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Morphological Characterization of the Blood Plum (*Haematostaphis barteri* Hook. F. (Anacardiaceae)) in the Republic of Benin

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Abstract: Understanding species morphological variation across geographical ranges can serve as a first step for germplasm collection and the conservation of genetic resources. The morphological variability of *Haematostaphis barteri* Hook. F. (Anacardiaceae) in Benin (West Africa) was studied, using 11 traits related to panicles, fruits, leaves and leaflets. A total of 1,485 panicles, 1,485 fruits, 990 leaves and 4,950 leaflets were sampled. It was found that the sample provenance and site topography have a significant influence on the morphological traits. The discriminating morphological traits were the length of the panicles, the number of fruits per panicle, the length and width of fruits, the mass of the fresh fruit pulp mass, the length of leaves and petioles, the number of leaflets per leaf, length and width of leaflets. On the basis of these traits, four different morphotypes of *H. barteri* were identified, with however a small intra and inter group variability. The morphotype from sites established on the tops and the high slopes of hill produced larger and heavier fruits with higher pulp mass. This morphotype could be of interest for future varietal selection programs for the species in Benin.

Key words: Benin, *Haematostaphis barteri*, morphological variability, provenance, topography.

1. Introduction

The improvement of plant genetic resources is an immediate solution to the problems linked to the living conditions of farmers in rural areas, especially when it comes to local wild fruit trees. Wild fruit trees have morphological traits which are the result of their adaptation to environmental conditions, and play a dual role: supporting the subsistence of local populations and conserving biodiversity [1]. An improved understanding of ecology of local fruit trees would strengthen their production in cultivable lands and, consequently, improve the living conditions of farmers, while ensuring environmental stability.

In Benin there are several edible wild fruit trees including *Haematostaphis barteri* Hook. F. (Anacardiaceae), commonly known as blood plum, which is a dioecious, spontaneous fruit tree from tropical Africa. The species' range extends from Côte d'Ivoire to Sudan [2]. It grows exclusively in the Sudanese and Guinean savannas on rocky hills. In Benin, fragmented populations and isolated individuals of *H. barteri* are found in the phytodistrict of the Atacora chain, in the north-western part of the country [3-5]. *H. barteri* is a minor food species that has many uses and therefore plays an important socio-economic role for the local people of North Benin [6]. For example, the bark, roots and leaves of the species are used in traditional medicine to cure several diseases or symptoms [6, 7]. Fruit pulp is directly consumed and is an excellent source of vital nutrients [8]. The fruits are systematically collected and marketed in certain local markets, which thus contributes to improving household income [6]. The socio-economic interest that *H. barteri* provides to rural people leads to its overexploitation which could compromise the

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long-term availability of the resource, and the persistence of the species. This strong harvesting pressure on the species, combined with climatic variability, limited natural recruitment and aging stands of *H. barteri*, makes this tree species one of the most vulnerable in the Atacora Chain of Mountains [3, 9].

Sustainable management and tree conservation strategy cannot be implemented without better knowledge of the species on ecological, morphological, biochemical and genetic characteristics in order to differentiate best individuals to select for genetic enrichment [10]. Previous studies have been carried out on the morphological variability of several woody species which are of interest to humans [11-13]. The study of morphological variability of forest resources is necessary for genetic improvement and varietal selection, because it facilitates the identification of traits that are sensitive to environmental factors [14]. Domestication process begins with the exploitation of existing natural variability to select individuals with the most interesting phenotypes [15]. The objective of this study was to analyze the morphological variability of *H. barteri* according to topographic parameters and provenances, and to characterize the identified morphotypes.

2. Materials and Methods

2.1 Sampling and Data Collection

H. barteri trees were sampled from eight provenances distributed in three districts of Benin (Natitingou, Boukombé and Toucountouna) within the same agro-ecological zone (Fig. 1). Sampling schemes took into account the topography of the sites, as followed: top and high slope, mid-slope, down-slopes and plateau (Table 1).

Across the eight provenances, 99 *H. barteri* trees were sampled according to their accessibility and the presence of fruits. These trees were organized into clusters which correspond to all the female trees surrounding a male tree (Fig. 2). The clusters were at least 100 m apart within a given provenance. Sampled trees were numbered, identified by small metal plates, and their global positioning system (GPS) coordinates recorded.

Eleven (11) morphological traits related to the panicles, fruits and leaves were selected. Morphological description of panicles was carried out directly on the field and focused on the length of the panicle and the number of fruits per panicle. The length of the panicle was measured from the point of attachment of the stem to the end of the last fruit using a graduated ruler with an accuracy of 0.1 cm. A total of 15 panicles were chosen at random on each tree, for a total of 1,485 panicles measured. Fifteen (15) fruits per tree were sampled for a total of 1,485 fruits.

Data were collected on fruits' length and width, the whole fruit fresh weight, the weight of the pericarp and that of the kernel (endocarp + almond). Fruit length was measured from the point of attachment of the peduncle to the end and its width was measured in the median part of the length in two perpendicular directions and the average value was retained. The length and width of the fruit were measured using an electronic caliper with an accuracy of 0.01 cm. The fresh weight of the fruit was determined by weighing. The pericarp of the fruit was carefully removed and weighed. The rest of the fruit (pulp + kernel) was securely wrapped in a thick cloth to remove the pulp [16]. The core obtained at the end of this operation was dried in ambient air for 4 h and then weighed using an electronic scale with an accuracy of 0.01 g. The weight of the pulp was determined according to Eq. (1):

$$M\text{ (pulp)} = M\text{ (fruit)} - [M\text{ (peel)} + M\text{ (kernel)}] \quad (1)$$

where M (pulp) is the weight of the fruit pulp, M (fruit) is the weight of fresh whole fruit, M (peel) is the weight of the pericarp of the fruit and M (kernel) is weight of the fruit kernel.

Ten leaves were sampled per tree for a total of 990 leaves, packaged in plastic bags until their dimensions were measured approximately 4 h later in the laboratory. Five leaflets, both the largest and the smallest, were collected on each leaf, i.e., 50 leaflets per tree for a total of 4,950 leaflets. Data on leaf and petiole length, the number of leaflets per leaf, the length and width of leaflets were collected. The length of the leaf was measured from the point of attachment of the petiole to the branch to the end of the terminal leaflet; the length of the petiole was measured from the point of attachment of the petiole to the branch to the first leaflet. The length of the leaflet was measured from the point of attachment of the petiolule to the main rib to the tip of the leaflet. The width of the leaflet was measured in the middle of the length of the leaflet. All these measurements were made using a graduated ruler with an accuracy of 0.1 cm.

2.2 Statistical Analysis

The variability between the morphological traits was assessed using the coefficient of variation (CV).

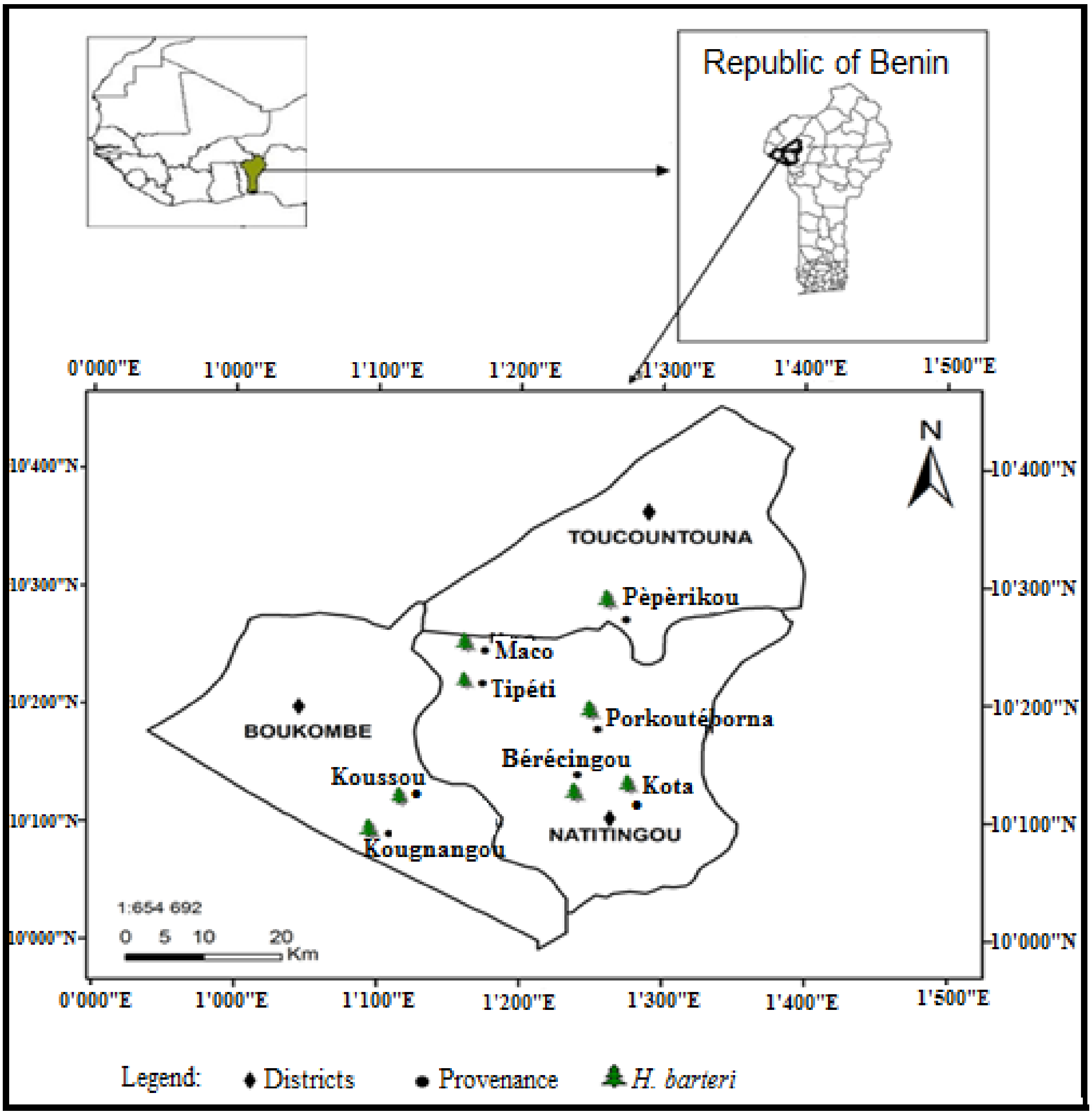

Fig. 1 The study area.

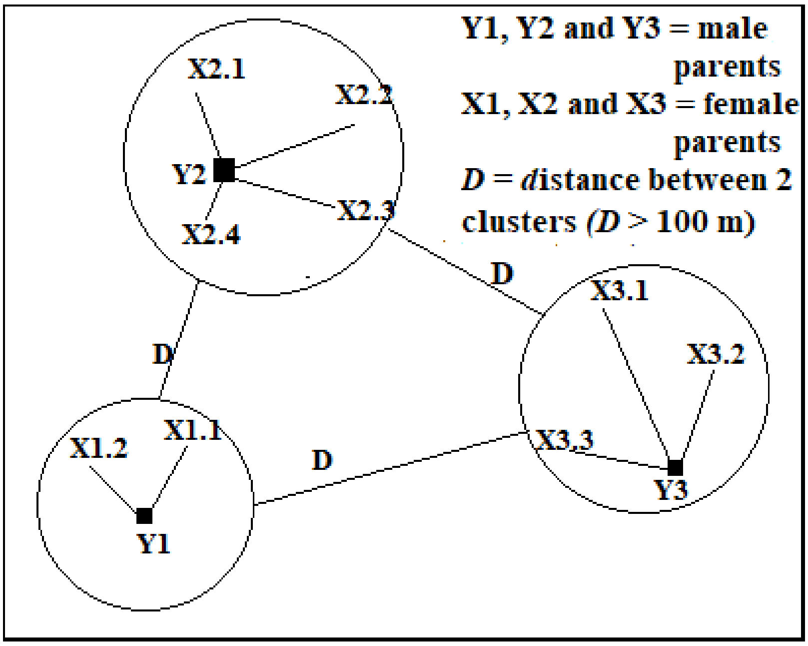

Fig. 2 Scheme of sampled *Haematostaphis barteri* clusters formation.

Table 1 Agro-ecological characteristics of the eight localities of Benin in which the fruits and leaves of *Haematostaphis barteri* were collected.

Provenances	Sampling number	Topography of the site	Type of soil	Longitude (E)	Latitude (N)	Altitude (m)
Bérécingou	9	High slope and top	Brown yellowish red, ferruginous tropical little deep, impoverish and concretions sat on the quartzite.	01°40′05.6″	10°23′40.5″	420
Borna	9	High slope and top	Reddish yellowish brown, shallow tropical ferruginous, depleted and concretions sitting on quartzite.	01°42′52.9″	10°21′14.7″	449
Koussou	19	High slope and top	Olive reddish brown, tropical ferruginous, deep concretions and hydromorphs.	01°20′26.1″	10°19′06.9″	570
Maco	13	Mid-slope	Red, shallow, ferruginous, impoverished and seated concretions, on quartzite.	01°28′35.0″	10°40′51.5″	525
Tipéti	22	Mid-slope	Reddish yellowish brown, shallow tropical ferruginous, depleted and concretions sitting on quartzite.	01°30′32.2″	10°38′49.0″	540
Kougnangou	9	Down slope	Olive reddish brown, tropical ferruginous, deep concretions and hydromorphs.	01°19′39.7″	10°16′26.1″	370
Kota	4	Plateau	Reddish yellowish brown, shallow tropical ferruginous, depleted and concretions sitting on quartzite.	01°46′17.2″	10°25′24.6″	580
Pèpèrikou	14	Plateau	Red, shallow, ferruginous, impoverished and seated concretions, on quartzite.	01°46′02.5″	10°45′14.9″	506

Morphological variation within and among provenances in one part and within and among sites topography on the other hand, was assessed using a scale proposed and tested on the bio-system of west-African *Parkia biglobosa* provenances [17]. The same scale was successfully used by Kouyaté *et al.* [18] and Dadegnon *et al.* [19] and defined as followed: small variation (CV = 0-10%); average variation (CV = 10%-15%); fairly large variation (CV = 15%-44%); significant variation (CV > 44%). Analysis of variance was used in R software version 2.15.3 to compare mean values of each trait between provenances and topography, followed by the Student-Newman-Keuls post-hoc test. Prior to the analysis of variance, the Shapiro-Wilk normality test was carried out to verify the normality of the residuals and the Levene's test to verify the homogeneity of variances. The hierarchical classification (*Euclidean distances*) was conducted to identify morphotypes.

3. Results

3.1 Morphological Characteristics of H. barteri

Overall, panicles' length varied from 6 cm to 71 cm with an average of 29.42 (± 9.62) cm (Table 2). The number of fruits per panicle ranged from 2 to 130 with an average of 21 (± 14) fruits per panicle. Fruits length varied from 20.40 mm to 36.90 mm with an average of 27.49 (± 2.15) mm and the width varied from 18.25 mm to 32.25 mm with an average of 24.43 (± 1.87) mm. The weight of the fresh whole fruit varied from 4.33 g to 20.93 g with an average of 9.83 (± 2.06) g and the weight of the fruit pulp varied from 0.96 g to 14.45 g with an average of 5.79 (± 1.66) g. Leaves length ranged from 21.50 cm to 57 cm, whatever the provenance, with an average of 35.98 (± 4.41) cm. Petiole length varied from 2.00 cm to 14.20 cm with an average of 8.08 (± 1.65) cm, and the number of leaflets per sheet, varied between 10 and 31 with an average of 19 (± 2) leaflets. The length of the leaflets varied from 3 cm to 12 cm with an average of 7.34 (± 1.13) cm while the width of the leaflets varies from 1.20 cm to 5.60 cm with an average of 2.86 (± 0.56) cm.

3.2 Morphological Variability of H. barteri according to Provenance

The analysis of variance revealed highly significant differences ($p < 0.001$) between provenances for all morphological traits related to panicles, fruits and leaves (Table 3). The longest panicles (35.28 cm) were recorded in Kota and the shortest (22.47 cm) in Bérécingou. The panicles with the highest number of fruits (27 fruits) were recorded in Maco and those with the lowest number of fruits (13 fruits) in Borna. The largest fruits (28.8 mm long and 25.59 mm wide) having the highest fresh weight (11.23 g) with a large pulp weight (6.87 g) were from Bérécingou. On the other hand, the smallest fruits (26.81 mm long and 23.86 mm wide) with the lowest fresh weight (9.15 g) and pulp weight (5.13 g) were found at Pèpèrikou. The longest leaves (37.45 cm) were observed in Kota, and the longest leave petioles (8.34 cm) were recorded at Tipéti and Kougnagou, while the shortest leaves (34.24 cm) were recorded at Maco and shortest leaves petiole (7.60 cm) recorded at Pèpèrikou. The leaves with the largest leaflets (8.09 cm long and 3.09 cm wide)

Table 2 Morphological characteristics of *H. barteri*.

Variables	Mean	Standard deviation	Minimum	Maximum
Panicule length (cm)	29.42	9.62	6.00	71.00
Number of fruits per panicle	21.00	14.00	2.00	130.00
Fruit length (mm)	27.49	2.15	20.40	36.90
Fruit width (mm)	24.43	1.87	18.25	32.25
Fruit mass (g)	9.83	2.06	4.33	20.93
Pulp mass (g)	5.79	1.66	0.96	14.45
Leaf length (cm)	35.98	4.41	21.50	57.00
Petiole length (cm)	8.08	1.65	2.00	14.20
Number of leaflets per leaf	19.00	2.00	10.00	31.00
Leaflet length (cm)	7.34	1.13	3.00	12.00
Leaflet width (cm)	2.86	0.56	1.20	5.60

Table 3 Morphological traits of panicle, fruit and leaf of *H. barteri* studied by provenance.

Provenance	Parameters	Lpan (cm)	Nfruit	Lfruit (mm)	Lafruit (mm)	Mfruit (g)	Mpulp (g)	Lleaf (cm)	Lpetiole (cm)	Nfoliole	Lleaflet (cm)	Laleaflet (cm)
Bérécingou	Mean	22.47^{e}	14.26^{c}	28.80^{a}	25.59^{a}	11.23^{a}	6.87^{a}	36.61^{abc}	7.97^{ab}	19.47^{bc}	7.98^{a}	2.81^{c}
	SE	0.57	0.87	0.25	0.24	0.27	0.22	0.64	0.17	0.2	0.16	0.08
	CV (%)	29.48	70.66	10.23	10.77	27.57	36.53	15.51	19.77	9.39	39.78	18.71
Borna	Mean	24.05^{e}	12.50^{c}	28.10^{b}	25.27^{a}	10.21^{b}	6.28^{b}	35.22^{cd}	8.08^{ab}	20.24^{ab}	7.27^{c}	2.94^{b}
	SE	0.66	0.59	0.11	0.12	0.13	0.1	0.51	0.18	0.3	0.04	0.07
	CV (%)	31.70	54.51	4.74	5.66	14.87	17.99	15.48	21.15	14.65	12.94	50.61
Kota	Mean	35.28^{a}	20.33^{b}	27.05^{c}	24.22^{c}	10.59^{b}	6.05^{bc}	37.45^{a}	8.21^{ab}	20.38^{a}	7.60^{b}	2.92^{b}
	SE	1.4	1.43	0.2	0.21	0.18	0.14	0.9	0.35	0.41	0.09	0.03
	CV (%)	30.83	54.52	5.72	6.86	13.20	17.65	13.98	24.68	14.18	15.84	16.90
Tipéti	Mean	32.15^{b}	26.64^{a}	27.13^{c}	23.95^{c}	9.50^{c}	5.67^{cd}	35.62^{bcd}	8.34^{a}	18.81^{c}	7.29^{c}	2.96^{b}
	SE	0.5	0.87	0.01	0.1	0.09	0.22	0.24	0.09	0.11	0.03	0.002
	CV (%)	28.23	59.52	6.57	6.82	16.98	20.22	10.03	17.14	10.63	13.65	20.98
Kougnagou	Mean	26.14^{d}	15.21^{c}	26.92^{c}	24.13^{c}	9.27^{c}	5.40^{de}	37.11^{ab}	8.34^{a}	18.9^{c}	7.15^{c}	2.90^{b}
	SE	0.68	0.76	0.18	0.15	0.17	0.01	0.43	0.13	0.2	0.05	0.03
	CV (%)	30.29	57.74	7.88	7.00	20.83	31.32	11.43	22.17	9.67	13.43	19.56
Koussou	Mean	28.46^{c}	18.27^{b}	28.09^{b}	24.86^{b}	10.21^{b}	5.92^{bc}	36.77^{abc}	7.93^{ab}	19.63^{ab}	7.19^{c}	2.63^{d}
	SE	0.58	0.69	0.13	0.1	0.12	0.1	0.28	0.13	0.15	0.03	0.14
	CV (%)	34.39	63.30	7.88	6.69	20.06	29.92	11.69	22.95	11.02	13.72	16.96
Maco	Mean	32.45^{b}	27.38^{a}	27.12^{c}	24.09^{c}	9.46^{c}	5.59^{cd}	34.24^{d}	7.94^{ab}	19.76^{ab}	6.67^{d}	2.74^{c}
	SE	0.75	1.35	0.14	0.12	0.13	0.11	0.33	0.14	0.19	0.04	0.03
	CV (%)	32.40	68.90	7.25	6.76	18.97	27.68	10.95	18.01	10.31	16.45	23.50
Pèpèrikou	Mean	31.94^{b}	20.25^{b}	26.81^{c}	23.86^{c}	9.15^{c}	5.13^{e}	36.12^{abc}	7.60^{b}	18.77^{c}	8.09^{a}	3.09^{a}
	SE	0.54	0.62	0.15	0.12	0.14	0.11	0.34	0.1	0.17	0.04	0.02
	CV (%)	24.41	44.32	7.84	7.28	22.01	30.19	10.45	18.63	10.07	13.51	13.27
Probability (*p*)		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0025	< 0.001	< 0.001	< 0.001
General minimum		6.00	2.00	20.40	18.25	4.33	0.96	21.50	2.00	10.00	3.00	1.20
General mean		29.42	20.52	27.49	24.43	9.82	5.79	35.98	8.08	19.00	7.34	2.86
General maximum		71.00	130.0	36.9	32.25	20.93	14.45	57.00	14.20	31.00	12.00	5.60
General SE		0.25	0.36	0.06	0.05	0.05	0.04	0.12	0.05	0.06	0.02	0.008
General CV (%)		32.70	67.50	7.83	7.63	20.95	28.65	12.25	20.42	11.04	15.39	19.69

Lpan: panicle length; Nfruit: number of fruit per panicle; Lfruit: fruit length; Lafruit: fruit width; Mfruit: fruit weight; Mpulp: pulp weight; Lleaf: leaf length; Lpetiole: petiole length; Nfoliole: number of leaflet per leaf; Lleaflet: leaflet length; Laleaflet: leaflet width; SE: standard error; CV: coefficient of variation; Mean is the average value of morphological traits per provenances of *H. barteri*. Numbers followed by the same letter (a, b, c, d, e), in a column are not significantly different at 5% of confidence, according to the average comparison test of Student Newman Keuls.

were distinguished at Pèpèrikou, while the shorter leaflets length (6.67 cm) and shorter leaflets width (2.63 cm) were observed in Maco and Koussou, respectively.

The intra-site variability for the length of panicles was moderate (15% < CV < 44%) in all sites while it was high (CV > 44%) for the number of fruits per panicle (Table 3). The intra-site variability for the length and width of the fruits was medium (10% < CV < 15%) in Bérécingou and low (0% < CV < 10%) in all other sites. The intra-provenance variability in the weight of the whole fresh fruit was low (10% < CV < 15%) in Borna and Kota but average (15% < CV < 44%) in the other provenances whereas it was fairly large for the weight of the pulp across provenances.

The intra-provenance variability of the length of the leaves was quite significant (15% < CV < 44%) in Bérécingou and Borna but average (10% < CV < 15%) in the other provenances whereas it was quite significant (15% < CV < 44%) for the length of the petiole in all provenances. For the number of leaflets per leaf, the intra-provenance variability was low (0% < CV < 10%) in Bérécingou and Kougnangou but medium (10% < CV < 15%) in the other provenances. The intra-provenance variability for the length of the leaflets was quite significant (15% < CV < 44%) in Bérécingou, Kota and Maco but average (10% < CV < 15%) in the other provenances. On the other hand, the intra-provenance variability in the width of the leaflets was medium (10% < CV < 15%) in Pèpèrikou and quite significant (15% < CV < 44%) in the other provenances.

3.3 Impact of Site Topography on Morphological Variability of H. barteri

Significant differences ($p < 0.001$) were noted in *H. barteri* panicles, fruits and leaves traits among different level of site topography (Table 4). The shortest panicles (25.93-26.14 cm) with the lowest number of fruits (15-16 fruits) were observed on down slope and high slopes and on hill tops. However, this was associated with the largest fruits (28.27 mm long and 25.14 mm wide), with the highest weight (10.46 g) and a large weight of pulp (6.24 g). The longest panicles (32.68 cm) with average number of fruits (20 fruits) and, the longest leaves (36.72 cm) with large leaflets (7.98 cm length and 3.06 cm width) were found at down-slopes hill and plateau with, however, smaller fruits (26.86 mm long and 23.94 mm wide) and smaller weight of pulp (5.34 g).

Within-site variability was high (CV > 44%) for the number of fruits per panicle, but quite significant (15% < CV < 44%) for panicles length, weight of fresh whole fruit, weight of pulp and length of petiole irrespective of topography. Within-site variability was low (0% < CV < 10%) for fruits length and width, average (10% < CV < 15%) for leaves length but concerning the number of leaflets per leaf, the intra-site variability is low at mid-slope and down slope, average at high slope and plateau. Average within-site variability was noted for length of leaflets (10% < CV < 15%) on high slopes and tops, plateaus and down slopes, but quite significant (15% < CV < 44%) at mid-slopes. On the other hand, for the width of the leaflets, intra-site variability was average on plateaus (10% < CV < 15%) but quite significant on other topographic sites.

3.4 Classification of Provenances according to the Characteristics Studied

The hierarchical cluster analysis based on traits related to panicles, fruits and leaves features revealed eight different origins clustered into four morphotype groups for *H. barteri* in Benin (Fig. 3). The first morphotype included provenances from Bérécingou and Borna in the district of Natitingou. This morphotype was characterized by the production of large fruits with a high weight (10.72 g) with a large pulp weight (6.58 g). The panicles were however short (23.26 cm) with few number of fruits (13 fruits). The leaves were composed about 20 leaflets which are much longer (7.63 cm) with average width (2.88 cm) leaflets (Table 5). This morphotype was named sub-population of Natitingou I. The second morphotype, represented by the provenances of Kota and Pèpèrikou, had individuals with smaller fruits (26.93 cm long and 24.04 cm wide), with a small amount of pulp (5.60 g). Their panicles were long (33.61 cm) with an average number of fruits (20 fruits). Leaves were large (36.78 cm) and support up of 20 leaflets, which were long (7.63 cm) and wide (3.01 cm) (Table 5). This morphotype includes a mixture of individuals from the districts of Toucountouna and county of Kota (district of Natitingou), and was named mixed subpopulation.

Table 4 Morphological traits of panicles, fruit and leaf of *H. barteri* according to the topography.

Topography	Parameters	Lpan (cm)	Nfruit	Lfruit (mm)	Lafruit (mm)	Mfruit (g)	Mpulp (g)	Lleaf (cm)	Lpetiole (cm)	Nfoliole	Lleaflet (cm)	Laleaflet (cm)
High slope and top	Mean	25.93^{b}	15.89^{c}	28.27^{a}	25.14^{a}	10.46^{a}	6.24^{a}	36.30^{a}	7.89^{b}	19.81^{a}	7.35^{b}	2.73^{c}
	SE	0.38	0.55	0.09	0.08	0.09	0.07	0.22	0.08	0.19	0.03	0.01
	CV (%)	34.67	66.21	8.01	7.80	21.84	30.39	14.02	21.76	12.14	14.81	18.49
Mid-slope	Mean	32.27^{a}	26.91^{a}	27.12^{b}	24.00^{b}	9.48^{b}	5.64^{b}	34.94^{b}	8.20^{ab}	19.13^{b}	7.06^{c}	2.88^{ab}
	SE	0.39	0.56	0.09	0.08	0.09	0.07	0.21	0.08	0.10	0.03	0.01
	CV (%)	29.84	63.25	6.83	6.80	17.72	23.19	10.60	17.64	9.79	15.25	22.19
Down slope	Mean	26.14^{b}	15.21^{c}	26.92^{b}	24.13^{b}	9.27^{b}	5.40^{b}	36.73^{a}	8.47^{a}	19.21^{b}	7.15^{c}	2.90^{ab}
	SE	0.78	1.11	0.18	0.15	0.17	0.14	0.38	0.14	0.19	0.05	0.03
	CV (%)	30.29	57.74	7.88	7.00	20.83	31.32	11.43	22.17	9.67	13.43	19.56
Plateau	Mean	32.68^{a}	20.27^{b}	26.86^{b}	23.94^{b}	9.47^{b}	5.34^{b}	36.72^{a}	7.98^{b}	18.99^{b}	7.98^{a}	3.06^{a}
	SE	0.55	0.79	0.13	0.11	0.12	0.1	0.24	0.09	0.12	0.04	0.02
	CV (%)	26.52	46.68	7.42	7.20	20.96	28.19	11.47	21.21	11.18	14.24	14.27
Probability (p)		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
General minimum		6.00	2.00	20.40	18.25	4.33	0.96	21.50	2.00	10.00	3.00	1.20
General mean		29.42	20.52	27.49	24.43	9.82	5.79	35.98	8.08	19.00	7.34	2.86
General maximum		71.00	130.0	36.9	32.25	20.93	14.45	57.00	14.20	31.00	12.00	5.60
General SE		0.25	0.36	0.06	0.05	0.05	0.04	0.12	0.05	0.06	0.02	0.01
General CV (%)		32.70	67.50	7.83	7.63	20.95	28.65	12.25	20.42	11.04	15.39	19.69

Lpan: panicle length; Nfruit: number of fruit per panicle; Lfruit: fruit length; Lafruit: fruit width; Mfruit: fruit weight; Mpulp: pulp weight; Lleaf: leaf length; Lpetiole: petiole length; Nfoliole: number of leaflet per leaf; Lleaflet: leaflet length; Laleaflet: leaflet width; SE: standard error; CV: coefficient of variation; Mean is the average value of morphological traits per topographic sides of *H. barteri*. Numbers followed by the same lette (a, b, c) in a column, are not significantly different at 5% confidence according to the average comparison test of Student-Newman-Keuls.

Table 5 Morphological traits of panicle, fruits and leaf of four morphotypes identified in *H. barteri*.

Morphotypes	Parameters	Lpan (cm)	Nfruit	Lfruit (mm)	Lafruit (mm)	Mfruit (g)	Mpulp (g)	Lleaf (cm)	Lpetiole (cm)	Nfoliole	Lleaflet (cm)	Laleaflet (cm)
I	Mean	23.26^{c}	13.38^{d}	28.45^{a}	25.43^{a}	10.72^{a}	6.58^{a}	35.92^{b}	8.03^{b}	19.86^{a}	7.63^{a}	2.88^{b}
	SE	0.79	0.88	0.35	0.16	0.51	0.295	0.695	0.055	0.385	0.355	0.065
	CV (%)	4.80	9.30	1.74	0.89	6.73	6.35	2.74	0.97	2.74	6.58	3.20
II	Mean	33.61^{a}	20.29^{b}	26.93^{c}	24.04^{c}	9.87^{b}	5.60^{b}	36.79^{a}	7.91^{c}	19.58^{b}	7.63^{a}	3.01^{a}
	SE	1.67	0.04	0.12	0.18	0.72	0.46	0.67	0.31	0.81	0.25	0.09
	CV (%)	7.03	0.28	0.63	1.06	10.32	11.64	2.56	5.46	5.82	4.42	4.00
III	Mean	32.3^{a}	27.01^{a}	27.13^{c}	24.02^{c}	9.48^{c}	5.63^{b}	34.93^{c}	8.14^{a}	19.29^{c}	6.98^{c}	2.85^{b}
	SE	0.15	0.37	0.01	0.07	0.02	0.04	0.69	0.20	0.48	0.31	0.11
	CV (%)	0.66	1.94	0.03	0.41	0.30	1.00	2.79	3.47	3.48	6.28	5.46
IV	Mean	27.3^{b}	16.74^{c}	27.51^{b}	24.5^{b}	9.74^{b}	5.66^{b}	36.94^{a}	8.14^{a}	19.27^{c}	7.17^{b}	2.77^{c}
	SE	1.16	1.53	0.59	0.37	0.47	0.26	0.17	0.21	0.37	0.02	0.14
	CV (%)	6.01	12.93	3.01	2.11	6.82	6.50	0.65	3.56	2.68	0.39	6.90
General mean		29.12	19.36	27.50	24.50	9.95	5.86	36.14	8.05	19.50	7.41	2.87
General SE		1.61	1.94	0.26	0.23	0.26	0.19	0.38	0.09	0.22	0.16	0.05
General CV (%)		15.65	28.33	2.64	2.68	7.33	9.32	2.96	3.08	3.23	6.29	4.97

Lpan: panicle length; Nfruit: number of fruit per panicle; Lfruit: fruit length; Lafruit: fruit width; Mfruit: fruit weight; Mpulp: pulp weight; Lleaf: leaf length; Lpetiole: petiole length; Nfoliole: number of leaflet per leaf; Lleaflet: leaflet length; Laleaflet: leaflet width; SE: standard error; CV: coefficient of variation; Mean is the average value of morphological traits per morphotypes of *H. barteri*. Numbers followed by the same letter (a, b, c, d) in a column are not significantly different at 5% confidence according to the average comparison test of Student-Newman-Keuls.

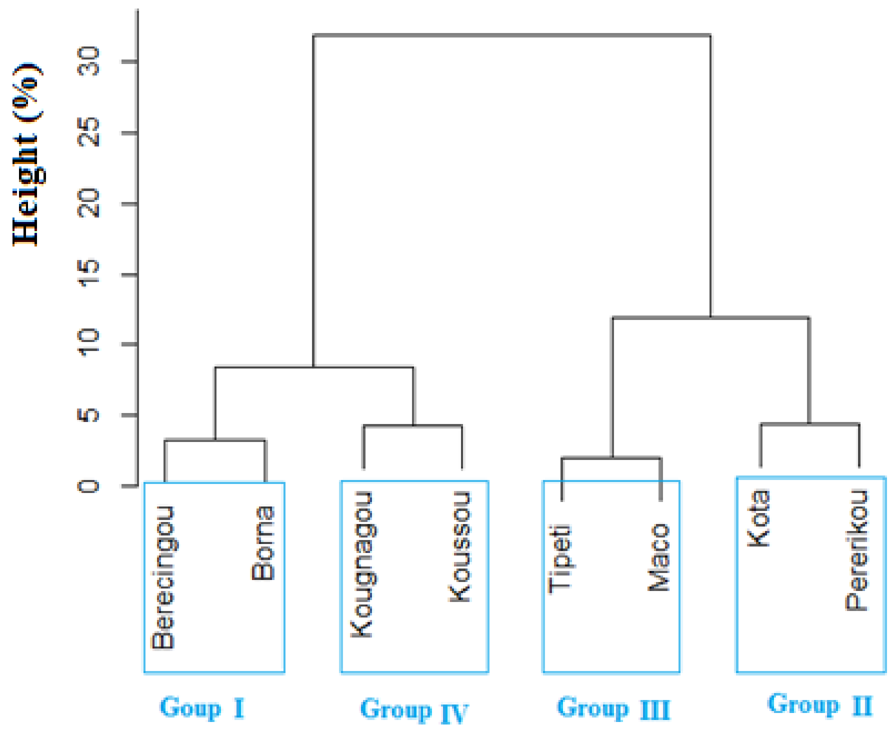

Fig. 3 Ascending hierarchical classification of eight localities using morphological characteristics of *H. barteri* fruits and leaves in Benin.

The third morphotype has also been identified, which included provenances from Tipéti and Maco in the district of Natitingou. Individuals in this group had panicles of medium size (32.3 cm) with however a very high number of fruits (27 fruits). These fruits were smaller with a low pulp mass (5.63 g). Leaves were small (34.93 cm) with the shortest leaflets (6.98 cm) and medium width (2.85 cm). This morphotype was named Natitingou II subpopulation. In addition to this morphotype, the fourth morphotype, which included provenances from Kougnangou and Koussou in the district of Boukombé was identified. Trees in this group had medium-sized fruits (27.51 mm long and 24.5 mm wide) with medium pulp weight (5.66 g) and whole fruit weight medium (9.74 g). The leaves were long (36.94 cm) and composed of an average of 19 leaflets of similar size. This morphotype was named sub-population of Boukombé.

Apart from the number of fruits per panicle and the length of the panicles which showed a fairly significant variability among subpopulations (15% < CV < 44%), other morphological traits related to fruits and leaves showed weaker inter subpopulations variability (0% < CV < 10%).

4. Discussion

The morphological characterization of *H. barteri* carried out in Benin revealed huge phenotypic plasticity driven by provenances and site topography. Significant intra-provenance and intra-site topography variability observed in certain traits such as panicle length, number of fruits per panicle and pulp weight may have genetic basis given that quantitative morphological traits are used to be partially correlated to genetic traits in tree species [20]. In addition, there are other secondary factors including micro-variations in soil characteristics [21] and to some extent, anthropogenic effects and pest attacks can reduce tree growth [22]. However, the low intra and inter sub-population variability observed for fruit morphological traits (length and width of the fruits) except for fruit and pulp, could be explained by cross-fertilization (allogamy), given that *H. barteri* is a dioecious species. The variability in fruit and pulp weight observed between subpopulations is probably due to the effects of the environment [23].

Significant influence of sites topography was found on morphological traits for panicles, fruits and leaves. *H. barteri* trees sampled on high slopes and hilltops presented the largest fruits with, however, shorter panicles and supported few fruits. Similar observation was also made for the Bérécingou and Borna provenances, of which almost all of the trees were sampled on the high slopes and hilltops. Therefore, it is has been deduced that limited impact of anthropogenic disturbance (vegetation fires, agriculture) could explain the larger size fruits. According to Agbogan *et al.* [9] and Agbogan *et al.* [24], low impact of human influence on the population of *H. barteri* on the flanks of the Atacora in Togo is due to the topographic positions that the species occupies (mainly on rocky tangles in altitude) which make it difficult to reach and protect the trees from frequent harvesting. In addition, these authors suggest, like the findings of this study, that the remoteness of these sites from human dwellings also contributes to protecting these stands and limiting human disturbance.

Low intra- and inter-morphotypes variability (subpopulations) was found for most of the morphological traits and particularly for fruit and leaves indicating that these four groups of *H. barteri* were therefore fairly phenotypically close. This could suggest low genetic diversity and differentiation for the study species in these habitats [25, 26]. Previous studies found similar links for *Chrysophyllum albidum* G. Don in Benin by Dadegnon *et al.* [19], the fruits and seeds of *Jatropha curcas* by Gbemavo [22]. However, these findings were not supported by studies by Fandohan *et al.* [12] on the fruits and seeds of *Tamarindus indica*, on *Adansonia digitata* [18], on the fruits of *Balanites aegyptiaca* [27], on the fruits of *Blighia sapida* [28]. The low variability in fruit traits in particular may also be linked to phenotypic plasticity. Pompelli *et al.* [20] indicated that the flowering period, the type and the number of inflorescence, the color and texture of the leaves are the quantitative traits that contribute much more to the variations of the plant. These traits were not considered in this study. Nonetheless, a weak influence of the environment and the genotypic × environment interaction on the traits could explain the low intra and inter morphotype variability.

As fruits and pulps were highly exploited from the species, the results could serve as basis for guidelines to establish selection programme for *H. barteri* using the subpopulation I that includes provenances of Bérécingou and Borna where the fruits were larger with a large pulp mass. Such selection of programme will use pulp characteristics (being the most edible part of the fruit in Benin), as main criterion for varietal selection.

5. Conclusions

This study showed that provenances and sites topography have significant influence on the morphological variability of *H. barteri* in Benin. Four different morphotypes (subpopulations) were identified for *H. barteri*, with however a low intra and inter subpopulations variability (0% < CV < 10%) for most of the morphological traits indicating that these four subpopulations are fairly phenotypically close. Such low variability suggests a low genetic diversity of *H. barteri*. The results provide essential guidelines for varietal selection, an important step for the domestication of the species and the improvement of fruit access for rural people. *H. barteri* trees from Bérécingou and Borna (morphotype I), which showed the best characteristics in terms of fruit size and the quantity of pulp could be used for varietal selection in Benin.

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