South African Journal of Botany 147 (2022) 731–740

Contents lists available at ScienceDirect

South African Journal of Botany

journal homepage: www.elsevier.com/locate/sajb

Morphological diversity of *Bobgunnia madagascariensis* (Desv.) J. H. Kirkbr. & Wiersema, across the Sudanian and Sudano-Guinean zones of Benin Republic

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A R T I C L E I N F O

Article History:
Received 4 November 2021
Revised 28 February 2022
Accepted 6 March 2022
Available online xxx

Edited by I. Doležalová

Keywords:
Benin
In situ characterization
Conservation
Diversity
Domestication

A B S T R A C T

Although *Bobgunnia madagascariensis* is an important tree species known in traditional medicinal with a well-recognized galactogenic properties, it remains poorly documented. In Benin, little information is available on this species which is highly threatened in its natural habitat. In this study, the morphological variability of 51 trees of *B. madagascariensis* from Sudanian (28 trees) and Sudano-Guinean zones (23 trees) of Benin was evaluated using 20 descriptors, including 7 qualitative and 13 quantitative traits. A hierarchical ascending classification followed by principal component analysis, analysis of variance and quantitative traits correlation analysis were used to describe the intraspecific diversity of *B. madagascariensis* in the study areas. Analysis of morphometric data revealed the existence of three morphological groups within the species with a distinct morphological organization among the trees sampled. The discriminating morphological descriptors included the total height of the tree, the diameter at 1.30m, the bole height, the leaf length, the number of leaflets of the leaf, the fruit weight, the fruit length and width, as well as the seed length and weight. Individuals in group 3 had the highest values for nine of the 10 most discriminating traits. A significant and positive correlation was found between trees' total height and seed length, as well as between fruit traits (fruit weight, fruit length) and seed traits (seed weight, seed length). In addition, the diameter at 1.3 m was positively correlated with the leaf width. The results also revealed a significant difference between the trees observed in the Sudanian zone and those in the Sudano-Guinean zone with the number of leaflets, the petiole length, the fruits width, the seeds weight and length as discriminating traits. This study provided preliminary data on the morphological variability of *B. madagascariensis* and will serve as basis for a selection, conservation and domestication program.

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1. Introduction

Bobgunnia madagascariensis (Desv.) J. H. Kirkbr. & Wiersema is a tree species belonging to the Leguminosae family. The species is distributed along the savannas and dry forests of tropical and southern Africa (https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:995543-1; https://www.gbif.org/occurrence/search?taxon_key=2981738&occurrence_status=present). Different organs (leaves, bark and roots) of this species are reported to be used in traditional medicine to treat several diseases such as malaria, fever, syphilis and leprosy (Ouattara et al., 2016; Thokozani et al., 2011; Sani et al., 2016; Chingwaru et al., 2020). The species is also valued in ruminant feed, particularly as fodder (leaves) and food supplement (fruits) (Sidi et al., 2015; Kanyinji et al., 2017). It is also used as a pesticide plant in agriculture (Thokozani et al., 2011). Solvent extracts from the leaves, stem and root bark of the *B. madagascariensis* showed antifeedant activity against *Tribolium casteneum*, Hbst; a storage pest of maize grain and its products (Adeyemi et al., 2010; Adeyemi and Amupitan, 2011).

In Benin Republic (West Africa), *B. madagascariensis* is mainly present in the Northern part of the country (Kirkbride and Wiersema, 1997). This species is used by local population mainly as herders and agro-pastoral farmers as a galactogenic plant, among the other multiple purposes including fodder and medicinal plant (Salifou et al. 2017; Imorou et al. 2021). The anthropogenic pressure

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https://doi.org/10.1016/j.sajb.2022.03.013
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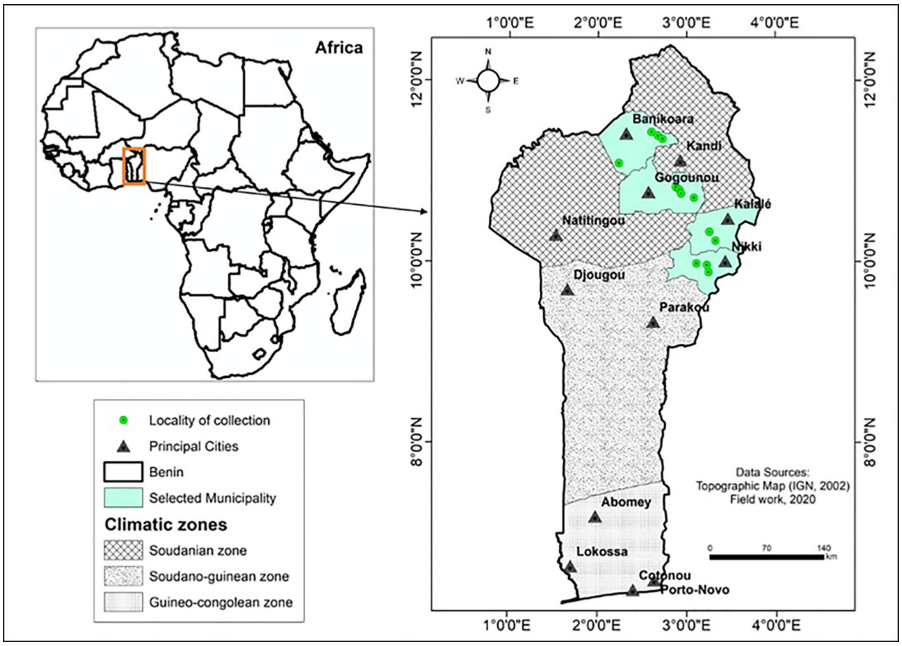


Fig. 1. Location of study population of B. madagascariensis in the Sudanian and Sudano-Guinean zones of Benin Republic

on the species is the proof of its multiple uses which have put the species under a real threat. Unfortunately, very little research has been conducted on the species' variability (phenological, morphological and genetic) (Pinto et al., 2016). It has been reported that many plant species in the natural population exhibit intraspecific genetic variability allowing them to adapt to fluctuations in environmental conditions; this is generally reflected by morphological variability (Ewédjè et al., 2012). Most studies carried out around the world on *B. madagascariensis* (works carried out in Switzerland on species collected in Tanzania) (Borel and Hostettmann, 1987), Burkina Faso (Ouattara et al., 2006), Malawi (Thokozani et al., 2011) and Zimbabwe (Chingwaru et al., 2020) focused on the medicinal, food and pesticide potential of the species. Current pression on the species mainly in Benin Republic points out the need to deepen the knowledge on the existing morphological variability. Such knowledge is important since it helps to capture basic information needed for better management and sustainable *in situ* and / or *ex situ* conservation of the species (Kosh-Komba et al., 2017) as the case of some tropical species such as *Detarium microcarpum* Guill. & Perr., *Moringa oleifera* Lam. (Gandji et al., 2019), *Cola acuminata* (P. Beauv.) Schott and Endl., and *Garcinia kola* Heckel (Dah-Nouvlessounon et al., 2016). Therefore, the objective of this paper was to investigate the existing morphological variability within and across *B. madagascariensis* in the Sudanian and Sudano-Guinean zones of Benin for a better management, use and improvement of this species. It is expected that this study will pave the way for further studies on the improvement, domestication and conservation of *B. madagascariensis* in Benin Republic.

2. Material and methods

2.1. Study area

The study was conducted in the Sudanian and Sudano-Guinean zones of Benin. The Sudanian zone is located between 9°45′ and 12°25′ N and the Sudano-Guinean zone is located between 7°30′ and 9°45′ N (Gandji et al., 2019; Ahoyo et al., 2021).

In the Sudano-Guinean zone, rainfall is unimodal, from May to October, with mean annual rainfall varying between 900 mm and 1110 mm. Mean annual temperature ranges from 25°C to 29°C, and the relative humidity from 31% to 98%. The rainfall is also unimodal in the Sudanian zone, but mean annual rainfall is often less than 1000 mm, the relative humidity varies between 18% and 99% (highest in August) and temperature varies between 24°C and 31°C (Gandji et al., 2019).

Sudanian and Sudano-Guinean zones are reported as natural distribution zones of *B. madagascariensis* in Benin Republic (Kirkbride and Wiersema, 1997). For this study, the municipalities of Banikoara, Kalalé, Gogounou and Nikki within the Sudanian and Sudano-Guinean zones were surveyed (Fig 1). These municipalities were selected based on the availability of species following the results of a survey carried out in 2019 on galactogenic plant species (Imorou et al., 2021). In each municipality, local guides were hired to locate the *B. madagascariensis* trees on which the measurements were made.

2.2. Sampling and data collection

Data were collected on 51 *B. madagascariensis* trees, including 28 in the Sudanian zone and 23 in the Sudano-Guinean zone. These trees were selected randomly and georeferenced using the Global Positioning System (GPS). Since the species were somewhat rare in the study area because of the anthropogenic pressure (Lawin et al., 2016; Agbani et al., 2018), apparently adult trees presenting no morphological deformation were systematically considered. Data collecting was performed on the fruits and leaves of the species. Regarding the fruits, five mature fruits were harvested from each *B. madagascariensis* tree. The fruits were selected at the most accessible branches as advised by Houehanou et al. (2019) and Johnson et al. (2020). Overall, 255 fruits of *B. madagascariensis* were harvested. Regarding the leaves, five fully developed and healthy leaves were randomly selected from each tree on the most accessible branches to measure leaf length, leaf width and leaflets number per leaf.

Quantitative and qualitative data were collected for the morphological characterization of *B. madagascariensis*. The quantitative and qualitative data were related to trees, leaves, fruits and seeds. The morphological diversity evaluation of *B. madagascariensis* was performed based on adapted descriptors from both IBPGR (1980) and Kouyate (2005) for the related species *Detarium microcarpum* Guill. &

Table 1
Morphological descriptors used to characterize *B. madagascariensis* in the study area

Type	Traits	Variables	Codes	Definition and data collection method
Quantitative	Tree	Total height (m)	Htp	Distance from the ground surface to the end of the tree top
		Bole height (m)	Htf	Distance from the ground surface to the first branch of the tree
		Diameter at 1.30 m (cm)	Dbh	Ratio of the circumference at breast height on π ($Dbh = \frac{C}{\pi}$, π = 3,14)
	Leaf	Length (cm)	Lfe	Distance between the point of leaf insertion on the stem and the tip of the apex of the terminal leaflet
		Width (cm)	Lfe	Lateral distance of the leaf
		Number of leaflets	Nfo	Total number of leaflets observed on a leaf
		Petiole length (cm)	Lpe	Distance between the point of attachment of the petiole on the main vein and the point of attachment on the tree
	Fruit	Weight (g)	Pfr	Weight of mature fruit
		Length (cm)	Lfr	Distance between the point of insertion of the fruit on the pedicel and the end of the fruit
		Width (cm)	Lfr	Lateral distance from the fruit
	Seed	Weight (g)	Pgr	Weight of the seeds from the mature fruit
		Length (mm)	Lgr	Distance between the two tips of the seed
		Width (mm)	Lgr	Lateral distance from the fruit
Qualitative	Fruit	Fruit color	Cfr	Visual and tactile observations and comparison with descriptors established by IBPGR (International Board for Plant Genetic Resources) (1980)
		Fruit shape	Ffr	
	Seed	Seed color	Cgr	
		Seed shape	Fgr	
	Leaf	Leaf type	Ffe	
		Leaf division	Dfe	
		Leaflet shape	Ffo	

Perr., both species belonging to Leguminosae family. Thirteen quantitative traits and seven qualitative descriptors were measured on trees, leaves, fruits and seeds of *B. madagascariensis* (Table 1).

2.3. Data analysis

Hierarchical ascending classification (HAC) (Chabi Sika et al., 2015) was performed on the quantitative traits to assess the intraspecific diversity of *B. madagascariensis*. Tree clusters obtained were put into relation to the different variables using a Principal Component Analysis (PCA) (Dah-Nouvlessounon et al., 2016) using the "FactoMineR" and "factoextra" packages of the R software. The variables that were selected for interpretation of each component were those that are highly correlated with them with a coefficient greater than or equal to 0.5. Quantitative data of different groups and those of the diversity of *B. madagascariensis* between the Sudanian and Sudano-Guinean zones were subjected to a one-way analysis of variance (ANOVA) and the means and standard deviations were determined. When significant, the ANOVA tests were followed by Student Newman Keul's test (SNK) at a significance level of 5% for the separation of means. Relationships between quantitative traits were analyzed by subjecting the data to matrix correlation to determine correlation coefficients. All analysis were performed with R software version 4.1.1 (R Core Team, 2021).

3. Results

B. madagascariensis is a shrub or small tree up to 10-15 m high, with multi-stemmed or a single bole up to 40-60 cm in diameter. The surface of the bark is grey-black. The leaves are alternate, imparipinnated and compound with 3-13 leaflets. The petiole is 2-4 cm long. The fruit is a cylindrical pod up to 20cm, shiny dark brown to black when ripe, indehiscent with 10–15-seeded. The seeds are oblong to kidney-shaped, flattened and bright brown or greyish (https://prota4u.org/).

3.1. Variability of qualitative characteristics of B. madagascariensis in Sudanian and Sudano-Guinean zones of Benin Republic

Collected data on qualitative characteristics of *B. madagascariensis* trees revealed some variations in the fruit and seeds (Fig 2). The leaves are of the compound type and they are made up of several leaflets. Fruits varied in shape and color (Table 2, Fig. 3). The fruits are brown or black when ripe (Fig. 2C). Among the two fruit colors observed, the brown color was the most dominant (88 % of collected fruits). Fruits are generally cylindrical (97 %) but also oblong (3 %). From the two seed colors observed, the blackish dark brown color was the most dominant 53% against 47 % for the yellowish light brown color. The seeds are flattened (Table 2, Fig. 2B).

3.2. Quantitative characteristics variability of B. madagascariensis

Tree height observed for *B. madagascariensis* varies between 3.60 and 25 m with an average of 10.50 ± 4.19 m. *Bobgunnia madagascariensis* trees have an average diameter at 1.3 m of 10.44 ± 3.94 cm

Fig. 2. Tree (A) in Sudano-Guinean, seed (B) and fruits (C) in Sudanian zone zone of B. madagascariensis, Benin

Table 2
Variations within 51 accessions of *B. madagascariensis* based on fruits, seed and leaves qualitative traits

Morphological trait	Class	Frequency (%)
Fruit color	Brown	88
	Black	12
Fruit shape	Cylindrical	97
	Oblong	3
Seed color	Yellowish light	47
	Blackish dark brown	53
Seed shape	Flattened	100
Leaf type	Compound	100
Leaf division	Several leaflets	100
Leaflet shape	Elliptical	100

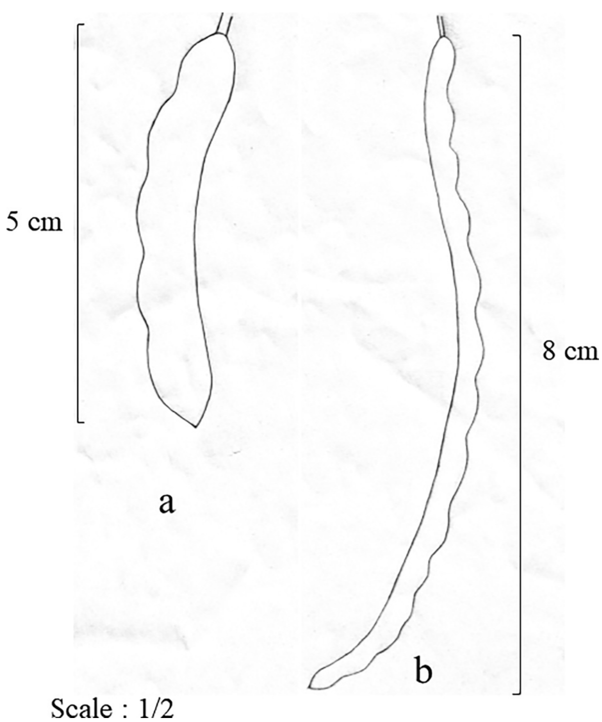


Fig. 3. Oblong (a) and, Elongate and cylindric (b) fruit shape of B. madagascariensis in Sudanian and Sudano-Guinean zones of Benin

Table 3
Mean, minimum and maximum values and coefficients of variation (CV) of morphological traits of *B. madagascariensis*

Morphological traits	Mean	Minimum	Maximum	CV
Tree				
Total height (m)	10.50±4.19	3.60	25.00	0.40
Bole height (m)	2.48±1.18	1.00	6.12	0.47
Diameter at 1.30 m (cm)	10.44±3.94	5.01	22.77	0.38
Leaf				
Length (cm)	16.36±1.58	13.81	20.52	0.10
Width (cm)	10.41±1.50	3.99	13.64	0.14
Petiole length (cm)	3.29±0.60	1.70	4.87	0.18
Number of leaflets	9.49±1.01	8.00	13.00	0.12
Fruit				
Weight (g)	10.75±3.93	4.58	20.13	0.37
Length (cm)	16.94±5.34	7.85	29.12	0.32
Width (cm)	1.07±0.05	0.97	1.17	0.04
Seed				
Weight (g)	0.09±0.00	0.09	0.10	0.02
Length (mm)	7.82±0.32	6.62	8.44	0.04
Width (mm)	4.82±0.20	4.45	5.05	0.03

Table 4
Correlations between the first and two axes and morphological traits

Morphological traits	PCA1	PCA2
Total tree height	0.98	0.17
Bole height	0.63	0.78
Diameter at 1.30 m	0.99	0.17
Leaf length	0.99	0.10
Leaf width	0.93	-0.37
Petiole length	0.99	0.01
Number of leaflets	0.91	0.41
Fruit weight	-0.31	0.95
Fruit length	-0.13	0.99
Fruit width	-0.31	0.95
Seed weight	0.88	-0.47
Seed length	0.80	0.59
Seed width	0.94	-0.33
PCA eigenvalues and proportions		
Variance	8.54	4.45
% of var	65.74	34.26

(Table 3). The leaves showed a length and a width of 16.36±1.58 and 10.41±1.50 cm respectively and their petioles measured 3.29±0.60 cm. The leaves had an average of 9.49±1.01 leaflets. Mature fruits measured 16.94 ± 5.34 cm long by 1.07 ± 0.05 cm wide and weighed 10.75 ± 3.93 g.

Of the 13 morphological traits used to assess morphological variations across the sampled 51 accessions, six (tree total height, bole height, diameter at 1.3 m, petiole length, fruit weight and length) showed high variability with a coefficient of variation (CV) varying between 0.18 and 0.47. Tree total height, bole height and diameter at 1.3m, showed a high CV values (CV > 0.3 or 30 %) revealing a high level of morphological diversity among individuals for these morphological traits.

3.3. *Intra-specific diversity of* B. madagascariensis *in Sudanian and Sudano-Guinean zones of Benin*

Three groups of *B. madagascariensis* were observed at a distance of 1.0 (Fig. 4). Group 1 was the largest with 21 trees (41.2% of total trees), followed by group 3 comprising 20 trees (39.2% of total trees). Group 2 contained only 10 individuals (19.6% of total trees).

3.3.1. *Quantitative morphological traits characteristic of trees groups*

The first two axes of principal component analysis revealed 100 % of total variance (Table 4). With exception of fruit variables, all the other variables measured (Total tree height, tree diameter, leaf length, leaf width, petiole length, number of leaflets, seed weight, and seed width) were significantly and positively correlated with axis 1 (|correlation| ≥ 0.5). Furthermore, fruits weight, length and width were positively correlated with axis 2 while the seed weight negatively correlated with the same axis. Tree trunk and Seed length were positively correlated with both axes 1 and 2.

The correspondences from the projection of groups and quantitative morphological traits on the axis systems showed that the individuals of cluster 3 were the tallest with a greatest diameter at 1.3 m. In addition, they have the longest and widest leaves with more leaflets and a longer petiole (Fig. 5). On the other hand, individuals of cluster 2 have the widest, longest, and largest fruits unlike individuals of cluster 1.

3.3.2. *Quantitative morphological traits discriminative of groups*

The one-way variance analysis (ANOVA) performed on the quantitative data for the three groups trees of *B. madagascariensis* showed that 10 of measured quantitative parameters were discriminative traits and enabled to observe a variation across the groups. The results showed that the individuals of cluster 2 had significantly larger (15.91 ± 3.35 g), longer (22.59±4.07cm) and wide (1.11 ±0.04cm) fruits than that of cluster 1. In fact, those three variables are the ones that clearly differentiated the individuals of cluster 1 from

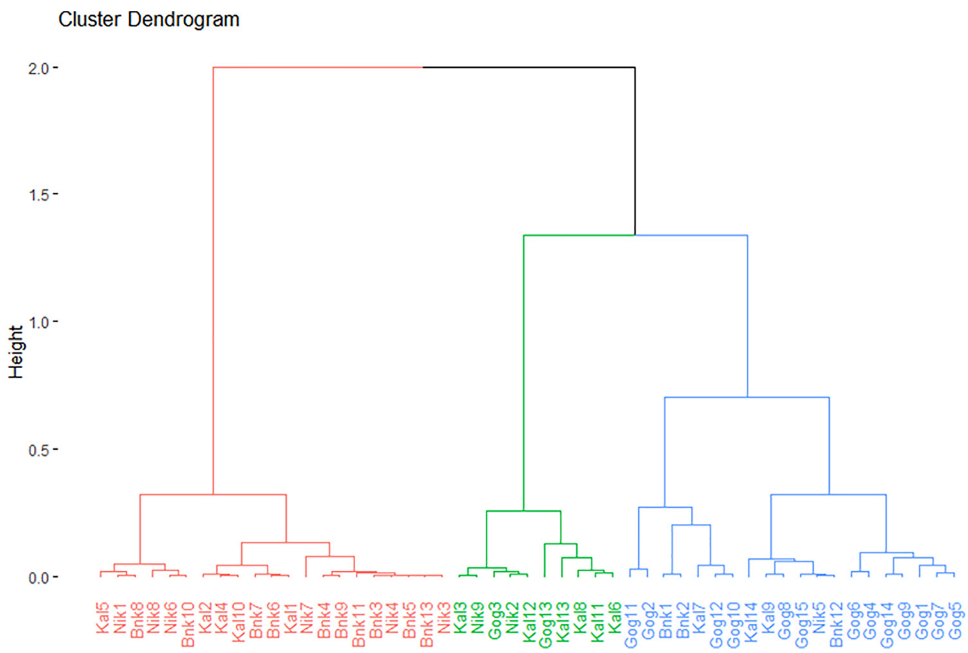


Fig. 4. Dendrogram showing the diversity and the classification of the different morphotypes of *B. madagascariensis*

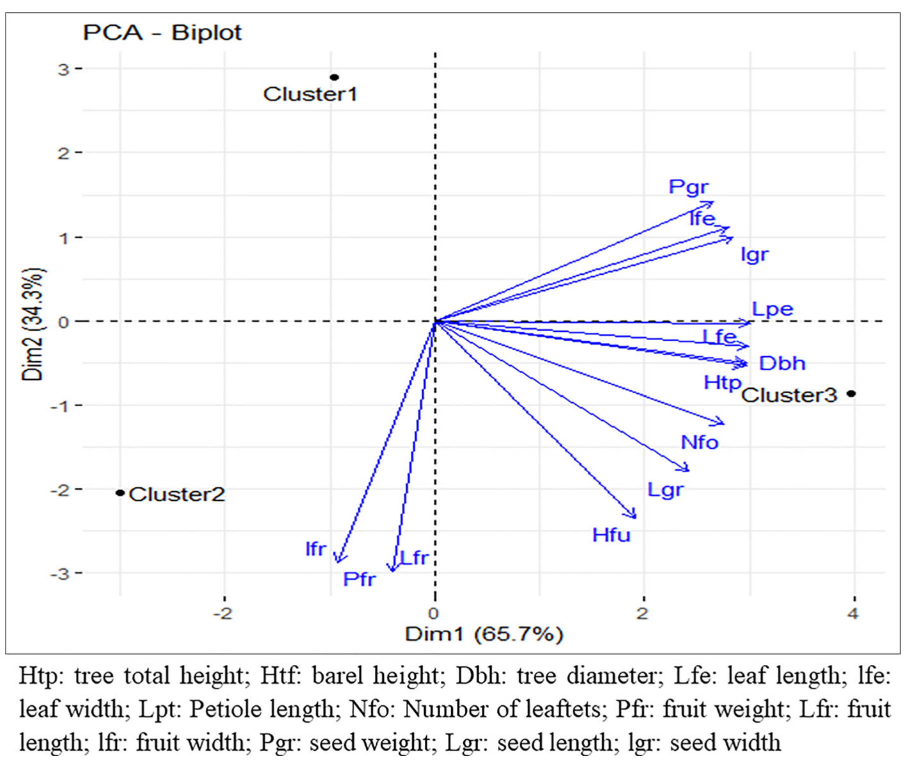


Fig. 5. Projection of B. madagascariensis trees clusters and the descriptors in the factorial axis system

those of cluster 2 (Table 5). However, cluster 3 was composed of individuals with the highest values of total height (13.09 ± 5.06 m), bole height (3.08 ± 1.36 m) and diameter at 1.3 m (13.11 ± 3.94 cm). In addition, individuals in this cluster were clearly differentiated from those in clusters 1 and 2 by their significantly longer leaves with more leaflets (Table 5). Seeds of individuals from clusters 2 and 3 were longer than those from cluster 1.

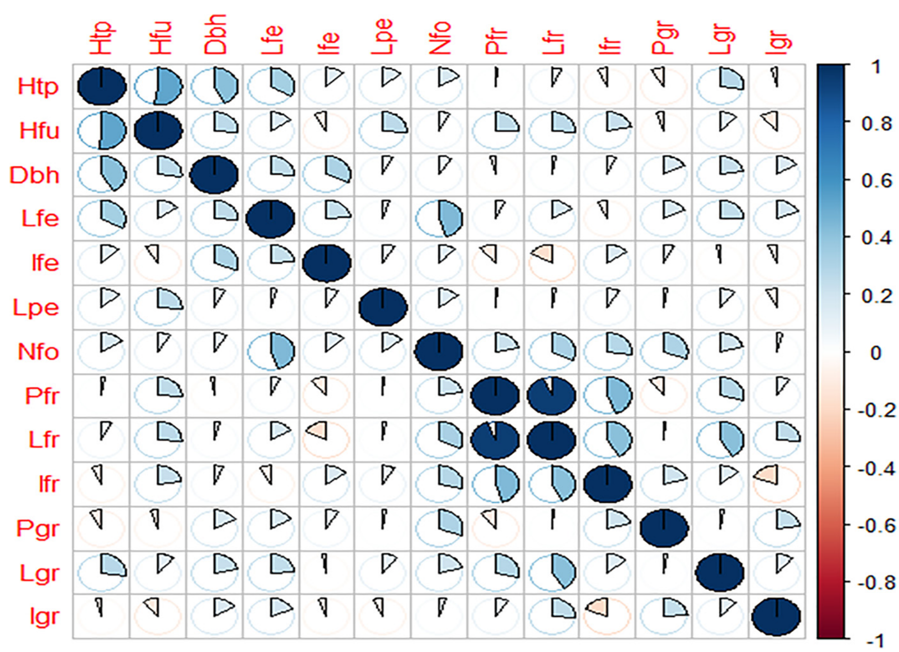
3.3.3. Correlation between B. madagascariensis *descriptors*

Correlation analysis revealed a positive and significant association between several traits (Fig. 6). Total tree height showed a strong and positive correlation with bole height, diameter at 1.3m, and seed length. The diameter at 1.30 m was positively correlated with the width of the leaf. Likewise, the leaf length showed a strong and positive correlation with the number of leaflets. Also, there was a positive and significant correlation between the fruit characters (length, width and weight) and this correlation was very strong between fruit length and weight. A strong and positive correlation was also observed between fruit length and seed length. On the other hand, a negative correlation was observed between certain traits, but this was weak and not significant (Fig. 6).

Table 5
Quantitative traits variation following the groups of B. madagascariensis trees

Morphological traits	Clusters			F	P
	1(N[a]=21)	2 (N=10)	3(N=20)		
Tree					
Total height (m)	9.01±1.98a	8.44±3.13a	13.09±5.06b	8.25	**0.001**
Bole height (m)	1.88±0.46a	2.55±1.29ab	3.08±1.36b	6.59	**0.003**
Diameter at 1.30 m (cm)	8.92±2.88a	8.28±2.97a	13.11±3.94b	10.60	**0.000**
Leaf					
Length (cm)	15.71±0.91a	15.23±0.83a	17.62±1.61b	17.86	**0.000**
Width (cm)	10.39±1.65a	9.83±0.93a	10.30±1.03a	1.21	0.308
Petiole length (cm)	8.90±0.77a	9.10±0.88a	10.30±1.03a	2.44	0.098
Number of leaflets	8.91±0.20a	9.10±0.29a	10.30±0.20b	13.47	**0.000**
Fruit					
Weight (g)	7.52±1.84a	15.91±3.35c	11.57±2.32b	44.16	**0.000**
Length (cm)	12.39±2.41a	22.59±4.07c	18.88±4.17b	33.45	**0.000**
Width (cm)	1.05±0.05a	1.11±0.04b	1.07±0.03ab	6.78	**0.003**
Seed					
Weight (g)	0.10±0.00b	0.09±0.00a	0.10±0.00b	3.21	**0.049**
Length (mm)	7.69±0.37a	7.80±0.16ab	8.01±0.26b	5.87	**0.005**
Width (mm)	4.83±0.16a	4.79±0.14a	4.86±0.19a	0.54	0.587

[a] : individuals' number by cluster; P: probability; Bold values indicate the significant values of the probability P; F: Fisher value; CV: coefficient of variation; F: Fisher value; Values followed by the same number within the same line are not significantly different



Htp: total tree height, Hfu, bole height, Dbh: diameter at 1.30m, Lfe: leaf length, lfe: leaf width, Lpe: petiole length, Nfo: number of leaflets, Pfr: weight of the fruit, Lfr: length of the fruit, lfr: width of the fruit, Pgr: weight of the seed, Lgr: length of the seed; lgr: seed width. Positive correlations are displayed in blue and negative correlations in red.

Fig. 6. Correlogram showing the correlation between quantitative traits

3.4. Morphological diversity of B. madagascariensis *across climatic zones*

3.4.1. Mean, minimum and maximum values and coefficients of variance of morphological traits of B. madagascariensis *according to climatic zones*

Apart from fruits weight, the other morphological characters showed slightly higher values in the Sudanian zone than in the Sudano-Guinean zone (Table 6). Coefficients of variation (CV> 0.30) were high for total tree height, bole height, diameter at 1.30 m, fruit weight and fruit length in both climatic zones, showing a strong morphological variability of individuals of *B. madagascariensis* within each climatic zone.

3.4.2. Effect of climatic zones on morphological traits of B. madagascariensis

One-way analysis of variance revealed significant differences among 6 out of the 13 morphological traits (Table 6) of *B. madagascariensis* trees across climatic zones with. Those six main variables included leaf length, number of leaflets, petiole length, fruits width, seeds weight and length. Values of leaf traits (length, number of leaflets and petiole) were significantly higher in Sudanian zone than in Sudano-Guinean zone (Table 6; Fig. 7A, B and C). Likewise, seed

Table 6
Morphological traits variation of *B. madagascariensis* within each climatic zone

Morphological traits	Sudanian zone				Sudano-Guinean zone				One-way ANOVA	
	Mean	Minimum	Maximum	CV	Mean	Minimum	Maximum	CV	F	P
Tree										
Total height (m)	10.81±4.98	3.6	25	0.46	10.12±3.01	5.2	16.87	0.3	0.34	0.561
Bole height (m)	2.59±2.33	1.19	6.12	0.51	2.34±0.99	1	5.83	0.42	0.56	0.452
Diameter at 1.30 m (cm)	10.89±3.53	5.67	18.79	0.32	9.88±3.39	5.01	22.77	0.44	0.85	0.362
Leaf										
Length (cm)	16.77±1.76	13.81	20.52	0.1	15.87±1.19	14.4	19.93	0.08	4.42	**0.04**
Width (cm)	10.63±1.39	7.43	13.3	0.13	10.15±1.62	3.99	13.64	0.16	1.74	0.264
Petiole length (cm)	3.51±0.72	1.7	4.87	0.2	3.02±0.23	2.59	3.41	0.08	9.89	**0.002**
Number of leaflets	9.78±1.23	8	13	0.13	9.13±0.81	8	11	0.09	4.8	**0.033**
Fruit										
Weight (g)	10.35±3.69	5.55	20.13	0.37	11.25±4.22	4.58	19.81	0.38	0.66	0.42
Length (cm)	17.08±5.67	10.09	29.12	0.33	16.76±5.02	7.85	28.12	0.3	0.05	0.831
Width (cm)	1.08±0.03	1.02	1.17	0.03	1.06±0.06	0.97	1.17	0.05	5.16	**0.03**
Seed										
Weight (g)	0.10±0.00	0.09	0.1	0.02	0.09±0.00	0.09	0.1	0.02	7.35	**0.009**
Length (mm)	7.94±0.28	7.15	8.44	0.03	7.72±0.35	6.62	8.08	0.04	6.11	**0.017**
Width (mm)	4.84±0.19	4.45	5.05	0.04	4.82±0.14	4.53	5.05	0.03	0.24	0.627

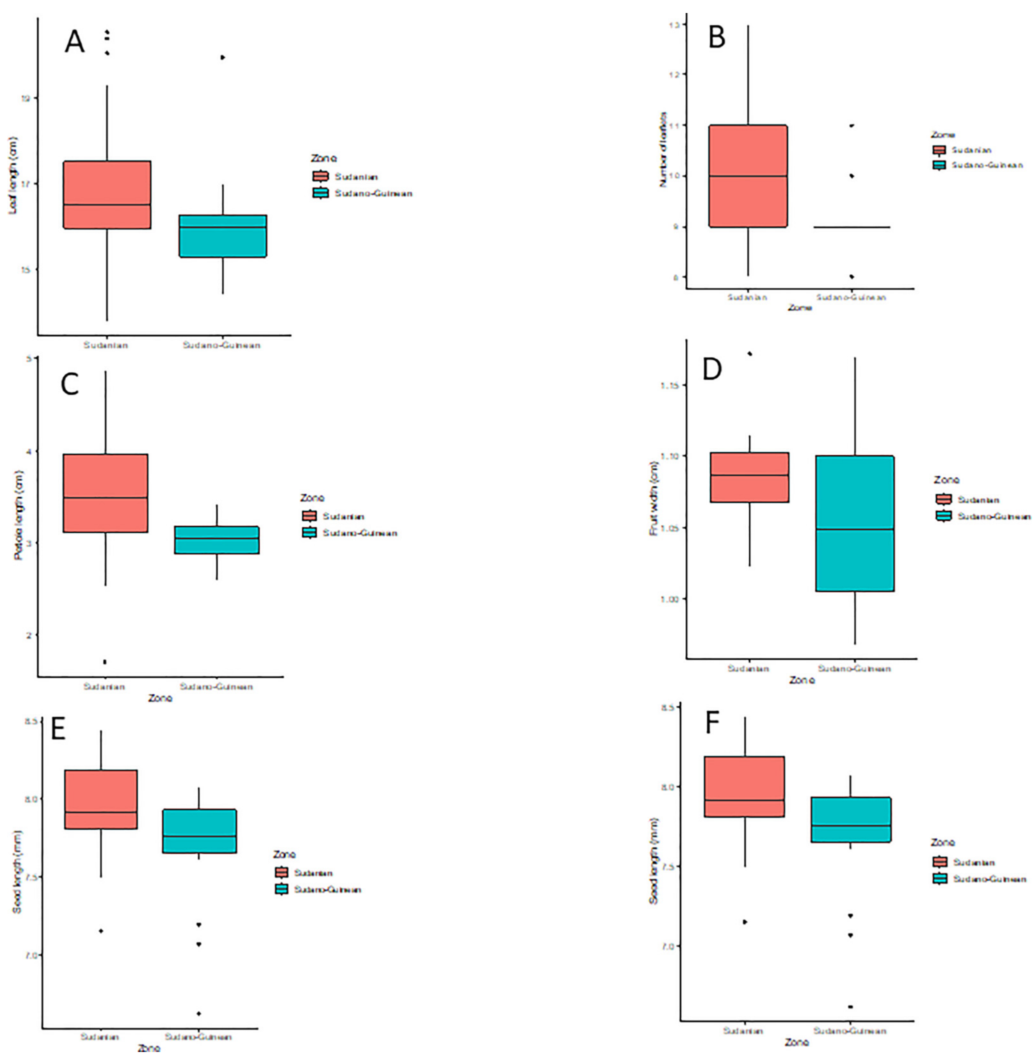


Fig. 7. Variation of mean of the discriminating morphological traits leaf length (A), number of leaflets (B), petiole length (C), fruit width (D), seed weight (E) and seed length (F) of *B. madagascariensis* across two climatic zones

weight and length, and fruit width were the highest in the Sudanian zone (Fig. 7D, E and F).

4. Discussion

4.1. Intra-specific diversity of B. madagascariensis in Sudanian and Sudano-Guinean zones

Knowledge regarding the variability of species is vital to any conservation measure. This is essential for selecting attractive genotypes for domestication. The study assessed the variation of morphological characters (dendrometric parameters, leaves, fruits, and seeds) of *B. madagascariensis* in Sudanian and Sudano-Guinean zones in Benin. In fact, morphological characters are markers which reveal important variations between individuals of the same population. They make it possible to highlight the genetic variations linked to the geographical origin of species (Morgenstern, 2011). In the study, three morphotypes significantly different from each other were detected within *B. madagascariensis* species. Discriminating morphological descriptors for these three morphotypes are tree total height, diameter at 1.30 m, bole height, leaf length, number of leaflets, fruit weight, fruit length and width, as well as seed length and weight. Similar results were found by several authors with other tropical species. For instance, the work by Dah-Nouvlessounon et al. (2016) identified 7 morphotypes within *Cola nitida* (Vent.) Schott and Endl., four morphotypes within *Cola acuminata* (P. Beauv.) Schott and Endl., and five morphotypes within *Garcinia kola* Heckel in southern Benin. Discriminating descriptors associated with these morphotypes include tree total height, diameter at 1.30 m, fruit weight and length and width, seed length and width. Similar results were found in Southern Nigeria with Ashiru et al. (2018) who revealed intraspecific variability of *G. kola* with diameter at 1.30 m, tree crown diameter, leaf length and width, and leaf petiole length. Also, some authors demonstrated intraspecific variability of *Pterocarpus erinaceus* Poir. on the basis of tree morphological characters such as leaf width, number of leaflets, fruit weight, fruit length and length. and seed width (Goba et al., 2019; Johnson et al., 2020). Similar results were also recorded in India on species such as *Melicoccus oliviformis* Kunth (Jiménez-Rojas et al., 2019) and *Prunus armeniaca* L. (Chauhan et al., 2020). This variation in phenotype of *B. madagascariensis* trees could be due to genetic and environmental factors (Diouf et al., 2019). In the study area, *B. madagascariensis* population is undergoing genetic erosion, its trees are becoming increasingly rare as evidenced by few numbers of individuals recorded in the study area. In such conditions, the intraspecific variability observed in the current study constitutes potentially an opportunity for improvement programs, *in situ* and *ex situ* conservation and domestication whereby specific morphotypes could be selected and reproduced by sexual or asexual methods.

A significant and positive correlation was observed between the number of leaflets, fruit traits in particular between length, width, and weight of the seed. This result shows a clear functional link or association between these traits and suggests that trees with leaves having many leaflets would tend to produce longer, wider fruits with large seeds. This information is very important for the orientation of breeding programs. Fruit weight was positively and significantly associated with fruit length, fruit width, and seed length. An increase in fruit length is associated with an increase in fruit width and seed length; what would make breeding and selection easier since an action on one trait would tend to have positive effects on other associated traits. Moreover, relationships between some traits can guide breeders in setting goals for parental partner selection and breeding (Dicenta and Garcia 1992; Tahir et al., 2002; Khadivi-Khub and Etemadi-Khah, 2015) Dah-Nouvlessounon et al. (2016)., Diouf et al. (2019) reported positive correlation between morphological traits of *G. kola, Saba Senegalensis* (A. DC.) Pichon. Also, studies by Abasse et al. (2011) depicted a strongly correlation between fruits and seeds dimensions (length and width), fruit weight and seed dimensions of *Balanites aegyptiaca* (L.) Del.

4.2. Diversity of B. madagascariensis across climatic zone

The study revealed morphological variability of *B. madagascariensis* species following the climatic zone. Among the 13 morphological traits measured, 6 traits varied significantly between the Sudanian zone and the Sudano-Guinean zone. Leaf length, the number of leaflets, petiole length, fruit width, seed weight and length. *Bobgunnia madagascariensis* trees from the Sudanian zone showed significantly higher values for the 6 discriminant traits of the morphotypes. The environmental effects on the morphological characters of plant species have been reported by several authors. In fact, Houehanou et al. (2019) reported a significant variation in fruit weight, fruit length and width, seed length and width of *Afzelia africana;* species of the same botanical family as *B. madagascariensis*. With regard to the climatic zones of Benin, the highest values of these 6 traits were recorded in Sudanian zone. Similar results were observed for *Adansonia digitata* L. (Assogbadjo et al., 2011) and *Strychnos spinosa* Lam. (Avakoudjo et al., 2021). Furthermore, Dicko et al. (2019) reported the effect of the zone in fruit weight variation of *Lophira lanceolata* between two phytodistricts of the Sudanian zone (Borgou-Nord and Atacora Chain) and the phytodistrict (Borgou-Sud) of the Sudano-Guinean zone. Lawin et *al.* (2021) also noted that the morphological traits of the fruits of *Cola millenii* K. Schum. varied significantly following phytogeographical districts in Benin. Furthermore, Nafan et al. (2007) reported in Cameroon similar information on *Vitellaria paradoxa* C.F.Gaertn. based on morphological traits measured on tree trunk, fruit, nut and leaf. In Mali, a significant variability was observed with *A. digitata* according to origin zones (Kouyaté et al., 2011) based on discriminating morphological descriptors such as fruit peduncle length, leaf lobes length, leaf lobes width and the number of leaf lobes. The variability observed between the trees of *B. madagascariensis* in the Sudanian zone and those in the Sudano-Guinean zone could be the response to environmental factors such as rainfall, temperature, sunshine, types of soil, winds, relative humidity, etc. (Escuredo et al., 2020; Maya-García et al., 2020; Keivani et al., 2021). Indeed, a single species can produce different phenotypes in different environments. This fundamental property of organisms is known as phenotypic plasticity (Sultan, 2000). It is one of the strategies that plant species develop for environmental adaptation. Thus, trees can respond to their environment by modifying their morphological traits to optimize their development (Houehanou et al., 2019). In addition to ecological factors, anthropogenic pressures (fields, pastures) could also lead to morphological variability. This hypothesis is confirmed by the recent work by Mohammed et al. (2021) which revealed greater diversity within tree species of *B. aegyptiaca* in undisturbed sites than in disturbed sites in Sudan.

4.3. Implications for conservation and utilization of B. madagascariensis genetic resources

The morphological characterization performed in this study has crucial implications for the rational utilization of *B. madagacariensis* genetic material. Variability in quantitative leaf, fruit and seed traits suggest that this species has a broad genetic basis for these traits, and significant genetic advancements can be made when targeted for breeding. The observed discriminating traits constitute selection markers for the identification of phenotypes adapted to the different climatic zones of Benin. *Bobgunnia madagascariensis* diversity in the Sudanian and Sudano-Guinean zones of Benin paves the way for selection and improvement studies of this species given the threats due to fruit harvesting and other human activities (Agbani et al., 2018). Also, the results of this study will serve as a benchmark for any possible molecular characterization study on this species. In addition, it was generally observed that the few *B. madagascariensis* trees found in the study area had a small diameter (10.44 cm on average). However, in suitable environment, the adult trees of this species can reach 40 to 60 cm in diameter at 1.30 m (https://prota4u.org/). This indicates a very poor performance of the species in the study area, thus drawing attention on the risk to this genetic resource and the need to take conservation measures, for example preservation and protection of *B. madagacariensis* trees in fields.

5. Conclusion

The present study focused on the morphological characterization of *B. madagascariensis* made it possible to highlight an important diversity within this species. Three morphotypes have been identified. The discriminating morphological characters of these morphotypes were total height, bole height, diameter at 1.30m, leaf length, number of leaflets, fruit weight, fruit length, fruit width, seed weight and seed length. Also, there are significant differences in leaf length, petiole length, number of leaflets, fruit width, seed weight and tree length *B. madagascariensis* between individuals from the Sudanian zone and those from the Sudano-Guinean zone. These different results depicted the intraspecific richness of B. *madagascariensis* in Northern of Benin. The demonstration of this genetic variability through morphological traits is an essential step for more in-depth studies on this species. Indeed, any genetic improvement program is necessarily based on morphological variability. This study therefore provides breeding researchers with essential information necessary for breeding and improvement work. Nevertheless, a molecular characterization study is necessary to confirm or deny this intraspecific and inter-climatic zone morphological diversity observed on *B. madagascariensis* species. Moreover, the results of this study will help to better use and conserve the diversity of this species in agrosystems by introducing the best morphotypes in the agroforestry systems.

Funding

This work was supported by the University of Abomey-Calavi (UAC), Benin Republic, through the Research Competitive Funds allocated to the PROLAIT project Number 626-2018/UAC/SG/SAF/VR-RU/SPRSP/SA.

Author contribution statement

LI conceived the work with advice from NVFN, EAD, HAS and LEA. LI and HGSG collected the data. LI and NVFN processed the data and performed the statistical analyses. LI, LEA, NVFN, ECT, DB, and HAS drafted the manuscript with significant contribution of EAD. LEA, EAD and HAS supervised the work. All authors read and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Acknowledgements

The authors acknowledge the Ministry of Higher Education of Benin and the University of Abomey-Calavi for the financial support through the Research Competitive Funds allocated to the PROLAIT project. The authors also extend their special thanks to all the fellow doctoral students who have contributed to this work. We are also grateful to the anonymous reviewers for their constructive comments on this work.

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