Agro-Science Journal of Tropical Agriculture, Food, Environment and Extension
Volume 23 Number 1 (January 2024) pp. 1 - 8

ISSN 1119-745

VARIABILITY OF MORPHOLOGICAL CHARACTERISTICS OF *Sclerocarya birrea* (A. Rich) Hoscht. IN THE FERLO OF NORTHERN SENEGAL

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ABSTRACT
The importance of Sclerocarya birrea (A. Rich) Hoscht populations has prompted studies on domesticating the species in order to make better use of its potential. According to some studies, this multi-purpose species in Africa has a high morphological variability that may be of interest in a varietal improvement program. The aim of our work is to characterize the morphological variability of S. birrea in the Ferlo zone. The study was carried out on woody stands of the species composing a sample of 75 individuals spread over three sites. For each individual, 14 quantitative characteristics of the fruit and four dendrometric measurements of the trees were assessed. There were significant variability in the traits studied within the population. Relationships were observed between fruit and nut characteristics. Signicant correlations were obtained between fruit mass and each of pulp mass and kernel mass. Principal Component Analysis showed that morphological diversity is structured, with trees divided into three distinct groups based on the following discriminating characteristics; fruit diameter, nut mass and height of the tree's first branch. The observed morphological variability of the species shows that there is potential for selections with a view to improving and domesticating this species.

Key words: *Sclerocarya birrea*, Ferlo, morphological variability

INTRODUCTION
Multi-purpose woody forest products are useful for rural populations, particularly for their contribution to meeting health and food needs. In Africa, the utilization of wood from woody species, which remains the most important being 175,086,000 m^3 in 2000 (Bekele, 2001); however, rural communities are increasingly turning to the exploitation and marketing of non-wood forest products such as fruit, gum and oils (Diop *et al.,* 2010). In the Sahel region of Senegal, the socio-economic importance of certain woody species has been taken into account in the phytoremediation project in the Great Green Wall (GMV) zone. These value-added species include gum trees such as *Acacia senegal* (L.), fruit trees such as *Ziziphus mauritiana* Lam. and *Boscia senegalensis (*Pers.) Lam. ex poir. and, above all, oleaginous fruit trees such as *Adansonia digitata* L., *Balanites agyptiaca* (L.) Del and *Sclerocarya birrea* (A. Rich) Hoscht (Dia and Duponnois, 2012).

Sclerocarya birrea (A. Rich) Hoscht, commonly known as the African plum, is one of the fruit and oil-producing species that should be preserved in Ferlo ecosystems. The threats to this woody species are real and worrying. These threats are essentially linked to timber harvesting (Niang *et al*., 2014), but above all to the notorious lack of regeneration of the species in its natural environment (Ndiaye *et al*., 2014 ; Kébé *et al*., 2020). An assisted regeneration program is therefore needed to maintain the species in its environment. To do this, a good knowledge of its biological material is needed to conserve its genetic diversity with a view to domesticating the plant and making better use of its potential.

Some works carried out on the species in South Africa, Namibia (Leakey *et al*., 2005a) and Burkina *Faso* (Bationo *et al*., 2008) has shown that there is a wide variation in the morphological characteristics of the fruits (weight of the kernel, seed, kernel shell and number of seeds per kernel). In Senegal, scientific studies on the species focus on the uses and biochemical and nutritional characteristics of its fruits (Sène *et al*., 2018) as well as its phenology (Sène *et al*., 2020). Few studies have been carried out to assess its morphogenetic diversity. The aim of this study is to investigate the morphological variability of *Sclerocarya birrea* (A. Rich) populations. It is based on the hypothesis that populations of the species have different morphological characteristics in the Ferlo zone.

Please cite as: Sene A.L., Diallo A., Sarr O., Sagna M.B., Ngom D. and Guisse A. (2024). Variability of morphological characteristics of *Sclerocarya birrea* (A. Rich) Hoscht. in the Ferlo of Northern Senegal. *Agro-Science*, **23 (1)**, 1-8.
https://dx.doi.org/10.4314/as.v23i1.1

MATERIALS AND METHODS

The Study Area

The study was carried out in Senegal, a country in West Africa. Senegal has an eco-geographical region in the North called the Ferlo. Within this region, this study was carried out in four localities; Widou Thiengoly (15° 56' 02.5"N; 15° 11' 43.1"W), Tessékéré (15° 52' 11.5"N; 15° 04' 45.5"W), Labgar and Amaly (15° 45' 02.0"N; 15° 16' 33.3"W) (Figure 1). These localities were chosen because they have particularly dense populations of *Sclerocarya birrea* (A. Rich).

Climatically, the Ferlo is characterized by two alternating seasons; a nine-month dry season (October to June) and a three-month rainy season. Rainfall remains low and very unstable, with an average of 422.6 mm. The average temperature is around 27.73°C (Faye *et al.*, 2011). The study sites belong to sandy domains with a topographical landscape in the form of low, monotonous plateaux and sandy dune formations separated by low-lying areas that from temporary pools in the rainy season (Michel, 1969). It is a savannah with trees and shrubs dominated by *Balanites aegyptiaca* (L.) Del, *Boscia senegalensis* (Pers.) Lam. Ex Poir, *Acacia senegal* (L.), *Acacia tortilis* (Forsk.) Hayne ssp. *raddiana* (Savi) Brenan, and *Calotropis procera* (Aiton) (Ndiaye *et al*., 2013; Niang *et al*., 2014).

Choice of Trees

The trees inventoried were those fruiting. In each site, a sample of 25 individuals spaced at least 20 m apart bi-directional were selected. This precaution was taken to avoid collecting material from individuals that were physically and genetically close (Graudal, 1998). The individuals listed were geographically referenced using a GPS. The dendrometric descriptors used were : trunk diameter at 1.30 m from the ground (D 1.30), height of the first branch (Hbr), total height of the tree (HT) and crown diameter (H). A total of 75 individuals were randomly sampled at three sites (i.e., 25 individuals per site). The individuals sampled were coded from the names of the sites at which they were surveyed, together with the number assigned.

From each tree, 10 fruits (Figure 2a) were taken at random for morphometric measurements and weighing. The samples were collected in July 2018.

Evaluation of Morphological Descriptors

The morphological variability of *S. birrea* was assessed using a descriptor system inspired by those proposed by several authors (IBPGR, 1980; Leakey *et al*., 2000, 2005a, 2005b; Kouyaté, 2005; Bationo *et al.,* 2008). Of the parameters measured, 14 were used to study *S. birrea*.

Dendrometric descriptors

Four agroforestry descriptors were used:

- the diameter of the trunk at 0.3 m and 1.30 m from the ground (D), measured using a tape measure and a forestry compass;
- the height of the first branch (Hbr), measured using a tape measure;
- the height of the tree (HT), measured using a Blum-Leiss; and
- the crown (H), measured with a tape measure.

Morphological descriptors of fruit

Twenty-five individuals on each axis and 10 fresh, unparasitized fruits per individual were observed, for a total of 750 *S. birrea* fruits. The length in mm (LF) and diameter in mm (DF) of each fruit (Figure 3) were measured using a Vernier Calliper with an accuracy of ± 0.1 mm. The mass of the fruit (MF), expressed in grams, was determined using a PRECIA 300S/300SCS series balance (reading accuracy of 0.0001 to 1 g). Other variables were calculated from the data obtained. These are the ratios between the length and diameter of the fruit (LF/DF), the length and thickness of the nut (LN/EN), the mass of the kernel and the mass of the nut (MA/MN), the mass of the shell and the mass of the nut (MC/MN), the mass of the pulp and the mass of the fruit (MP/MF).

Morphological descriptors of the nut and pulp

The samples were stripped of their shells and depulped using moderate mechanical pressure. The kernels were isolated to measure the length (LN) and thickness (EN) of the nut in mm, then weighed to determine its mass (MN) in *g*. The nuts were recovered and crushed manually to extract the kernels, whose mass (MA) and that of the shells were measured using a PRECIA 300S/300SCS series balance. The mass of the pulp was determined by the difference between the mass of the fruit (MF) and the mass of the nut (MN), i.e., $MP = MF - MA$.

Data Processing and Analysis

The data were processed using Excel spreadsheets and *R* studio's *R* Markdown software. Analysis of variance was used to assess differences between tree characteristics. Relationships between characteristics were highlighted by correlation tests. In all cases, an effect is considered significant when the probability (p - value) is ≤ 5%. Trees were grouped using hierarchical ascending classification (HAC). Discriminant factor analysis (DFA) and principal component analysis (PCA) were used to characterise the groups formed by the HAC.

RESULTS

Morphological Characteristics of the Parameters Measured and Analysis of Variance (F) Results

Comparison of different morphological descriptors

Table 1 presents the statistical analysis of the data obtained from the measurements of the morphometric traits. Discriminant factor analysis is combined with descriptive statistics to identify the variables that best explain the morphological characteristics of *S. birrea* populations (Figure 4).

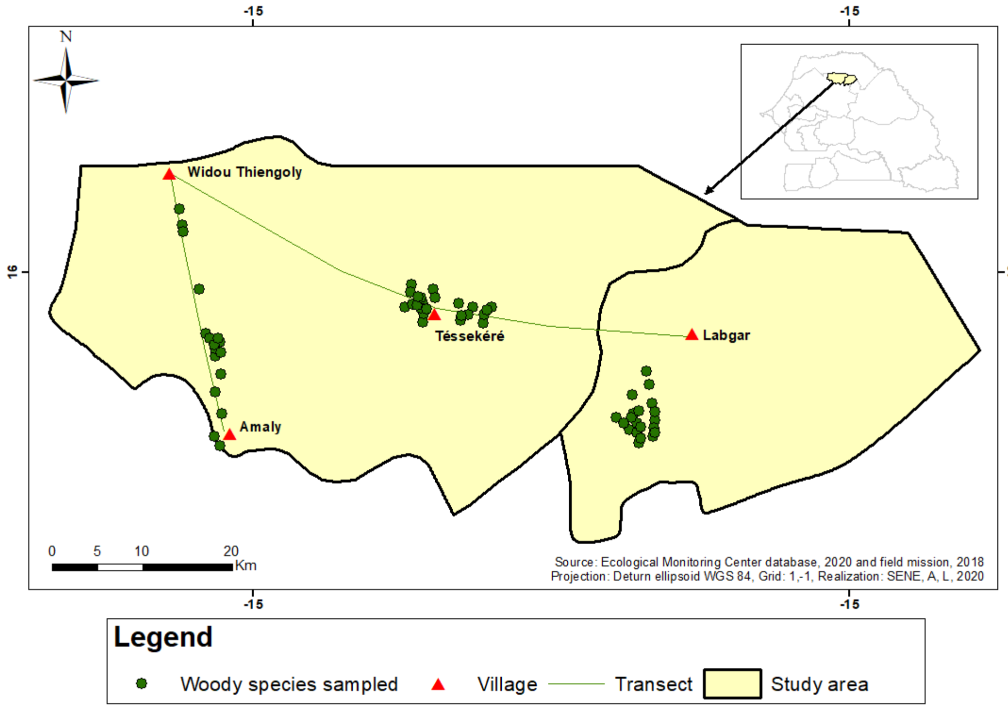

Figure 1: Presentation of the sampling area and sites

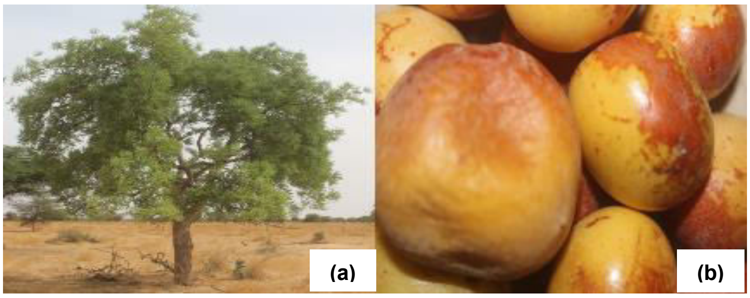

Figure 2: (a) *Sclerocarya birrea (A. Rich): (a) adult tree, (b) ripe fruits*

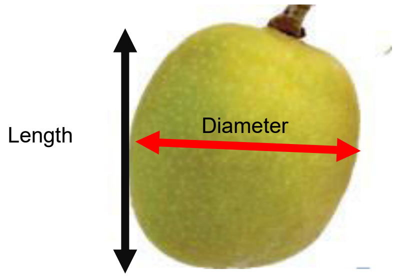

Figure 3: Measurement of *S. birrea* fruit dimensions (Source: Awa Latyr Sene, 2015)

Table 1: Average tree performance for measured morphometric parameters and results of analysis of variance (F)

Parameters	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation	F
Dh (m)	6.25	15.55	9.89	1.83	18.6	0.023 *
HT(m)	6.50	16.50	9.13	1.74	20.3	0.007 **
Hbr (m)	1.15	4.50	2.04	0.63	31.1	0.098 ^{ns}
D1.30 (m)	0.19	0.73	0.33	0.09	28.0	0.388 ^{ns}
D0.3 (m)	0.12	0.49	0.35	0.07	21.3	0.912 ^{ns}
DF (mm)	18.43	37.00	26.68	3.21	12.3	2e-05 ***
LF (mm)	21.33	52.09	28.88	4.05	14.5	0.1 ^{ns}
MF (g)	3.80	28.40	12.77	4.20	33.8	0.0047 **
MP (g)	3.00	23.16	10.64	3.55	34.2	0.00231 **
EN (mm)	7.72	37.00	19.67	2.83	15.0	<2e-16 ***
LN (mm)	9.21	37.80	21.39	2.55	12.8	<2e-16 ***
MN (g)	0.63	4.16	1.77	0.63	36.5	0.00311 **
MA (g)	0.04	0.50	0.21	0.10	44.4	0.127 ^{ns}
MC (g)	0.48	3.86	1.55	0.56	37.2	0.00257 **
LF/DF	0.85	1.20	1.04	0.10	9.78	0.00069 ***
LN/EN	0.66	1.33	1.01	0.13	12.4	0.00547 **
MP/MF	0.69	0.94	0.83	0.04	4.83	1.1e-12 ***
MA/MN	0.05	0.27	0.12	0.04	32.3	0.0675 ^{ns}
MC/MN	0.63	2.65	1.06	0.04	4.59	0.0872 ^{ns}

(Dh - diamètre du houppier, HT - Hauteur totale de l'arbre, Hbr - hauteur moyenne de la première ramification, D - diamètre du tronc, DF - diamètre des fruits, LF - longueur des fruits, MF - masse des fruits, MP - masse de la pulpe, EN - épaisseur de la noix, LN - longueur de la noix, MN - masse de la noix, MG - masse de l'amande, MC - masse de la coque, DF - diamètre des fruits; ns - différences non significat. * and *** - différences significat at 5% and 0.10%, respectively according to the SNK test.

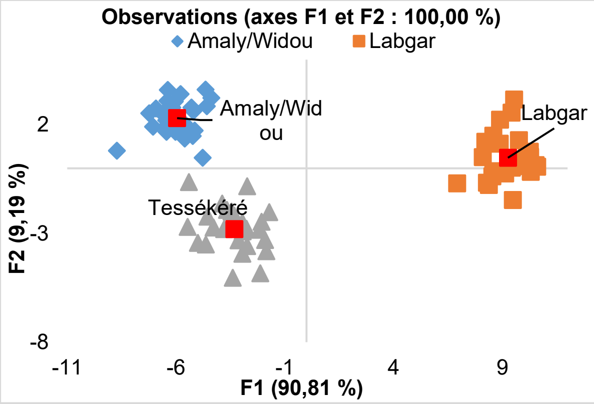

Figure 4 : Representation of individuals from each site on the plane formed by the two first axes

Discriminant factor analysis carried out on the individuals sampled at the three sites produced Figure 4, in which each colour represents a sampling site. The red dot represents the center of the samples collected at each site. The analysis of variance yielded a value of F equal to 7.26, whereas the critical value of F was 1.19 with a probability of less than 0.001, that these groups are distinct entities that differ from one another ($p < 0.001$). The distributions of the scatter plots on the SFM axes indicate the existence of close links between the individuals and the sites of their sampling. However, the population of plum trees in Amaly-Widou is closer to that in Téssékéré than in Labgar.

The first two axes are deemed sufficient to summarize the initial information about the correlations among the variables studied of *S. birrea*, as they take all the variables into account (Figure 5). Horizontal component 1, which accounts for 47.35% of the variances, isolate the variables (LN, EN, MC, MN, DF, MF and MP) with correlation coefficients greater than 0.5 in the positive abscissa. Component 2, which accounts for 15.3% of the variances, contrasts the group of variables (LF/DF, LN/EN, H and HT) on the positive ordinates with the group of variables (MP/MF) on the negative ordinates.

Relationships between the Various Morphological Descriptors

To identify the most important variables for discriminating *S. birrea* populations, a PCA was carried out. Table 2 gives the eigen values and percentage of the variance of the first four axes.

The first dimention (Dim.1) explains 47.35% of the variances in the raw data table and the second dimention (Dim. 2) explains 15.26%. These first two components explain more than 50% (i.e., 62.61%) of the variances in the raw data table, which is sufficient to guarantee accurate interpretation. The data were analysed and interpreted on the factorial plane composed of these first two dimensions (Dim. 1 × Dim. 2). The variables that contributed to the different axes are shown in Table 3. Fruit-related variables, in particular fruit diameter, nut thickness, nut length and masses (fruit, nut, shell and pulp), provide more information on the first dimension. The dendrometric parameters crown and total height (H and HT) and those of the ratios between the length and the diameter of the fruit (LF/DF), the length and the thickness of the nut (LN/EN), the mass of the pulp and the fruit contribute to the formation of dimensions 2 and 3.

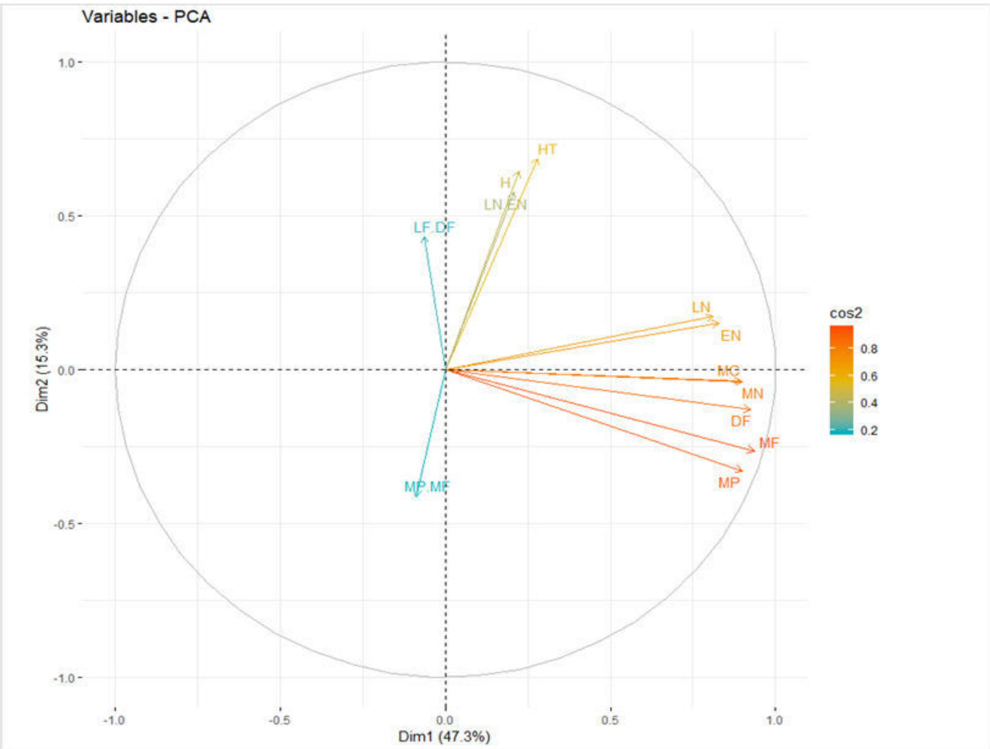

Figure 5: Correlation circle

Table 2: Eigen values and proportion of variances

	Eigen value	Inertia (%)	Cumulative %
Dim.1	5.68	47.35	47.35
Dim.2	1.83	15.26	62.61
Dim.3	1.54	12.85	75.46
Dim.4	1.30	11.00	86.46

Table 3: Contribution of variables (%) to the different axes of the PCA ($p < 0.0001$)

	F1	F2	F3	F4
H	0.8761	23.1526	19.9831	5.3123
HT	1.3714	26.2755	18.8462	1.2700
DF	15.0485	0.9206	0.2746	0.8793
MF	15.4115	3.8616	0.0567	0.1268
EN	12.1039	1.3019	0.1155	11.8193
LN	11.5861	1.7019	0.1983	15.1122
MN	14.3053	0.1092	3.4877	5.4721
MC	14.0899	0.0900	3.7669	5.5243
MP	14.2480	5.8865	1.0851	0.4611
LF/DF	0.0585	9.9697	12.0452	21.1399
LN/EN	0.7519	17.9683	15.8910	3.5287
MP/MF	0.1489	8.7621	24.2496	29.3540

The projection of the sampled units onto the plane formed by the two axes is shown in Figure 6. An examination of Figures 5 and 6 indicates that trees unitslocated on the positive side of dimension 1 are characterized by fruits with higher masses (fruit, pulp, nut, shell and kernel) with respective proportions of 12.8 ± 4.20 g, 10.6 ± 3.55 g, 1.77 ± 0.63 g, 1.55 ± 0.56 g, 0.21 ± 0.10 g, respectively ; They also had larger diameters (DF=26.7 ± 3.21 mm) and greater nut lengths (LN = 21.4 ± 2.55 mm) and thicknesses (EN= 19.7 ± 2.83 mm). Individuals on the positive side of dimension 2 are characterized by large trees (HT = 9.13 ± 1.74 m), large crowns (H = 9.29 ± 2.15 m), nuts that are longer than they are wide (LN/EN = 1.01 ± 0.10 mm) and a larger ratio (LF/DF = 1.04 ± 0.10). On the other hand, the individuals sampled on its negative side are characterized by fruits with a higher MP/MF ratio (0.83 ± 0.04).

Morphological Similarities between Sampled Individuals

Individuals were grouped using hierarchical ascending classification (HAC based on the weighted averages of *S. birrea* fruit characteristics and Euclidean distances, to obtain the trees shown in Figure 7. Truncation at the 68.49 inertia level gives three groups with respective numbers of 24, 37 and 14 trees.

Class 2 contains the largest number of individuals (37), followed by class 1 (24 individuals) and class 3 (14 individuals). Class 2 is, therefore, more morphologically heterogeneous than the others. The dendrogram shows a very heterogeneous distribution of individuals discriminated by PCA. The composition and characteristics of the three groups are shown in Table 4. The first group is made up of provenances characterized by small-sized individuals that produce small fruit and low mass (fruit, almonds, walnuts). The second group is made up of individuals that are large in size and produce medium-sized fruit with medium mass (fruit, almonds, walnuts). The third group consists solely of medium-sized trees. These trees are characterized by large fruits with large masses (fruits, almonds, nuts).

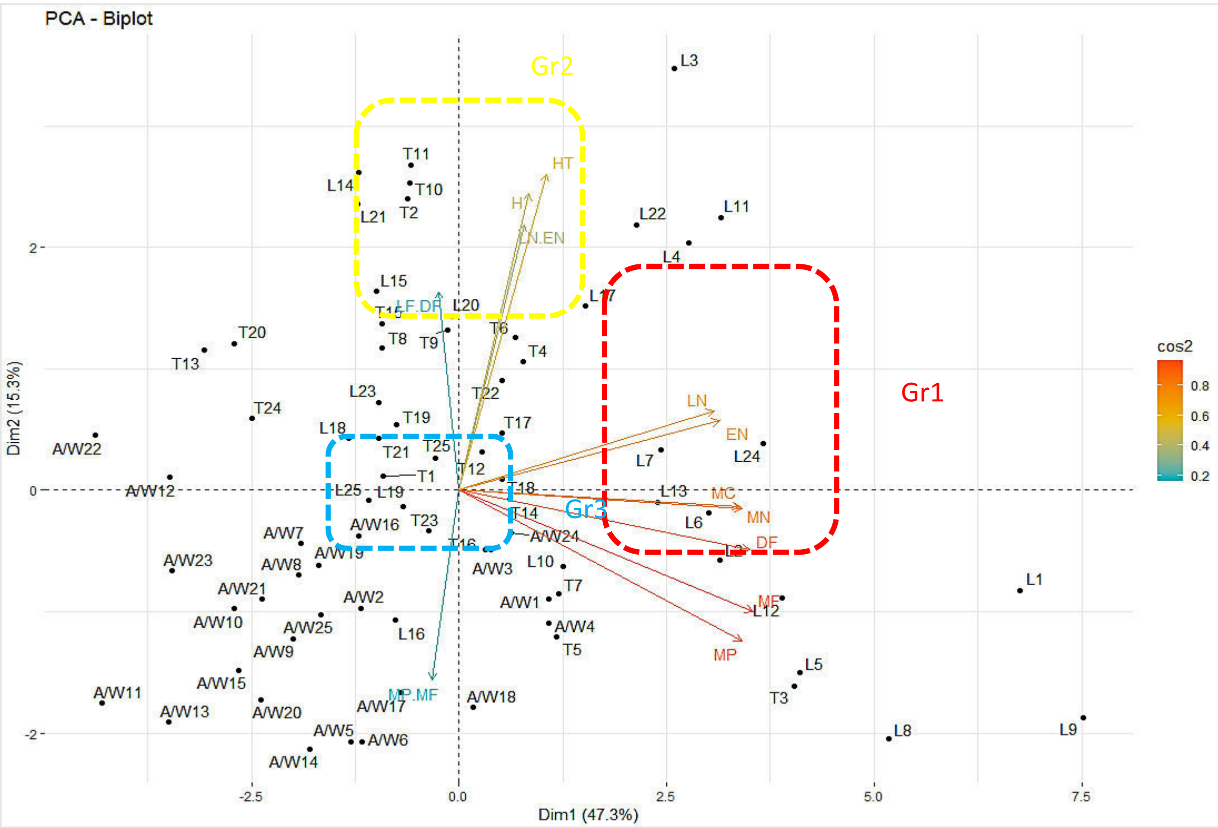

Figure 6: The projection of sampled individuals on the plane formed by the two dimensions

The projection of the individuals sampled onto the plane formed by the two dimensions gives Figure 8, in which each colour represents a sampling site. The yellow point represents the center of gravity of the samples collected from each site. The first dimension, 1, which explains 47.35% of the variances, is strongly correlated with the variables LN, EN, MC, MN, DF, MF, MP, and is the fruit and nut performance dimension. Dimension 2, which explains 15.3% of the variances, is strongly correlated with the variables H, HT, LF/DF, LN/EN, i.e., the dimension of tree span, and negatively correlated with the characters MP/MF.

DISCUSSION

The present study, which focused on the variability of morphological traits, showed that *Sclerocarya birrea* subsp *birrea* is characterized by significant specific variability, both within and between populations. Such variability was observed in the same species (Bationio *et al.,* 2008), and also in other species such as *Saba senegalensis* (Diouf *et al.,* 2019) and *Balanites aegyptiaca* (Sam *et al.,* 2020). The tree morphology traits studied show phenotypic variation between trees throughout the study area and within sites. Moreover, the one-factor analysis of variance followed by the Fisher's test at the 5% threshold shows that tree height varies significantly depending on the collection sites. Tree heights varied on average by 9.89 m, with disparities depending on the zone. The highest trees were recorded in Labgar at 10.4 m, while the shortest trees were in Amaly-Widou at 9.04 m. The age of the trees would explain this discrepancy between sites. The diameters at 1.30 m varied from 31 to 34 cm and the height of the

Table 4: Composition and characteristics of groups from the CAH

	Group 1 (24 individuals)	Group 2 (37 individuals)	Group 3 (14 individuals)
Composition of groups	T20 T13 A/W22 T24 A/W12 A/W7 A/W23 A/W16 A/W19 A/W8 A/W21 A/W10 A/W2 A/W25 A/W9 A/W15 L16 A/W20 A/W11 A/W13 A/W14 A/W5 A/W6 A/W17	L14 L21 T11 T10 T2 L22 L15 T15 T8 L20 T9 T6 T4 L17 L23 T19 T22 T17 L18 T21 T2 T12 T18 T1 L19 T14 T23 A/W3 A/W24 T16 L10 T7 A/W1 A/W4 T5 A/W18	L3L4 L11 L7L24 L13L6 L2 L12 L5 L1 T3 L8 L9
Characteristics of individuals	Small sizes Small fruits Masses (Fruits, almonds, walnuts) low	Large sizes Medium fruit Masses (Fruits, almonds, walnuts) medium	Average sizes Large fruits Masses (Fruits, almonds, nuts) important

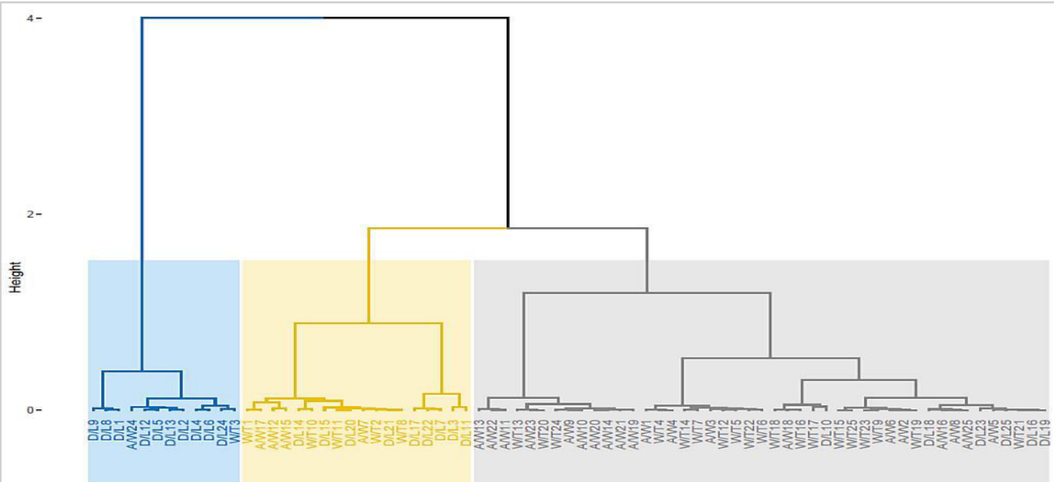

Figure 7: Dendrogram from hierarchical ascending classification of trees negative to MP/MF characters

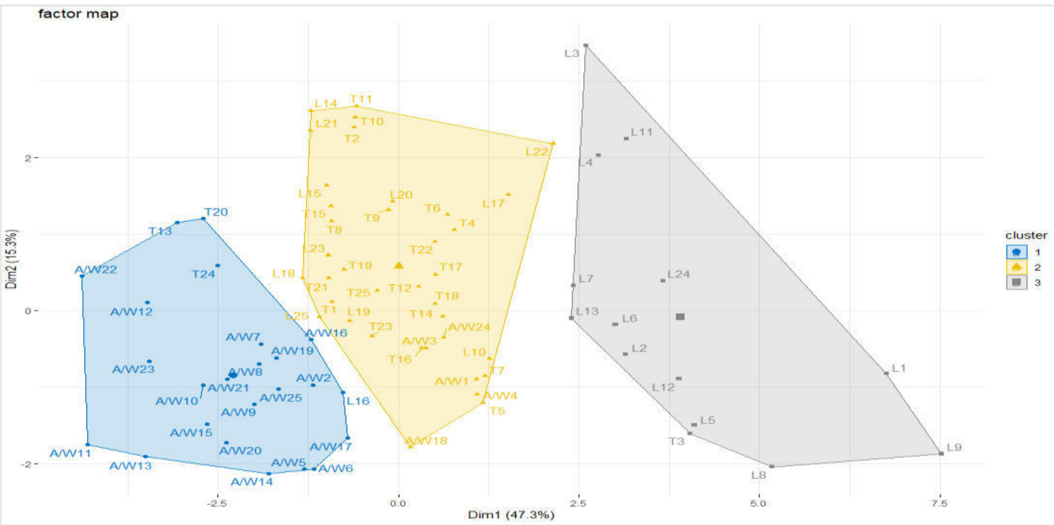

Figure 8: Population distribution of *S. birrea* in the plan defined by dimensions 1 and 2

first living branch from 1.96 to 2.26 m for the Amaly-Widou and Labgar sites respectively. These variations are only apparent, as the difference between the diameter of the individuals and the height of their first basal branch was not significant. Our results showed that the *S. birrea* populations, though located in different topographical units, had the same diameter at 1.30 m and the same height of the first large branch. This also indicates that these two traits are influenced not by the environment but by the gene mechanism (Kamal *et al.*, 2020). These traits could not be the differentiation criteria for the species. Coefficients of variation of 18.6%, 20.3%, 31.1% and 28% for H, HT, Hbr and D1.30, respectively indicate that the variability linked to these equitable traits is worthy of being exploited for selection. On the other hand, high variability has been observed in the same species (Bationo *et al.,* 2008) and other dry savannah species (Kouyaté, 2005; Abasse *et al.,* 2011; Abdoulaye, 2016). The decrease in tree size from Labgar to Amaly-Widou could be linked to the worsening in climatic conditions moving eastwards, given that tree size is greatly influenced by environmental factors.

Our results show a highly significant effect for nut length (LN) < 2e-16***, nut thickness (EN) < 2e-16*** and fruit diameter (DF) 2e-05*** between trees for the whole study area and between sites. The largest fruits were found at the Labgar site, averaging 30.4 cm in length and 28.7 mm in diameter. On the Amaly-Widou site, the fruits are less voluminous, with a length of 28 mm and a diameter of 24.1 mm. The length and thickness of the nut of fruits from Labgar are twice those from Amaly-Widou. The mean lengths and diameters of the fruit of *S. birrea* are of the same order as those obtained by Thiong'o *et al.* (2002), 3 to 5 cm in diameter and those of Bationo *et al.* (2008), 2.18 to 3.68 cm in length and 2.24 to 3.68 cm in diameter. The standard deviations show that the values are not widely dispersed around the mean. The gradient from West (Widou) to East (Labgar) linked to humidity would have had a positive influence on fruit size. With low coefficients of variation, variability is indeed low for these three characteristics. On the other hand, the coefficients of variation were very high for fruit characteristics (MP and MF) and nut and kernel characteristics (MN and MC), indicating very high variability between trees for these variables. These results are in line with those of Bationo *et al.* (2008) and (Muok *et al.*, 2011). The mean pulp mass was 10.64 ± 3.55 g. This mass is higher than that found by Bationo *et al.* (2008). The pulp mass/fruit mass (PM/MF) percentage of 69% is an important characteristic for technological valorization of the fruit. According to Shackleton *et al.* (2002), in Burkina Faso, the skin and pulp are used to make beer, fruit juice and jelly. This value is higher than the 59% value obtained by Abasse *et al.* (2011) but comparable to that observed by Bationo *et al.* (2008). The average mass of the pulp of 10.64 ± 3.55 g is also comparable to that observed by Soloviev *et al.* (2004) with little variability between accessions. These authors also showed that fruit weight varied significantly according to ecological zone.

The [length/diameter] ratio of the fruits, which reflects their shape, varied between 0.85 and 1.20. This ratio [length/diameter] of the fruit of S. *birrea*, according to Clopton's classification (2004), is between levels 3:2 and 6:5. This confirms the ovoid shape of the fruit described in the literature.

The very strong correlations between D1.30 and characteristics such as fruit diameter, shell mass and nut mass do not corroborate the results of Bationio *et al.* (2008). Similarly, there was a correlation between HT and morphological characteristics of the fruit. The largest fruits are generally rich in pulp. However, the strong correlation between fruit weight and seed weight is in line with Leakey *et al.* (2005b) for *S. birrea* subsp *caffra* and Atangana *et al.* (2002) for *Irvingia gabonensis*. The very high correlations among fruit traits support the results of Abasse *et al.* (2011), Diouf *et al.* (2019), and Kamal *et al.* (2020).

Discrimination between the three groups was based on fruit and kernel characteristics of the trees that may be influenced by environmental conditions. The distribution of trees in the three types defined by the AFD shows that each type is found in almost all the sites. The first group is made up of provenances from the three axes and is characterized by production of small fruit and low mass (fruit, almonds, nuts). The individuals are small in size. A second group was made up of the three provenances. The fruit produced is characterized by medium-sized fruit and medium mass (fruit, almonds, walnuts). The individuals are large. A third group is made up solely of medium-sized trees; these trees are characterised by large fruits and large masses (fruits, almonds, nuts). This result seems important for a selection and improvement program, as all the variability is represented in each site. It could also help to begin the process of selecting and domesticating this species.

CONCLUSION

This work has enabled us to gather information on the level and structure of morphological diversity of *Sclerocarya birrea* subsp *birrea* in Senegal. Variability was observed throughout the study area for all the traits studied. Based on this natural variability, any attempts to improve the species could be made. As far as the fruits, nuts and almonds are concerned, the variability for fruit length, diameter and nut thickness is not large, but large for the other characters. This phenotypic variability is due more to the genotype of the individuals than to age and environmental conditions. Trees with different fruit sizes can be found on the same site. Of the characteristics studied, only pulp mass and nut mass can be of agronomic interest. Since the variability observed is the result of the interaction of several factors (genetics, ecology, age, etc.), further studies using other methods with expansion of sample size will make it possible to address the effect of these different factors.

ACKNOWLEDGEMENTS

This work has benefited from State aid managed by the Agence Nationale de la Recherche under the LabEx DRIIHM, "Investissements d'avenir" programme, reference ANR-11-LABX-0010, and the Unité mixte Internationale laboratory (IRL 3189 "Environnement, Santé, Sociétés" Université Cheikh Anta Diop - UCAD).

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