Morphotype Classification Criteria, Nomenclature of Shea Varieties [*Vitellaria Paradoxa* (C.F. Gaertn)], And Influence of Sociocultural Factors on Perceived Shea Natural Variation Across Parklands in Benin

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Abstract

Background: Local knowledge and perception are crucial to undertake the domestication of useful species such as *Vitellaria paradoxa* that makes significant contribution to rural household economy in Africa. This study aims to document shea morphotypes diversity based on folk knowledge especially the main criteria farmers used to distinguish shea trees and to examine the influence of sociodemographic characteristics on that knowledge.

Methods: 405 respondents were surveyed across shea parklands in Benin using semi-structured questionnaire. We used the relative citation frequency of criteria followed by Kruskal-Wallis test to evaluate the influence of sociodemographic attributes on local knowledge of Shea morphotypes variation. Factorial Correspondence Analysis described the links between the different morphotypes and parklands, and Principal Components Analysis was used to characterize farmers perception on morphotypes' abundance, fruits and butter yields.

Results: Respondents identified 13 morphotypes based on the five most cited criteria which are fruit size (55.5%), tree fertility (15.40%), bark colour (10.51%), timing of production (5.38%) and pulp taste (3.42%). The citation frequency of classification criteria varied significantly depending on the age, the education level and the sociolinguistic group of the respondent. The Bembèrèkè zone shea parkland revealed higher diversity of morphotypes traits. The small fruit type ('Yanki') was reported to be widespread. It produces higher fruit and butter yields according to respondents.

Conclusions: From our findings, farmers perceived an important diversity of shea traits that are used to classify morphotypes with economic or sociocultural importance. The revelation of that natural variation in shea tree is a key step toward the development of shea improvement program that could focus on the morphotype Yanki reported to be potentially high in fruit production and butter yield.

Background

Wild edible fruit trees are primary alternative sources of income for many rural communities [1, 2]. Wild tree foods are essential components of many African diets, especially in period of seasonal food shortage [3]. Moreover, such plants are valuable genetic resources for new crop development [4, 5]. Unfortunately, some of them are vulnerable or threatened by factors such as overexploitation, habitat fragmentation, climate change, and invasive species. A long-term utilization of those resourceful trees requires an informed strategy for conservation. To this end, rural communities' knowledge of their environmental resources has proven vital for conservation but also for domestication of wild tree species with high economic potential [6]. Indigenous knowledge of species traits can serve as a valuable starting point for understanding natural variations in key phenotypic traits [7]. Based on these traits, farmers recognize different morphotypes, or locally defined taxa or classifications for a given species [8]. Moreover, farmers prioritize certain morphotypes of a given wild species than others. For example, trees with robust growth patterns and desirable fruit and nut traits are deliberately selected and protected by farmers [9]. It is subsequently expected that local people would have some local selection criteria of individual trees presenting interesting characteristics and they might be particularly targeted for collection, not only for consumption and other uses but also for conservation and possibly cultivation [10]. Then, understanding local knowledge systems and preferences can inform the selection and domestication of useful trees species and the development of plant improvement programs to increase local

incomes and food and nutrient availability. In tropical Africa, wild fruit tree species of high economic importance include *Vitellaria paradoxa* (C.F. Gaertn) referred to as Shea tree.

Vitellaria paradoxa (Sapotaceae), is a prominent multipurpose species occurring in a 500 km wide belt from Senegal to South Sudan. The tree is mostly valued for its oil-rich nuts [11–13]. Shea is a widely used traditional staple cooking oil. The average consumption of its oil is estimated at 21 g per person per day in rural areas [14]. In Benin, shea ranks among the top local wild edible trees that farmers protect or grow in their fields, and is mostly used for food processing and ceremonies [15]. Shea tree is also exported for use as a primary cocoa butter equivalent in the chocolate industry and a high-quality ingredient in cosmetics. The European Union's authorization to use shea up to 5% in chocolate products has resulted in a significant growth of international demand in the last twenty years [14]. The local sale of fresh shea fruits, kernels and butter also provides an alternative source of income to households in rural communities, particularly for women who are the main collectors and processors of shea nuts and also retailers of shea products. In Benin, shea products contribute up to 36 to 46% of the income of rural households in Atacora, Donga and Borgou regions [16]. Apart from its use for cooking, shea oil is also used in traditional medicine (nasal decongestant, treatment of wounds, child birth facilitation), in cosmetics (soap making, skin and hair moisturizers and skin lotion) and for rituals such as in traditional marriages as reported by Gwali et al. [17] in Uganda. Shea trees provide shade for farmers, herders and their animals and the ripe mesocarp (fruit pulp) is a key source of energy during the preparation of fields in the rainy season when grain supplies from the previous season are low [11, 18, 19]. The roots and bark also have numerous medicinal uses in the treatment of dysentery, suppurating wounds and other ailments [20]. Due to its importance, shea has been protected through participatory management involving a complex mix of traditions and customs [17].

Despite the importance of this species for thousands households in Benin, shea densities are declining and shea populations are ageing. This state of things is due to extended forest land clearing and the discontinuation of fallowing spell required for the natural regeneration of shea. Other causes include agricultural land expansion and mechanization for commercial crops, tree cutting and removal out of crop fields, firewood and charcoal production [9, 21]. Moreover, shea resources degradation results in a loss of agricultural diversity and implicitly a potential loss of currency in the sector [22].

Studying the species' diversity and documenting traditional knowledge and local classification systems are prerequisite to support conservation action and crop improvement [23]. They are instrumental in understanding phenotypic variation and help guide the selection of ethnovarieties that address local priorities. Theories suggest that people's socio-cultural and demographic attributes such as gender, age, and ethnicity influence their preference of a given species [24]. Moreover, people's preferences for a given species determine their conservation attitudes toward that species [25]. Tietiambou et al [6] also reported that attitudes toward the conservation of species vary according to socio-demographic profiles (gender, age, education, ethnicity) of local people, their geographical location and preferences based on use and market values.

In Benin, ethnobotanical studies have been conducted on some wild fruit tree species such as tamarind [2], African locust bean tree [26], baobab tree [27], marula or cider tree [28]. So far, very little has been done to document phenotypic diversity and local knowledge systems on shea tree. The study by Glèlè et al [29] analysed the structure of shea butter trees in parklands located in different climatic regions of Benin. Gnanlè

[30] reported that shea is an economically, socially and culturally important tree for northern and central Benin. In addition, Agundez et al [31] have recently studied local preferences for shea nut and butter production in Northern Benin. To date, no study have been undertaken to assess local knowledge on shea morphotypes traits and how they can be used in shea cultivars development.

This study documented folk knowledge of shea tree morphotypes, including classification criteria, nomenclature, perceptions on abundance and yields in Benin; it also unravelled the underlying sociodemographic factors that influence folk knowledge across the shea tree range in Benin. We hypothesized that (i) shea classification criteria by farmers are based on both fruit and tree traits and (ii) shea morphotypes knowledge is influenced by socio-demographic factors such as age, gender, instruction level and sociolinguistic groups in Benin.

Materials And Methods

Study area

The study villages are located in the shea parkland zones identified and described by Gnanglè [30] in Benin based on North-South and East-West rainfall gradient, socio-cultural groups, plant production period, and soil types [30,32]. We chose villages in close collaboration with resource persons of National Institute of Agricultural Research in Benin and shea industry (Fludor) staff. The choice of villages was proportional to the size and the dominant sociolinguistic groups of each of the shea parkland zone. In total, we surveyed ten villages in five shea parklands zones including Bohicon, Savè, Parakou, Bembèrèkè and Kandi (Figure 1).

Bohicon zone shea parklands is located between latitudes 7° and 8°N and includes the entire shea population stretching from Bohicon to Dassa-Zoumè. The average annual rainfall in the park is 1200 mm. Three types of soils can be distinguished, namely: the weakly desaturated ferralitic soils or “terre de barre” that stretches south of the park; the impoverished tropical ferruginous soils encountered in the center of the park and the hydromorphic soils north of the park. The average density of shea tree was 15 trees per hectare. The village Setto was selected in this zone for the study. The dominant sociolinguistic group was Fon.

The Shea park of the Savè region is located between latitudes 8° and 9°N and covers the shea population stretching from Glazoué to south of Tchaourou. The average annual rainfall is between 1100 mm to 1200 mm. Soils are basically leached or depleted tropical ferruginous soils. The Shea population of the Savè region has an average density of 26 trees per hectare. The village Toui was selected in this zone for the study. The dominant sociolinguistic group was Nagot

The shea parklands of Parakou zone extends between latitudes 9° and 10°N and includes all the shea population located between Tchaourou and N'dali and between Parakou and Djougou. It is an area characterized by a Sudanian climate with an average annual rainfall ranging from 1000 to 1200 mm. In some places, moderately desaturated ferralitic soils are found. The average density of the park was 26 trees per hectare. The village Barei, and Sirarou were selected in this zone for the study. The dominant sociolinguistic group were Yoa and Bariba.

The Bembèrèkè zone shea parklands is located between latitudes 10° and 11°N and includes all the shea population extending from Bembérékè to Gogounou. The average annual rainfall in this park is 1100 mm. The average density of the park was 25 trees per hectare. Four villages namely Bensékou, Béroubouay, Soaodou, and Dipokor 2 were selected. The dominant sociolinguistic groups included Boko, Bariba and Ditamari. Three types of soils can be distinguished in this park: tropical ferruginous soils slightly leached, whether concreted or not on kaolinic material. In the depressions hydromorphic soils were found while under a vegetative cover we found ferralitic soils moderately unsaturated.

The shea parklands of Kandi zone is located beyond 11°N. It brings together the entire shea population ranging from Kandi to Malanville and from Kandi to Banikoara. This parkland receives an average rainfall of 800 mm. The average density of the park was 31 trees per hectare. The villages Birni-Lafia and Kokey were selected. Dominant sociolinguistic groups in those villages included Dendi and Bariba people. Soils types encountered included poorly evolved soils, tropical ferruginous soils slightly leached and the hydromorphic soils.

The rural population of the five zones host 1,637,434 inhabitants [33]. Livelihood activities carried out by the people of these sociolinguistic groups include agriculture, ranching, fishing, hunting, processing of agricultural products, trade and craft [34]. Women mainly practice the processing of agricultural products individually or in groups with rudimentary equipment. The main processed products are *Vitellaria paradoxa* nuts (processed into butter), seeds of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don (processed into a food condiment), the grain of *Sorghum bicolor* (L.) Moench (processed into an alcoholic beverage and used in some traditional ceremonies), groundnuts (*Arachis hypogaea* L.) processed into oil [34].

Socio-demographic profile of respondents

The characteristics of the study population varied according to the proportion of respondents' age, instruction level and sociolinguistic groups. Respondents age vary from 19 to 90 years old. There were mostly adults surveyed in all parklands and the majority of them were not educated. In Bembèrèkè, Bohicon and Savè zones, both genders were well represented while in Kandi and Parakou, more women than men were surveyed (Table 1).

In total, seven sociolinguistic groups were represented in the study. Six sociolinguistic groups were found in one municipality only. The Bariba sociolinguistic group was found in four survey villages (Sirarou, Soaodou, Beroubouay and Kokey). The Fon and Tchabè/Nagot (in Setto and Toui villages) belong respectively to the subgroups "gbe" and "ede", and both belong to the large linguistic group "Kwa". The other five groups (Bariba, Boko, Ditamari, Yoa and Dendi) belong to the large group of languages known as "Gur" or "Voltaïque" comprising most of the languages of the northern part of the country [35].

Study species

Vitellaria paradoxa is the only Sapotaceae tree species living on dry soil in the Sudanian and Sudano-Guinean phytocoria [36]. Shea trees are allogamous. Flowers appear between 10-15 years. The tree attains full fruit production after 45–50 years. The pulp of the fruit, which is normally sweet, is an important source of nutrients for humans, other mammals, birds and bats. Each fruit generally carries one or rarely two nuts [23]. The shea

tree is generally stocky, 10 to 15 m high, with short bole (3-4 m) which can reach rather large diameters (80 cm and more). It is easily recognizable by its gray or blackish bark with thick and square scales. Unlike young plants, older plants have a woody bark that is deeply cracked into more or less rectangular plates recalling the crocodile's skin [37]. The edge of the bark is reddish and exudes latex that is found in all parts of the plant. The fruit is an ovoid 4-5 cm long, yellowish green drupe. The nut contains an almond whose fat content (shea butter) is close to 50%.

Data collection

In the study area, we were granted verbal permission from traditional leaders before starting the surveys. Semi-structured interviews were conducted using the respondents' preferred language which were Fon, Nagot/Tchabè, Bariba, Boko, Yoa, Ditamari or Dendi. To facilitate the communication between the respondents and the first author (where necessary) she was accompanied by a well-trained local guide (who understood both the interviewee-spoken language and Fench) in each village to facilitate the questions/answers translation. A total of 39 to 45 farm household respondents were surveyed per village in ten villages totalling 405 respondents. Respondents were chosen through a random walk in all hamlets of the village. However, when the selected participant was not available or did not want to be interviewed, the random walk continued until another consenting respondent was found. The first section of the questionnaire dealt with informants' age, gender, sociolinguistic group, and education level. The second part focused on the different morphotypes known to the respondent, the local names and their meaning and her /his perception on the morphotypes' relative abundance, fruit yield and butter yield after processing. Data are made available as additional files in Table S1 and Table S2.

Data analysis

We evaluated the relative frequency of sociodemographic attributes, especially age group, gender, sociolinguistic group, level of education. We used Fisher exact test to analyse contingency tables. We performed frequencies distributions by using the number of citation of each criterion by all respondents and the total number of citations of all criteria to estimate proportions of main morphotypes classification criteria cited by farmers and rank them from the most to the least important. Only variables exhibiting a relative frequency of citation of at least 1% (approximately 9 out of 405 respondents) were used in further analysis and interpretation. In addition, a detailed analysis of the diversity of shea morphotypes was carried out with BiodiversityR package [38]. The variation in local knowledge on shea morphotypes traits composition in zones was measured by computing Sorensen index using betapart package. in R. To characterize morphotype abundance and performance, we performed a Principal Component Analysis (PCA) using respondents perceptions of morphotype traits. Variables included frequency distribution, fruit and butter yields estimated using qualitative scales (e.g. low, medium, high).

To evaluate the influence of socio-demographic factors on local knowledge of shea morphotype traits, a generalized linear mixed model (with Poisson error family) was performed using the number of morphotype traits known by the respondent as the response variable. Fixed factors included zones of occurrence, age group, gender, education level and sociolinguistic group; and village provenance was used as a random factor. We performed a Kruskal-Wallis test on the relative frequency of citation of morphotypes traits per zone, age group, education level, gender and sociolinguistic groups, with the package Agricolae. A Factorial

Correspondence Analysis was carried out to assess the most cited morphotypes traits across the parklands zones. All analyses and graphics were performed in R 3.5.1 software environment (R Core Team, 2018).

Results

Identification and characterization of shea morphotypes

Criteria used by farmers for shea morphotypes identification and classification

Overall, farmers identified 35 different traits based on sixteen primary criteria related to fruit, tree, and nut variants (Table 2). Eleven traits were mentioned based on fruit characteristics (size, shape, fruiting period, and yield) and five were identified primarily according to characteristics of the fruit pulp (e.g. taste and density). Ten traits were identified based on tree characteristics (bark colour, height, scales size, heartwood colour and trunk shape) and another five were identified based on shea nut traits (size, presence and number of seeds). Farmers also differentiated shea trees based on leaf colour which could be light or dark green. The top five classification criteria reported by farmers were fruit size (56.47%), tree fertility (15.67%), bark colour (10.70%), fruiting period (6.34%) and pulp taste (3.48%). Farmers reported 13 shea morphotypes traits across the phytogeographical zones in Benin. Some criteria were seldom used. Traits with a citation frequency lower than 1% were not further considered in the analyses.

Shea tree name in the sociolinguistic group of surveyed areas include Sombou (Bariba), Boulanga (Dendi), Tam (Yom), Wougo (Fon), Egui èmè (Tachabè), Kouli (Boko), and Mouta, Koacha, or Taou in Ditamari. Table 3 presents the local names of the most mentioned traits by farmers in the different zones. These names recorded across the shea parks of Benin were based on morphological and organoleptic traits. Shea tree traits according to local communities were mainly related to bark colour, fruiting period and fruit size; other traits were based on tree fertility and pulp taste. Farmers distinguished shea trees having white, black or red bark; they also differentiated early fruiting trees (that bear fruits before the beginning of the rainy season), trees that have normal fruiting time (they produce fruits during the rainy season) and the ones, which have late production (they fructify after the two previous ones). Some trees produce fruits with sweet or insipid pulp and others produce large, small or medium size fruits. Farmers also reported that there are male and female shea trees. Based on the fruiting ability of shea trees, local people distinguished two types of shea tree: the “female,” fruit-producing trees, and the “male” trees, which never produce fruits. However, in the Ditamari sociolinguistic group, early maturing genotypes were referred to as “Nda” which means “male” ; this comparison was borrowed according to them from the rule of male gametes during fecundation. In the Ditamari community, the production of fruit in shea trees is comparable to the conception of a child; the male seed gives fruit very early (whereas the female keeps pregnancy for several months before giving birth. That is why they equate this trait with a male.

Diversity of shea morphotypes traits in shea parks of Benin

Local knowledge on shea morphotypes traits diversity and Shannon index diversity varied from one zone to the another (Table 4). Based on the classification criteria used, different numbers of morphotypes traits were recorded across parks. Our results indicated that traits richness was greater in Bembèrèkè, Parakou, Kandi and Savè zones than in Bohicon shea parkland zone.

The pairwise analysis allows the identification of patterns of dissimilarity between zones based on Sorensen index. The Sorensen index values range from 13.0 to 88.3% (Figure 2), taking into account ten combinations of pairwise comparison : Bembèrèkè – Bohicon (BB-BH), Bembèrèkè – Kandi (BB-KD), Bembèrèkè – Parakou (BB-PK), Bembèrèkè – Savè (BB-SV), Bohicon – Kandi (BH-KD), Bohicon – Parakou (BH-PK), Bohicon – Savè (BH-SV), Kandi – Parakou (KD-PK), Kandi – Savè (KD-SV), Parakou – Savè (PK-SV). The dissimilarity in terms of shea traits natural variation between northern zones (Parakou, Bembèrèkè and Kandi) is rather low (<25%). In contrary, dissimilarity index values were higher between northern and southern (Bohicon) zones (60-88.3%). There is a big difference in local knowledge between the northern zones and southern zone.

In order to understand how the richness of the morphotypes traits varied according to the number of zones considered, we realized the cumulative curve of morphotypes richness (Figure 3). Which revealed that the morphotypes richness increases and then becomes stable when all five zones were explored.

Characterization of shea morphotypes' traits performance

Respondents reported three different level of shea morphotypes' abundance attribute such as 'widespread', 'few' and 'scarce'. Trees fruit yield and butter yield after processing could be according to respondents 'high', 'medium' or 'low'. Principal Component Analysis (PCA) performed on the perception scores of the distribution, the morphological and performance traits showed that the first two dimensions accounted for 79.96% of the observed variation (Figure 4). The first component is positively correlated with the variables medium and low yield (fruit yield), medium and low quantity of butter after processing (medium butter and low butter) and scarce and few distribution frequencies. The second component is negatively correlated with the variable null yield (no fruit production), and positively with the variables high yield, high butter and widespread.

According to the biplot of morphotypes and abundance, fruit yield and butter yield characteristics (Figure 4), it appears that, based on farmers' perception, shea morphotypes having the trait Yanki (small fruit) are characterized by high fruit yield, a high amount of butter after nuts processing and are widespread. On the other hand, shea morphotypes with the trait Bakanou (large fruit) and are rare (scarce) or very little spread (few). They may have medium and low fruit production and the nuts inside their fruits produce an average amount of butter after processing. The morphotypes characterized by the trait Akô (male tree) do not have ability to produce fruit (null yield). All other morphotypes traits do not reveal any particular characteristics. No specific trend of these variables has been recorded for the other morphotypes traits.

Influence of occurrence and sociocultural factors on local knowledge of shea morphotypes natural variation

The average number of traits cited by each respondent did not vary significantly ($p > 0.05$) regarding the parkland, age, gender, instruction level, and sociolinguistic group.

However, the relative frequency of citation of the 13 main local morphotypes varied very highly significantly regarding shea parklands zones ($p < 0.001$). Factorial correspondence analyses (FCA) plot (Figure 5) shows traits mostly mentioned by farmers in each zone. Morphotypes that have red bark (Soarou), large and small fruit size (Bakanou and Yanki) were more common in Parakou and Kandi zones. Local morphotypes identified based on the pulp taste such as sweet and insipid (Dourobou and Yenyiando) were mostly mentioned in Kandi park than in others. Morphotypes traits relative to the timing of production, medium fruit size (Saganin) and

bark colour specifically morphotype having white and black bark, were common in Bembèrèkè shea parklands zone. On the other hand, the morphotypes traits Akô and Abô were mostly cited in the Savè and Bohicon zones.

With exception to gender ($p = 0.218$), all socio-demographic characteristics very significantly ($p < 0.001$) influence the relative frequency of the 13 main traits of shea morphotypes (Figure 6). Figure 6 shows the relative citation frequency (RCF) of traits according to age groups, gender, instruction level and sociolinguistic groups. All traits were known to the three age groups; however, local knowledge varied from an age group to another. The relative frequency of citation decreased from adult to old people passing by young for all traits except the trait “Dourobou” which was most reported by elders than young respondents.

General trend for the influence of instruction level is the decrease of local knowledge on morphotypes traits from illiterate to literate respondents. Morphotypes citation frequency were higher for illiterate ($25 < \text{RCF} < 85\%$) and respondents with primary school level ($1 < \text{RCF} < 80\%$) than those of respondents who attained secondary and university ($0 < \text{RCF} < 25\%$). Relative citation frequency of traits citation varied also from a sociolinguistic group to another. All sociolinguistic groups cited the female trait Abô and except Dendi, all sociolinguistic groups recognised the trait Akô which is qualified as male by farmers. Bariba sociolinguistic group cited all traits mainly than those related to fruit size (Yanki, Saganin and Bakanou), bark colour (Kpika and Wonka) and pulp taste (Dourobou and Yeniyando) with $\text{RCF} > 50\%$. The Fon sociolinguistic group mentioned only female and male traits. Shea morphotypes traits identified based on timing of the fruit production (Nina, Nda and Niendembou) were registered mostly within Ditamari sociolinguistic group ($70 < \text{RCF} < 80\%$). The differentiation of morphotypes according to fruit size, pulp taste, bark colour criteria were almost common to Bariba, Dendi, Yom and Boko sociolinguistic groups located in the Northern part of the country.

Discussion

Classification criteria of shea morphotypes in Benin

Farmers reported several classification criteria across shea parklands zones based on their importance. Fruit size, tree fertility (male and female), bark colour, timing of production and pulp taste were the top five classification criteria most reported by farmers. Among those criteria, fruit size was the first one mainly used to distinguish morphotypes. This result confirms that shea tree classification is mainly based on fruits variants as reported by Gwali *et al.* [39] in Uganda, Karambiri *et al.* [23] and Sandwidi *et al.* [37] in Burkina Faso. Ekué *et al.* [40] also reported for *Blighia sapida* K.D. Koenig that differentiation criteria included fruit size which was by far the most quoted criterion by farmers in Benin. Similarly, in a study on farmer classifications of baobab tree (*Adansonia digitata* L.) in West Africa, they recognized ‘male’ and ‘female’ baobab trees [41]. These authors also reported that, local perceptions of baobab differentiation vary from one country to another. For instance, in Uganda and Burkina Faso, local shea classification was not based only on fruits but on nuts variants also. This finding revealed that variation can be observed in classification criteria depending on the geographical or sociolinguistic group. For example, local communities from Bohicon and Savè zones with Fon and Tchabè as dominant sociolinguistic groups have commonly distinguished male and female morphotypes. Moreover, the differentiation of morphotypes according to bark colour criterion among others, were almost common to Bariba, Boko, Ditamari and Yom sociolinguistic groups which belong to Bembèrèkè zone. As the result of the above, it seems that, contrary to what Sandwidi *et al.* [37] have observed in Burkina Faso, certain sociolinguistic

groups in specific area in Benin were able to identify individual shea trees by merely looking at the bark colour of shea trees. This result confirms the first hypothesis of this study concerning the using of tree characteristics to classify morphotypes. Assogbadjo *et al.* [42] reported that farmers can also distinguish different types of baobab trees using their own criteria based on the colour of the bark among others. Furthermore, utilization of the fruit variants as main description criterion could be linked to the fact that the description of the tree is related to the most important tree features for producers. Indeed, in the Bohicon zone, farmers distinguished trees on the basis of fertility and it is linked to the size and vigour of the tree, they also talked about the heartwood of the tree and ease of cutting or not. In fact, the wood only interests them. While in other sociolinguistic groups, the male morphotype is linked either to the capacity to produce the fruit, or to the time of production for others. Indeed, for these communities, the fruit is the most important part.

Diversity of shea morphotypes

Overall, farmers identified 35 different shea morphotypes based on thirteen primary criteria relative to fruit, tree and nut variants. The number of morphotypes reported in literature varies from one country to another and from one area to another inside the same country. According to Karambiri *et al.* [23] who obtained a lower number of ethnovarieties in comparison of Gwali *et al.* [39] study, the larger number of ethnovarieties identified in a study could be linked to the size of the study area. This means that, larger the study area will be, larger will be the number of morphotypes identified. This study confirmed this assertion. Indeed, richness increases according to the number of citation and zones at first and then becomes stable at the maximum reached for five zones (Fig. 3). In other words, to assess the whole diversity, it is necessary to go through all shea distribution range. Indeed, Akohoué *et al.*, [43] who recorded five Kersting's groundnut (*Macrotyloma geocarpum* (Harms) Maréchal & Baudet) landraces in Benin and Togo while previous authors reported three traditional cultivars only, asserted that this is due to the fact that previous studies did not include all production areas and as result, a part of the existing genetic diversity was left out. More recently, Coulibaly *et al.* [44] collected six different phenotypic groups of *Macrotyloma geocarpum* in Burkina Faso and Ghana. It appears based on the analysis that, till the whole distribution range of a species has been explored, the entire cultivars or morphotypes diversity could not be caught. For this study, the diversity was greater in the Bembèrèkè zone and very low in the Bohicon. This finding could be linked to the scale of the zone and trees density. Bembèrèkè shea parkland zone is the largest with the highest average density per hectare (43 stems/ha) [29, 30].

Characterization of shea morphotypes

Knowledge of the agromorphological diversity of the identified shea trees is essential to begin any program of improvement of the species [45]. Since the most treasured product of the shea tree is its butter extracted from the kernels[46] which also depends on trees production, there is a need to assess the potentialities of the available diversity in terms of abundance of morphotypes and their fruit production yield and butter yield associated. This study revealed that farmers' perception concerning the abundance and the fruit and butter production of the Yanki morphotype is unanimous while for the Bakanou morphotype it varies. On the one hand morphotypes Yanki (with small fruits) were reported to be widespread and characterized by high yield and high amount of butter. Moreover, morphotypes Bakanou (with large fruits) were reported to give an average amount of butter and were reported to be rare or very little spread. To date, no prior study on shea morphotypes abundance had been conducted. Since rural communities' knowledge on *Tamarindus*' ecological range was congruent with scientific findings [47], then, there is a crucial need to fill this gap to better

understand factors that influence this state of affairs which should meet farmers' preferences. In addition, perceptions were scattered among farmers about this morphotype' fruit production which can be high, medium and sometimes very low. Across the study areas, farmers associated fruit size with soil fertility and as such, the rarity of these morphotypes could be linked to the low level of soils fertility in their area. A major problem for cropping systems in the tropics is the reduction in soil productivity that accompanies most systems of continuous cultivation [48]. The past decades have shown a rapid decline of land productivity and soil fertility in particular [49]. Moreover, the observed inter-annual yield variability in fruit yield [50] can explain the absence of consistency among farmers about these variables. In fact, the main constraints encountered with nut production are the remarkable decrease of the production and its huge fluctuation from year to year [51]. Authors have hypothesized many combined biotic and abiotic factors underlying the annual variation of shea trees' fruit production but this process still not fully understood.

Influence of ecology and sociolinguistic attributes on the knowledge of Shea morphotypes knowledge

Analysis of determinants of shea morphotypes knowledge shows that none of the socio-demographic characteristics significantly influence the number of shea morphotypes known to the respondent (Prob > 0.05). This result is in agreement with Karambiri *et al.* [23] who also reported a similarity across the villages they surveyed. There is therefore a minimum threshold of shea morphotypes knowledge reached by almost all respondents regardless of their origin, age category, sociolinguistic group and level of education. However, sociolinguistic groups strongly influenced the diversity of morphotypes traits reported. For instance, the criterion timing of production were specifically reported by Ditamari sociolinguistic groups than in others and could be linked to the degree of interest carried by each specific group or area. For instance, Gwali *et al.* [39] have also found a significant influence of ethnicity on ethno-variety nomenclature and claimed that the variation in folk knowledge among the various ethnic groups may be due to the intensity of utilization of the shea tree and its products. Moreover, morphotype knowledge increased following south and north gradient and this is reflected by morphotypes' diversity and specific richness (number of different kind of morphotypes traits) mentioned by zone. Based on these results we can assert that shea morphotype knowledge was low in Bohicon zone, medium in Savè, and high in Parakou, Bembèrèkè and Kandi zones. In addition, certain morphotypes traits were specific to a given sociolinguistic group as found by Fandohan *et al.*, [34] for *Synsepalum dulcificum* (Schumach. & Thonn.) Daniell which belongs to the same family as *Vitellaria paradoxa*. The intercultural differences observed in the knowledge of the uses of *S. dulcificum* are related to the environment and the availability of the plant resource [28]. Surprisingly gender does not influence the frequency of citation of the most reported traits. Meaning that both men and women have similar knowledge of the shea morphotypes. Currently, studies reported differences in men and women knowledge on plants. According to Laleye *et al.* [52] in a case study related to knowledge of plants in traditional treatment of diabetes in Benin republic, the fact that men cited more species than women may be due to the close association of men's knowledge with the treatment of diabetes. The same level of knowledge of morphotypes between men and women reported in this study reveals that shea butter is certainly of different but important interest for both men and women. Indeed, the level of knowledge of the species by women is justified, as they are the main actors from the beginning to the end of the entire shea production chain. Women control shea production as 92 % of the collection and 98 % of the processing activities were performed solely by women and girls even if shea fruits are consumed by both men and women [53]. Men also have the power to make

decisions about the conservation of shea trees since they are the owners of lands that shelters shea trees. Gender influence could be perceived in processing of shea nuts where men were not involved. Along the same lines, Agúndez *et al.*, [31] suggested that the development of shea resources management and conservation programs should include ethnic preferences and consider gender, to avoid reducing women's profits in the shea butter local market.

Conclusions

Our study provides insight in the most reported traits of *Vitellaria paradoxa* in the five shea parks zones of Benin. Number of morphotypes cited by a respondent does not vary significantly according to sociodemographic factors revealing that shea morphotypes knowledge is almost the same across the shea parklands. However, classification criteria of morphotype were diverse and strongly influenced by age, instruction level, and sociolinguistic group. In fact, particularities specific to certain zones and sociolinguistic groups concerning classification criteria have been underlined and emphasis the need to take into account sociocultural aspects to assess indigenous knowledge and by implication to identify indigenous preference of shea morphotypes. Local characterization of shea morphotypes should be taking into account for selection and breeding programs of the species.

Abbreviations

BB: Bembèrèkè,

BH: Bohicon,

KD: Kandi,

PK: Parakou,

SV: Savè.

Declarations

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Authors' contribution

FMF, EAD, CG and JMB conceived the study. FMF and EK conducted the fieldwork, FMF analysed the data and drafted the manuscript. FMF, EAD, CG and JMB reviewed the manuscript. EAD and CS supervised the study. All authors read and approved the final manuscript.

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Availability of data and material

The datasets supporting the conclusions of this article are included within the article (and its additional files).

Ethics approval and consent to participate

A verbal agreement was obtained from traditional authorities of local communities and the informants prior to administering the questionnaire. A clear presentation of the study objectives made this easier.

Consent for publication

Prior and informed consent of local people’s had been obtained for pictures publication.

Competing interests

The authors declare that they have no competing interests

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Tables

Table 1: Socio-demographic and sociolinguistic groups characteristics of survey population. *n*: number of respondents. Numbers in brackets represent total respondent surveyed in each zone.

Variables	Modalities	Survey zones									
		Bembèrèkè		Bohicon		Kandi		Parakou		Savè	
		(161)		(40)		(79)		(80)		(40)	
		n	%	n	%	n	%	n	%	n	%
Socio-demographic factors											
Age category	Young (<30 y.)	100	62	34	85	50	63	52	65	26	58
	Adult (30≤A≤60y.)	51	32	6	15	21	27	18	23	16	36
	Old (>60y.)	10	6	0	0	8	10	10	13	3	7
Gender	Female	90	56	16	40	56	71	51	64	19	42
	Male	71	44	24	60	23	29	29	36	26	58
Instruction level	Illiterate	127	79	27	68	58	73	58	73	20	44
	Primary	17	11	8	20	18	23	18	22.8	8	18
	Secondary	14	9	5	13	3	4	3	4	12	27
	University	3	2	0	0	0	0	0	0	5	11
Socio-linguistic groups											
	Fon	-	-	36	90	-	-	-	-	-	-
	Tchabè (Nagot)	-	-	-	-	-	-	-	-	12	27
	Bariba	80	50	-	-	36	46	33	41	-	-
	Yoa	-	-	-	-	-	-	35	44	-	-
	Boko	37	23	-	-	-	-	-	-	-	-
	Ditamari	40	25	-	-	-	-	-	-	-	-
	Dendi	-	-	-	-	33	42			-	-
	Others	4	3	4	10	10	13	12	15	33	73

Table 2: Identification criteria of shea morphotypes used by farmers and associated traits.

Criteria	Traits	Number of citation	Trait relative frequency (%)	Criteria relative frequency (%)
Fruit size	Small	218	27.11	56.47
	Large	212	26.37	
	Medium	24	2.99	
Tree fertility	Male	75	9.33	15.67
	Female	51	6.34	
Bark colour	White	34	4.23	10.70
	Black	32	3.98	
	Red	20	2.49	
Timing of production	Precocious	20	2.49	6.34
	Normal	12	1.49	
	Late	19	2.36	
Pulp taste	Sweet	15	1.87	3.48
	Insipid	11	1.37	
	Astringent	2	0.25	
Fruit shape	Oblong	7	0.87	1.24
	Ellipsoid	3	0.37	
Nut size	Small	7	0.87	1.62
	Large	6	0.75	
Fruit yield	Low	6	0.75	1.37
	Medium	1	0.12	
	High	4	0.50	
Tree height	High	5	0.62	1.24
	Low	5	0.62	
Nut presence in fruit	Absent	3	0.37	0.50
	Present	1	0.12	
Scales size	Big	2	0.25	0.24
Leaves colour	Light green	1	0.12	0.25
	Dark green	1	0.12	
Pulp density	Thick	1	0.12	0.25

	Thin	1	0.12	
Number of seed	Twin	1	0.12	0.12
Heartwood colour	Brown	1	0.12	0.25
	White	1	0.12	
Trunk shape	Right	1	0.12	0.25
	Curled	1	0.12	

Table 3: Most mentioned shea local morphotypes in Benin.

N°	Local Names of traits	Language	Main criteria	English meaning of local names
1	Kpika	Bariba	Bark colour	White bark
2	Wonka			Black bark
3	Soarou			Red bark
4	Nda	Ditamari	Timing of production	Precocious
5	Nina			Normal
6	Niendembou			Late
7	Abô	Tchabè (Nagot)	Fertility	Female
8	Akô			Male
9	Dourobou	Bariba	Pulp taste	Sweet pulp
10	Yeni yando			Insidious pulp
11	Bakanou	Bariba	Fruit size	Large fruit
12	Saganin			Medium fruit
13	Yanki			Small fruit

Table 4: Shannon index diversity, and shea traits richness per park.

Park	Traits richness	Shannon index value
Bembèrèkè	11	2.002
Bohicon	2	0.693
Kandi	10	1.394
Parakou	12	1.734
Savè	8	1.743

Figures

Figure 1

Surveyed areas across shea parks in Benin and major sociolinguistic groups (in brown italics).

Figure 2

Bar plots showing the pairwise dissimilarity index between the five shea parks. BB=Bembèrèkè, BH=Bohicon, KD=Kandi, PK =Parakou, SV=Savè.

Figure 3

Cumulative curve of morphotypes richness in shea based on number of citation.

Figure 4

PCA biplot showing shea morphotypes and their frequency of distribution, fruit and butter yield characteristics. Yanki= Fruit with small size; Bakanou= Fruit with big size; Saganin= Fruit with medium size; Akô=Male shea tree; Abô=Female shea tree; Kpika= White bark; Wonka= Dark bark; Soarou=Red bark; Nda:Precocious production; Nina=Normal production; Niendembou=Late production; Dourobou=Sweet; Yeni yando=Insipid; High Yield= high shea fruit production; Medium Yield= Average shea fruit production; Low yield= Low shea fruit production; Nul Yield=No fruit production; High butter = High amount of butter after nuts processing; Medium butter= Average amount of butter after nuts processing; Low butter= Low amount of butter after nuts processing.

Figure 5

Factorial Correspondence Analysis biplot showing the main traits cited in the five shea parklands zones.

Figure 6

Relative citation frequency of the 13 main local morphotypes according to age, gender, instruction level, and sociolinguistic groups.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TableS1Determinants.xlsx](#)

- [TableS2PErceptionofFruitandshebutteryield.xlsx](#)