*Taam Goonsé*) was only found in Yarci (Arbolé) and in You (Titao). Ethnovarieties V8 (*Taam Poonsa*) and V10 (*Taam Yiiba*) were not identified in Yantenga (Diabo). The names of the EV in local language some-

TABLE 2. Names of shea ethnovarieties (EV) in *Mooré* language at the sites of Yantenga, Yarsi and You, Burkina Faso.

EV	Characteristics	Yarci	Diabo	You
V1	Small fruit	*Taam Bonoogo*	*Taam Bonlogo*	*Taam Kidsé*
V2	Elongated fruit	*Taam Tolma*	*Tam Tolma*	*Taam Tolma*
V3	Large fruit	*Taam Boara*	*Taam Bèda*	*Taam Bourdou*
V4	Rounded fruit	*Taam Guilissi*	*Taam Guilissi*	*Taam Guilissi*
V5	Fruit with pointed end	*Taam Goonsé*		*Taam Goonsé*
V6	Fruit with yellow flesh/pulp	*Taam Miidou*	*Taam Dondo*	*Taam Miidou*
V7	Unripened fruit	*Taam Guissé*	*Taam Guissé*	*Taam Guissé*
V8	Bland fruit rotten when ripe	*Taam Poonsa*		*Taam Zouhan*
V9	Fruit with astringent taste resembling that of potash	*Taam Zèem*	*Taam Zoun Pèlga*	*Taam Poporoaga*
V10	Fruit containing sometimes 2 or 3 shea nuts	*TaamYiiba*		*Taam Yemraogo*

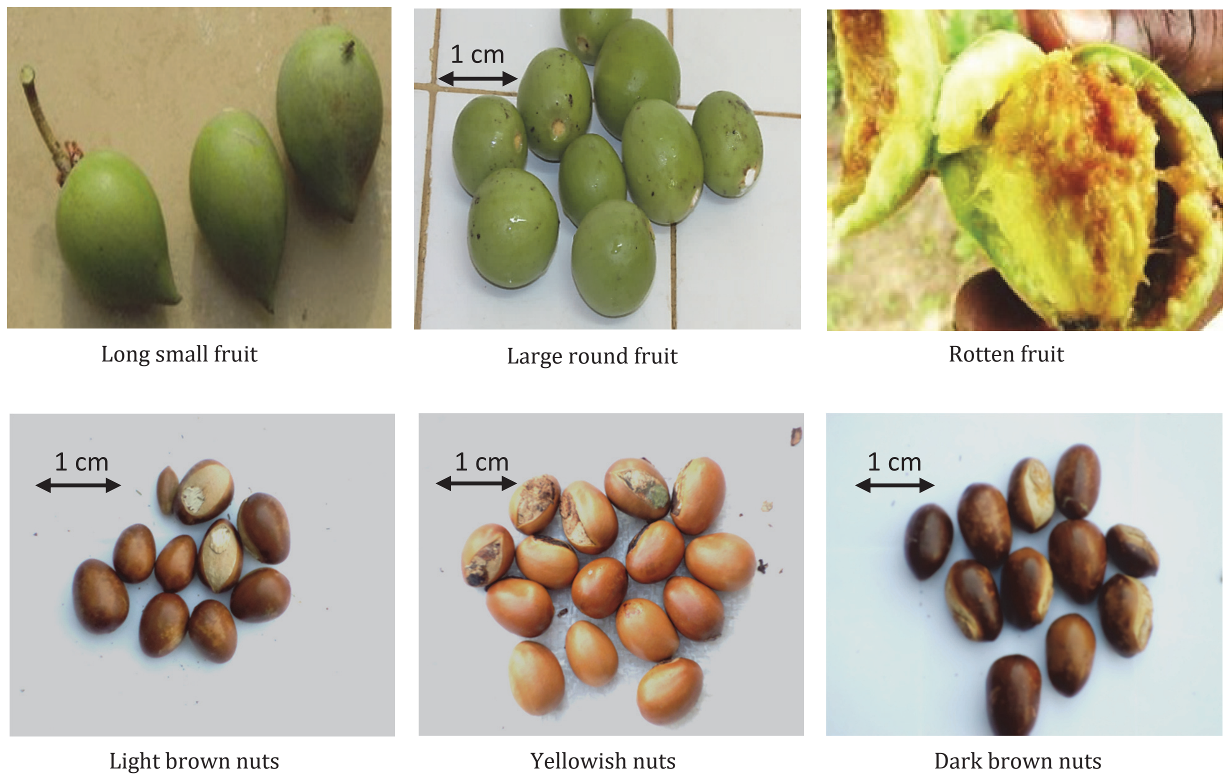


FIGURE 3. Illustration of some morphological characters of the fruit and nuts of various shea ethnovarieties collected in Burkina Faso.

times differ by site, but they are patently synonyms (Table 2). Three ethnovarieties (V11: *Taam zuun Pelga*, V12: *Taam Labidjeli* and V13: *Taam Malfajet*) were added during the description in the focus groups in Yantenga village. The absence of these EV in our collection can be explained by the fact that the maturity period did not coincide with the period of data collection.

Similarities in local naming of the ethnovarieties in the different sites in the *Mooré* language constitute a strong signal that such naming is anchored in local community lore from time immemorial and has been handed down over the centuries from one generation to the next. Certain EV appearing in one site were absent from others. Two theories can be advanced for this: (i) The maturity season for the fruit did not coincide with the period when data was being collected; (ii) These EV are absent or rare in the collected areas as a result of deliberate preferential selection by the local population, as mentioned by Faye *et al.* (2010) concerning woody species in Sahelian agroforestry plantations. In fact, a choice by the local population in favour of superior quality trees can have slowly improved the yield from the particular species (Lovett and Haq, 2000) without in anyway affecting the level of diversity.

Characterisation of ethnovarieties by rural community

The characterisation of the shea EV as given by the local producers of shea butter was based on the tree's architecture, the form of the crown, the leaf density (the extent of the shade provided), the shape of the leaves and the amount of butter the kernels provided. Table 3 summarises the descriptions given for each EV by representatives of the local population.

Affectation of the EV as a function of the characterisation given by the local population

The correspondence analysis carried out on the contingency table created using the characterisations from the focus groups produced four EV groups (Figure 4): (i) EV valued for their flesh/pulp; (ii) EV valued for their butter; (iii) EV valued for both flesh and butter but with limited yield of both (flesh or butter); (iv) EV with no suitable flesh and poor butter yield.

Table 4 classifies the various identified shea EV as a function of their primary value and gives the period when fruit for each one reaches maturity. This study has been able to take account of the indigenous population's local knowledge of the shea tree in identifying and characterising the ethnovarieties of the species. For each site, the key descriptors used by the local population to describe a typology of the varieties present on their land are the characteristics of the fruit (size, shape, taste, color of the flesh/pulp and the nut). For each variety they use the tree's structure (branch formation, wood production, shade afforded), the morphology of the leaves (size and density), the butter yield from the kernels, the size of the fruit and the taste of the flesh. This is simply the confirmation of the key descriptors used by farmers for centuries to differentiate the various local plants. These descriptors, already used in India on *Tamarindus indica* (tamarind) (El-Siddig and Lüdders, 1999), have already been used to describe forest plants in the Sahel such as shea by Compaoré (2010) and Karambiri *et al.* (2017) in Burkina Faso on *Vitellaria* subsp. *paradoxa*, in Uganda by Gwali *et al.* (2011, 2012, 2015) on subsp. *nilotica*, but also *Adansonia digitata* by Assogbadjo *et al.* (2008) (baobab) in Benin, Burkina Faso, Ghana and Senegal. Local knowledge on cultivated plants has been taken into account in the work of: Adoukonou-Sagbadja *et al.* (2006) on

Table 3. Characteristics of some shea ethnovarieties (EV) as described by the local populations of three sites in Burkina Faso.

EV	English meaning of local names	Characteristics of flesh/pulp and nuts	Characteristics of the tree (leaves and shading)	Butter yield
V1	Small fruit	Sweet flesh with small light-brown nut	Small leaves, little shade offered	Good
V2	Fusiform-shaped fruit	Sweet flesh with light-brown elongated nut	Long leaves affording considerable shade	Moderate
V3	Large fruit	Generous sweet flesh with large medium-brown nut	Short leaves with medium shading	Moderate
V4	Round medium-sized fruit	Moderately sweet meagre flesh with large bright red nut	Long slender leaves affording medium shade	Moderate
V5	Fusiform fruit with pointed end	Sweet flesh with small bright-red nut	Long leaves affording plenty of shade	Moderate
V6	Ellipsoid fruit with yellow flesh	Sweet yellow flesh with average-sized yellowish nut	Small leaves affording little shade	Good
V7	Pulp fruit firm at maturity	Consistent flesh with astringent taste– large light-brown nut	Long leaves affording plenty of shade	Average
V8	Fruit always putrefied at maturity	Flesh permanently rotten with bland taste and a small dark-brown nut	Long slender leaves affording medium shade	Good
V9	Average-sized fruit with a taste resembling potash	Flesh with astringent taste and a large medium-brown nut	Long leaves affording plenty of shade	Poor
V10	Fruit containing two or three nuts	Generous sweet flesh with small medium-brown nut	Long leaves affording plenty of shade	Poor
V11	Large fleshy fruit	Generous very sweet white flesh with small whitish nut	Small leaves, little shade offered	Poor

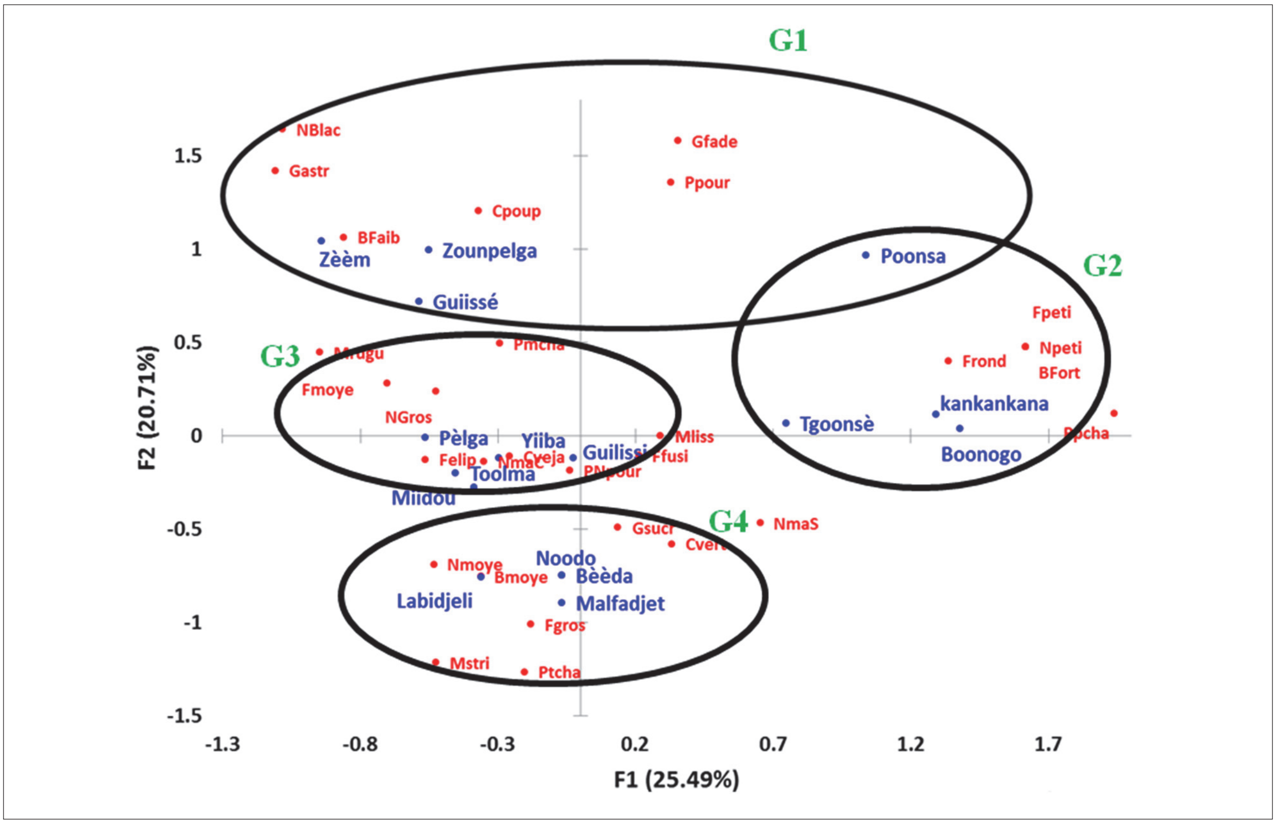


Figure 4. Correspondence analysis of the variables and the individuals in the ½ (F1/F2) design. Symmetric graph along the axes F1 and F2 (explaining 46.21% of the variability) where F1 axis is defining the butter yield, and F2 axis is defining the consistency of the pulp. Groups G1: Flesh/pulp unfit for human consumption and poor butter yield; G2: Excellent butter yield but limited flesh; G3: Moderate butter yield and flesh/pulp edible; G4: Generous sweet flesh and moderate butter yield.

Fonio millet (*Digitaria exilis*, *D. iburua*) in Togo, Appa Rao *et al.* (2002) on rice in the Lao People's Democratic Republic but also on *Manihot esculenta* (cassava) by Sambatti *et al.* (2001) in Brazil. Added to this are domesticated fruit trees such as mango or papaya. All these studies have shown that Sahelian species have enormous genetic diversity (Diallo *et al.*, 2010; Abasse *et al.*, 2011). Our results on the focus groups are similar to those reported by Diarrasouba *et al.* (2009) in their typology of the various vegetable species present in agroforest parkland.

Table 4. Description and illustration of some shea ethnovarieties (EV) according to their morphological and production characteristics.

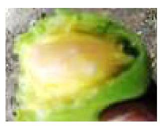
	EV	Morphological and production characteristics	
Ethnovarieties with limited fleshy pulp but with good butter yield	V1	(i) small fruit meagre flesh not very sweet (ii) small round light-brown seed (iii) intermediate fruit ripening (July–August) (iv) good butter yield	
	V8	(i) moderately fleshy fruit with bland taste (ii) small oval light-brown seed (iii) intermediate fruit ripening (July–August) (iv) good butter yield	
	V4	(i) small fruit with sweet somewhat meagre flesh (ii) small round dark-colored seed (iii) ripe in season (July–August) (iv) good butter yield	
	V5	(i) small green fusiform fruit with sweet somewhat meagre flesh (ii) small dark-brown fusiform nut (iii) intermediate fruit ripening (July–August) (iv) good butter yield	
Ethnovarieties with generous sweet flesh and moderate butter yield	V6	(i) large oval, greenish-yellow, fruit with striations (ii) very sweet generous flesh/pulp (iii) late ripening (August–September) (iv) moderate butter yield	
	V10	(i) fusiform green fruit with generous sweet flesh/pulp (ii) small dark-brown ellipsoid nut (iii) fruit ripening in July–August (iv) good butter yield	
	V3	(i) fusiform purple-green fruit with generous sweet flesh/pulp (ii) small dark-brown fusiform nut (iii) intermediate fruit ripening (July–August) (iv) good butter yield	
	V4	(i) large fruit with generous sweet flesh (ii) medium-sized dark-brown seed (iii) late ripening (August–September) (iv) moderate butter yield	
	V12	(i) large ellipsoid green fruit which crack open on falling to the ground when ripe (ii) generous very sweet pulp/flesh (iii) late ripening (September) (iv) moderate butter yield	
	V2	(i) fusiform greenish-yellow fruit with generous sweet flesh/pulp (ii) medium-sized dark-brown nut (iii) intermediate fruit ripening (July–August) (iv) moderate butter yield	
	V13	(i) fusiform fruit with generous sweet flesh/pulp (ii) very small dark-brown nut (iii) intermediate fruit ripening (July–August) (iv) zero butter yield	
Ethnovariety with no alimentary interest	V11	(i) fusiform fruit with generous bland flesh/pulp (ii) medium-sized whitish nut (iii) intermediate fruit ripening (July–August) (iv) poor butter yield	

TABLE 5. Variance analysis of the different variables taken from shea ethnovarieties in the villages of Yarci, You and Yantenga in Burkina Faso. F: Fisher's test; *P*: Probability; SD: Standard deviation. Variables: LgB: Length of the blade; WiB: Width of the blade; LgS: Length of the stalk; DSV: Density of secondary veins; LgFr: Length of the fruit; WiFr: Width of the fruit; WtFr: Weight of the fruit; Circum: Circumference.

Variables	You			Yarci			Yantenga		
	F	*P*	SD	F	*P*	SD	F	*P*	SD
LgFr	4.60	0.005 **	0.395	1.88	0.139 ns	0.452	10.39	0.0001 ***	0.289
WiFr	1.61	0.198 ns	0.298	0.42	0.903 ns	0.495	6.56	0.001 **	0.235
WtFr	1.60	0.203 ns	0.417	2.94	0.035 *	5.103	8.66	0.0001 ***	5.582
WiB	0.30	0.964 ns	3.323	1.37	0.286 ns	2.231	2.43	0.068 ns	2.190
LgB	0.71	0.693 ns	0.804	1.30	0.318 ns	0.633	1.98	0.122 ns	0.855
LgS	1.42	0.262 ns	1.062	0.27	0.973 ns	1.362	0.86	0.544 ns	0.993
DSV	1.33	0.302 ns	4.528	1.17	0.384 ns	3.490	0.55	0.765 ns	4.282
Circum	0.28	0.971 ns	67.970	1.15	0.392 ns	40.070	0.38	0.879 ns	43.140

*: Significant difference at 5% threshold; **: Very significant difference at 1% threshold; ***: Extremely significant difference at 1‰ threshold; ns: Not significant.

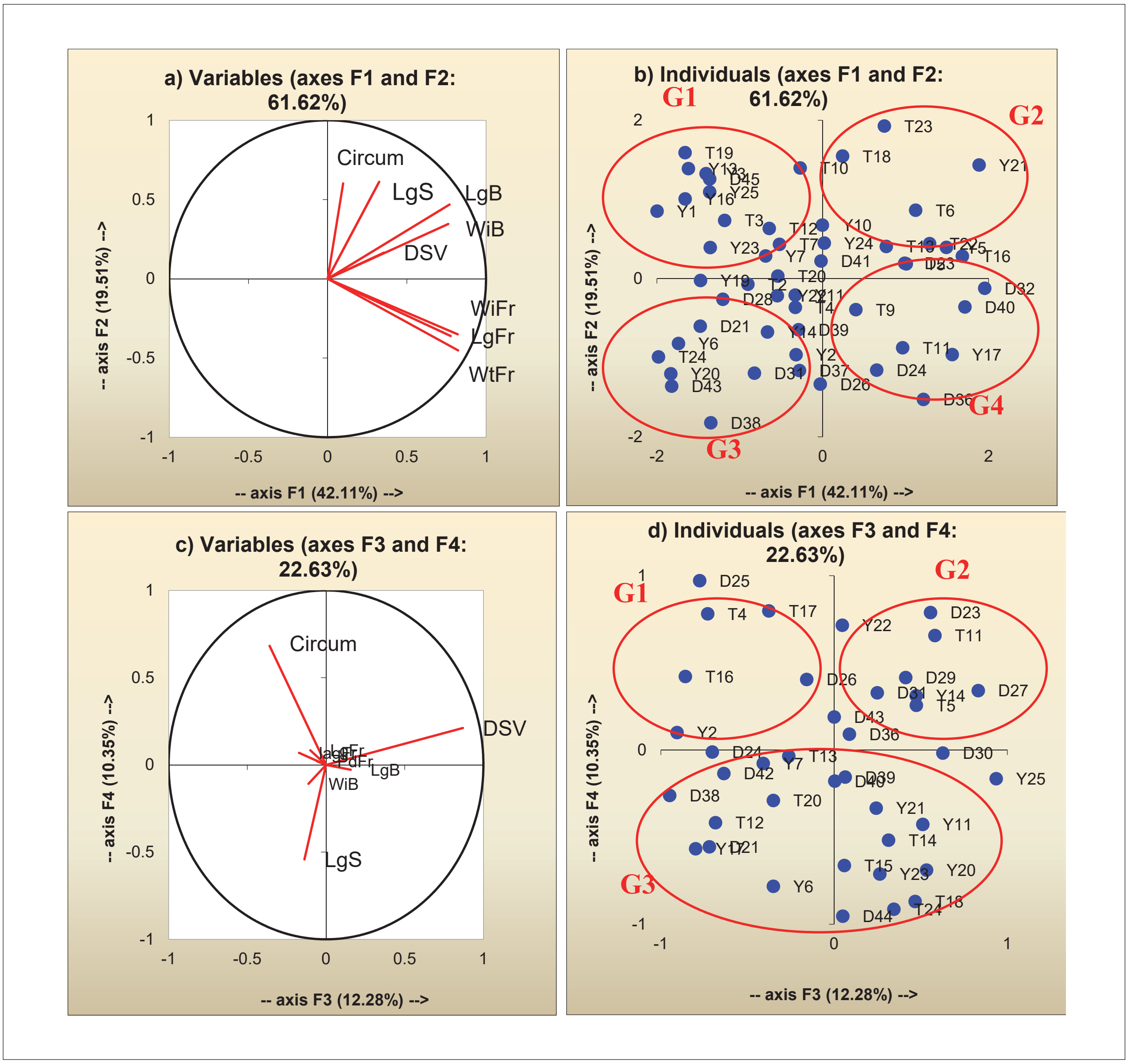


FIGURE 5. Representation of the variables and individuals in F1/F2 and F3/F4 designs. G1, G2, G3, and G4 are each group of homogeneous individuals for one or more of the following characters: LgB: Length of the blade; WiB: Width of the blade; LgS: Length of the stalk; DSV: Density of secondary veins; LgFr: Length of the fruit; WiFr: Width of the fruit; WtFr: Weight of the fruit; Circum: Circumference.

Characterisation of EV based on the biometric data

Univariate analysis

For the characteristics of the leaves, and the circumference of the tree trunk at a height of 1.3 m, no significant difference was found between the shea EV, irrespective of the variable used and the study site (Table 5). In Yarci, the variance analysis of the variables concerning the fruit shows a significant difference ($P = 0.035$) between EV when taking weight as the variable. In Yantenga the variance analysis shows very significant differences between EV in terms of length ($P = 0.0001$), width ($P = 0.001$) and weight ($P = 0.0001$) of the fruit. In You, significant differences between EV were observed only when using the length of the fruit as the variable ($P = 0.005$).

The differences between the various EV are essentially due to the different characteristics of the fruit, which confirms the ancestral choice of the local farming community. In addition, the characteristics of the fruit appeared in all the descriptions given by the locals, which show just how important such characteristics are in differentiating the various varieties.

The absence of difference in leaf characteristics between the various EV shows that these parameters are not important either in differentiating or in describing shea tree varieties. Using the morpho-adaptive character of a plant material seems not particularly helpful in identifying particular varieties. However, these parameters are very relevant for describing ecotypes, as they are influenced by environmental factors (Sanou *et al.*, 2006). Interestingly, during a study carried out in the classified forest of Dindéresso, not a single variety of shea tree has been identified by the local producers by mentioning the morphology of the leaves (Compaoré, 2010). In addition, the existence of variants within a partic-

Table 6. Proportion and composition of tree groups obtained in the three sites (Diabo, Yarci and Titao) by the hierarchical cluster analysis (HCA).

Groups	Proportion of individuals (%)			Composition depending on the groups
	Diabo	Arbolé	Titao	
1: A1	33.00	33.00	33.00	Heterogeneous group with a mixture of individuals from Diabo, Arbolé and Titao
2: A2	82.35	17.70	0	Group comprising mainly individuals from Diabo with a few from Arbolé
3: B1	7.70	7.70	84.60	Group comprising mainly individuals from Titao with a very small number from Diabo and Arbolé
4:B2	35.70	35.70	28.60	Heterogeneous group with a mixture of individuals from Diabo, Arbolé and Titao
5: C1	0	43.00	57.00	Heterogeneous group with a mixture of individuals from Arbolé and Titao
6: C2	14.30	57.10	28.50	Heterogeneous group with a mixture of individuals from Arbolé, Titao and Diabo

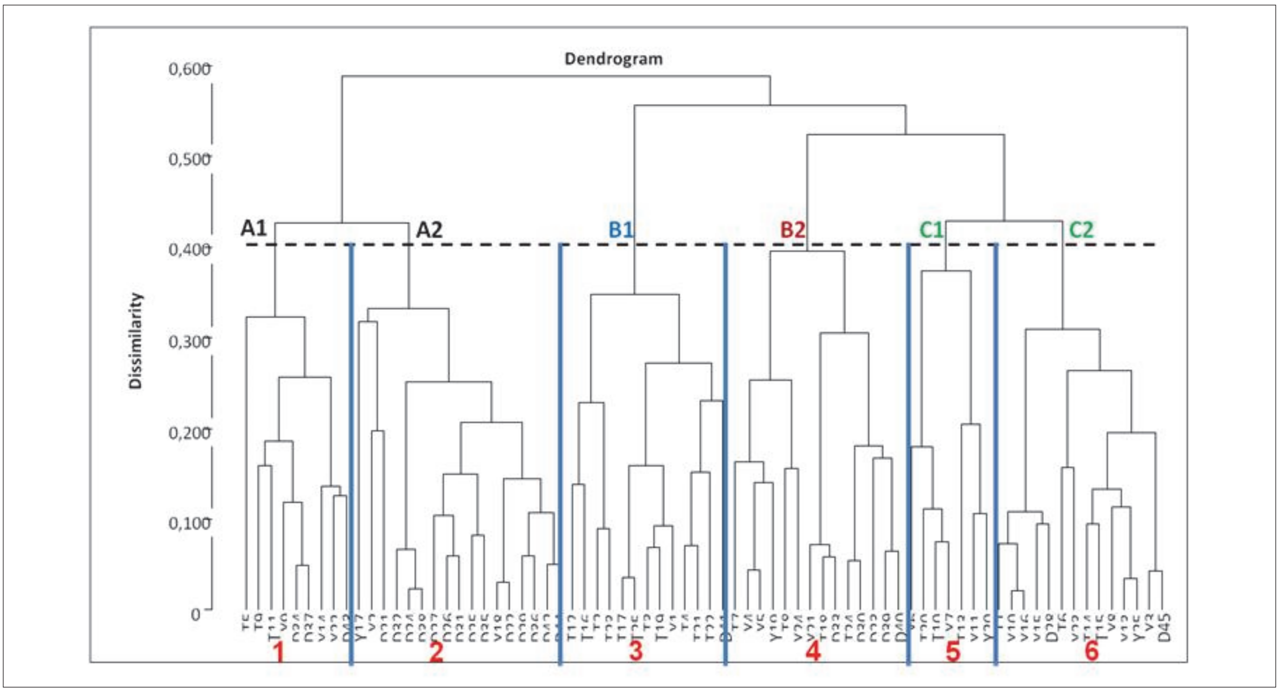


Figure 6. Dendrogram of the phenotypic structuring of all ecotypes of shea collected in three villages of Burkina Faso.
(A1) 1: Heterogeneous group with a mixture of individuals from Diabo, Yarci and Titao.
(A2) 2: Group comprising mainly individuals from Diabo with a few from Yarci.
(B1) 3: Group comprising mainly individuals from Titao with a very small number from Diabo and Yarci.
(B2) 4: Heterogeneous group with a mixture of individuals from Diabo, Yarci and Titao.
(C1) 5: Heterogeneous group with a mixture of individuals from Yarci and Titao.
(C2) 6: Heterogeneous group with a mixture of individuals from Yarci, Titao and Diabo.

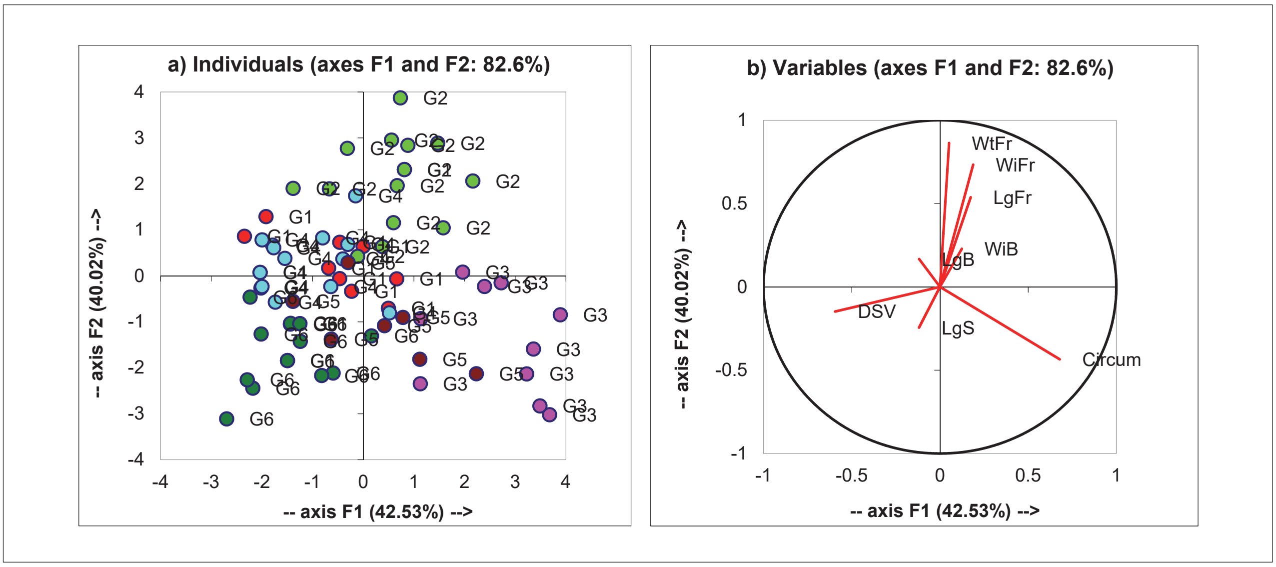


FIGURE 7. Representation of the (F1; F2) factorial design discriminating groups and variables. Dots represent the homogeneous individuals of the different groups G1 to G6. LgB: Length of the blade; WiB: Width of the blade; LgS: Length of the stalk; DSV: Density of secondary veins; LgFr: Length of the fruit; WiFr: Width of the fruit; WtFr: Weight of the fruit; Circum: Circumference.

ular tree population, which the locals differentiate by ethnovarieties, confirms the wide intra-population variability demonstrated by genetic analysis (Bouvet, 2011; Logossa *et al*., 2011). This variability observed at a plantation level is the result of a long process instigated both by deliberate selection by the agroforestry management team, and by adaptation to the local ecological conditions. Considering that there is a relationship between the level of diversity and the survival of specific populations (Hamrick and Godt, 1996; Ellstrand and Elain, 1993), then the latter are not in danger in the short term. However, such a situation can quickly change if the prevailing conditions may change (Hamrick and Godt, 1996).

Principal component analysis

A principal component analysis (PCA) carried out on all shea EV enabled constituting sub-groups of individuals as a function of all the variables taken together. The two principal axes, F1 and F2, display more than half of the existing variability (Figure 5a-b). They explain in total 61.62% of the phenomenon observed, with individual contributions of 42.11% for F1 and 19.51% for F2. The variables contributing to axis F1 are the length of the fruit (LgFr), the width of the fruit (WiFr), the weight of the fruit (WtFr), the length of the blade (LgB) and the width of the blade (WiB). Those contributing to axis F2 are the trunk circumference (Circum) of the mother tree, the length of the stalk (LgS) and the length of the blade (LgB) (Figure 5a). The representation of each individual following these axes gives specimen sub-groups which can be characterised by certain variables better represented in the design formed by F1 and F2. One can see two categories of individuals, with each category having two sub-groups. The first category comprises (Figure 5b):

(i) Sub-group G1: characterised by low values of LgFr, WiFr, WtFr, LgB, WiB that can be found on the negative side of axis F1;
(ii) Sub-group G2: comprising individuals with high values for these variables, placed on the positive side of axis F1;
(iii) Sub-group G3: comprising individuals with high values of Circum, LgS, LgB, placed on the positive side of axis F2; and
(iv) Sub-group G4: characterised by low values for these variables that can be found on the negative side of axis F2.

Another part of this variability is observed in the design created by F3 and F4, complementary to the F1/F2 design. These axes explain in total 22.63% of the variability with individual contributions of 12.28% for axis F3 and 10.35% for axis F4 (Figure 5c-d). The variables best represented in this design are the trunk circumference (Circum), the density of secondary veins (DSV) and the length of the stalk (LgS) (Figure 5c). The representation of the individual trees in the design formed by axes F3 and F4 gives 3 sub-groups of individuals (Figure 5d): (i) Sub-group G1 is best characterised by the circumference of the individual trees; (ii) Sub-group G2 is best described by the density of secondary veins in the leaves; and (iii) Sub-group G3 can be characterised by the length of the stalk.

Creation of groups by the degree of similarity

The hierarchical cluster analysis (HCA), based on the similarity indices, enabled separating the individuals within the sub-groups according to their degree of similarity. The dendrogram using the weighted averages of the calculated Euclidean distances shows significant variations between the various shea EV under study (Figure 6). Truncation at the level of 40% in the dendrogram gives 6 groups of individuals (Table 6). The composition of these sub-groups is illustrated by the multiple discriminant analysis (MDA) (Figure 7). The individual trees are spread amongst the sub-groups independently of their ethnovariety name. However, only Group 1 contains individuals from all identified EV.

All the statistical analyses – correspondence analysis, HCA and MDA – carried out on all the parameters observed showed that there is significant morphological structuring. One sees sub-groups created that are independent of the ethnovariety description given by the local population and that highlight a homogeneous set of individuals for certain of the parameters observed. This significant variability was pointed out by the very first botanists who described the species (Ruyssen, 1957; Aubréville, 1950) in the naturally-occurring shea tree populations. The groupings created from the biometric information used in the HCA do not correspond with those made by the rural population based on the qualitative characteristics of the fruit. This can be explained by the fact that the local communities use qualitative variables rather than quantitative ones.

Conclusion

Fruit characteristics are the main descriptors used by local communities to differentiate ethnovarieties. This indigenous knowledge transmitted over the centuries is fundamental to strategies for managing plant genetic resources in rural areas. In fact, a rational management of the shea germplasm should take into account the basic knowledge held by local populations on shea morphotypes. The great diversity of ethnovarieties provides two key sets of information: (i) It is highly probable that the observed shea diversity results from the choice of producers according to their production objective (fruit pulp, butter or wood); (ii) There is no risk of short-term genetic drift in the current management of the shea parks in the studied sites. However, such a situation can change rapidly following the management methods and production objectives. Further study of the genetic diversity by molecular analysis of microsatellites would help clarify the observed morphological diversity.

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