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Contribution to the Management of Genetic Resources of a Vulnerable Species in Agroforestry Parks in Northern Côte d'Ivoire: The Baobab (*Adansonia digitata* L.)

Saraka Didier Martial Yao[1,2], Gnigouan Kadio Guy Roland Anzara[3], Wentoin Alimata Marie Pierre Daramcoum[1,2*], Hounwanou Jérôme Agongnon[4], Kpagni Antoine Ble[1,2], Eric Blanchard Zadjehi Koffi[1], N'Guessan Ysidor Konan[1,2], Nafan Diarrassouba[1,2]

[1]Genetics Research Unit, Department of Biochemistry and Genetics, Faculty of Biological Sciences, Peleforo Gon Coulibaly University (UPGC), Korhogo, Côte d'Ivoire
[2]African Center for Research and Applications on Shea (CRAK), Korhogo, Côte d'Ivoire
[3]Faculty of Agroforestry, Jean Lorougnon Guédé University (UJLoG), Daloa, Côte d'Ivoire
[4]Laboratory of Rural Economics and Social Sciences for Sustainable Development (LERSSoDD), National University of Agriculture, Cotonou, Benin
Email: *mariepierrekiss@yahoo.fr

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Abstract

This study aims to generate data on the genetic resources of the baobab (Adansonia digitata L.) in Côte d'Ivoire in order to optimize their local management. Two methodological approaches were used. The first involved conducting a survey of 101 individuals across three departments in northern Côte d'Ivoire: Korhogo, Boundiali, and Ferkessédougou. The questionnaire developed for the survey comprised three sections to assess the conservation status of the species: i) respondent characteristics, ii) knowledge of existing baobab populations in northern Côte d'Ivoire, and iii) uses and economic data related to the baobab. The second approach consisted of characterizing the morphology of mature fruits from 12 baobab trees in Korhogo, using small-scale pomological morphological markers to investigate intraspecific diversity. Survey results revealed that only 10.6% of respondents were aware of any dense baobab populations in the studied areas. Generally, the fruit—particularly its pulp—is the most commonly used part of the baobab in these regions. The pulp sells for 1000 FCFA per kilogram, while ground dried leaves used in sauces sell for 500 FCFA per kilogram. Morphometric analysis showed that, except for fruit polar diameter, the nine other pomological traits discriminated among baobab genotypes. Heavier baobab fruits tended to be longer and wider, with a greater

pulp mass and a higher seed count. The correlations between fruit dimensions, fruit weight characteristics, pulp content, and the number of seeds contained in the fruit were all positive and greater than +0.6. Trees producing more seeds tended to bear fruits with thicker shells. The correlation value between number of seeds per fruit (NSF) and shell mass (MS) was rNSF/MS = +0.896. In addition to highlighting the baobab's socio-economic importance, the pomological diversity structure revealed in this study identified three morphogroups that should be considered in conservation and genetic improvement strategies for baobab in Côte d'Ivoire.

Keywords

Adansonia digitata L., Population, Uses, Fruit Morphology, Côte d'Ivoire

1. Introduction

The African continent is one of the most biodiverse regions in the world [1]. Unfortunately, climate change and increasing human pressure on ecosystems—particularly through agriculture—have led to the destruction of vast forested areas, resulting in the disappearance or extinction of numerous plant species. Côte d'Ivoire, for example, has lost more than two-thirds of its forest cover in just 50 years, with an annual deforestation rate estimated at 10% [2]. Addressing this issue requires the promotion and sustainable use of locally available natural resources that are already integrated into rural cultural practices. These local natural resources form the biological foundation of food security and agricultural sustainability. Among them is the baobab (*Adansonia digitata* L.), an agroforestry species of significant importance due to its multiple functions [3] [4].

The baobab is widely used for nutritional, medicinal, economic, and sociocultural purposes. Its leaves are rich in nutrients, particularly vitamins A and C [5]. In Senegal, baobab pulp is used in various cereal-based dishes such as porridges, couscous, and sauces [4]. The seeds' kernels serve as a traditional mustard or as a thickening agent in sauces. Medically, the bark is applied to wounds to aid healing, while the seed kernels are used to treat hiccups. The leaves are used to treat hemorrhoids, and the roots are utilized in epilepsy treatment [6]. Economically, baobab products are traded both nationally and across borders, generating substantial income for households, particularly for women [7] [8]. In Benin, the price of baobab pulp can reach 1000 FCFA per kilogram (€1.52/kg), which exceeds the average price of cocoa per kilogram (€1.37/kg) in Côte d'Ivoire [9].

Given its socio-economic importance, every part of the baobab tree—pulp, bark, seeds, etc.—is heavily exploited by local communities. However, the intensive harvesting of leaves and regular fruit collection hinder the natural regeneration of the species. Moreover, baobab trees are not currently subject to any specific conservation or protection measures in Côte d'Ivoire. According to the International Union for Conservation of Nature (IUCN), the baobab is classified as a vul-

nerable species due to overexploitation and the lack of adequate conservation efforts. Basic knowledge required for its sustainable use remains extremely limited. Nevertheless, several morphological characterization studies have been conducted in other countries—such as Mali [10], Senegal [11], Togo [12], and Benin [13]—to improve understanding of the species. In Côte d'Ivoire, however, very limited information is available on the genetic resources of baobab.

Gaining such knowledge is essential to optimizing baobab resource management and to better assess its potential for local development. It is therefore necessary to understand the characteristics of natural populations in order to maximize the benefits of their use. Against this background, the present study was initiated to first assess the conservation status of baobab through a field survey in northern Côte d'Ivoire, and second, to explore the species' diversity using fruit-based morphological markers as a foundation for its sustainable management.

2. Materials and Methods

2.1. Study Area

Field surveys and investigations to collect information on the baobab were conducted in three departments located in northern Côte d'Ivoire, more than 600 km from Abidjan. These departments are Korhogo, Boundiali, and Ferkessédougou, which serve respectively as the administrative centers of the Poro, Bagoué, and Tchologo regions (**Figure 1(a)**). The northern region is considered a primary baobab production zone, where baobab agroforestry parks are still present. The climate is classified as tropical dry, specifically of the Sudanian-Sahelian type, characterized by two main seasons: a pronounced dry season and a marked rainy season, with an average annual rainfall of approximately 1200 mm. The vegetation consists primarily of open forest and various savanna types—wooded, shrubby, or grassy. Forest cover has largely disappeared in recent decades due to unsustainable exploitation by local populations. The savanna region is dominated by moderately to heavily leached ferralitic soils, with a consistent mineralogical composition [14].

2.2. Plant Material

The plant material studied was the baobab, on which surveys were conducted in the departments of Korhogo, Boundiali, and Ferkessédougou. A morphological diversity study was carried out specifically in the department of Korhogo. The selection of the Korhogo department as the study site for morphological diversity is justified by its geographical location between the departments of Boundiali and Ferkessédougou. This choice aims to assess the diversity in this area, which could reflect the overall state of diversity across all the departments surveyed during the investigation. Morphological characterization of the fruit was performed on 48 mature fruits collected from 12 baobab trees or genotypes, with four mature fruits sampled per genotype. The selected trees were located at a minimum distance of 1 km from each other, positioned along the four cardinal directions from the center of the Korhogo department (**Figure 1(b)**).

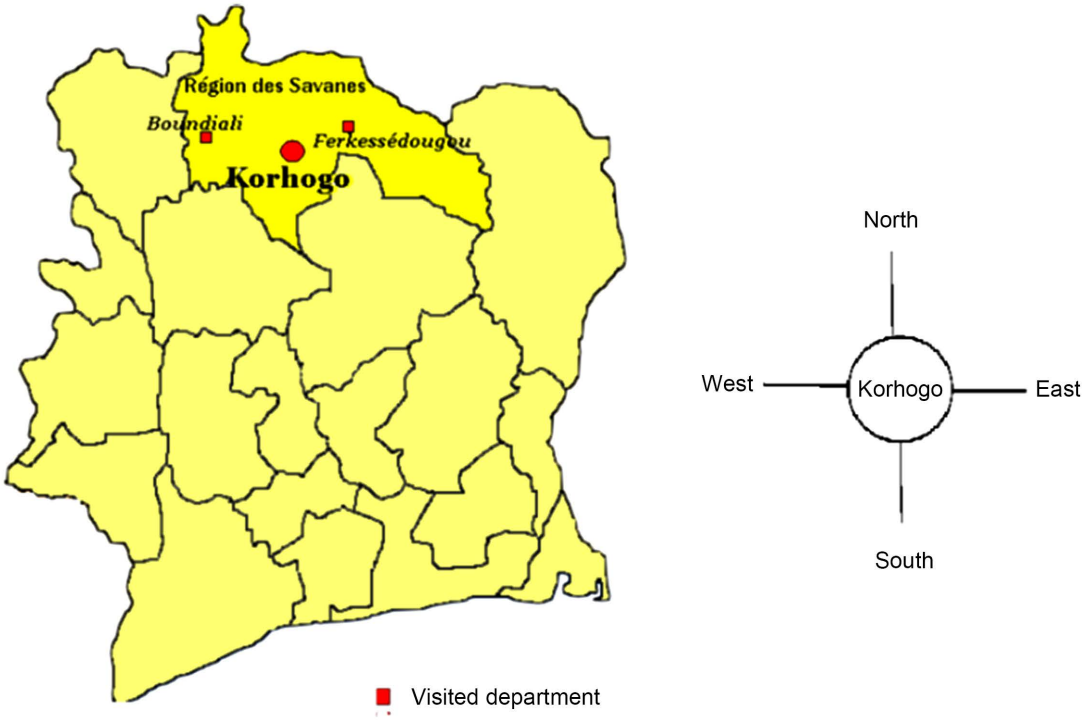

Figure 1. Map of Côte d'Ivoire showing the study area. (a) Departments visited during the survey; (b) Locations of the three sampled baobab trees within the Korhogo department.

2.3. Methodology

2.3.1. Survey Implementation

Field surveys were conducted in each locality based on information gathered from interviews with 101 respondents, including 81 women and 20 men. Information was collected through direct interviews with randomly selected individuals from the different surveyed localities. The survey method was based on a predefined questionnaire developed in alignment with the study's objectives. It included sections on the profile of the respondents (name, gender, contact information, age, origin, and occupation), the conservation status of baobab in the surveyed areas, as well as economic data and the various uses of the baobab.

2.3.2. Agromorphological Evaluation of Baobab Fruits

Fruits were harvested from different baobab trees in the Korhogo area for the assessment of morphological and agronomic traits. For each of the 48 whole fruits sampled, five morphological characteristics were measured: peduncle length, fruit length, equatorial circumference, polar diameter, and total fruit mass (Table 1).

Each fruit was then cracked open. Seeds and pulp were extracted using the traditional method reported by local villagers during the survey. The following parameters were then evaluated and/or calculated: shell mass, total number of seeds per fruit, seed mass per fruit, pulp mass per fruit, and pulp yield per fruit (Table 1; Figure 2).

Table 1. Morphological variables of the fruit, their units, and methods of measurement.

Morphological Variable	Code Used	Unit (SI)	Measurement Method
Peduncle length	LP	cm	Measured in centimeters using a measuring tape on 4 fruits per tree.
Fruit length	LF	cm	Measured in centimeters using a measuring tape on 4 fruits per tree.
Fruit Equatorial circumference	CE	cm	Measured in centimeters using a measuring tape on 4 fruits per tree.
Polar diameter of the fruit	PDF	cm	Measured in centimeters using a caliper on 4 fruits per tree.
Fruit mass	MF	g	Weighed in grams using a mechanical (needle) scale.
Shell mass	MS	g	Shell weighed in grams using an electronic scale.
Number of seeds per fruit	NSF	-	Total number of seeds manually counted per fruit.
Seed mass per fruit	MSF	g	Total seed mass per fruit measured in grams using an electronic scale.
Pulp mass per fruit	MPF	g	Variable calculated using the following formula $MPF = MF - MC - MGF$
Pulp yield per fruit	PYF	%	Variable calculated using the following formula $RPF = (MPF \times 100)/MF$

Figure 2. Methods for measuring morphological variables of the baobab fruit. (a) Measurement of fruit length, (b) Measurement of equatorial circumference, (c) Measurement of polar diameter, (d) Measurement of fruit weight, (e) Crushed fruit, (f) Pulp extraction, (g) Measurement of shell weight, (h) Baobab seed, and (i) Baobab pulp.

2.3.3. Statistical Analysis of the Data

Survey data were subjected to descriptive statistical analysis (frequency, mean, percentage). The results are presented in the form of tables and charts. Quantitative data collected from the fruits were analyzed using a one-way Analysis of Variance (ANOVA 1), with the tree as the classification criterion, to compare means across different baobab trees. To assess the morphological diversity structure of the fruits, a Principal Component Analysis (PCA) was performed to identify homogeneous groups based on variable relationships. Additionally, a phylogenetic tree was constructed using a Euclidean distance matrix derived from the morphological data. This analysis aimed to cluster baobab trees exhibiting similar traits into the same group. All statistical analyses were conducted using SPSS software, version 16.

3. Results

3.1. Sociodemographic Profile of Respondents

During the survey, 101 individuals were interviewed, including 81 women (80.20%) and 20 men (19.80%). Respondents' ages ranged from 20 to over 40 years, with a majority (54.46%) being over 40 years old. The majority of respondents were indigenous, primarily of Senoufo origin (84.16%), while non-indigenous individuals accounted for 15.84% (Table 2).

Table 2. Sociodemographic profile of farmers.

Designation	Category	Number	Percentage (%)
Gender	Men	20	19.80
	Women	81	80.20
Age	Up to 40 yrs	46	45.54
	Over 40 yrs	55	54.46
Origin	Indigenous	85	84.16
	Non-Indigenous	15	15.84

3.2. Knowledge of Existing Baobab Stands

Respondents across the surveyed cities shared their views on the existence of baobab stands, changes in tree population, and the presence of baobab varieties. The survey revealed that no formal baobab plantations were reported in the three localities. However, only 10.6% of respondents were aware of the existence of dense baobab stands. In the surveyed areas, dense stands are reported to be rare and mostly found in sacred protected forests (Figure 3).

Regarding the evolution of baobab tree numbers in the study zones, most respondents reported a decrease (49%) or no change (47.2%) in tree numbers. The number of baobab trees remained most stable in Ferkessédougou, followed by Boundiali and Korhogo, with respective stability rates of 85.7%, 60%, and 38.7%. Fewer than 5% of respondents observed an increase in tree numbers. The greatest decline in tree population was reported in Korhogo, followed by Boundiali and

Ferkessédougou, at 56.3%, 40%, and 14.3% respectively (Figures 3-5).

Only 15.3% of respondents in the study area were aware of the existence of different baobab varieties. The criteria used to distinguish these varieties included pulp color (white, brown, yellow), leaf color (light green, dark green), and fruit size (small and large).

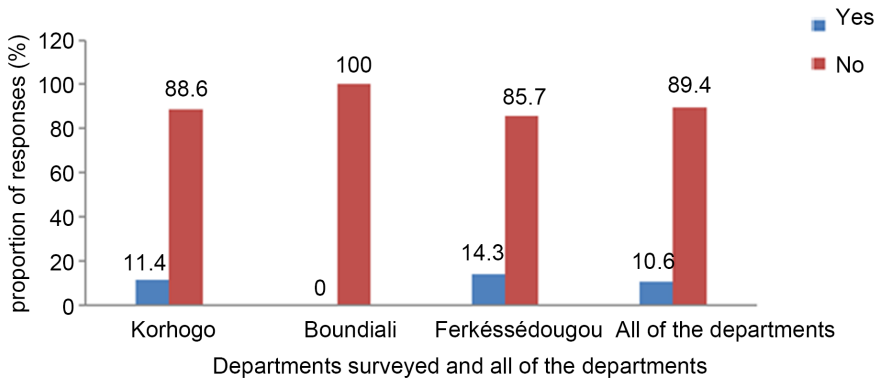

Figure 3. Responses regarding the awareness of baobab stands in the departments of Korhogo, Boundiali, and Ferkessédougou in northern Côte d'Ivoire.

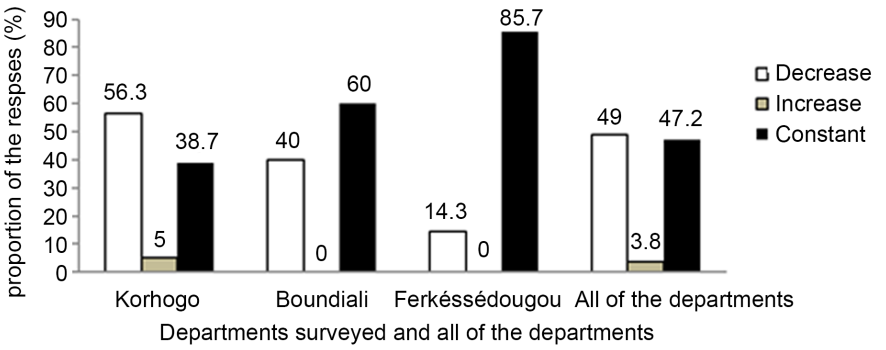

Figure 4. Responses concerning the evolution of the number of baobab trees in the departments of Korhogo, Boundiali, and Ferkessédougou in northern Côte d'Ivoire.

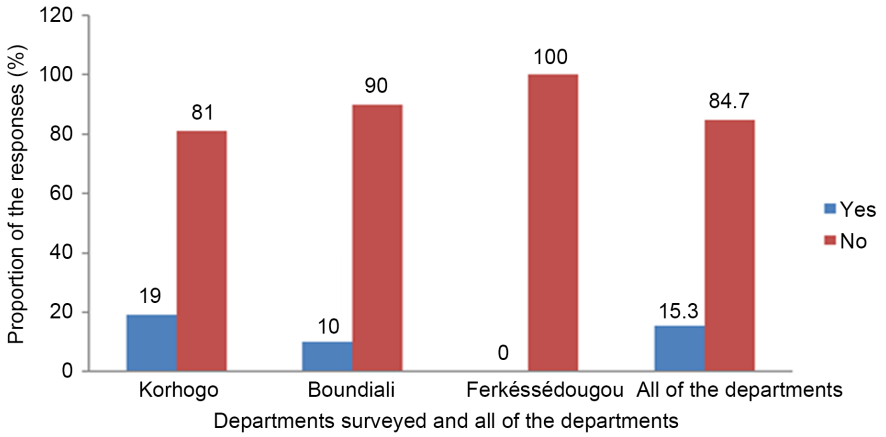

Figure 5. Responses regarding the awareness of baobab varieties in the departments of Korhogo, Boundiali, and Ferkessédougou in northern Côte d'Ivoire.

3.3. Economic Aspects and Uses of Baobab

The price of baobab leaves and pulp varies depending on the time of year, market conditions, and availability. In the departments of Korhogo, Boundiali, and Ferkessédougou, the price of one kilogram of baobab pulp is 1000 FCFA. A kilogram of dried baobab leaves sells for 500 FCFA. Fresh baobab leaves are sold in small bundles, typically priced at 25 FCFA each. Quantities of pulp and dried baobab leaves (in powdered form) intended for sale are commonly measured in urban markets using large tomato cans (Figure 6). Traders source baobab pulp either by harvesting the fruits themselves in the field or by purchasing them in bulk from village women.

Figure 6. Display and sale of baobab leaf and pulp powder.

All major parts of the baobab tree are used either for food or in traditional medicine. The most frequently cited parts are the pulp and the leaves, used for food purposes by 100% and 71.8% of respondents, respectively. Roots and wood, used for therapeutic purposes, are mentioned less frequently. The process of extracting pulp from mature fruits involves three main steps. First, the mature fruits are crushed, and the seeds coated with pulp are removed and sun-dried. Next, the pulp-coated seeds are pounded. Finally, the mixture is sieved to obtain the fine powdered baobab pulp (Figure 7).

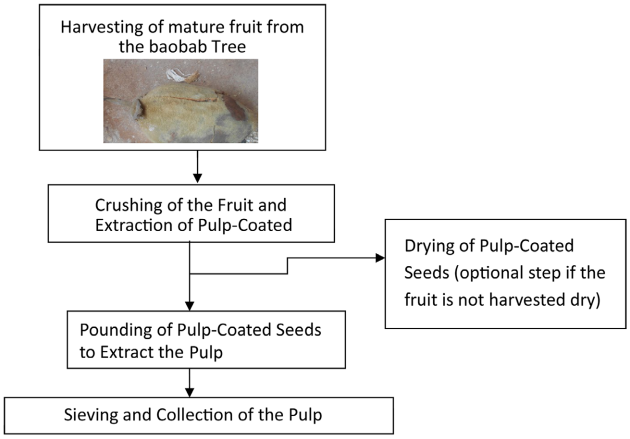

Figure 7. Traditional baobab pulp extraction process as reported by respondents in northern Côte d'Ivoire.

3.4. Baobab Fruit Morphometry

3.4.1. Variability of Traits Related to the Baobab Fruit

Among the ten quantitative traits measured on baobab fruits, only the polar diameter did not significantly differentiate trees located in the Korhogo department (Table 3). The fruits collected from different baobab trees were generally similar in shape and size at the base and apex. However, differences observed in the other nine parameters indicate variability among the collected baobab fruits.

Table 3. Variability of quantitative traits of baobab fruit in the Korhogo department.

	Minimum	Maximum	Mean	Standard Deviation	*P-value*
Peduncle Length (cm)	19.80	43.85	31.03	9.72	0.0085**
Fruit Length (cm)	35.50	12.07	31.03	6.18	<0.001***
Equatorial Girth (cm)	32.70	12.36	20.55	7.12	<0.001***
Polar Diameter (cm)	53.45	4.34	24.11	30.49	0.6831
Fruit Mass (g)	701.95	47.87	10.43	215.77	0.0017**
Shell Mass (g)	301.00	32.73	219.74	85.54	0.0009***
Total number of seeds	413.00	19.00	106.27	157.74	0.0009***
Seed Mass per Fruit (g)	344.25	12.38	127.92	111.67	0.0083**
Pulp Mass per Fruit (g)	115.76	6.26	76.26	45.65	0.0025**
Pulp Yield per Fruit (%)	45.49	3.08	38.05	14.49	0.0149*

3.4.2. Correlation between Baobab Fruit Traits

The degree of association between variables was estimated using Pearson's correlation coefficient (r). Several significant correlations were observed among the measured traits (Figure 8). The correlation matrix revealed 18 pairs of variables with strong and significant positive correlations ($r \geq 0.70$). Heavier and wider fruits were associated with higher pulp mass. Specifically, pulp mass per fruit was positively correlated with fruit diameter ($r = 0.678$) and fruit mass ($r = 0.777$).

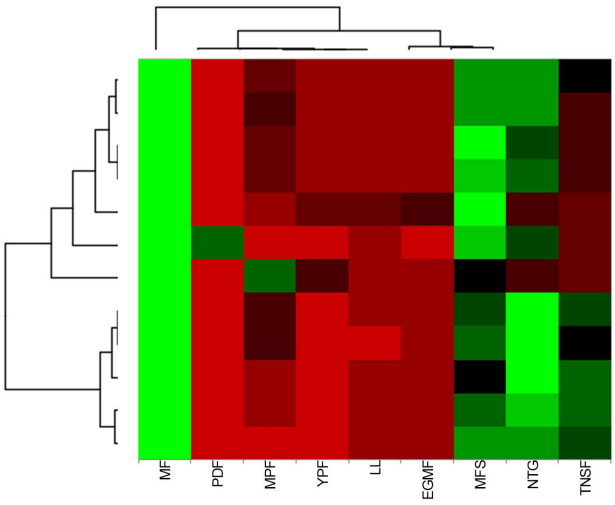

Figure 8. Heatmap illustrating the correlation relationships among assessed baobab fruit traits.

3.4.3. Structure of Morphological Diversity in Baobab Trees

To assess the distribution of the variables and the dispersion of the individuals (Figure 9), the first two principal components, which together account for 83.15% of the total variability, were considered.

Axis 1 (64.36%) is primarily defined by equatorial girth, polar diameter, fruit mass, and pulp mass per fruit, fruit length, shell mass, total number of seeds per fruit, and seed mass per fruit all of which are positively correlated with this axis.

Axis 2 (18.75%) is mainly defined by peduncle length, which is negatively correlated with it. Analysis of this trait, which contributes significantly to the formation of this axis, revealed that shorter peduncles are associated with wider and heavier fruits.

The distribution of individuals within this plane revealed two distinct groups. Group I, located on the right side of axis 1, consists of individuals 3, 10, and 12. Group II comprises the remaining individuals, which are positioned closer to axis 2.

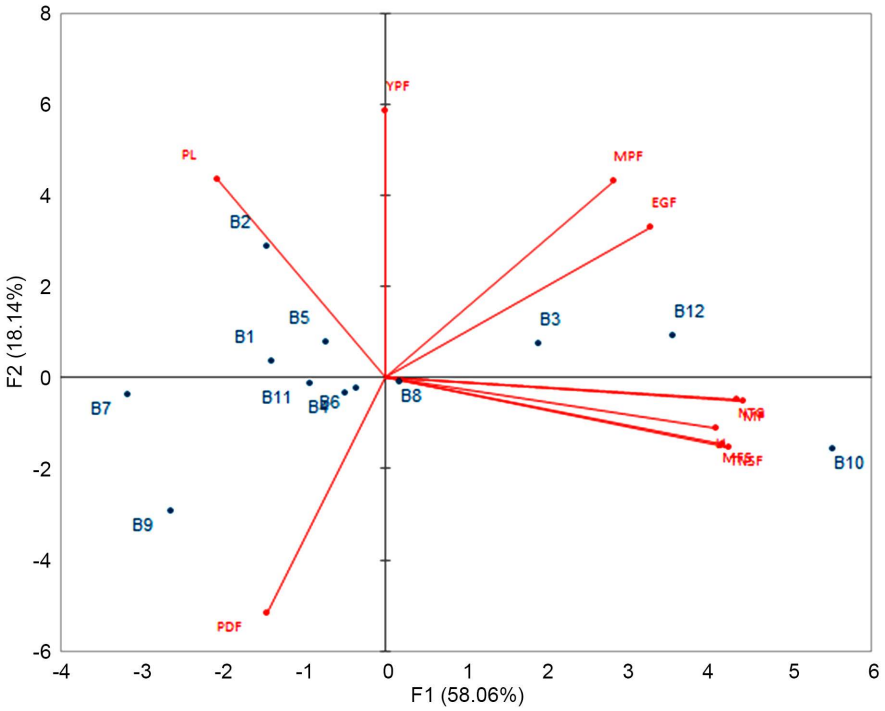

Figure 9. Biplot revealing morphological diversity in the PC1–PC2 plane of the PCA of baobab trees studied in the Korhogo department.

3.4.4. Adjustment of Individual Classification

The dendrogram constructed using the UPGMA method (Unweighted Pair Group Method with Arithmetic Mean) revealed two main clusters (Figure 10). The first group consists of nine baobab trees (B1, B7, B11, B9, B1, B4, B2, B6, and B8), while the second group includes four trees (B3, B12, and B10). Analysis of the dendrogram showed that, in general, the grouping of baobab trees does not correspond to their geographical proximity. For instance, trees B3 and B12, although geographically distant, are both placed in Group 2.

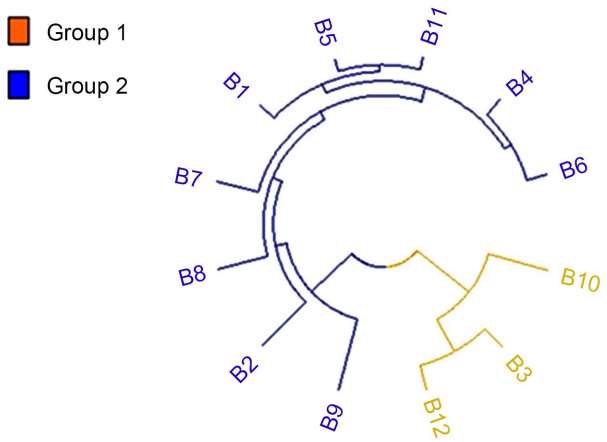

Figure 10. UPGMA dendrogram of baobab trees (*Adansonia digitata*) based on Euclidean distances.

4. Discussion

Surveys conducted in the three localities (Korhogo, Boundiali, and Ferkessédougou) enabled the identification of baobab trees within the study areas and the collection of information on the different uses of the species' parts. The level of knowledge about the baobab was found to be higher among respondents over the age of 40. The influence of age on baobab knowledge was also confirmed in Togo [12], who showed that individuals aged over 75 had more knowledge than those aged between 25 and 50. Among all respondents, women—over 80%—showed the greatest interest in baobab. In Africa, the sale of baobab products in markets (such as leaves, pulp, bark, etc.) is traditionally an activity carried out by women.

The regular use of various parts of the plant for sale or consumption, coupled with the absence of conservation and protection policies for baobab, has led to a gradual decline in the number of trees. This trend is further exacerbated by environmental degradation, particularly deforestation, which has an annual estimated rate of 4% [15]. Such conditions are not favorable to the expansion of baobab populations, and their long-term survival is under threat. Yet the baobab holds significant economic potential in Africa. According to Gustad *et al.* [16], baobab fruit pulp is among the most economically valuable non-timber forest products, sometimes fetching prices up to ten times higher than millet in Mali. In Côte d'Ivoire, the price per kilogram of baobab pulp is estimated at 1000 CFA francs, while the average fruit yield of a single baobab tree generates an economic value of 116,958 CFA francs in unprocessed fruit in Togo [17].

The morphometric evaluation of baobab fruits revealed variability among individual trees. Of the ten variables analyzed, nine were found to significantly differentiate between baobab individuals. Mass (of fruit, pulp, and seeds), length (of peduncle and fruit), equatorial girth, and seed number were the key morphological descriptors. In Benin, the most commonly used criterion by rural populations to distinguish baobab trees in terms of production potential is fruit shape [13].

These authors identified four fruit groups with significantly different size characteristics. Several fruit morphotypes have been observed in other countries such as Mali [10], Senegal [11], and Togo [12]. This variability in fruit characteristics likely results from underlying genetic diversity within baobab populations. The high level of trait diversity may also reflect human selection pressure on plant material. Human selection can, depending on its intensity, either reduce or increase morphological diversity. In our case, the high diversity observed in baobab could be explained by the fact that humans deliberately choose individuals exhibiting desirable morphological traits (fruit size, color, shape, yield, taste, etc.). These selected individuals are favored for reproduction, thereby increasing the frequency of these traits within the population.

The small number of individuals examined in this preliminary study on baobab, restricted to a single geographical area, represents a limitation to the generalization of the results on the species' diversity across northern Côte d'Ivoire. Indeed, morphological and genetic diversity can vary considerably from one region to another under the influence of environmental factors (climate, soil, water availability) and local human practices. Complementary studies, including a larger sample size and covering a broader geographical area, would therefore be relevant to better assess the overall diversity of the species.

5. Conclusion

This study contributes to the understanding of baobab in Côte d'Ivoire and supports efforts to optimize its management. Surveys conducted in the northern part of the country showed that women, representing more than 80% of respondents, demonstrate greater interest in the species. Respondents over 40 years old provided more information than those aged between 25 and 40. Some baobab stands still exist in specific areas of Korhogo and Ferkessédougou. However, the majority of respondents reported a significant decline in baobab tree numbers. Therefore, it is essential to implement conservation and preservation strategies such as reforestation, awareness campaigns, and protection of natural reserves, accompanied by alternative solutions that address the needs of local communities. The second group comprises four trees (B3, B12, and B10) that display markedly higher values for equatorial girth, polar diameter, fruit mass, pulp mass per fruit, fruit length, shell mass, total number of seeds per fruit, and seed mass per fruit compared to the first group. The latter consists of nine baobab trees (B1, B7, B11, B9, B1, B4, B2, B6, and B8) that exhibit these traits to a lesser degree. This clear separation into two morphological groups suggests that targeted selection within baobab populations could be an effective strategy for genetic improvement. Notably, the first group contains elite individuals expressing valuable agronomic traits, which could serve as a foundation for breeding programs aimed at enhancing the species.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Abbreviations

Peduncle Length	LP
Fruit Length	LF
Equatorial Girth of Fruit	CE
Polar Diameter of Fruit	PDF
Mass of Fruit	MF
Mass of Fruit Shell	MS
Total Number of Seeds	NSF
Pulp mass per Fruit	MPF
Pulp Yield per Fruit	PYF