

Exploring distinctive morphological traits in *Beilschmiedia mannii* georeferenced by GPS: Implication for conservation

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Abstract

Beilschmiedia mannii (Meisn.) Robyns and Wilczek is an underutilised fruit tree valued for its nutritional benefits, but threatened by habitat destruction in Nigeria. Morphological characterisation was performed in order to elucidate the insufficient information on its morphological attributes in southwestern Nigeria. The study aimed at characterising the species population using the fruits, seeds, leaves, and the trees morphological attributes according to the habitats georeferenced by GPS. Different mother trees of the species were sampled for the study. Two distinct fruit colours (green and black) were identified, along with corresponding seed colours (red and cream). The species exhibited three primary fruit shapes, with corresponding seed shapes (ellipsoid, globose, and oval). *B. mannii* was encountered in the riparian, mangrove, and upland habitats. Significant differences were observed in the fruit weight, width, and length, seed weight, length and width, as well as mesocarp weight, leaf length and width between the two distinct colours, and amongst the shapes, and the habitats. The dendrogram-based clustering analysis revealed that the green morphotype and ellipsoid-shaped fruits formed the first cluster, while combinations of black and green fruits resulted in morphotypes with globose and ovate shapes in the second cluster. These findings highlight the presence of intraspecific diversity in the species with significant potential for species selection, breeding and improvement. This empirical data has important implications for the initiation of species domestication and conservation efforts.

Keywords: characterisation; fruit colours and shapes; seed colours; spicy cedar; underutilised fruiting trees

Introduction

Spicy cedar (*Beilschmiedia mannii*) (Meisn.) Robyns and Wilczek, is a tree species in the Lauraceae family. This wild aromatic plant is primarily distributed across West and Central Africa (Nyunaïi, 2008; Jusu and Cuni-Sanchez, 2017). *B. mannii* can reach total heights of 10 m to 35 m, and a diameter at breast height of 60 cm to 100 cm at maturity (Nyunaïi, 2008). The plant has a straight branchless bole up to 20 m long and large root swellings or narrow buttresses up to 1 m tall. The leaves are simple and alternately oriented, while the

fruits are spindle-shaped or somewhat slanted berries with lengths ranging from 1.5-5.5 cm or 1.5-2.5 cm, respectively.

The species' primary habitats are secondary forest and riparian vegetation (Hawthorne and Jongkind, 2006), with domesticated stands being integrated into agroforestry systems (Nzi *et al.*, 2023). The seeds and fruits are highly valued in local diets because of their high protein, carbohydrate, mineral and unsaturated fatty acid contents (Nyunaïi, 2008; Sahoré *et al.*, 2012; Kouamé *et al.*, 2017). They contain antioxidants that help prevent oxidative damage, and enhance the build-up of immunity in humans and animals (Ahoua *et al.*, 2015). Hence, the seeds and fruits are highly priced, and this has led to the categorisation of the species as an underutilised plant with high potential socioeconomic relevance in West Africa (Ogunbanjo and Aina, 2013; Jusu and Cuni-Sanchez, 2017). The wood component of the tree has also been identified to be suitable for building and furniture-making (Mark *et al.*, 2014).

These nutritional, socioeconomic and therapeutic qualities make the species an appropriate candidate for domestication, cultivation and conservation. Therefore, it is essential to document the morphological attributes of locally delimited populations of the species. Furthermore, morphological characteristics such as fruit and seed shape, weight, length, mesocarp weight and colour have been proposed as factors influencing consumer preferences, and selection for domestication and conservation (Giuliani, 2007; Olajuyigbe and Adaja, 2019). In addition, there is limited empirical information on the species' distribution in its natural range (de Kok, 2019), in spite of the continued threats posed to wild populations by deforestation, habitat loss, and climate change at the local and regional levels (Ogunbanjo and Aina, 2013; Jusu and Cuni-Sanchez, 2017; Olajuyigbe and Adaja, 2019).

An inventory of the species' population, and the evaluation of its morphological variation would aid in the identification, processing and possible selection of superior genetic resources, for its improvement, and breeding (Sennhenn *et al.*, 2013). This study evaluated the morphological traits of georeferenced populations of *B. mannii* in southwestern Nigeria using quantitative and qualitative descriptors of fruits and seeds. The morphological technique was used to validate empirical evidence on the diversity and distribution of *B. mannii* populations, and identify suitable domestication as well as the conservation strategies for the species.

Materials and Methods

Site Description

The sampling covered the Southwestern region of Nigeria, a region which lies between longitudes 2.688°E and 6.056°E, and latitudes 5.836° and 9.961°N. The land area is approximately 76,672 km², with the highest sampled point at 227 m above sea level. The region's tropical climate experiences wet (April-November) and dry seasons (November-March). Annual rainfall ranges between 1500 mm and 3000 mm, while temperatures range from 21 °C to 34 °C (Agboje *et al.*, 2013).

Site selection

Previous reports obtained from the Forestry Herbarium of the Forestry Research Institute of Nigeria indicated that specimens of *B. mannii* had been collected from Ogun State in southwestern Nigeria. As a result, the forestry departments in the remaining five southwestern states (Ekiti, Ondo, Osun, Lagos and Oyo) were visited to consult field specialists on the potential locations of *B. mannii* stands, in the respective states. The distribution of the species in local government areas (LGAs) of each state were determined based on personal communication with forestry officials, farmers' associations, and key informants' assistance as well as assessment of vegetation maps. Consequently, the *B. mannii* stands were located in the rainforest belt in two other states (Figure 1): Ogun (Ijebu East and Ogun Water Side LGAs) and Ondo (Okitipupa, Irele, Ilaje, Ese-Odo, and Odigbo LGAs). The sampling locations were stratified into three distinct habitats: mangrove,

riparian, and upland. Based on availability, 31 trees were located in the field and geo-referenced using a hand-held Global Positioning System (GPS) device (Figure 1).

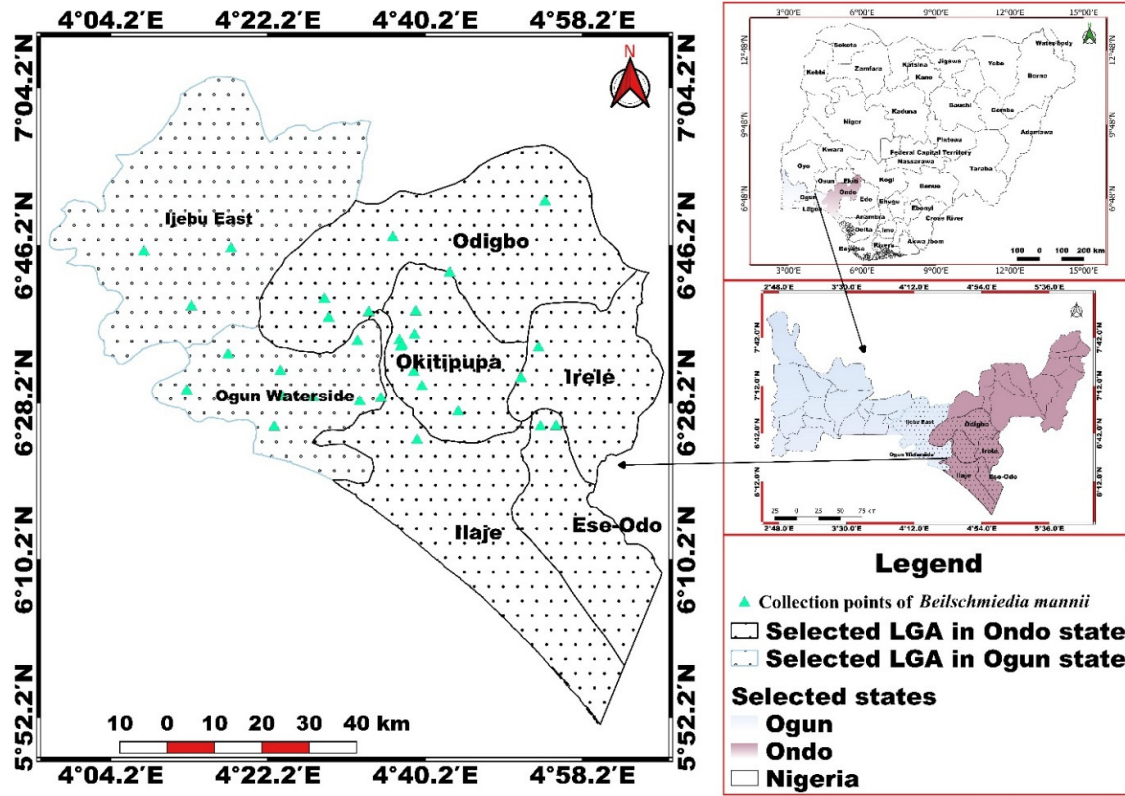


Figure 1. Map of sampled location for *Beilschmiedia mannii* stands in southwestern Nigeria (inset: Maps of Nigeria, Ondo and Ogun states)

Morphological characterisation

Following the methods of Kehlenbeck *et al.* (2015), forty-seven (47) morphological features were used to characterise *B. mannii* (Table 1). The total height, and diameter at breast height of sampled trees were measured, and 30 leaves and fruits were randomly collected from each tree. The weight of the mesocarp was determined by processing the fruit, and the seeds were extracted. The Royal Horticultural Society Colour Chart was used to determine the colour of fruits and seeds.

The total length, and width of individual fruits were used to estimate two fruit shape indices, that is Roundness Ratio (RR) and Ellipsoid Ratio (ER); using equations 1 and 2 (Vihotogbe, 2012):

$$\text{Roundness Ratio (RR)} = \frac{L}{\sqrt{D_1 \times D_2}} \quad (1)$$

$$\text{Ellipsoid Ratio (ER)} = \frac{D_1}{D_2} \quad (2)$$

Where:

L = total length of the fruit; D_1 and D_2 are the largest and smallest diameters, respectively.

Therefore, fruit shape was categorised as follows: elliptical fruit ($1.1 \leq ER \leq 1.5$), round fruit ($1.0 \leq ER < 1.1$), ovate fruit ($0.9 < RR \leq 1.15$), oblate fruit ($0.86 < RR \leq 0.9$), and oblong fruit ($RR \geq 1.15$).

Table 1. Selected morphological descriptors (32 qualitative and 15 quantitative) used in the characterization of *Beilschmiedia mannii* genotypes from southwestern Nigeria

Morphological descriptor		Scale of measurement
Trees traits	Total height	Scale: m
	Merchantable height	Scale: m
	Crown diameter	Scale: m
	DBH	Scale: cm
Fruit traits	Length	Scale: mm
	Width	Scale: mm
	Weight	Scale: g
	Mesocarp weight	Scale: g
	Shape	1 = ellipsoid, 2 = globose, 3 = ovate
	Fruit apex shape	1 = acute, 2 = globose
	Fruit colour	1 = green, 2 = black
	Fruit beak	1 = present, 2 = absent
	Fruit cross sectional area	1 = contoured, 2 = not contoured
	Fruit pigment	1 = present, 2 = absent
	Fruit fragrance	1 = present, 2 = absent
	Fresh fruit pigment	1 = present, 2 = absent
	Fruit juice	1 = present, 2 = absent
Seed traits	Length	Scale: mm
	Width	Scale: mm
	Weight	Scale: g
	Seed odour	1 = odour, 2 = odourless
	Shape	1 = ellipsoid, 2 = globose, 3 = ovate
	Seed apex shape	1 = acute, 2 = globose
	Seed colour	1 = red, 2 = cream
	Seed odour when dried	1 = odourless, 2 = mild odour
	Seed beak	1 = present, 2 = absent
	Fresh seed pigment	1 = present, 2 = absent
	Fresh seed fragrance	1 = present, 2 = absent
Leaf traits	Width	Scale: cm
	Length	Scale: cm
	Petiole length	Scale: cm
	Leaf shape	1 = elliptic, 2 = oblong
	Leaf base shape	1 = acute, 2 = acuminate, 3 = attenuate
	Leaf apex shape	1 = Acute, 2 = acuminate, 3 = globose
	Leaf fragrance without squeezed	1 = present, 2 = absent
	Leaf fragrance when squeezed	1 = present, 2 = absent
	Leaf attitude in relation to branch	1 = erect, 2 = horizontal, 3 = drooping
	Leaf margin	1 = Entire, 2 = serrated

	Dry leaf retention	1 = present, 2 = absent
	Young leaf colour	1 = green, 2 = pale green
	Matured leaf colour	1 = green, 2 = pale green, 3 = dark green
	Young leaf hairiness	1 = present, 2 = absent
	Matured leaf hairiness	1 = present, 2 = absent
	Number of matured leaves	1 = simple, 2 = two leaflets, 3 = three leaflets
	Secondary vein in leaves	1 = alternate, 2 = opposite 3 = alternate and opposite

Data Analysis

Analysis of Variance (ANOVA) was used to determine differences in the tree, fruit and seed growth characteristics using SPSS (version 20.1). Significantly different means were separated using Tukey's test. PAST (version 3.0) was used to perform Principal Component Analysis (PCA) to discover significant factors of variance and correlation among morphological descriptors. The qualitative and quantitative morphological features were grouped using hierarchical cluster analysis based on Squared Euclidian distances. The T-test analysis was used to compare the two most distinct fruit and seed colours, while Pearson correlation analysis was utilised to determine the relationship between fruit and seed traits.

Results

Distribution of B. mannii in southwestern Nigeria

The species was found growing in both planted, and naturally occurring locations in the mangrove, riparian and upland habitats of Ogun and Ondo states. Nineteen of the trees encountered were wild populations, while the remaining (12 trees) were domesticated. The tree either produced black or green coloured fruits. Fourteen trees were found in the upland habitat, thirteen in the riparian habitat and four in the mangrove habitat (Table 2, a and b).

Table 2a. Selected qualitative morphological characteristics and locations (GPS, habitats, elevation) of samples of *B. mannii* collected from Ogun state, Nigeria

S/NO	Location	Latitude	Longitude	Hab.	FC	FSS	Elev.	Sources
1	Ogbere	N06.75791	E004.13368	RH	Green	Ellipsoid	39	Wild
2	Oni	N06.65339	E004.22432	MH	Green	Ellipsoid	-3	Wild
3	Abigi 1	N06.48369	E004.39952	MH	Green	Ellipsoid	14	Planted
4	Abigi 2	N06.48159	E004.39817	MH	Green	Ellipsoid	13	Planted
5	Olojumeta	N06.48453	E004.21195	MH	Green	Ellipsoid	15	Wild
6	Ilusin	N06.53073	E004.39381	UH	Green	Globose	17	Planted
7	Ibiade	N06.56232	E004.29439	UH	Green	Globose	40	Planted
8	Olojumeta 2	N06.49347	E004.21532	MH	Green	Globose	19	Wild
9	Efire	N06.47996	E004.45621	UH	Black	Globose	28	Wild
10	Ayila	N06.58779	E004.54102	UH	Black	Globose	42	Wild

Hab. = Habitat, UH = Upland habitat, MH = Mangrove habitat, RH = Riparian habitat, FC = Fruit colour, FSS = fruit and seed shapes, Elev. = Elevation

Table 2b. Selected qualitative morphological characteristics and locations (GPS, habitats, elevation) of samples of *B. mannii* collected from Ondo state, Nigeria

S/NO	Location	Latitude	Longitude	Hab.	FC	FSS	Elev.	Sources
1	Erekiti – Luwoye 1	N06.58936	E004.62108	RH	Black	Ovate	46	Wild
2	Asewele Oja 1	N06.85312	E004.89869	RH	Green	Ovate	46	Planted
3	Asewele Oja 2	N06.84654	E004.89754	RH	Green	Ellipsoid	15	Planted
4	Basola 1	N06.63148	E004.47970	RH	Green	Ellipsoid	32	Planted
6	Basola 2	N06.63189	E004.48601	RH	Green	Ellipsoid	19	Planted
6	Igbotako	N06.57676	E004.62313	RH	Green	Ellipsoid	22	Planted
7	Erekiti – Luwoye 2	N06.58707	E004.62202	RH	Green	Globose	41	Wild
8	Idi – Obilayo	N06.64281	E004.56261	RH	Green	Ellipsoid	35	Planted
9	Adekugbe	N06.51759	E004.85271	RH	Green	Ellipsoid	16	Wild
10	Olowolomo	N06.57549	E004.88622	RH	Green	Ellipsoid	57	Wild
11	Erinje	N06.45211	E004.73312	RH	Green	Ovate	24	Planted
12	Kajola	N06.71772	E004.71672	RH	Green	Ellipsoid	52	Wild
13	Olorunto	N06.66809	E004.47780	RH	Black	Ellipsoid	30	Wild
14	Lalepa	N06.78482	E004.60839	RH	Green	Ellipsoid	107	Wild
15	Ilutitun	N06.52890	E004.64825	UH	Green	Globose	16	Planted
16	Mahintedo	N06.47871	E004.58573	UH	Black	Globose	22	Wild
17	Ago – Titun	N06.64425	E004.65211	UH	Black	Ovate	61	Wild
18	Ajagba	N06.42445	E004.91962	UH	Black	Ovate	31	Wild
19	Igbotu	N06.42330	E004.88995	UH	Black	Ovate	33	Wild
20	Erekiti – Luwoye 3	N06.58030	E004.62621	UH	Black	Globose	45	Wild
21	Iju- Oke	N06.5994	E004.64966	UH	Black	Ovate	61	Wild

Hab. = Habitat, UH = Upland habitat, MH = Mangrove habitat, RH = Riparian habitat, FC = Fruit colour, FSS = Fruit and seed shapes Elev. = Elevation

Morphology of B. mannii trees in southwestern Nigeria

The total height of the trees ranged from 3 m to 24.5 m. The minimum tree height of the black-fruit bearing trees was 16.5 m, while the highest height was 22 m. The minimum DBH for black fruit-producing trees was 25.4 cm, while the highest DBH was 75.74 cm (Table 3). The green fruit-producing trees had a total height that ranged from 3 m to 24.5 m. The DBH of green fruit-producing trees varied from 5.41 cm to 22.9 cm (Table 3). The riparian and mangrove habitats had the highest values for quantitative vegetative morphology. However, the values were not significantly different between the two habitats (Table 4). The leaf blade shape was elliptic, with an acute apex base, and an entire leaf edge. The secondary vein was alternating and opposite, but there was no hairiness in the young and mature leaves. The leaves were upright in relation to the branches (Figure 2) and had a scent which became pronounced when the leaves were squeezed.

Table 3. Growth variables of *B. mannii* trees from the two morphotypes in southwestern Nigeria

Morphotype	Height and DBH	Trees
Black morphotype	Height range (m)	Numbers of trees
	11 – 20	7
	21 – 30	3
	DBH Range (cm)	Numbers of Trees
	25 – 35	5
	36 – 45	2

Green morphotype	46 – 55	2
	56 – 65	
	66 – 75	1
	Height Range (m)	Numbers of Trees
	1 – 10	16
	11 – 20	3
	21 – 30	1
	DBH Range (cm)	Numbers of Trees
	1 – 10	2
	11 – 20	15
	21 – 30	1
	31 – 40	1
	41 – 50	1

Table 4. Vegetative morphological characteristics of *B. mannii* trees from three habitats in southwestern Nigeria

Variable	Source of variation	Mean	Min.	Max.
Leaf length (cm)	Riparian habitat	20.11±5.26 ^a	6.1	33
	Upland habitat	19.99±3.96 ^a	10	34
	Mangrove habitat	21.59±2.8 ^a	17.1	28.48
Leaf width (cm)	Riparian habitat	7.7±1.74 ^a	4.5	14
	Upland habitat	6.43±1.47 ^a	3.5	10.6
	Mangrove habitat	7.96±1.17 ^a	6.2	10.3
Leaf petiole length (cm)	Riparian habitat	1.09±0.17 ^a	0.5	1.7
	Upland habitat	1.11±0.19 ^a	0.7	1.7
	Mangrove habitat	1.15±0.27 ^a	0.7	2
DBH (cm)	Riparian habitat	17.83±17.87 ^a	13.37	22.92
	Upland habitat	18.19±10.72 ^a	5.41	41.38
	Mangrove habitat	32.49±4.13 ^b	12.73	75.76
Total Height (m)	Riparian habitat	8.6±6.79 ^a	3.67	24.5
	Upland habitat	14.29±6.39 ^b	5.52	22
	Mangrove habitat	12.5±6.02 ^{bc}	4.46	18
Crown Diameter (m)	Riparian habitat	7.64±3.05 ^a	4.49	14
	Upland habitat	8.08±2.29 ^a	4.87	11
	Mangrove habitat	7.75±2.36 ^a	6.14	11

Note: Different letter indicates significant differences among the habitats (Tukey's test $p < 0.05$)



Figure 2. Elliptic leaf shape of *B. mannii* trees from southwestern Nigeria

Morphological characteristics of fruits and seeds of B. mannii

The green fruits had red seeds (Figure 3a and b), whereas the black fruits contained cream-coloured seeds (Figure 4a and b). Three shapes (ellipsoid, globose, and ovate) were observed for the fruits and seeds (Figure 5 a, b, and c). There were more green fruit-producing trees (74%) than the black fruit-producing trees (26%). Ellipsoid fruit shape represented 51% of the sampled population, while globose and ovate fruit shapes accounted for 29%, and 19%, respectively. Green-coloured, ellipsoid-shaped fruits and seeds had the higher values for their quantitative morphological features (Tables 5 and 6). Trees in the riparian habitat exhibited the highest quantitative variables. There were significant differences in seed weight and length of samples from the different habitats. Substantial differences were observed for the mesocarp weight of fruits from the riparian, and upland environments, while samples from the mangrove, and riparian habitats did not differ significantly (Table 7). There were strong and direct relationships between the fruit and seed quantitative variables (Table 8). The black fruits had a strong and attractive scent, producing exudates when ripe. The Scree plot revealed that the first component of the PCA could be preserved in order to draw meaningful conclusions about variables that could explain variability in the species population (Figure 5). The biplot of the PCA revealed that fresh fruit and seed weight; fresh fruit and seed length; mesocarp weight, fresh fruit and seed width; as well as leaf length and width had large positive loadings on component 1 and were responsible for the observed variability. Conversely, leaf petiole length had negative correlations with Principal Component 2 (Figure 6). The populations were classified into two major groupings (Figure 7). The first group included fruits with the largest weights (ellipsoid shaped, green-coloured fruits), while the second group included fruits with lower weights (black-coloured fruits with a combination of ovate and globose shaped fruits).

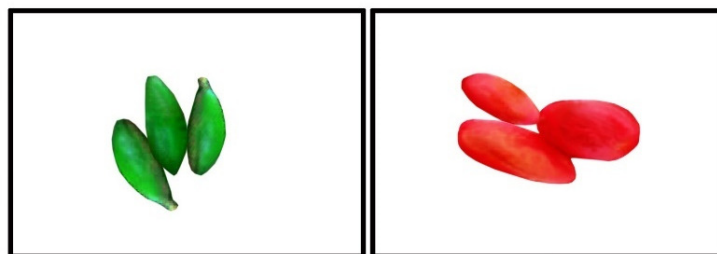


Figure 3. Green fruits of *B. mannii*, and their corresponding red seed colour



Figure 4. Black fruits of *B. mannii*, and their corresponding creamy seed colour

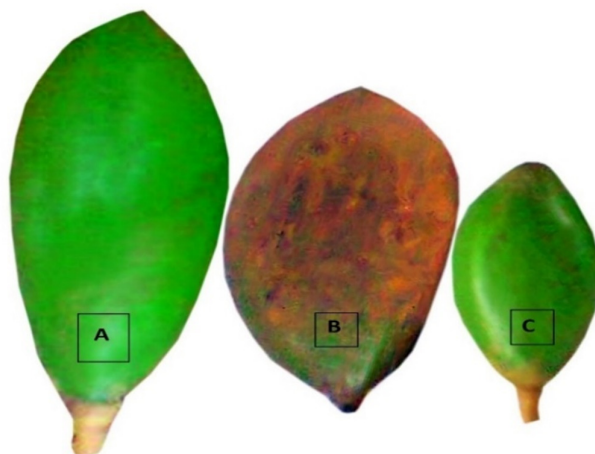


Figure 5. Fruit shapes of *B. mannii* (A = Ellipsoid, B=Globose, C =Ovate)

Table 5. Morphological variation among black and green fruit morphotypes of *B. mannii* in southwestern Nigeria

Variables	Source of Variation	Mean
Fruit weight (g)	Green	12.84±1.11
	Black	7.59±4.59
Fruit length (mm)	Green	42.19±8.70
	Black	37.77±8.64
Fruit width (mm)	Green	24.68±4.95
	Black	19.08±2.02
Seed weight (g)	Red	8.35±3.18
	Cream	5.04±1.10
Seed length (mm)	Red	36.51±8.23
	Cream	26.65±4.17
Seed width (mm)	Red	22.93±4.59
	Cream	16.38±3.60
Mesocarp weight (g)	Green	8.35±3.20
	Black	5.04±1.09

Table 6. Quantitative parameters of fruit and seed shapes of *B. mannii* from southwestern Nigeria

Shape	Ellipsoid	Globose	Ovate
	Fruit weight (g)		
Mean	13.73±4.28a	7.58±1.87b	7.05±1.31b
Minimum	6	4.55	5.69
Maximum	24.5	10.81	10.2
	Fruit length (mm)		
Mean	42.74±8.64a	32.29±4.18b	32.38±3.04b
Minimum	26.5	23.52	27.82
Maximum	59.82	44.23	37.91
	Fruit width (mm)		
Mean	24.82±4.84a	20.4±4.01b	19.52±2.73b
Minimum	15.56	14.91	14.66
Maximum	36.42	33.42	27.43
	Seed weight (g)		
Mean	9.03±2.91a	4.1±1.02b	3.95±0.64b
Minimum	3.5	3.29	3.6
Maximum	17.15	7.93	5.2
	Seed length (mm)		
Mean	37.96±8.56a	26.64±4.12b	26.64±3b
Minimum	19.77	13.75	13.75
Maximum	53.52	39.96	39.96
	Seed width (mm)		
Mean	23.13±4.72a	16.88±3.96b	18.71±2.37b
Minimum	13.98	10.24	22.83
Maximum	32.54	29.93	32.92
	Mesocarp weight (g)		
Mean	4.5±1.5a	3.31±1.3b	2.91±0.95b
Minimum	1.71	1.57	1.68
Maximum	7.2	6.71	4.78

Note: Different letters in rows indicate significant differences among the shapes (Turkey's test $p < 0.05$)

Table 7. Variation in quantitative traits of *B. mannii* fruits and seeds from different habitats in southwestern Nigeria

Habitat	Morphological characters	Mean	Minimum	Maximum
Riparian (Fresh water swamp)	Fresh fruit weight (g)	14.23±4.56 ^a	5.00	24.5
	Fresh fruit length (mm)	38.88±8.2 ^a	26.77	58.65
	Fresh fruit width (mm)	24.62±4.55 ^a	14.66	36.42
	Fresh seed weight (g)	9.13±3.3 ^a	3.2	17.1
	Fresh seed length (mm)	34.03±8.08 ^a	13.75	53.52
	Fresh seed width (mm)	22.74±4.2 ^a	10.24	35
	Mesocarp weight (g)	4.76±1.27 ^a	1.6	7.2

Mangrove (Mangrove swamp)	Fresh fruit weight (g)	12.53±3.95 ^a	6	18.6
	Fresh fruit length (mm)	37.19±7.2 ^a	27.64	59.82
	Fresh fruit width (mm)	22.3±3.77 ^{ab}	16.37	29.9
	Fresh seed weight (g)	8.34±2.71 ^{ab}	3.6	12.5
	Fresh seed length (mm)	33.9±6.68 ^a	21.8	53.19
	Fresh seed width (mm)	23.74±6.12 ^a	14.82	26.87
	Mesocarp weight (g)	4.43±1.01 ^{ab}	2.9	6.1
Upland	Fresh fruit weight (g)	7.81±1.08 ^b	3.5	10.8
	Fresh fruit length (mm)	32.45±4.17 ^b	23.52	45.23
	Fresh fruit width (mm)	19.82±3.16 ^{ab}	15.56	35.5
	Fresh seed weight (g)	5.22±1.16 ^{ab}	3.2	7.9
	Fresh seed length (mm)	31.5±4.09 ^b	19.57	50.58
	Fresh seed width (mm)	17.93±4.46 ^a	11.44	33.8
	Mesocarp weight (g)	3.08±0.92 ^{ab}	1.5	5.8

Note: Different letters in column indicate significant differences among the habitats (Turkey's test at $p < 0.05$)

Table 8. Correlation analysis of morphological traits of *B. mannii* sampled in southwestern Nigeria

Variable	LPL	LW	LL	FFWD	FFW	FFL	FSW	FSL	FSWD
Leaf petiole length (cm)	1								
Leaf width (cm)	-0.073	1							
Crown diameter (m)	0.277	0.018							
Leaf length (cm)	0.056	0.641**	1						
Fresh fruit width (mm)	-0.06	0.372 [*]	0.064	1					
Fresh fruit weight (g)	-0.073	0.309 [*]	0.12	0.638**	1				
Fresh fruit length (mm)	0.004	0.279	0.027	0.632**	0.796**	1			
Fresh seed weight (g)	-0.074	0.371 [*]	0.029	0.705**	0.887**	0.728**	1		
Fresh seed length (mm)	0.003	0.347 [*]	0.052	0.717**	0.753**	0.944**	0.768**	1	
Fresh seed width (mm)	-0.012	0.395 [*]	0.064	0.840**	0.505**	0.504**	0.650**	0.659**	1

FFL = Fresh fruit length, FFWD = Fresh fruit width, FFW = Fresh fruit weight, FSL = Fresh seed length, FSW = Fresh seed weight, FSWD = Fresh seed width, LPL = Leaf petiole length, LW = Leaf width, LL = Leaf length, CD = Crown diameter

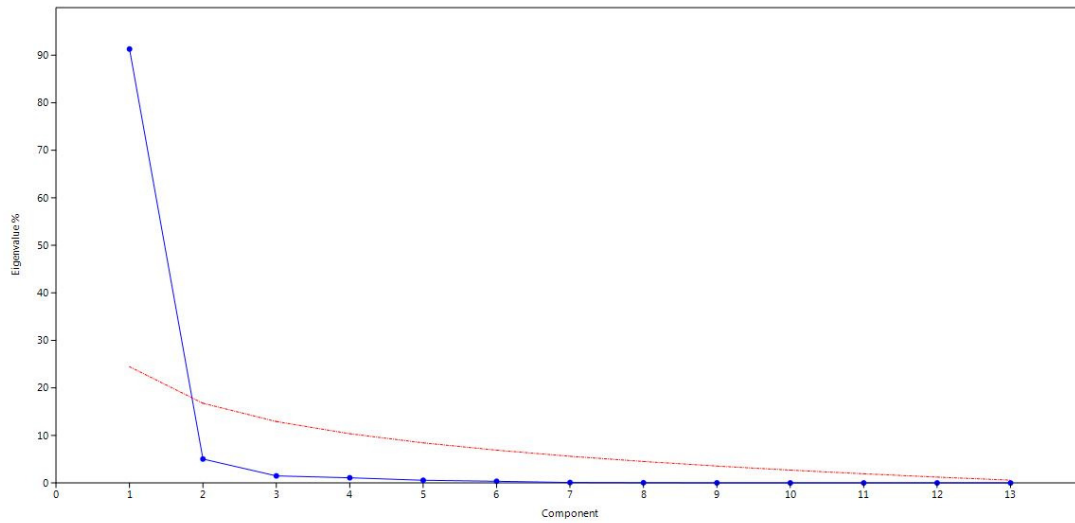


Figure 5. Scree plot of the Principal Component Analysis (PCA) of samples of *B. mannii* in southwestern Nigeria

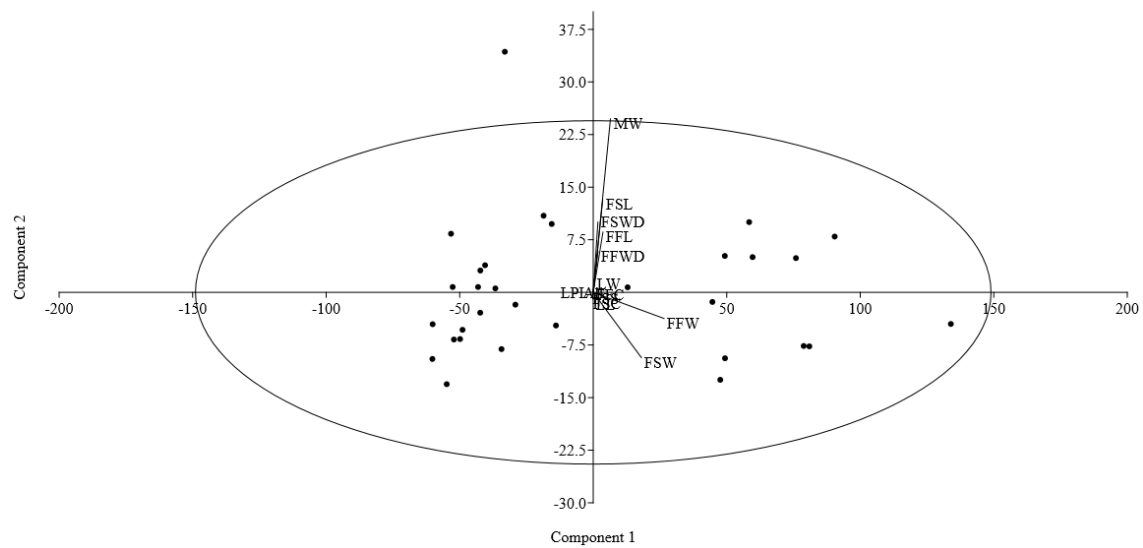


Figure 6. Biplot of the PCA of *B. mannii* in southwestern Nigeria

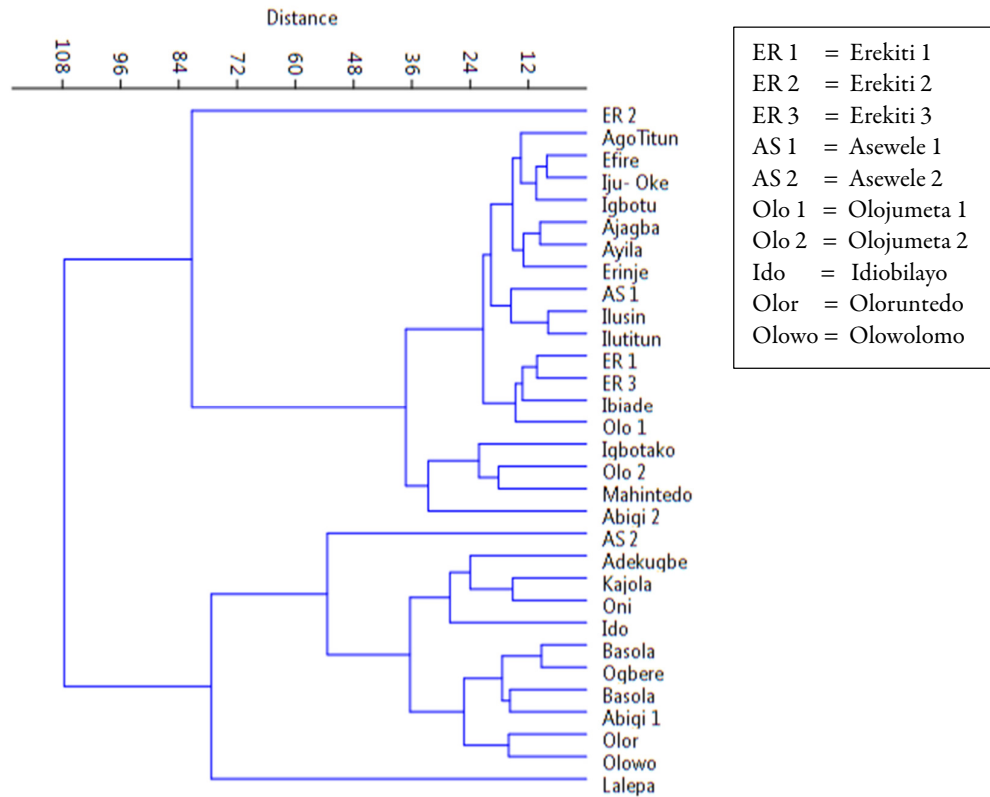


Figure 7. Dendrogram classification of *B. mannii* populations based on morphological characters in southwestern Nigeria

Discussion

The intraspecific variations observed in *B. mannii* populations in southwestern Nigeria highlight the importance of the species' delimitation, with the fruit, and the seed related features being effective discriminant characters. Qualitative and quantitative differences have also been reported for fruits, and seeds of tropical fruit bearing trees such as *Dacryodes edulis* (Ondo-Azi *et al.*, 2009), *Mangifera indica* (Sennhenn *et al.*, 2013) and *Cola acuminata* (Andrew *et al.*, 2013). However, the findings were not in agreement with the morphological features employed to delimit *Ficus* sp. (Mubo *et al.*, 2004) and *Acalypha* sp. (Soladoye *et al.*, 2008). In those studies, only leaf morphological features were the primary sources of variation. Three shapes (ellipsoid, globose, and ovate) were observed with fruit, and seed quantitative characteristics varying across shapes. The ellipsoid shaped fruits had the highest quantitative variables, and this was similar to the shape patterns identified for *Irvingia gabonensis* in the Dahomey gap (Vihotogbe, 2012), *Adansonia digitata* in Sudan (Gurashi *et al.*, 2014) and *Pcynanthus angolensis* in Nigeria (Bello and Adesakin, 2020). In this study, the ovate shaped fruits had the least quantitative morphological attributes. Despite these variations, the three fruit and seed shapes were found in all domesticated populations, indicating their selection by local communities. The main distinguishing qualitative characteristics were the green and black colours of fruits, as well as the red and cream colours of the seeds. Ranjitha *et al.* (2021) had opined that fruit colour was a useful qualitative attribute for the delimitation of *Persea americana*, while Lawal *et al.* (2007) reported that fruit qualitative features were the most dependable morphological characters for delimitation of *Lycopersicon esculentum*. Similarly, qualitative characteristics of fruits and seeds were used for the delimitation of *Bobgunnia madagascariensis* (Imorou *et al.*, 2022).

In Nigeria, local communities have used qualitative features such as fruit colour to identify, select, consume and conserve *B. mannii*, from time immemorial. This local approaches to species delimitation, based on colour and shape of fruits and seeds, demonstrate the value of indigenous knowledge in species categorisation, and could serve as a foundation for taxonomic examination of plant species (Nesbitt *et al.*, 2010; Arshad *et al.*, 2014; Rimlinger *et al.*, 2021).

The two morphotypes observed may have an influence on consumer preferences and affect their purchasing decision (Munthali *et al.*, 2012). In addition, the qualitative and quantitative characteristics of the fruits, and seeds could influence processors' varietal selection in order to increase yield (Barret *et al.*, 2010; Rimlinger *et al.*, 2021). For example, Femi-Oyewo *et al.* (2009) recognised the species' potential utility in the production of biological gum (an organic binding agent) for the pharmaceutical industry. The gelatinous qualities of the green fruit bearing morphotype were reported to be a major factor influencing its selection for planting in southwestern Nigeria (Femi-Oyewo *et al.*, 2009). In this study, black-coloured fruit-producing trees were found to be underrepresented in the domesticated stands, and the fruits were rarely consumed. This morphotype, on the other hand, had a strong scent and is used as a main ingredient in the brewing of a local juice. This supports the statement that the species could be suited for juice production, particularly given the craving fragrance attribute of Lauraceae family members (Nyunaïi, 2008). The positive correlations among the fruit and seed morphological variables concurs with previous findings for *Scelerocarya birrea* and *Dacryodes edulis* (Mkwezalamba *et al.*, 2015; Mboujda *et al.*, 2022). The physiological phenomenon, where auxins in developing seeds promote fruit growth, drives the process of larger fruits producing larger seeds.

Morphological heterogeneity was detected among the riparian, mangrove, and upland habitats, with fruit weight, length, and width, as well as seed weight, length, and width, differing between habitats. The higher quantitative values observed for samples from the riparian habitat could be attributed to adequate water availability during the phenophases of the trees. Regional weather-induced water deficits and variability, have been demonstrated to have deleterious impacts on the quantitative characteristics of *Bobgunnia madagascariensis* fruits (Imorou *et al.*, 2022); and *Vitellaria paradoxa* fruits and nuts in Nigeria (Ugbese *et al.*, 2009). As a fact, fruit and seed quantitative characteristics are negatively altered by limited access to precipitation (Nafan *et al.*, 2007). For instance, fruits of *Parkia biglobosa* in Mali's wettest zone, have been demonstrated to have higher morphometric characteristics (Kelly *et al.*, 2022). *Elaeagnus angustifolia* also demonstrated significant differences in the fruit quantitative characteristics of trees from riparian and upland settings (Espeland *et al.*, 2014). In this study, the differences in fruit and seed attributes of trees from riparian and upland environments, were most likely due to abiotic stress resulting from water deficits, and high temperatures in the upland areas (Espeland *et al.*, 2014; Fernandez *et al.*, 2018). During fruit development, insufficient water inhibits cell division and expansion, respiration, absorption, and transfer of mineral nutrients from the soil (Sharma *et al.*, 2018). Hence, micro-climatic conditions play important roles in the development of quantitative morphological characters in fruits (Raina, 2003). The leaf features (width, length, and width) did not differ across habitats, although the variables of leaf samples from riparian and the mangrove habitats were higher than those from the upland habitat. This was consistent with studies on *Parkia biglobosa* in Mali, where leaf quantitative characteristics were similar, despite wide variation in precipitation access among habitats (Kelly *et al.*, 2022).

Implications on the conservation, and domestication of B. mannii

There is an urgent need for the conservation, domestication, and increased propagation of this underutilised species. This will help to increase its contributions to livelihoods, and protect the species from habitat destruction (de Kok, 2019; Imorou *et al.*, 2022; Oloyede *et al.*, 2023). However, conservation, and domestication of *B. mannii* will require adequate information on its morphological and genetic diversity (Leakey, 2017). Therefore, the findings of this research are important evidence necessary for species quality assessment, possible clone description, selection and breeding for improvement.

Nevertheless, the fruit, and seed shapes might not be the most important parameters in the selection of elite trees for breeding, and genetic improvement in the species. This is because the ellipsoidal fruit and seed shapes were encountered only in the riparian habitats, and their high quantitative characters may be due to phenotypic plasticity. This environmental influence on fruit shape has also been isolated for *Irvingia gabonensis* and *Adansonia digitata* (Leakey, 2017; Omondi *et al.*, 2019). Hence, there are limitations in the use of only morphological attributes for varietal delimitation in plant breeding and tree improvement. The other two fruit shapes (ovate and globose) that occurred in the three habitats indicate that their expression in the populations was probably due to their genotypes. For example, the fruit shape of *Prunus persica* (Cirilli *et al.*, 2021) and *Pyrus* sp. (Kumar *et al.*, 2019; Simionca Mărcășan *et al.*, 2023) have been reported to be strongly dependent on their genetic influences. Therefore, genetic analysis is required for effective utilisation of the species and genetic resources (Monforte *et al.*, 2014). The observation that only the green fruit producing morphotype was being planted by farmers may be a clear indication of the presence of inherent properties, and domestication syndrome. Some caution is however, required because the lack of cultivation of the black fruit producing morphotype may result in its local extinction, especially as existing stands are being harvested for timber (Mark *et al.*, 2014).

Continuous deforestation coupled with the conversion of natural habitats to other land uses pose a serious threat to the species' survival in Nigeria. As a result, there is an urgent need for the development of conservation mechanisms to ensure the proliferation and long-term use of the two morphotypes. The most suitable conservation strategies for the species will be the application of *ex-situ* conservation mechanisms. This can be achieved by enlightening, encouraging, and incentivising farmers through the provision of seedlings. Seedlings of the two morphotypes could also be planted in green areas such as botanical gardens, community forests and sacred grove forests.

Conclusions

This study characterised geo-referenced populations of *B. mannii* in southwestern Nigeria, and established the presence of two distinct fruit colours (black and green), and their corresponding seed colours (red and cream). It also confirmed three fruits and corresponding seed shapes that include; ellipsoid, globose, and ovate. There were high variations among the quantitative traits of the leaves, fruits and seeds. The fruit and seed had a positive relationship, and riparian habitat exhibited the highest favourable conditions for cultivation of the species. Preference for the domestication of green fruit producing trees was probably threatening the existence of the second morphotype. The morphological characterisation of underutilised species such as *B. mannii*, could help to standardise species-specific traits in Nigeria, when coupled with genetic analysis.

Acknowledgements

Authors wish to thank the reviewers for providing essential inputs and comments that have helped to improve the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Author's Contributions

Conceptualization: AAA and SOO. Methodology: AAA. Data collection: AAA. Analysis: AAA. Validation: AAA and SOO. Original draft preparation: AAA. Review and editing: SOO. Supervision: SOO. Both authors read the manuscript and approved it for submission.

Ethical Approval

Not applicable

Conflicts of interests

There are no conflicts of interest related to the article

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