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Local knowledge and morphological variations in local landraces *Mangifera indica* L. in Northern Benin (West Africa)

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Local landraces of mango (*Mangifera indica* L.) occupy an important position in household consumption in Sub-Saharan Africa. This study assessed the local knowledge of *M. indica* landraces, the variation in their morphological traits, and the influence of environmental variables on the variability of morphotypes in Northern Benin. Two hundred and three households were interviewed using a semi-structured questionnaire based on the characteristics of local *M. indica* landraces recognized by the local inhabitants. In addition, 165 individuals of *M. indica* local landraces, along with 1650 leaves, fruits, and seeds, were sampled and characterized by 17 morphological traits of tree, fruits, and leaves. The local inhabitants recognized two local landraces of mango, and this local knowledge depended significantly on ethnicity and phytodistrict. Morphological analyses yielded four morphotype classes of trees according to phytodistricts. Morphotype G1 consisted of the smallest, roundest, and longest stone fiber fruit and was found mostly in the Bassila, Mekrou-Pendjari, and Atacora Chain phytodistricts. Morphotype G2 consisted of trees with mostly leathery-textured leaves, whereas Morphotype G3 included trees with the largest and heaviest fruit. The results can help select new superior local mango accessions for future breeding programs and develop conservation strategies in the present context of climate change.

Key words: Conservation, fruit, leaves, mango, morphotype, morphological traits.

INTRODUCTION

The mango (*Mangifera indica* L.) of the Anacardiaceae family, often referred to as the “king of fruits,” is one of

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the most widely cultivated tropical and subtropical fruit trees in the world (Rajwana et al., 2011). It is rich in vitamins and minerals and is a valuable food consumed by a large proportion of the world (Ribeiro et al., 2007). *M. indica* originated from Asia and now grows in more than 60 other countries worldwide (Griesbach, 2003). In West Africa, monoembryonic and polyembryonic landraces are the main varieties (Rey et al., 2004b). Polyembryonic landrace varieties were first introduced in West Africa in the 19th century (Rey et al., 2004a). Over several centuries, these landraces have adapted to the environmental conditions of the countries in which they were introduced. Although the introduction of mangoes in West Africa is recent, the inhabitants distinguish between "local mangoes" or polyembryonic varieties and "improved or imported mangoes" known as monoembryonic varieties that are multiplied by grafting (Rey et al., 2004b). In Benin, polyembryonic and monoembryonic mangoes are produced by small-scale farmers, who generally have a mixture of landraces in their orchards. These mangoes are mainly traded on the domestic market but also regionally, in Niger and Nigeria (Van Melle and Buschmann, 2013). In southern Benin, where the human population is the highest in the country, mangoes are estimated to be the most consumed fruit (13.3 kg per person per year, 42%), followed by bananas (7.6 kg per person per year, 24%), mandarins (11%), oranges (8%), and avocados (7%) (Tossou et al., 2012). Thus, during the mango fruiting season, a large quantity of mangoes is produced in the northern part of Benin and sent south for the local market.

Regarding the importance of this fruit tree species, there is a lack of factual data on mango breeding in West Africa, including Benin. Although local cultivars are the main rootstocks for transplanting because they provide the highest and most stable yields and require little management, mango growers often choose improved landraces over local varieties due to their small size, high fiber content, and low market value (Van Melle and Buschmann, 2013). The local landraces are tolerant to abiotic and biotic stresses, and the absence of their documentation and characterization can lead to a significant loss of these genetic resources (Ramessur, 2011). Therefore, there is a need for studies that explore and find ways to protect these available resources, which can be an important component in the improvement and selection of future mango varieties. For this purpose, characterization and documentation of local mango landraces are considered essential to identify potential candidates for improved future breeding programs (Ramessur, 2011), identify or develop high-yielding, pest, and disease-resistant landraces, and prevent genetic erosion (Sennhenn et al., 2014). In this regard, morphological characterization of local varieties and several mango cultivars have been documented worldwide (Begum et al., 2012; Gálvez-López et al., 2010; Gitahi et al., 2016; Sennhenn et al., 2014). Moreover, morphological characterization is the first step before in-depth molecular or biochemical studies can be carried out (Elgozuli, 2011).

Morphological characterization studies have been performed in East Africa (Gitahi et al., 2016; Sennhenn et al., 2014), West Africa (Akin-Idowu et al., 2020; Arogundade et al., 2022), and many other continents (Khadivi et al., 2022; Zhang et al., 2020). Although local *M. indica* landraces are important in household consumption in West Africa in general and in Benin in particular, their identification and morphological characterization have rarely been documented.

In Africa, local inhabitants hold a great deal of useful ecological knowledge that can be integrated into the valorization of natural resources and the development of conservation strategies. Several studies have confirmed the importance of indigenous knowledge in the sustainable management and conservation of plant genetic resources (Fandohan et al., 2010; Gaoue and Ticktin, 2008; Houehanou et al., 2011; Pei et al., 2020). Therefore, documenting how local people describe the resources in their environment serves as a reference point for better knowledge and evaluation of the targeted resources. Assessing how farmers recognize the local mango landraces they grow, as well as the local descriptors they use, will help future breeding programs improve the available local varieties. Local knowledge can underpin the perceived consequences of adopting a particular local landrace or its derived improved varieties.

Therefore, this study assessed (i) local knowledge of *M. indica* landraces, (ii) variation in morphological traits of *M. indica* landraces, and (iii) the influence of environmental variables on the variability of morphological traits. Achieving these objectives can help to better understand the available diversity and develop future conservation and management strategies for *M. indica* genetic resources.

MATERIALS AND METHODS

Study environment and species

This study was conducted in the Republic of Benin, specifically in the communes of the northern part of the country where mango production is significant. The communes of Tanguiéta (74,675 inhabitants), Natitingou (103,843 inhabitants), Boukoumbé (82,450 inhabitants), Toucountouna (39,779 inhabitants), Matéri (24,490 inhabitants), and Cobly (67,603 inhabitants) in the department of Atacora; the communes of Djougou (267,812 inhabitants), Bassila (46,569 inhabitants), Ouaké (74,289 inhabitants), and Copargo (70,938 inhabitants) in the department of Donga; and the communes of Parakou (255,478 inhabitants), Pèrèrè (78,988 inhabitants), Tchaourou (223,123 inhabitants), Nikki (151,232 inhabitants), and N'dali (113,604 inhabitants) in the department of Borgou were selected. These communes in the North of Benin constitute the main mango production area of the country (Van Melle and Buschmann, 2013) and are located in the agricultural development poles 3 and 4, where mango production is the most important. These communes were chosen with the help of the agricultural extension services of poles 3 and 4 and represent the

Table 1. Ecological characterization of agricultural development poles and phytogeographical districts.

Agricole development pole	Phytogeographic districts	Rainfal regime	Rainfall (mm)	Major soil types
Pole 3	Atacora chain	Unimodal	1000-1200	Poorly evolved and mineral soils
	Mekrou-Pendjari	Unimodal	950-1000	Ferruginous soils with concretions on sedimentary rocks
Pole 4	Bassila	Tendency to unimodam	1100-1300	Ferrallitic soils with concretions and breastplates
	South Borgou	Tendency to unimodam	1100-1200	Ferruginous soils on crystalline rocks

Source: Adomou (2005).

communes located in the northern part and in poles 3 and 4. The study area has a tropical, humid Sudanese-type climate with a dry season and a rainy season (Table 1). Two types of soil are generally distinguished: ferruginous and hydromorphic soils. This variation in soils allows for the cultivation of tubers, roots, and legumes. The three main types of savannah (grassy savannah, shrubby savannah, and tree savannah) are also present in this area, as well as gallery forests along rivers and streams. Although the genus Mangifera contains 41 valid species in Asia, all local mango cultivars belong to the single species *M. indica* L. (Mukherjee, 1949), and all have the same chromosome number, 2n=40.

Sampling and data collection

Interviews

An exploratory survey was conducted among 70 randomly selected people in the study area. This allowed us to determine the proportion (*P*) of respondents who were aware of the existence of at least one local accession of *M. indica*. Afterwards, the size n of the survey population was determined by the formula of Dagnelie (1998):

$$n = \frac{U_{1-\alpha/2}^{2} \times P(1-P)}{d^{2}}$$

where *n* is the sample size; *P* is the proportion of people aware of the existence of at least one local accession of the species at the time of the survey, $U_{1-\alpha/2}^{2}$ = 1.96 is the value of the normal random variable for a probability value of α = 0.05, and d is the margin of error set at 3%.

The estimated sample size n was approximately 175 individuals. In total, we sampled 203 households. The number of respondents per commune was allocated by considering the population size of each commune. Socio-economic data were collected using a semi-structured questionnaire. Interview data were collected from the contact person of each household, typically the head of the household, or from another available household member. The free and informed consent of the participants was obtained before the interview. In some cases, interviews were conducted in local languages, and a translation into French was conducted with the help of local translators and guides. The questionnaire was based on known local mango accessions and criteria for differentiating between known local mango trees.

Morphological traits evaluation

In each commune, at least 10 fruit-bearing trees of local *M. indica* landraces were selected during the fruiting season. In total, 165 individuals of local mango accessions were sampled and characterized using morphological traits.

Additionally, from each sampled tree, 10 healthy and undamaged leaves and 10 ripe fruits were randomly selected, giving a total of 1650 leaves, 1650 fruits, and 1650 seeds for measurement. A total of 56 morphological traits, including 21 quantitative and 35 qualitative traits, were assessed according to the Biodiversity International mango descriptors (IPGRI, 2006). These descriptors related to the morphological characteristics of the trees, leaves, fruits, skins, pulp, stones, and seeds. The list of descriptors used is reported in Table 1. Each leaf and fruit was measured within 24 h of harvest to determine their morphological characteristics, avoiding shrinkage that could distort the measurements. All stones and seeds inside a fruit were measured to determine their morphological characteristics. For leaves, the length was measured from the base of each leaf to the tip of the blade using a digital caliper. Similarly, the petiole of the leaves was measured with a caliper. The greatest leaf width was assessed by measuring the lower 1/3 (widest part) of 10 leaves per plant. Related qualitative traits such as leaf shape, leaf color, leaf base, leaf texture, leaf apex shape, and other quality traits were assessed by visual inspection. After the skin was removed, its thickness was measured by an electronic caliper and the weight by a precision balance. Then, the pulp was removed from each fruit by peeling. The aroma of the pulp or at least of the fruit was measured by olfactory inspection. The weight of the pulp was assessed as done by Gouwakinnou et al. (2011) and Lawin et al. (2021). The formula used at the individual fruit level to obtain the pulp weight was as follows:

$$Wp = W_{ps} - P_s$$

where W_p is the weight of the pulp, W_{ps} is the weight of the pulp and pit combined, and P_s is the weight of the pit containing the seed.

After removing the pulp from the stone, the stone was kneaded with sand and rinsed to ensure that all the pulp had been removed. After drying the stone in the sun for about 15 min, measurements were taken for the stone and then for the seeds. The seed was removed from the stone by opening it with a sharp knife. The thickness of the skin, stone, and seed was measured with an electronic caliper, and weight measurements were made using a 0.01 g precision balance.

The geographical location of each sampled tree was recorded using a global positioning system (GPS) (Figure 1). These GPS coordinates were used to download online bioclimatic data from the WorldClim website (https://www.worldclim.org/data/cmip6/cmip6climate.html). In total, 19 bioclimatic variables related to temperature and humidity were downloaded.

Data analysis

The number of accessions recognized by local people was recorded. The features reported by respondents for local accessions of *M. indica* were summarized. For each accession, a citation frequency was calculated for each feature by dividing the number of people citing the trait by the number of respondents. We used Fisher's test and the chi-square test of independence to compare the frequency of citation of a trait between the recognized accessions. The effect of ethnic group and phytodistrict on local recognition of accessions was tested by performing a chi-square test of independence.

For the assessment of morphological variability, the different measured traits were analyzed. Qualitative traits that did not show variability were excluded from the analyses. Relationships between the quantitative variables were evaluated with the Pearson correlation test, and the quantitative variables were reduced when a strong significant correlation ($r > 0.60$ and $p < 0.05$) was found. The morphological variability was finally calculated using 17 selected morphological descriptors (9 qualitative and 8 quantitative) (Table 1).

To determine the morphotypes of the fruits and leaves, a hierarchical ascending classification (HAC) was performed with the function "HCPC" of the package "FactoMineR". The traits of the fruit (length of fruit, weight of fruit, fruit shape, depth of fruit stalk cavity, fruit stalk attachment), pulp (pulp content, pulp juiciness), and stone (length of stone fiber) were used to discriminate the morphotypes of fruits, whereas the traits of the leaf (leaf blade length, leaf blade width, leaf texture, leaf apex shape, leaf margin) were used for leaf morphotype definition. The fruit and leaf morphotypes were matched to each individual tree by performing a multiple correspondence analysis (MCA) based on the fruit and leaf morphotypes. The MCA was performed with the "FactoMineR" function. The morphotypes of trees were obtained by performing a HAC with the same function of the "FactoMineR" package on the fruit and leaf morphotypes obtained for each tree and the variables taken from the tree (height of mature tree, trunk circumference, crown shape, foliage density).

The mean and standard deviation of each quantitative morphological trait were calculated for each fruit, leaf, and tree morphotype to describe their characteristics. A one-factor analysis of variance followed by the Turkey test was used to test for differences in morphological traits between morphotypes. The Turkey test was used only when a significant difference was detected between the fruit, leaf, and tree morphotypes. The chi-square test of independence was used for qualitative parameters to compare discriminated morphotypes. The diversity of the qualitative data were assessed by the Shannon diversity index by using the traits proportions. The Shannon diversity index is a measure of the diversity of a given categorical descriptor. It is given by the following formula:

$$H = -\sum_{i=1}^{n} P_i ln P_i$$

where H is the Shannon diversity index, n is the total number of levels of the descriptor concerned, i is the descriptor level, P_i is the proportion of the total number of entries in the i^{th} class, otherwise the proportion of a descriptor level to the total number of descriptors (n) in this study. Canonical discriminant analysis (CDA) was used on the obtained morphotypes to assess their degree of distinctness by considering all used traits. The CDA was performed with the "candisc" function of the "FactoMineR" package.

The values of the bioclimatic variables were compiled using the GPS coordinates of the sampled individual trees. Values corresponding to these variables were extracted in the ArcGIS software using the "extract" function. Relationships between these variables were evaluated with Pearson's correlation test. The number of bioclimatic variables was finally reduced to four (bio1: Average annual temperature, bio12: Annual precipitation, bio14: Precipitation in the driest month, and bio15: Seasonality of precipitation) due to the highly significant correlation ($r > 0.60$ and $p < 0.05$) between variables.

A PCA showing the relationship between tree morphotypes and environmental factors (bioclimatic variables, latitude, phytodistrict) was performed with the “FactoMineR” package. All descriptive and statistical analyses were performed using R software version 3.6.3 (R Core Team 2020).

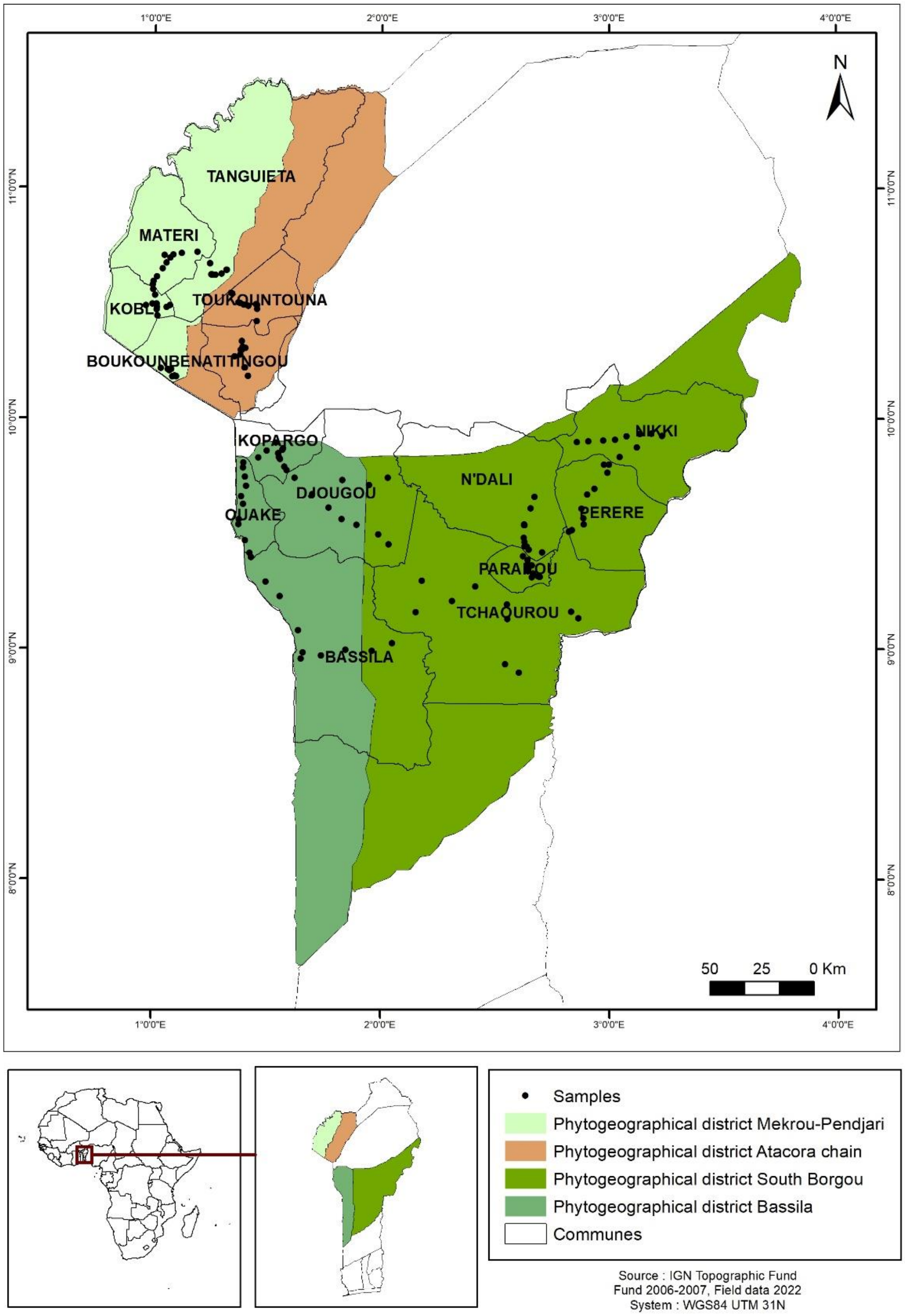
RESULTS

Local names of *M. indica* accessions in Northern Benin

Table 2 displays the various names given to the two local landraces identified by local inhabitants. Ethnic groups such as the Adja, Bariba, Haoussa, Kabiè, Mina, and Natimba did not assign specific names to both accessions, whereas the Bialhi, Boulba, Lokpa, Natèni, Ottamari, Ditammari, Waama, and Yom ethnic groups had distinct names for the two accessions. The Fon and Peulh seemingly named both accessions.

Local inhabitants recognized two local accessions of *M. indica* in the study area (Figure 2), with this local knowledge varying significantly by ethnicity ($p < 0.001$) and phytodistrict ($p < 0.001$). The Adja, Bariba, and Natimba ethnic groups did not recognize both local accessions. The Haoussa ethnic group recognized both accessions but did not assign a specific name to one of them. The Kabiè, Kotocoli, and Mina recognized both accessions without specific designations. On the other hand, ethnic groups such as Bialhi, Dendi, Ditammari, Fon, Idatcha, Lokpa, Naténi, Ottamari, Peulh, Waama, and Yom recognized both accessions with distinct names, ranging from one name per accession to three names.

In the Atacora chain phytodistrict, respondents recognized both landraces. In the southern Borgou and Bassila phytodistricts, the two local landraces were widely recognized, though to a lesser extent in the Mekrou-Pendjari and Atacora chain phytodistricts. Recognition of only one local landrace was minimal in the Mekrou-Pendjari and Bassila phytodistricts compared to the recognition in South Borgou (Figure 2).



Source : IGN Topographic Fund
Fund 2006-2007, Field data 2022
System : WGS84 UTM 31N

Figure 1. Study area showing data collection location in each commune and phytodistricts.

Local knowledge about traits of local *M. indica* accessions

The local inhabitants distinguished Accession 1 by its small trunk, rough bark, wind resistance, and smaller size, whereas Accession 2 was identified by its larger trunk, smooth bark, and less wind resistance (Figure 3A). The chi-square test of independence revealed a significant difference ($p < 0.01$) in the frequency of citation between the two accessions identified by the

Table 2. Local name of the two distinguished landraces of *M. indica* by ethnic groups.

Ethnic group	Local name	
	Local acccession 1	**Local acccession 2**
Adja	Agboninkui	-
Bariba	Mango, Mango kinkin-kinkin	-
Bialhi	Tamiécci, Tamindji, Tamiécci	Tantchéta
Boulba	-	Tatigna
Dendi	Mango, Mangu buruburu	Mangu gocci
Ditammari	Epèta, Etèni, Petania	Epètanna, Etada, M'pètatchè, Pètadaya
Fon	Manga yaya	Manga yaya
Haoussa	Cananan mangu	-
Idatcha	Mongo funfun	Mongo
Kabiè	-	-
Kotocoli	-	-
Lokpa	Mangu, Mangu buruburu	Mangu, Mangu gocci
Mina	-	-
Naténi	Tamindji, Tanabu	Taninbu, Tatine
Natimba	Mangu buruburu	-
Ottamari	M'pèta	M'pètatchè
Peulh	Mongo	Mongo
Waama	Epètaniya, Tadafa	Epètanna, Tanibu, Taniya
Yom	Saramanguyé	Monamanguyé

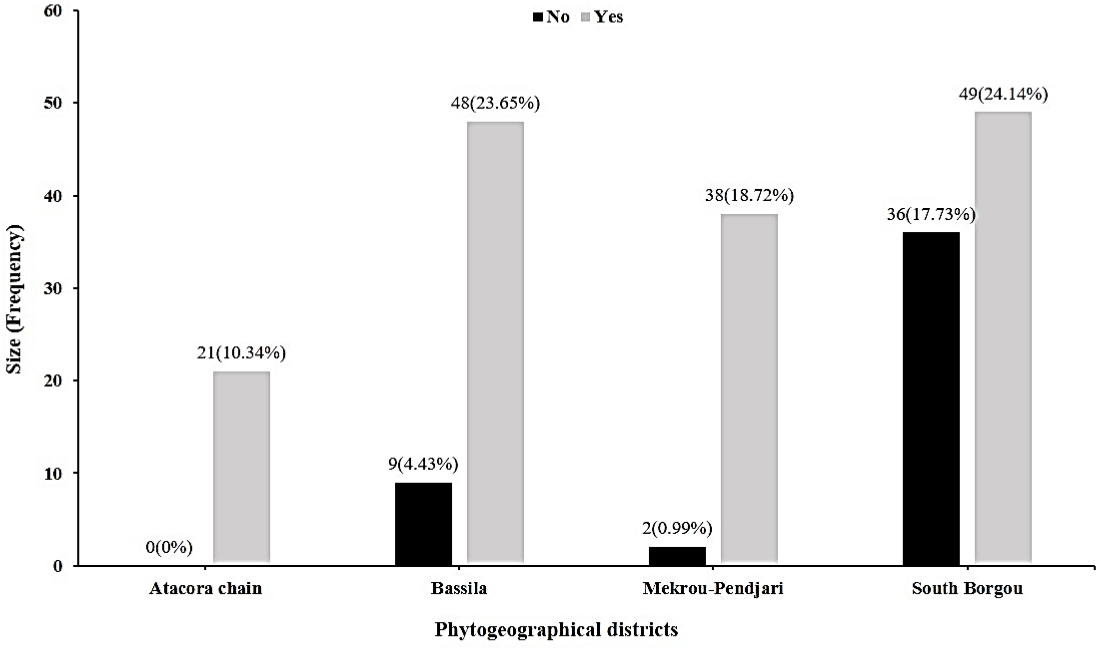


Figure 2. Variation in local knowledge about recognition of the two landraces according to phytogeographical district.

inhabitants for tree-related traits. Additionally, Fisher's test showed significant differences ($p < 0.01$) in organ-related traits such as leaves, fruits, pits, and seeds. The inhabitants recognized Accession 1 for its elliptical-shaped fruits, while Accession 2 was recognized for its rounded shape and very fibrous character (Figure 3B).

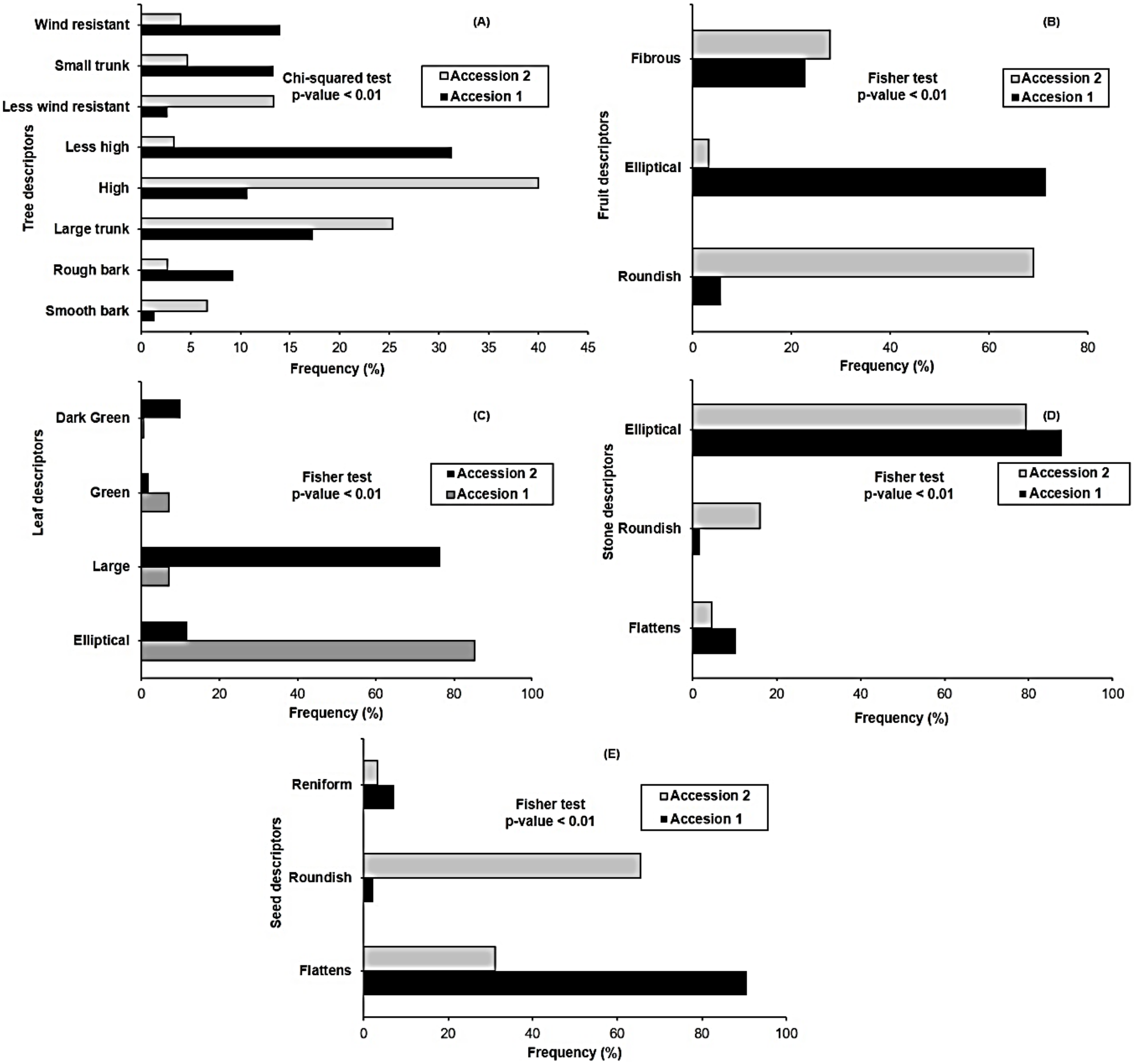


Figure 3. Local knowledge of morphological traits related to the tree (A), fruit (B), leaves (C), stone (D), and seed (E) that differentiate the two identified landraces.

Accession 1 was characterized by elliptical-shaped leaves with a green color, whereas Accession 2 had broad-shaped leaves with a dark green color (Figure 3C). The stone of Accession 1 was distinguished by its flattened and elliptical shape, while Accession 2 had a rounded shape according to the inhabitants (Figure 3D). Similarly, the seed of Accession 1 was described as flattened and kidney-shaped, whereas Accession 2 had a rounded shape (Figure 3E).

Morphological characterization

Fruit morphotypes characterization

The hierarchical classification suggested three fruit morphotypes (Figure 4). Morphotype Fr1 included the smallest fruits (fruit length = 7.36 cm) and the lightest fruits (fruit weight = 135.98 g; pulp content = 0.94), whereas morphotype Fr2 (21% of sampled fruits) had

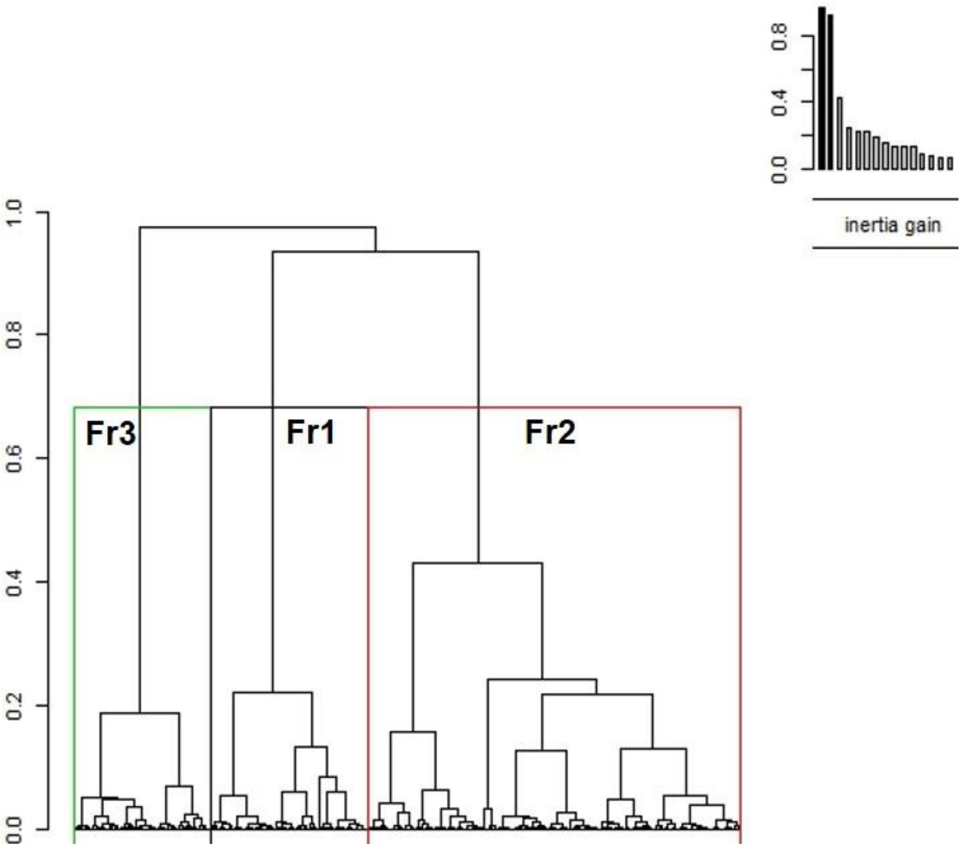


Figure 4. Dendrogram showing the different fruit morphotypes of local *M. indica* accessions.

Table 3. Quantitative characteristics of fruit morphotypes.

Descriptor	Fr1	Fr2	Fr3	F	Prob
	Mean ± sd				
Length of stone fibre	4.28^{c}±1.34	3.94^{b}±1.31	3.56^{a}±1.4	44.26	< 0.001
Fruit length	7.36^{a}±0.97	7.7^{b}±0.9	8.01^{c}±0.86	81.39	< 0.001
Fruit weight	135.98^{a}±43.78	167.92^{b}±49.47	178.37^{c}±45.29	134.7	< 0.001
Pulp content	0.94^{a}±0.3	1.1^{b}±0.31	1.18^{c}±0.32	91.14	< 0.001

On the same line and for each characteristic, values bearing the same letters are not statistically different (ANOVA followed by a Turkey test); F, Fisher's statistic; Probability; m, Mean; sd, Standard deviation.

intermediate characteristics (fruit length = 7.7 cm; fruit weight = 167.92 g; pulp content = 1.1) (Table 3). Morphotype Fr3 (49% of sampled fruits) had the largest fruits (fruit length = 8.01 cm) and the heaviest fruits (fruit weight = 178.37 g; pulp content = 1.18) (Table 4).

Regarding the quantitative traits of fruits, morphotype Fr1 had the longest stone fibers (stone fiber length = 4.28 cm) followed by the Fr2 morphotype (stone fiber length = 3.94 cm) and the Fr3 morphotype (stone fiber length = 3.56 cm).

Table 4 summarizes the distribution and diversity of qualitative morphological descriptors of *M. indica* fruit morphotypes. Fruits were mostly elliptical or oblong for the Fr3 morphotype (62.03 and 57.14% respectively). The Fr1 morphotype had rounded fruits (54.97%). The depth of the fruit stalk cavity was mostly very deep (100%) for the Fr1 morphotype, whereas for the Fr3 morphotype, it was less deep (84.62%) than for Fr1. The stems were strongly attached to the fruits of the Fr1 (41.61%) and Fr3 (40%) morphotypes, whereas the attachment was intermediate (55.76%) or light (52.44%) for the Fr3 morphotype. The Fr1 morphotype was mostly slightly juicy (86.73%). The Fr2 morphotype was very juicy (99.13%), and the Fr3 morphotype was juicy (90.93%).

Table 4. Qualitative characteristics of fruit morphotypes.

Descriptor	Descriptors level	Frequency (%)			Prob
		Fr1	Fr2	Fr3	
Fruit shape	Roundish	54.97	25.64	19.4	< 0.001
	Elliptic	21.07	16.91	62.03	
	Oblong	24.49	18.37	57.14	
	Obvoid	21.8	22.81	55.39	
Depth of fruit stalk cavity	Absent	29.32	25.25	45.42	< 0.001
	Medium	6.77	27.08	66.15	
	Shallow	37.39	16.97	45.63	
	Deep	11.54	3.85	84.62	
	Very deep	100	0	0	
Fruit stalk attachment	Intermediate	21.02	23.22	55.76	< 0.001
	Weak	21.25	26.32	52.44	
	Strong	46.61	13.39	40	
Pulp juiciness	Juicy	9.07	0	90.93	< 0.001
	Slightly juicy	86.73	0	13.27	
	Very juicy	0	99.13	0.87	

Figure 5. Diversity of fruit shape in the morphotypes obtained. The first accession of rounded shape (Fr1) and the second accession of elliptical shape (Fr3).

All qualitative variables of the fruit morphotypes showed the same variability (Shannon diversity index, H = 1.036), which was also quite high.

The CDA performed on the obtained fruit morphotypes showed a significant degree of distinction (Wilks' Lambda = 0.11, $p < 0.001$ for the first function; Wilks' Lambda = 0.83, $p < 0.001$ for the second function). Pulp content and fruit shape clearly distinguished the Fr3 morphotype, while pulp juiciness distinguished the Fr2 morphotype (Figure 5).

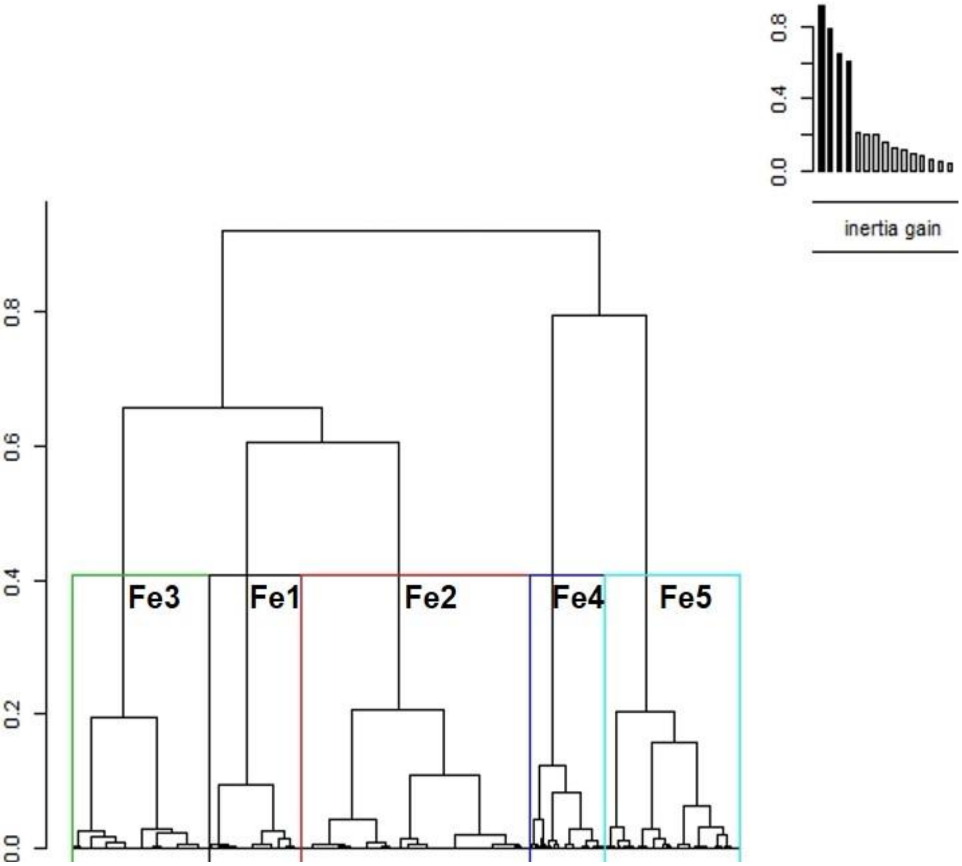


Figure 6. Dendrogram showing the different leaf morphotypes of local *M. indica* accessions.

Table 5. Quantitative characteristics of leaf morphotypes.

Morphotypes	Descriptor (mean ± sd)	
	Leaf blade width	Leaf blade length
Fe1	5.82^{ab}±1.46	24.35^{ab}±5.22
Fe2	5.76^{a}±1.2	24^{a}±4.99
Fe3	6.01^{ab}±1.15	24.68^{ab}±5.15
Fe4	6.04^{b}±1.32	25.17^{b}±6.54
Fe5	5.85^{ab}±1.1	24.82^{ab}±5.35
F	3.292	2.841
Prob	0.0107	0.0231

In the same row and for each characteristic, values with the same letters are not statistically different (ANOVA followed by a Turkey test); F, Fisher's statistic; Probability; m, Mean; sd, Standard deviation.

Leaf morphotypes characterization

The hierarchical grouping showed five leaf morphotypes (Figure 6). Morphotype Fe2 had the highest proportion of leaves (34%), followed by morphotypes Fe4 and Fe5, each comprising 20% of the total number of leaves. Morphotypes Fe1 and Fe3 accounted for 14 and 11% of leaves, respectively (Figure 6).

For quantitative traits related to the width and length of the leaf blade, there were no significant differences between morphotypes Fe1, Fe3, and Fe5 (Table 5). Morphotypes Fe2 and Fe4 differed from each other and from the other morphotypes in terms of leaf blade width (5.76 and 6.04 cm, respectively) and leaf blade length

Table 6. Qualitative characteristics of leaf morphotypes.

Descriptor	Descriptors level	Frequency (%)					Prob	H
		Fe1	Fe2	Fe3	Fe4	Fe5		
Leaf texture	Coriaceous	68.12	0	8.99	0	22.9	< 0.001	1.573
	Chartaceous	0	67.66	12.57	0	19.76		
	Membranous	0	0	9.15	71.49	19.36		
Leaf apex shape	Acuminate	0	0	0	0	100	< 0.001	1.443
	Acute	20.69	49.74	0	29.58	0		
	Obtuse	0	0	100	0	0		
Leaf margin	Entire	13.27	35.51	9.96	19.47	21.79	0.936	1.534
	Wavy	15.42	32.71	11.93	21.45	18.5		

Figure 7. Diversity of leaf shape within the characterized morphotypes. The first accession has an elliptical shape and the second accession a rather broad shape.

(24 and 25.17 cm, respectively) (Table 5).

The CDA performed on the obtained leaf morphotypes indicated a distinct separation (Wilks' Lambda = 0.00, $p < 0.001$ for the first function; Wilks' Lambda = 0.28, $p = 0.001$ for the second function). Leaf width was a prominent distinguishing feature (Figure 7).

Table 6 summarizes the distribution and diversity of qualitative morphological descriptors of *M. indica* leaves. Morphotype Fe1 predominantly had leathery textured leaves (68.12%), while morphotype Fe2 had chartaceous textured leaves (67.66%), and morphotype Fe4 exhibited a membranous texture (71.49%). The apices of morphotype Fe3 were entirely obtuse (100%), whereas those of morphotype Fe5 were acuminate (100%). The base of morphotype Fe2 was predominantly acute. Leaf margin did not show significant differences between the

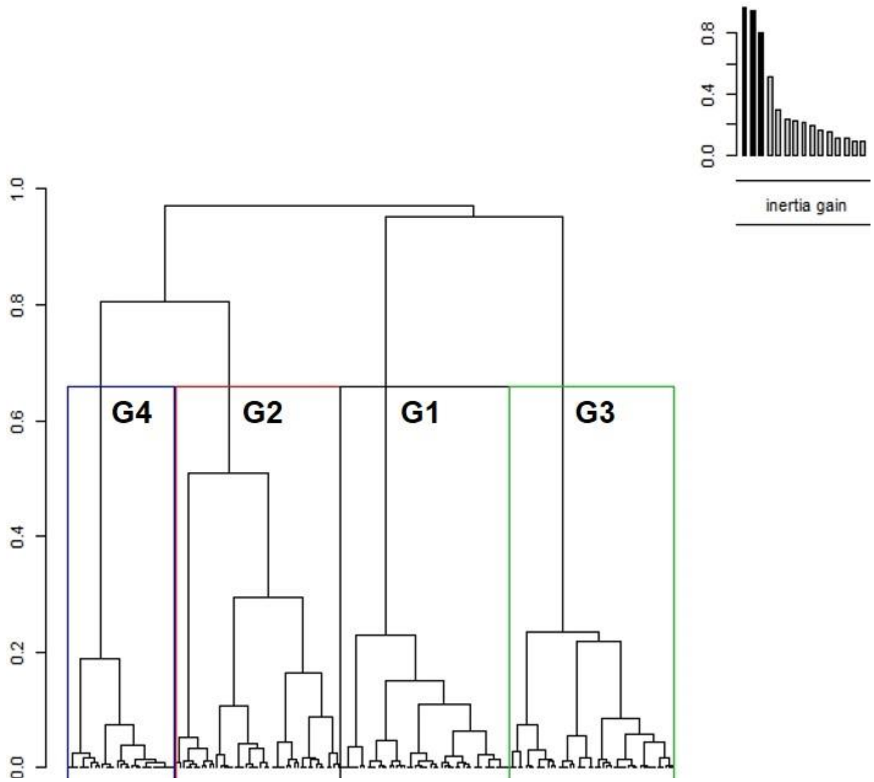


Figure 8. Dendrogram showing the different tree morphotypes of local *M. indica* accessions.

Table 7. Quantitative characteristics of the morphotypes of tree individuals.

Morphotype	Descriptor (Mean)	
	Trunk circumference	Height of mature tree
G1	194.94±69.37	11.10^{a}±3.32
G2	237.23±78.21	13.70^{b}±4.23
G3	226.55±90.79	11.56^{a}±3.36
G4	228.03±58.54	14.13^{b}±4.06
F	2.635	6.679
Prob	0.05167	< 0.001

In the same row and for each characteristic, values with the same letters are not statistically different (ANOVA followed by a Turkey test); F, Fisher's statistic; Probability; m, Mean; sd, Standard deviation.

identified morphotypes ($p < 0.05$). The highest variability was observed for leaf texture (Shannon diversity index, H = 1.573).

Tree morphotypes characterization

The dendrogram identified four tree morphotypes (Figure 8). Class G1 comprised 28% of the sampled tree individuals, class G2 25%, class G3 27%, and class G4 20% of the accessions. The circumference of the tree trunk did not differentiate significantly between the tree classes ($p > 0.05$) (Table 7). However, tree height varied significantly among the classes ($p < 0.001$). Classes G1 (11.10 m) and G3 (11.56 m) did not differ in height, similarly to classes G2 (13.70 m) and G4 (14.13 m) (Table 7).

The discriminated tree morphotypes showed significant differences (Wilks' Lambda = 0.08, $p < 0.001$ for the first function; Wilks' Lambda = 0.66, $p < 0.001$ for the second

Table 8. Characteristics of tree morphotypes based on fruit and leaf morphotypes and qualitative morphological descriptors related to the tree.

Descriptor	Descriptors level	Frequency (%)				Prob	H
		G1	G2	G3	G4		
Fruit morphotypes	Fr1	51.85	25.93	20.37	1.85	< 0.001	1.372
	Fr2	18.18	31.82	34.09	15.91		
	Fr3	16.42	19.40	26.87	37.31		
Leaf morphotypes	Fe1	6.82	93.18	0.00	0.00	< 0.001	1.341
	Fe2	0.00	0.00	100.00	0.00		
	Fe3	6.25	0.00	87.50	6.25		
	Fe4	100.00	0.00	0.00	0.00		
	Fe5	5.71	0.00	2.86	91.43		
Crown shape	Broadly pyramidal	18.18	45.45	36.36	0.00	< 0.001	1.37
	Oblong	25.93	11.11	33.33	29.63		
	Semi-circular	31.94	29.17	13.89	25.00		
	Spherical	33.33	6.06	39.39	21.21		
Foliage density	Dense	18.18	21.82	38.18	21.82	< 0.001	1.382
	Intermediate	40.54	21.62	22.97	14.86		
	Sparse	19.44	36.11	16.67	27.78		

function). Tree height was the quantitative trait that most effectively differentiated the tree morphotypes. The diversity and distribution of fruit and leaf morphotypes, as well as qualitative morphological descriptors of the trees, are presented in Table 8.

Class G1 mostly consisted of the Fr1 fruit morphotype (51.85%) and the Fe4 leaf morphotype (100%). The crown shape of class G1 was predominantly semi-circular (31.94%), and its foliage density was intermediate (40.54%) (Table 8).

Class G2 included accessions with Fe1 leaf morphotypes (93.18%) and a mix of Fr1 (25.93%) and Fr2 (31.82%) fruit morphotypes. Its crown shape was mainly pyramidal (45.45%), and foliage density was sparse (36.11%) (Table 8).

Class G3 featured the Fr3 fruit morphotype (34.09%) and Fe2 (100%) and Fe3 (87.50%) leaf morphotypes, with an oblong (33.33%) or spherical (39.39%) crown shape and dense foliage (38.18%) (Table 8).

Class G4 was characterized by the Fr3 fruit morphotype (37.31%) and Fe5 leaf morphotype (91.43%) (Table 9). The highest variability was observed for leaf density (Shannon diversity index, H = 1.382).

Relationship between tree morphotypes and environmental variables

The PCA performed on the environmental variables (phytodistrict, latitude, bioclimatic variables) and the obtained tree classes indicated that the first two principal components retained 91.1% of the initial information (Figure 9). Class G1 was primarily located in high-latitude areas, notably in Bassila, Mekrou-Pendjari, and the Atacora chain phytodistricts, benefiting from average annual temperature (bio1) and annual precipitation (bio12). Class G4, on the other hand, predominantly occurred in the South Borgou phytodistrict, characterized by low-latitude areas. Class G2 showed a stronger association with precipitation in the driest month (bio14). Both G2 and G3 were not restricted to specific phytodistricts and were observed across all four phytodistricts.

DISCUSSION

In this study, respondents across the study area consistently recognized two local landraces of *M. indica*. These findings align with similar observations in northern Benin, where previous studies also documented the recognition of two local mango varieties (Adjacou et al., 2022). The names used for these landraces varied among different socio-cultural groups, highlighting the importance of preserving biocultural diversity in the region. However, the number of locally recognized landraces in this study was fewer compared to reports from other regions (Begum et al., 2012; Drabo et al., 2022; Gitahi et al., 2016; Passannet et al., 2017; Raza et al., 2017; Sennhenn et al., 2014), which have

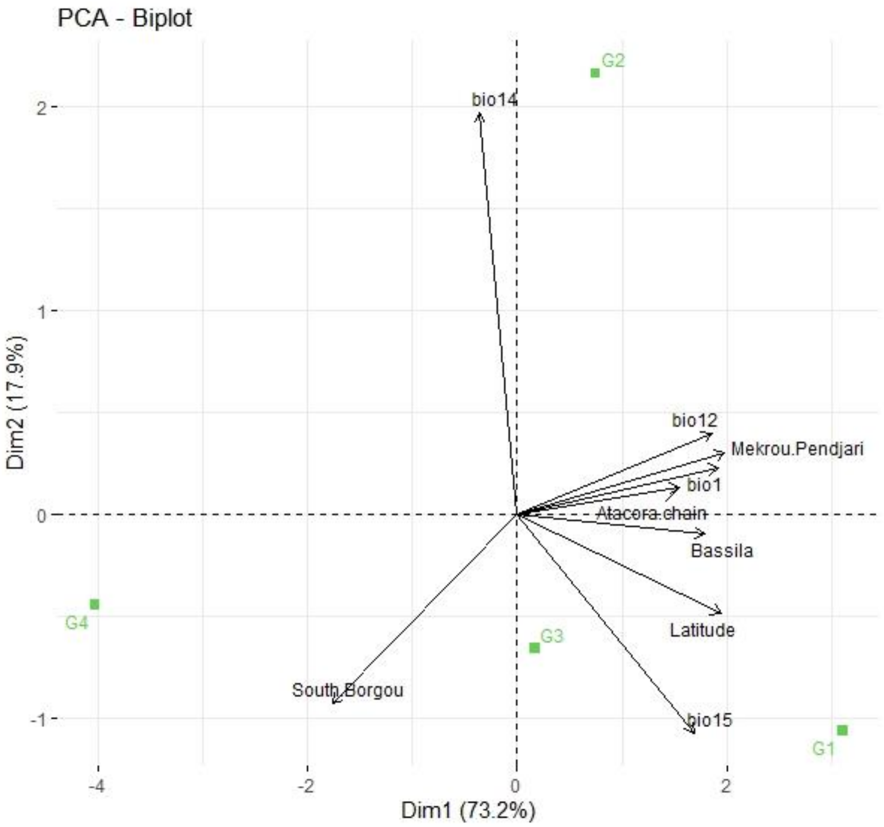


Figure 9. Projection of phytodistricts, bioclimatic variables and latitude on the first two axes of the principal component analysis (PCA). G1, morphotype 1; G2, morphotype 2; G3, morphotype 3; G4 morphotype 4; bio1, Average annual temperature; bio12, Annual precipitation; bio14, Precipitation in the driest month and bio15, Seasonality of precipitation.

documented a greater diversity of indigenous mango cultivars.

This discrepancy suggests that certain landraces may have already disappeared from the study area or that local climatic conditions may not favor the persistence of some cultivars. Hence, there is a pressing need to intensify efforts towards the conservation, sustainable utilization, and domestication of mango genetic resources in Benin. Studies like this one are crucial for preserving cultivars that can potentially contribute to future breeding programs.

Furthermore, the difference in mango diversity between West Africa and East Africa, as noted in the literature, may be linked to the historical introduction of mangoes. Polyembryonic mango trees were introduced in West Africa during the 19th century, whereas they have been present in East Africa since the 14th century (Griesbach, 2003; Rey et al., 2004a). This historical context may have influenced the current diversity and distribution of mango landraces observed in these regions.

The study also revealed that fruit shape and leaf shape were significant traits used by local people to distinguish between the two landraces. These findings underscore the local communities' ability to describe and classify the biodiversity in their environment, which is consistent with previous research on other plant species in Benin (Fandohan et al., 2010).

Given the importance of traditional ecological knowledge in natural resource management, integrating this knowledge into future breeding programs is critical. This approach can facilitate the selection and development of new mango cultivars that are resilient and resistant to both abiotic and biotic stresses, thereby providing tools to mitigate the impacts of climate change. Collaborating closely with local communities will be essential for conserving the available germplasm of *M. indica* and ensuring sustainable agricultural practices in Benin.

In this study, the diversity of 165 mango accessions from four different phytodistricts was evaluated using eight quantitative and nine qualitative traits to identify potential parents for breeding programs and conservation strategies. The results highlighted significant variability in the studied mango germplasm, particularly influenced by environmental variables. The greatest variability was observed in foliage density, along with several morphological traits of fruits and leaves.

This diversity was categorized into four distinct morphotype groups of *M. indica*. Group G1 comprised individuals with fruit morphotype Fr1, characterized by small, light, round, slightly juicy fruits, with strongly attached stems and a deep peduncle cavity. These individuals also exhibited leaf morphotype Fe4, featuring membranous texture and the largest leaf dimensions. Their trees typically had a semi-circular crown shape and intermediate foliage density.

Group G2 consisted of trees with leaf morphotype Fe1 (mostly leathery textured leaves), pyramidal crown shapes, and sparse foliage density.

Group G3 included individuals with fruit morphotype Fr3, characterized by large, heavy, elliptical or oblong fruits that were juicy. Their leaves were predominantly chartaceous (Fe2) or had an obtuse apex (Fe3), and trees exhibited oblong or spherical crown shapes with dense foliage.

Group G4 consisted of individuals with fruit morphotype Fr3 and leaf morphotype Fe5, characterized by the tallest trees observed in the study.

Throughout the study, considerable diversity was noted in the shape of tree crowns among the different accessions, underscoring the breadth of morphological variation present within the studied mango germplasm.

Fruit characteristics such as shape, pulp juiciness, depth of fruit stalk cavity, stalk attachment, length of stone fiber, length, weight, and pulp content exhibited significant variation among different local mango samples, making them valuable for identifying specific local landraces or morphotypes. This variability in fruit characteristics holds important implications for domestication efforts, suggesting opportunities for selecting elite individuals for future breeding programs (Leakey, 2006). These morphological descriptors are particularly practical for identifying mango landraces for commercial purposes, being easily evaluated and widely applied by various stakeholders including farmers, traders, processors, consumers, and nurserymen, who often use them to identify desired fruits for rootstocks.

However, one limitation of relying solely on fruit characteristics for landrace identification is the seasonal nature of fruit harvesting, which restricts the applicability of this method. Therefore, integrating leaf morphological traits alongside fruit characteristics can enhance the identification and classification of mango landraces and morphotypes.

In this study, five leaf morphotypes were identified; with morphotype Fe4 distinguished by its membranous texture and the largest leaf dimensions. Interestingly, unlike some previous studies (Bhamini et al., 2018; Khadivi et al., 2022; Khan et al., 2015; Mussane, 2010; Rajwana et al., 2011; Sennhenn et al., 2014), which emphasized leaf shape as a primary varietal identification trait, this study found that leaf shape did not significantly differentiate the identified morphotypes. Moreover, significant differences in crown structure, observed in this study and noted by Rajan et al. (2001) among Indian mango cultivars, underscore the importance of crown shape in mango tree morphological characterization. Studies by Rymbai et al. (2014), Toili et al. (2017), and Zhang et al. (2020) in various regions have similarly highlighted crown shape as a notable trait in mango trees, reinforcing its role in varietal characterization.

Furthermore, variations in tree height observed in this study align with findings from similar research (Bhamini et al., 2018; Khadivi et al., 2022), indicating its relevance in distinguishing mango varieties.

These variations in different traits can be attributed to various factors such as habitat benefiting from diverse environmental conditions, yearly fluctuations, genetic diversity among landrace genotypes, and interactions between genotypes and agro-climatic conditions (Bhamini et al., 2018; Khadivi et al., 2022). Even within the same region, the growth of a landrace can be influenced significantly by environmental variations (Khan et al., 2015). Therefore, relying solely on morphological parameters may not provide a definitive and reliable description because these traits, especially quantitative ones, are often strongly influenced by environmental factors.

The G1 class, found in high-latitude areas, benefits from factors like average annual temperature (bio1), annual precipitation (bio12), and precipitation seasonality (bio15). Conversely, the G4 class predominates in the South Borgou phytodistrict (a low-latitude area), while the G2 class shows a stronger association with precipitation in the driest month (bio14) and is distributed similarly to the G3 class across all phytodistricts. A study on Cola millenii K. by Lawin et al. (2021) in Benin similarly demonstrated the significant influence of phytodistrict on morphological variability, consistent with the findings of this study. The distinct characteristics observed among tree classes are likely shaped by local environmental and climatic conditions. For conservation purposes, it is recommended to select representative accessions from each tree class for conservation within their respective phytodistricts. This approach can help preserve the diversity of original germplasm specific to each area while optimizing resources allocated to germplasm conservation efforts. Furthermore, the insights gained from this study can inform the development of on-farm conservation strategies for mango germplasm, involving community engagement to raise awareness about the importance of mango genetic resources and identifying local custodians willing to participate in conservation initiatives.

Conclusion

Two local landraces were recognized based on local knowledge among inhabitants in northern Benin. Four distinct tree morphotypes were identified, each showing unique characteristics. Morphotypes G1 is characterized by smaller, rounded fruits with elongated stone fibers and longer leaves, predominantly found in the Bassila, Mekrou-Pendjari, and Atacora chain phytodistricts. Morphotype G2 is distinguished by leaves with a leathery texture, while morphotype G3 includes trees bearing the largest and heaviest fruits, often elliptical in shape, with fleshy-textured leaves. Both morphotypes G2 and G3 are distributed across all four phytodistricts. Morphotype G4 consists of the tallest trees and is primarily located in the South Borgou phytodistrict.

The high morphological variation observed presents opportunities for selecting specific mango types to enhance traits important for various uses. However, similar studies focusing on local mango accessions are needed in other regions of Benin to explore additional dimensions of morphological diversity and assess adaptations to abiotic and biotic stresses. To support a comprehensive conservation strategy for mango species globally, research into their genetic diversity is essential. Moreover, this study can serve as a model for investigating other underutilized naturalized fruit species.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Adjacou DM, Houehanou TD, Gouwakinnou GN, Natta AK (2022). Connaissances ethnoécologiques des variétés locales de *Mangifera indica* L. dans l’Atacora au Bénin : usages, diversité et perceptions du changement climatique. Annales de l'Université de Parakou - Série Sciences 12(1):15-28.

Adomou AC (2005). Vegetation Patterns and Environmental Gradients in Benin: Implications for Biogeography and Conservation. Available at: https://www.proquest.com/openview/6d220f1ecda2856491d92e086daa162b/1?pq-origsite=gscholar&cbl=44156

Akin-Idowu PE, Adebo UG, Egbekunle KO, Olagunju YO, Aderonmu OI, Aduloju AO (2020). Diversity of mango (*Mangifera indica* L.) cultivars based on physicochemical, nutritional, antioxidant, and phytochemical traits in South West Nigeria. International Journal of Fruit Science 20(2):S352-S3776.

Arogundade O, Matthew JO, Akinyoola OI, Akin-Idowu PE, Akinyemi SOS (2022). Phenotypic and Molecular Characterization of Mango Cultivars in Southwest Nigeria. International Journal of Fruit Science 22(1):151-159.

Begum H, Reddy MT, Malathi S, Reddy BP, Arcahk S, Nagaraju J, Siddiq EA (2012). Molecular analysis for genetic distinctiveness and relationships of indigenous landraces with popular cultivars of mango (*Mangifera indica* L.) in Andhra Pradesh, India. Asian Australas. Journal of Plant Biotechnology 6(1):24-37.

Bhamini K, Kumar A, Jaiswal US, Ahmad F, Rani R (2018). Morphological characterization of mango (*Mangifera indica* L.) germplasm using DUS testing. International Journal of Current Microbiology and Applied Sciences 7(5):2944-58.

Dagnelie P (1998). Statistiques théoriques et appliquées, de Boeck et Larcier. Brux. Belg.

Drabo C, Sanou J, Nikiema Z, Dao A, Sawadogo M (2022). Diversité variétale des manguiers (*Mangifera indica* L.) et des pratiques culturales associées à la production au Burkina Faso. International Journal of Biological and Chemical Sciences 16(2):787-97.

Drabo C, Sawadogo P, Sawadogo N, Sanou J, Sawadogo M (2024). Leaf and fruit description of 18 varieties of mango tree (*Mangifera indica* L.) in Burkina Faso. Available at: https://academicjournals.org/journal/AJAR/article-full-text-pdf/1A722B071944.pdf

Elgozuli AA (2011). Characterization and evaluation of selected mango (*Mangifera indica* L.) cultivars in Sudan using morphological descriptors and DNA molecular markers. Faculty of Agriculture, University of Khartoum, Sudan.

Fandohan AB, Assogbadjo AE, Kakaï RLG, Sinsin B, Van Damme P (2010). Impact of habitat type on the conservation status of tamarind (*Tamarindus indica* L.) populations in the W National Park of Benin. Fruits. EDP Sciences 65(1):11-19.

Gálvez-López D, Salvador-Figueroa M, Adriano-Anaya ML, Mayek-Pérez N (2010). Morphological characterization of native mangos from Chiapas, México. Subtrop. Plant Science 62:18-26.

Gaoue OG, Ticktin T (2008). Impacts of bark and foliage harvest on *Khaya senegalensis* (Meliaceae) reproductive performance in Benin. J. Appl. Ecol. Wiley Online Library 45(1):34-40.

Gitahi R, Kasili R, Kyallo M, Kehlenbeck K (2016). Diversity of threatened local mango landraces on smallholder farms in Eastern Kenya. For. Trees Livelihoods 25(4):239-254.

Gouwakinnou GN, Assogbadjo AE, Lykke AM, Sinsin B (2011). Phenotypic variations in fruits and selection potential in Sclerocarya birrea subsp. birrea. Scientia Horticulturae 129(4):777-783.

Griesbach J (2003). Mango growing in Kenya. World Agroforestry Centre.

Houehanou TD, Assogbadjo AE, Kakaï RG, Houinato M, Sinsin B (2011). Valuation of local preferred uses and traditional ecological knowledge in relation to three multipurpose tree species in Benin (West Africa). For. Policy Economy 13(7):554-562.

Khadivi A, Mirheidari F, Saeidifar A, Moradi Y (2022). Identification of the promising mango (*Mangifera indica* L.) genotypes based on morphological and pomological characters. Food Science Nutrition. Wiley Online Library.

Khan AS, Ali S, Khan IA (2015). Morphological and molecular characterization and evaluation of mango germplasm: An overview. Scientia Horticulturae 194:353-366.

Lawin IF, Fandohan AB, Salako KV, Assogbadjo AE, Ouinsavi CAIN (2021). Morphological variability of fruits of *Cola millenii* K. Schum. from seven phytogeographical districts in Benin: opportunity for domestication. Genetic Resources and Crop Evolution 68(3):1225-1242.

Leakey RRB, Page T (2006). The ‘ideotype concept’and its application to the selection of cultivars of trees providing agroforestry tree products. For. Trees Livelihoods 16(1):5-16.

Mukherjee SK (1949). A monograph on the genus *Mangifera*. Lloydia 22:73-136.

Mussane CRB (2010). Morphological and genetic characterisation of mango (*Mangifera indica* L.) varieties in Mozambique [PhD Thesis]. University of the Free State.

Passannet AS, Aghofack-Nguemezi J, Gatsing D (2017). Diversité de variétés, de production et de conservation de mangues au Tchad. International Journal of Biological and Chemical Sciences 11(3):1145-1164.

Pei S, Alan H, Wang Y (2020). Vital roles for ethnobotany in conservation and sustainable development. Plant Divers

42(6):399-400.

Rajan S, Kumar R, Negi SS (2001). Variation in canopy characteristics of mango (*Mangifera indica* L.) cultivars from diverse eco-geographical regions. Society for the Advancement of Horticulture.

Rajwana IA, Khan IA, Malik AU, Saleem BA, Khan AS, Ziaf K, Anwar R, Amin M (2011). Morphological and biochemical markers for varietal characterization and quality assessment of potential indigenous mango (*Mangifera indica*) germplasm. International Journal of Agriculture and Biology 13:151-158.

Ramessur A (2011). RAPD Marker-assisted Identification of Genetic Diversity among Mango (*Mangifera indica*) Varieties in Mauritius. International Journal of Agriculture and Biology 13(2):1560-8530.

Raza SA, Khan AS, Khan IA, Rajwana IA, Ali S, Khan AA, Rehman A (2017). Morphological and physico-chemical diversity in some indigenous mango (*Mangifera indica* L.) germplasm of Pakistan. Pakistan Journal of Agricultural Sciences 54(2).

Rey JY, Diallo TM, Vannière H, Didier C, Kéita S, Sangaré M (2004a). La mangue en Afrique de l'Ouest francophone: variétés et composition variétale des vergers. Fruits. EDP Sciences 59(3):191-208.

Rey JY, Diallo TM, Vannière H, Didier C, Kéita S, Sangaré M (2004b). La mangue en Afrique de l'Ouest francophone. Fruits. EDP Sciences 59(2):121-129.

Ribeiro SMR, Queiroz JH, de Queiroz MELR, Campos FM, Sant'Ana HMP (2007). Antioxidant in mango (*Mangifera indic*a L.) pulp. Plant Foods Humuan Nutrition 62(1):13-7.

Rymbai H, Laxman RH, Dinesh MR, Sunoj VJ, Ravishankar KV, Jha AK (2014). Diversity in leaf morphology and physiological characteristics among mango (*Mangifera indica*) cultivars popular in different agro-climatic regions of India. Scientia Horticulturae 176:189-93.

Sennhenn A, Prinz K, Gebauer J, Whitbread A, Jamnadass R, Kehlenbeck K (2014). Identification of mango (*Mangifera indica* L.) landraces from Eastern and Central Kenya using a morphological and molecular approach. Genetic Resources and Crop Evolution 61(1):7-22.

Toili MEM, Rimberia FK, Nyende AB, Sila D (2017). Diversity and differentiation of mango populations from eastern Kenya. Acta Horticulturae 1183:73-82.

Tossou CC, Floquet AB, Sinsin BA (2012). Relation entre la production et la consommation des fruits cultivés sur le plateau d'Allada au sud du Benin. Fruits. EDP Sciences 67(1):3-12.

Van Melle C, Buschmann S (2013). Analyse comparative des chaines de valeur de la mangue au Benin, au Ghana et au Burkina Faso. Reconstruire Potentiel Aliment. L'Afrique L'Ouest pp. 341-71.

Zhang C, Xie D, Bai T, Luo X, Zhang F, Ni Z, Chen Y (2020). Diversity of a large collection of natural populations of mango (*Mangifera indica* Linn.) revealed by agro-morphological and quality traits 12(1):27.