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Research Article

Morphological Variability of *Pterocarpus erinaceus* Poir. in Togo

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Pterocarpus erinaceus Poir. (Fabaceae), also called Vène or West African rosewood, is a multipurpose endemic forest species of Sahelo-Sudanian and Sudano-Guinean savannas and forests of West Africa. In Togo, the species is overexploited, which dangerously hinders its survival. The need and emergency of restoring declining stands, using seeds, or propagating material suggests an assessment of its morphological variability. The purpose of this study is to identify the discriminating morphological descriptors, allowing us to describe and also to characterize the species. Five provenances distributed over the whole geographical distribution area in Togo were evaluated for leaf (7 descriptors), fruit (4 descriptors), and seed (4 descriptors) traits. The coefficient of variation (CV) and the principal component analysis (PCA) are used to assess the variability among tree populations. Results show that the discriminating morphological descriptors for *P. erinaceus* in Togo are the width of the leaf and the terminal leaflet, the length and the width of the fruit, and length and the weight of the seed. These six main relevant variables allow us to discriminate three morphological groups of *P. erinaceus* population.

1. Introduction

The world forests cover almost 30% of the land area [1]. These forests regulate ecosystems, protect biodiversity, play an integral part in the carbon cycle, contribute to climate change mitigation, support livelihoods, help drive sustainable growth, etc. [2, 3]. However, the rapid population growth increases pressure on the forest ecosystems due essentially to anthropic activities (bush fire, selective trees logging for charcoal or fire wood and for timber, grazing and trampling by animals, cultural practices, etc.). These pressures lead to the regression of woody species, especially those more used in economic, social, and cultural activities [4].

Among the current most exploited and threatened species in Western Africa, *P. erinaceus* is an endemic and multipurpose species of Guineo-Sudanian and Sudano-Sahelian zones [5, 6]. In Togo, stands of *P. erinaceus* are present in the five ecological zones [7, 8]. The exploitation is mainly focused on its wood with technological qualities that are much appreciated. It is one of the best wood species of the sub region [9], chiefly used for commercialization purposes and construction, cabinet making, and heating and for arts. Its different parts are used as raw materials in the treatment of some diseases, as animals' fodder and for dyeing [8]. Owing to its economic, social, and high cultural potential, the species is submitted to high pressures causing an important regression of its stands [8].

With regard to this situation, domestication of *P. erinaceus* has been undertaken with seeds collected from trees in Sudano-Sahelian and Guinean-Sudanian zones in West Africa (Benin, Burkina Faso, Niger, and Togo). However, results are not conclusive since the behaviour of primary growth plants is not remarkable. Moreover, the *in situ* seedlings are infrequent [10]. To accelerate the reconstruction of *P. erinaceus* stands, it seems then essential to assure the regeneration of the species with seeds or materials of good quality. For instance, the selection of trees more efficient than the average and their identical multiplication would constitute a good option for the production of plants of good quality for sylviculture and restoration of the natural stands of *P. erinaceus*. In fact, the success of the domestication of wild species requires necessarily the control of their morphological characters related to the fruits, the leaves, and the trunk [11]. According to Sounigo et al. [12] and Zhang [13], the morphological characterization is necessary for the whole genetic improvement activities and the varietal selection of plants, for it enables targeting the interesting morphological descriptors and knowing those related to environmental factors. Hoyt [14] also testifies that the conservation of a wild species *in situ* demands firstly a sampling and a comparison of its genetic diversity in the whole geographical and ecological distribution zone for a domestication purpose.

The objective of the study is to contribute to the sustainable management of natural stands of *P. erinaceus*. Specifically, this study aims to access the morphological variability of spontaneous local populations of *P. erinaceus* in Togo.

2. Methodology

2.1. Study Zone Description. Togo, with a surface of 56,600 km^2, is located between the 6th and 11th degree of north latitude and extends 600 km along the 1°E meridian. Located in an intertropical zone, it undergoes two types of climates: a tropical Guinean with four seasons (two dry and two raining ones) in the southern part and tropical Sudanian with two seasons (one dry and the other one raining) in the northern part. The average yearly rainfall is 1168 m. From the south to the north, the average temperatures are from 30°C in Lome to 34°C in Mango; inversely, average temperatures diminish and are from 23°C in Lome to 13°C in Mango [15, 16].

The research area corresponds to the five ecological zones defined by Ern [7]. A site has been chosen per ecological zone (Figure 1). The survey has been conducted in the five sites between two contrasted areas: (1) protected area aiming at conserving biodiversity *in situ*, forest ecosystems, and landscapes, (2) exploited area where the species is harvested without any restriction (Table 1).

2.2. Data Collection. In each site, trees were selected on the basis of criteria defined by Kokutse et al. [17]. It is about: (i) merchantable height up of a minimum 3 meters, without apparent defects (pitchfork, fluting, bump, parasite attack, etc.); (ii) upright trunk with a circular base, and (iii) developed and well-balanced high crown tree, with thin branches (Figure 2). The distance between plants was at least 20 meters, and the place of every origin and every tree was geolocalized with GPS system (Geographical Positioning System).

A minimum of 25 mature trees per site were selected at the same time for morphological and dendrometric measurements (Table 2). For the dendrometry, a total of 142 trees were directly sampled on the sites.

Dendrometric parameters measured are the total height, the merchantable height, and the diameter at 1.30 m from the soil (Table 3). Heights (total and merchantable) were measured using a Blum-Leiss altimeter (reference: BL7 ref 2085B), and the diameter was measured at 1.30 m from the soil with a tape (Figure 3).

Five (5) leaves per tree were harvested randomly during the raining season. The length and width of the leaf and the length of the petiole were measured, and the number of leaflets was counted. To refine the analysis, the characteristics of the terminal leaflets, chiefly length and width, were measured (Table 3). The total length of the leaf was measured from the base of the petiole to the extremity of the final leaflet, and the length of the petiole was taken from the base of the petiole to the insertion point of the first leaflet. The width was taken at the level of the largest diameter of the leaf. For the final leaflet, its length was measured from the base of the little petiole to the extremity of the leaflet; its width corresponded to the diameter of the biggest limb of that same leaflet, and the length of its little petiole was from the base of the little petiole to the base of the limb of the leaflet (Figure 4).

Measurements were done with a graduated ruler of 40 cm for the leaf (total length and width and petiole length) and with a nondigital Vernier calliper with precision of 0.1 mm for the final leaflet using 650 leaves.

In each site, 30 fruits were directly selected on high crowned trees, at the level of the most accessible branches. The morphological characterization was measured in the Laboratory of Forest Research of University of Lomé, 15 days after the harvest in February 2018. We measured the length, the width, the weight, and the number of seeds per fruit (Table 4). A total of 4260 fruits from 142 sampled trees were measured.

The length of fruit was measured from the attach point of the fruit to the branch to the extremity of the fruit, and its width at the level of the largest diameter of the fruit (Figure 5). The number of the seeds was assessed after peeling the fruits. Measurements were done with a nondigital Vernier calliper having a precision of 0.1 mm and the determination of the weight with a laboratory scale of precision of 0.0001 g.

Ten (10) healthy and undamaged seeds extracted from fruits of each sampled trees were measured based on the three chosen descriptors: the length of the seed, its width, and weight (Table 4). A total of 1420 seeds were measured. Measurements were done with a nondigital Vernier calliper having a precision of 0.1 mm for length (Figure 6) and width and with a laboratory scale of a precision of 0.0001 g for the weight.

2.3. Data Analysis. Statistical analysis of data used R software [19]. Since the goal is the variability according to the origin, an analysis of variance (ANOVA) was performed, using a lineal model generalized for morphological characteristics. The adopted sampling plan corresponded to a mixed model of analysis of the variance, partially hierarchized. The random factor "tree" is nested in fixing factor "site." Thus, for every parameter, the test of ANOVA specifies the difference between the measured values averages according to the origin of the tree. Where a significant effect was found, the post hoc test of Tukey was used at the threshold of 5% for the determination of significant comparisons.

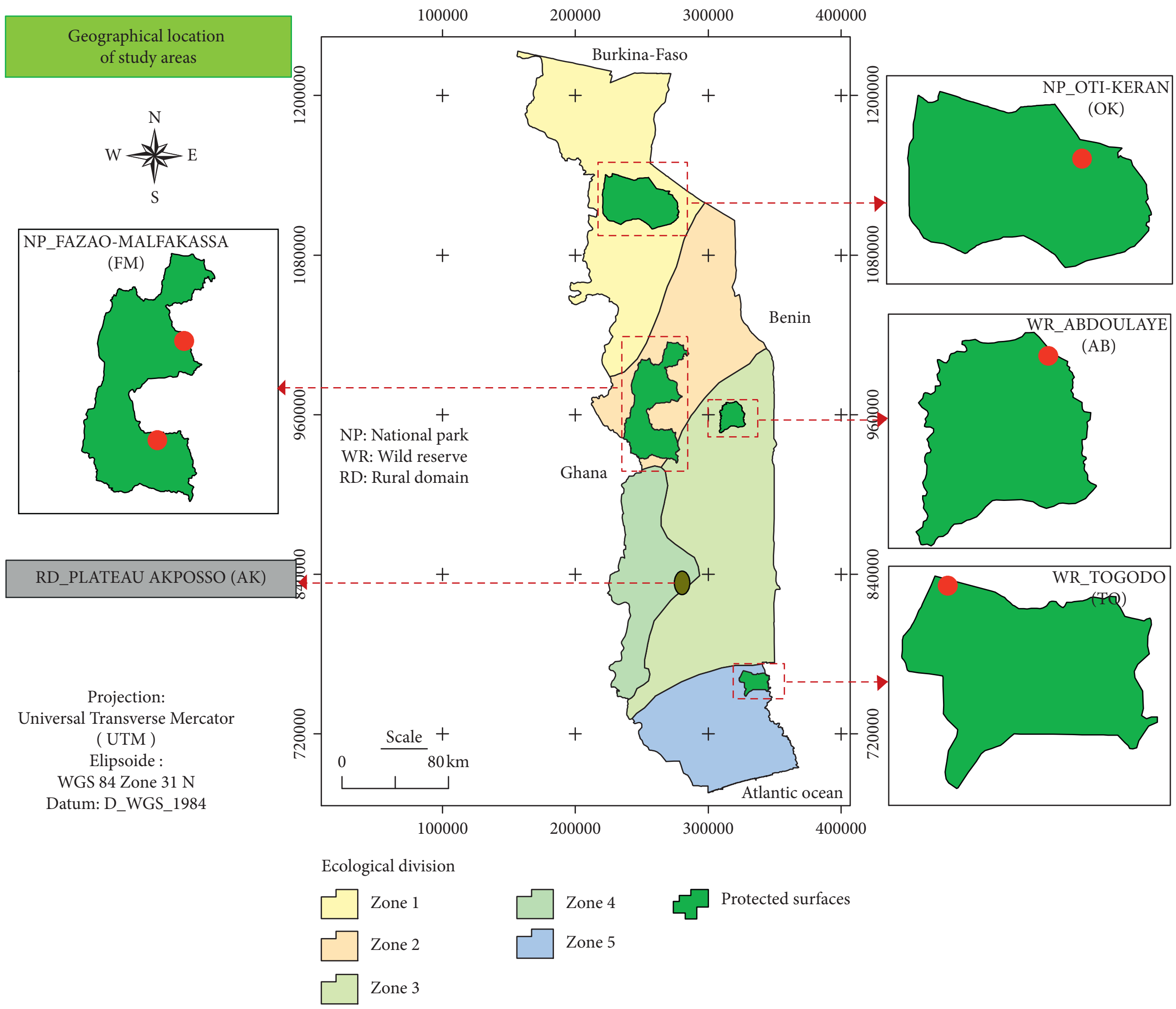


Figure 1: Location of analysed populations of *Pterocarpus erinaceus* in Togo from north to south: the National Park of Oti-Keran (OK), National Park of Fazao-Malfakassa (FM), Wildlife Reserve of Abdoulaye (AB), Rural Domain of Plateau Akposso (AK), and Wildlife Reserve of Togodo (TO).

Finally, populations were categorized according to the most discriminative morphological characteristics using the numerical classification method followed by a Principal Component Analysis (PCA) for the projection of plants.

3. Results

3.1. Dendrometric Characteristics of Variability of P. erinaceus. The mean value of the merchantable height was between 1.03 ± 1.2 m (mean $\pm$ standard deviation SD) and 3.5 ± 1.14 m. The highest mean values of merchantable heights were recorded in the three protected areas (OK, FM, AB), respectively, at 5.9 ± 1.65 m, 6.45 ± 1.14 m, and 5.96 ± 2.2 m, whereas TO and the rural domain AK were 4.59 ± 1.51 m and 4.03 ± 1.23 m (Table 5).

Trees with the maximum merchantable height (6.45 ± 1.14 m) were recorded in FM, and the lowest value of standard deviation illustrates the homogeneous distribution inside the population. On the other hand, trees encountered on the Plateau of Akposso (AK) presented the smallest merchantable height with a homogeneous population as well. It is only in AB populations that the distribution is most disparate, even though measured values were part of those best recorded (Figure 7).

Considering the total height of the trees, the results showed that on average, the highest trees are located in FM (19.18 ± 3.01 m). They were significantly different ($p = 2.2 * 10^{-16}$) from the three other protected zones. The weakest mean values are met in the rural domain AK, with values of 11.35 ± 2.08 m. Values for this parameter in OK, AB, and TO were not significantly different from each other (Table 5).

Diameters of trees varied significantly between each other ($p = 4.05 * 10^{-15}$). The FM population (42.78 ± 11.29 cm) and AB population (38.71 ± 9.36 cm) have the highest mean values, whereas the lowest ones are located in AK (22.05 ± 40.39 cm). OK and TO have statistically similar diameters (Table 5).

Table 1: Biophysical characteristics of study zones and sites.

Climatic zone	Ecological division	Biophysical characteristics of the division		Sites	Site name	Biophysical characteristics of the sites		
		Climate	Soils			Climate	Soils	Geographical details
Sudanian zone with a dry season and a raining season	Zone I: northern plains of Togo	Tropical	Sustained cut of laterite "Dembos"	Protected site: national park (NP)	Oti-Kéran (OK)	Sudanian with a dry season (5–6 months) and raining (5–6) with 800 to 1000 mm of rainfall per year; average temperature = 31.5°C	Tropical ironed soils of sustained laterite type	9°55′-10°20′N 0°25′-1°00′E
	Zone II: northern branch of Togo mounts	Marked by Sudanian-Guinean type of altitude	Stoned to rocky	Protected site: national park (NP)	Fazao-Malfakassa (FM)	Sudanian-Guinean with a dry season(5 months) and raining (7 months) with 1200 to 1500 mm of rainfall per year; temperature raising to 15°C–40°C	Red metal and sandy deep soils	8°19′-9°11′N 0°36′-1°27′E
Guinean-Sudanian zone or Transition zone with a dry season and a raining season	Zone III: central plains	Tropical	Very broad laterite	Protected site: wildlife reserve (WR)	Abdoulaye (AB)	Guinean with two dry seasons with 1200 to 1300 mm of rainfall per year; average temperature = 26.1°C	Slight deep soils with clayey texture	08°34′-08°46′N 01°13′-01°25′E
Guinean zone with two dry seasons and two raining seasons with equal durations	Zone IV: southern zone of Togo mounts	Subequatorial transition	Little bit deep and deep	Rural domain (RD)	Plateau Akposso (AK)	Guinean with two dry seasons and two raining with 1400 to 1700 mm of raining per year; average temperature = 26.3°C	Little advanced soils of erosion	9°55′-10°20′N 0°25′-1°00′E
	Zone V: coastal plain of the south	Subequatorial marked by a lack rain (800 mm/year in Lome)	Slightly sandy and coastal alluvium. Tropical ironed soils	Protected site: wildlife reserve (WR)	Togodo (TO)	Guinean with two dry season (3–9) with 1000 to 1200 mm of rainfall; average temperature = 27°C	Clayey soils with a sandy surface.	6°23′-7°N 1°23′-1°34′E

The analysis of variance showed significant differences from one climatic zone to another (Table 6). In the Guinean zone (TO and AK), the merchantable height of trees showed the lowest values, whereas those of the Transition (AB) and Sudanian (OK, FM) zones were higher. For total height, trees of the Sudanian (OK, FM) zone are the tallest and biggest. For diameter, the Guinean (PA, TO) zone' trees possessed the lowest values.

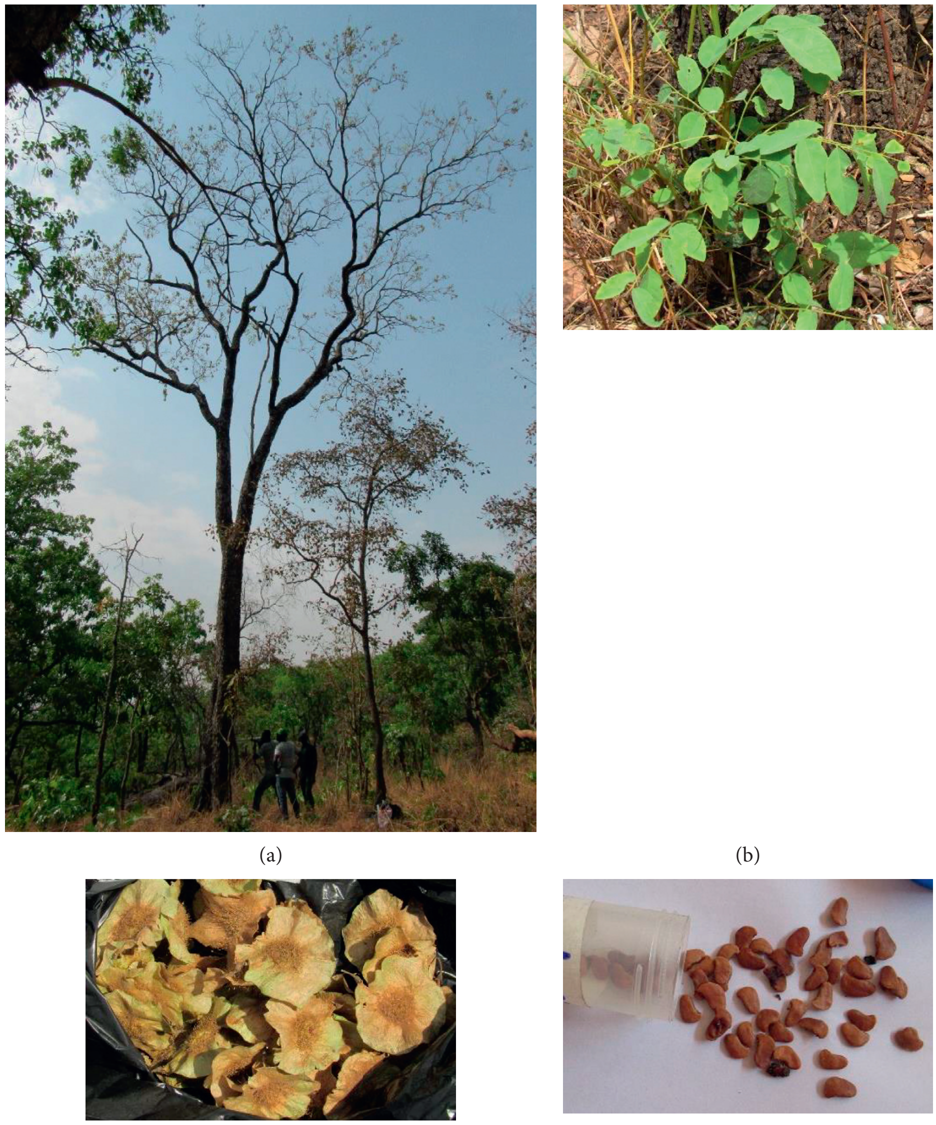
3.2. Variability of P. erinaceus Leaves' Characteristics. The results indicate that the highest average length of leaves was measured in FM (30.25 ± 7.52 cm), whereas the smallest leaves were from OK (25.56 ± 5.82 cm). On the other sites, AB, AK, and TO, leaves' length was similar (Figure 8).

When considering the width of the leaf, there are highly significant ($p = 4.39 * 10^{-8}$) interpopulation differences. The largest leaves were found in TO (15.41 ± 3.35 cm), and the smallest ones were in OK (10.70 ± 2.06 cm). Populations in other protected zones FM and AB had leaves with an average size of 12.24 ± 2.51 cm. Leaves of trees in rural domain AK were 13.59 ± 2.98 cm in width and similar to those of FM, AB, and TO (Table 7).

Results of length of the petiole indicated that plants in OK (4.79 ± 1.13 cm), FM (5.08 ± 1.24 cm), and TO (4.66 ± 0.97 cm) recorded the highest averages compared to AB, which had the smallest petioles (4 ± 0.93 cm). In AK, averages were similar to all the other populations.

As far as the number of leaflets is concerned, the only significant difference ($p = 0.0028$) appeared between OK (9.30 ± 1.85 leaflets) and FM (10.77 ± 1.95 leaflets). In AB, TO, and AK, leaves possessed on average 10.24 ± 1.71 leaflets. Hence, means of the leaflets' number in AB, TO, and OK were not significantly different from OK or from FM (Table 7).

The strongest positive correlation was observed between the length of the leaf and the length of the petiole ($R^2 = 0.69$, $p \ll 0.001$). The intrapopulation variability for leaf features



(a) (b) (c) (d)

Figure 2: *Pterocarpus erinaceus* tree (a), leaves (b),fruits (c),and seeds (d) (photo: Johnson B. N.).

Table 2: Number of trees sampled according to the site.

Sites	Number of sampled plants
Oti-Kéran (OK)	25
Fazao-Malfakassa (FM)	30
Abdoulaye (AB)	30
Togodo (TO)	31
Plateau Akposso (AK)	26
Total	142

at each site was significant according to coefficients of variation = SD/mean (20–30%).

Belonging to either one or the other of climatic zones had an influence on the external shape and dimensions (morphometry) of the leaves (Table 8). While the length of the leaves was similar for all areas, there was a difference ($p = 2.816 * 10^{-7}$) for width between the leaves of Sudanian (OK and FM) and Transition (AB) zones (smaller) comparatively to the Guinean (PA and TO) zone. For the length of the petiole, they were significantly ($p = 6.906 * 10^{-5}$) longer in the Sudanian zone compared to those of Transition (AB) and Guinean (PA and TO) zones.

Table 9 of the mean values of the features of the terminal leaflet reports the results of the analysis of variance made to compare the populations. The longest terminal leaflets were measured in TO (90.3 ± 22.3 mm), FM (86.9 ± 19.2 mm), and AK (81.7 ± 0.5 mm), whereas the smallest were in OK (69.5 ± 16.5 mm).

The average width of leaflet varied from 35.8 ± 9.3 mm in OK to 50.3 ± 11.4 mm in TO. In these two populations, the leaflets were significantly different ($p < 0.001$) from those of AK where the average width was 42.7 ± 12.1 mm. FM and AB populations were similar but had smaller leaflets than TO.

The longest petioles were collected in FM (5.56 ± 1.78 mm) and the shortest in PA (4.46 ± 1.23 mm).

Table 3: Leaf and dendrometric descriptors.

Level of description	Descriptors
Trunk and crown	Merchantable height expressed in meters (MH, m) Total height expressed in meters (TH, m) Diameter at 1.30 m from the soil in centimeters (DIA, cm)
Leaves	Total height of the leaf expressed in centimeters (LH, cm) Leaf width expressed in centimeters (LW, cm) Petiole leaf length expressed in centimeters (LPe, cm) Number of leaflets (Nle) Final leaflet length expressed in millimeters (LFle, mm) Final leaflet width expressed in millimeters (FleW, mm) Final leaflet and little petiole expressed in millimeters (LPeFle, mm)

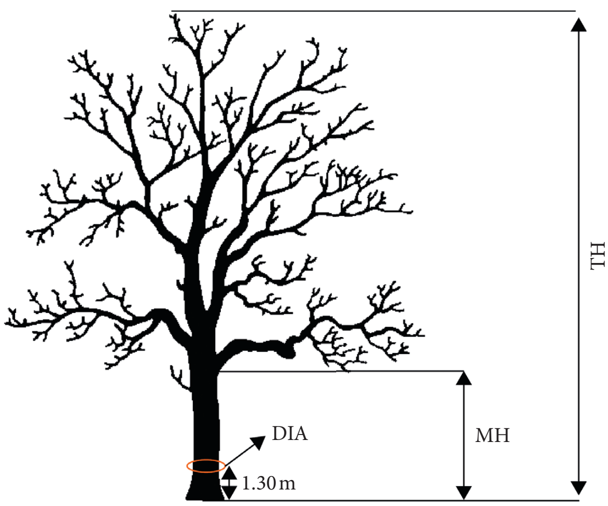


Figure 3: Dendrometric measurements (drawing: Johnson B. N.).

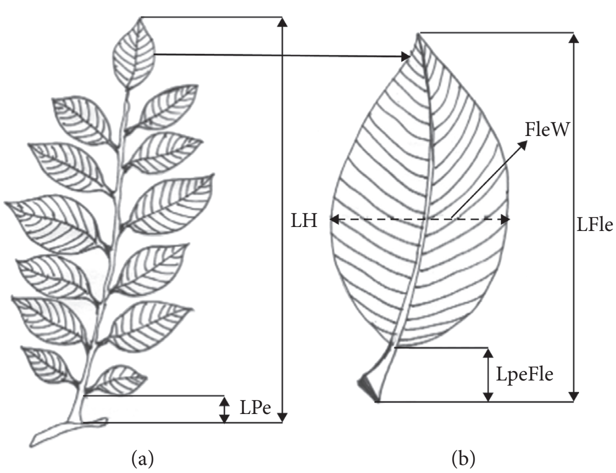


Figure 4: Measurement of leaf (a) and leaflet (b) of *P. erinaceus* (drawing: Johnson B. N.).

On the remaining sites, TO, AB, and OK had values not different from those of AK.

For all the descriptors evaluated the width of the leaf (LW) and terminal leaflet (FleW) are the most significant (p value (LW) = $4.3 * 10^{-8}$ and p value (FleW) = $4.07 * 10^{-10}$).

3.3. Variability of P. erinaceus Fruits' Characteristics. The length of the fruit in the protected area AB was the longest (58.61 ± 8.35 mm). Those from TO (51.92 ± 7.23 mm) and from the rural domain AK (51.41 ± 6.82 mm) have lower values ($p = 4.35 * 10^{-16}$). Populations of the protected area FM (48.63 ± 6.92 mm) and OK (46.47 ± 6.33 mm) had the lowest values (Table 10). Belonging to a protected area did not have an influence on this parameter because the minima as well as the maxima were found in this kind of area.

For the width of the fruit, the variance's analysis revealed significant differences ($p = 2.5 * 10^{-9}$). The classification by decreasing order of size was FM (5.62 ± 1.48 mm), OK (5.95 ± 1.44 mm), AK (5.62 ± 1.27 mm), AB (5.42 ± 1.25 mm), and then TO (4.78 ± 2.17 mm). The width of the fruit of populations was fairly homogeneous in view of the standard deviations and coefficients of variation, except in TO where this coefficient increased to 45%, which is double that of the other populations. The results also indicate that the minimal values as well as the maximal values were measured in the protected areas (Table 10).

There was a significant difference ($p = 0.0206$) in weight between the fruit from the protected area of AB at 372 ± 88 mg (highest mean values) and those of TO at 305 ± 87 mg. Fruit from other provenances, OK, FM, and AK, had similar weights (Figure 9).

The average number of seeds per fruit was one seed at each site. The fruits produced up to two seeds in OK and three seeds in the other provenances with significant differences ($p = 2.2 * 10^{-16}$) (Table 10).

The influence of the climatic zone on these descriptors (length, width, and weight) was observed for all fruits' characteristics. The longest fruits were found in the Transition (AB) zone while the weakest values were recorded in the Guinean (PA and TO) zone. For the width, the difference ($p = 1.568 * 10^{-7}$) was between Sudanian (OK and FM) trees (higher values) and Transition (AB) and Guinean (PA and TO) zones (lower values). The heaviest fruits were found in the Transition (AB) zone and the lightest where it rained most (Table 11).

3.4. Variability of P. erinaceus Seeds' Characteristics. The length of seeds varies very significantly ($p = 9.85 * 10^{-14}$) from one site to another. FM had the highest values (9.68 ± 1.06 mm), whereas the weakest were found in the

Table 4: Propagule descriptors.

Level of description	Descriptors
Fruits	Total length of the fruit expressed in millimeters (LFr, mm) Width of the fruit expressed in millimeters (WiFr, mm) Weight of the fruit expressed in milligrams (WeFr, mg)
Seeds	Number of seeds per fruit (NbS) Length of the seed expressed in millimeters (LS,mm) Width of the seed expressed in millimeters (WiS, mg) Weight of the seed expressed in milligrams (WeS, mg)

Figure 5: Measurement of the length of fruit (LFr) of *P. erinaceus* [18].

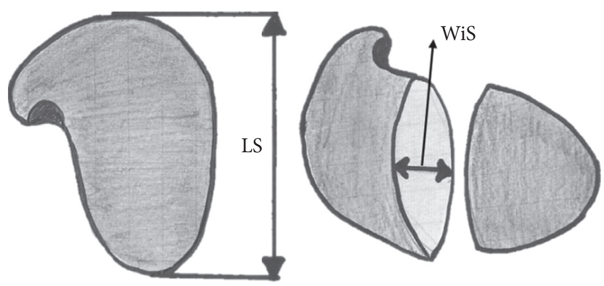


Figure 6: *P. erinaceus* seeds' measurements (drawing: Johnson B. N.).

Table 5: Mean values and coefficients of variation (CV in percentage) of dendrometric variables.

Dendrometric characteristics		Oti-Keran (OK)	Fazao-Malfakassa (FM)	Abdoulaye (AB)	Togodo (TO)	Plateau Akposso (AK)	p value
Merchantable height (MH, m)	Mean ± SD CV (%)	5.90 ± 1.65a (28)	6.45 ± 1.14a (17.81)	5.96 ± 2.2a (36.88)	4.59 ± 1.51b (33.05)	4.03 ± 1.23b (30.45)	$4.78.10^{-8}$***
Total height (TH, m)	Mean ± SD CV (%)	13.56 ± 3.12b (23.01)	19.18 ± 3.01a (15.72)	13.3 ± 2.46bc (18.53)	13.06 ± 2.24bc (17.16)	11.35 ± 2.08c (18.39)	$2.2.10^{-16}$***
Diameter to 1.30 m from soil (DIA, cm)	Mean ± SD CV (%)	34.06 ± 7.28b (21.37)	42.78 ± 11.29a (26.39)	38.71 ± 9.36ab (24.2)	34.49 ± 6.8b (19.72)	22.05 ± 4.39c (19.93)	$4.05.10^{-15}$***

SD: standard deviation; test of Tukey: the values followed by the same letter on one line are not significantly different at the threshold of alpha = 0.05. Codes of significance: * ≤ 0.05, ** ≤ 0.01, and *** = 0.001.

rural domain AK (8.84 ± 1.26 mm). The populations of OK (9.29 ± 1.22 mm), AB (9.14 ± 1.22 mm), and TO (9.31 ± 1.0 mm) were lower than FM but higher than AK. The lengths are very homogenous within every population (CV < 15%), but less so the width and the weight, where the variation coefficients exceed the threshold of 15% on average (Table 12).

The width of the seed according to the populations was significant ($p = 0.039$). The greatest width was in AB (2.43 ± 0.60 mm) and the lowest in FM (2.27 ± 0.62 mm). On the other sites OK, TO, and AK, the variance's analysis showed no significance.

OK (73.26 ± 18.72 mg) and FM (71.63 ± 24.08 mg) had the heaviest seeds. AB (66.13 ± 22.15 mg), TO (67.99 ± 13.9 mg), and AK (65.84 ± 19.42 mg) had the lightest seeds (Figure 10).

When we consider the climatic zone, the highest significant differences ($p < 0.001$) were for the length and the weight of the

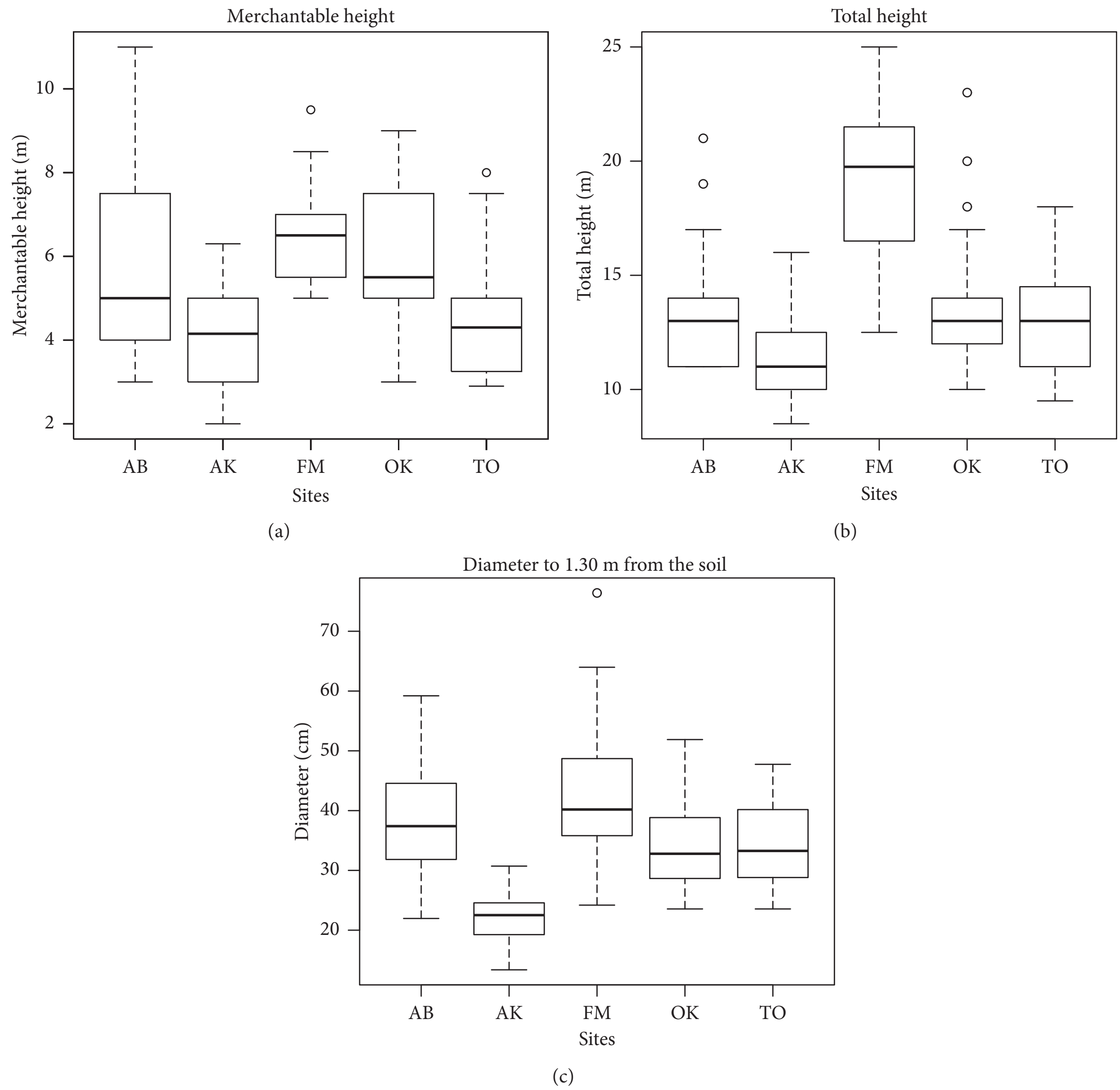


Figure 7: Distribution of tree dendrometric characteristics at the five sites.

Table 6: Mean values of dendrometric parameters according to the climate zone.

Climate zone		MH (m)	TH (m)	DIA (cm)
Sudanian (OK + FM)	Mean ± SD	6.2 ± 1.41a	16.63 ± 4.15a	38.82 ± 10.55a
Transition (AB)	Mean ± SD	5.97 ± 2.20a	13.3 ± 2.47b	38.72 ± 9.37a
Guinean (PA + TO)	Mean ± SD	4.34 ± 1.41b	12.28 ± 2.32b	28.82 ± 8.52b
p value		$1.033.10^{-8}$***	$8.229.10^{-11}$***	$6.601.10^{-8}$***

MH = merchantable height (m); TH = total height (m); DIA = diameter to 1.30 m from the soil (cm);SD: standard deviation; test of Tukey: the values followed by the same letter on one column are not significantly different at the threshold of alpha = 0.05. Codes of significance: * ≤ 0.05, ** ≤ 0.01, and *** = 0.001.

seed. Seeds of the Sudanian (OK and FM) zone were the longest compared with the Transition (AB) and Guinean (PA and TO) zones. Seeds are wider when they are produced in the Transition (AB) domain. Finally, seeds of the driest zone (Sudanian = OK + FM) are heavier than those of the Transition (AB) and Guinean (PA and TO) zones (Table 13).

In conclusion, length (LS) and weight (WeS) of the seed provided the most conclusive results ($p \ll 0.001$) and the protected sites registered most significant values of length and weight in comparison with those of the rural domain.

3.5. Pterocarpus erinaceus Populations Identified in Togo. Principal Component Analysis (PCA) enabled us to represent the positions of 142 trees with regard to the 6 most discriminating quantitative variables on the axes 1, 2, and 3,

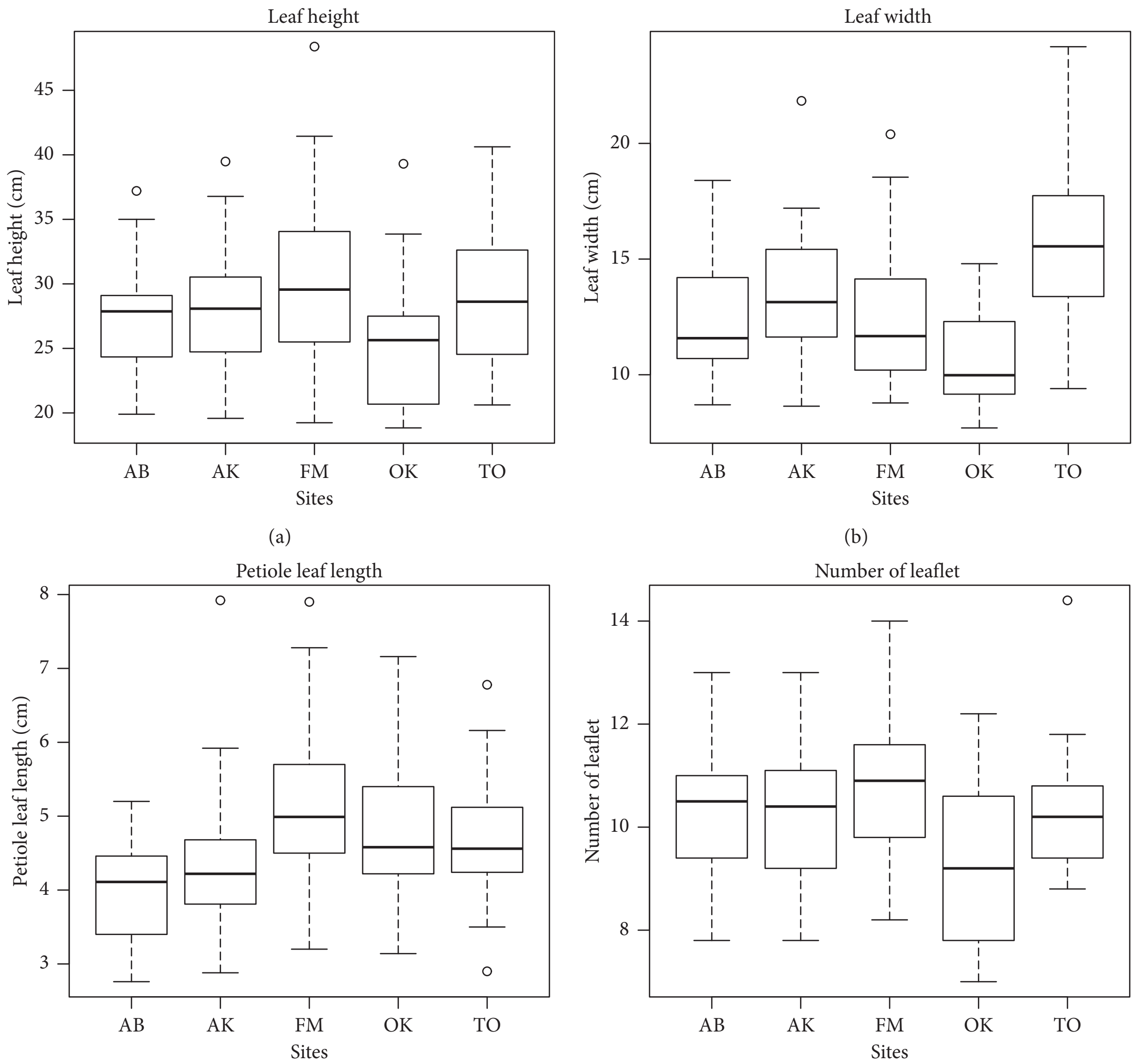


Figure 8: Distribution of trees' leaf characteristics at the five sites.

Table 7: Mean values and coefficients of variation (CV in percentage) of leaf variables.

Leaf characteristics		Oti-Keran (OK)	Fazao-Malfakassa (FM)	Abdoulaye (AB)	Togodo (TO)	Plateau Akposso (AK)	p value
Leaf height (LH, cm)	Mean ± SD CV (%)	25.56 ± 5.82b (22.78)	30.25 ± 7.52a (24.88)	27.45 ± 5.05ab (18.4)	29.44 ± 6.51ab (22.14)	28.16 ± 6.55ab (23.29)	0.01864*
Leaf width (LW, cm)	Mean ± SD CV (%)	10.70 ± 2.06c (26.44)	12.30 ± 2.85bc (29.22)	12.18 ± 2.18bc (24.12)	15.41 ± 3.35a (27.5)	13.59 ± 2.98ab (27.5)	$4.39.10^{-8}$***
Length of petiole (LPe, cm)	Mean ± SD CV (%)	4.79 ± 1.13a (23.74)	5.08 ± 1.24a (24.42)	4.00 ± 0.93b (23.28)	4.66 ± 0.97a (20.95)	4.43 ± 1.22ab (27.61)	0.00029***
Number of leaflets (nfo)	Mean ± SD CV (%)	9.30 ± 1.85b (19.97)	10.77 ± 1.95a (18.15)	10.2 ± 1.66ab (16.26)	10.29 ± 1.7ab (16.52)	10.23 ± 1.77ab (17.37)	0.0028**

SD: standard deviation; test of Tukey: the values followed by the same letter on one line are not significantly different at the threshold of alpha = 0.05. Codes of significance: * ≤ 0.05, ** ≤ 0.01, and *** = 0.001.

which represent 79.23% of the total inertia (Figures 11(a)–11(d)). It enabled us to distinguish three plantation groups. The first axis of the analysis (33.17% of the inertia) represents the fruit's characteristics (width) and the seeds (length and weight). The second axis (29.78%) shows the distribution of the trees according to the characteristics of leaves and terminal leaflets (width), and the third one shows the distribution according to the length of the fruit.

Table 8: Mean values of leaf parameters according to the climatic zone.

Climatic zone		LF (cm)	LW (cm)	LPe (cm)
Sudanian (OK, FM)	Mean ± SD	28.12 ± 6.36a	11.58 ± 2.63a	4.95 ± 1.03a
Transition (AB)	Mean ± SD	27.45 ± 4.12a	12.18 ± 2.18a	4.00 ± 0.71b
Guinean (PA, TO)	Mean ± SD	28.89 ± 5.51a	14.63 ± 3.3b	4.57 ± 0.91b
p value		0.521	$2.816{\times}10^{-7}$***	$6.906{\times}10^{-5}$***

LF: length of the leaf; LW: width of the leaf; LPe: length of the petiole of the leaf; SD: standard deviation; test of Tukey: the values followed by the same letter on one column are not significantly different at the threshold of alpha = 0.05. Codes of significance: *≤0.05, **≤0.01, and ***=0.001.

Table 9: Mean values of the terminal leaflet features of populations. .

Final leaflet measurements (mm)		Oti-Kéran (OK)	Fazao-Malfakassa (FM)	Abdoulaye (AB)	Togodo (TO)	Plateau Akposso (AK)
Length (LFle)	Mean ± SD	69.5 ± 16.5b	86.9 ± 19.2a	79.9 ± 14.5ab	90.3 ± 22.3a	81.7 ± 0.5a
Width (FleW)	Mean ± SD	35.8 ± 9.3c	38.1 ± 9.5bc	38.9 ± 9.4bc	50.3 ± 11.4a	42.7 ± 12.1b
Length little petiole (LpeFle)	Mean ± SD	4.50 ± 1.42b	5.56 ± 1.78a	4.70 ± 0.85b	4.94 ± 1.47ab	4.46 ± 1.23b

SD: standard deviation; test of Tukey: the values followed by the same letter on one line are not significantly different at the threshold of alpha = 0.05.

Table 10: Mean values and coefficients of variation (CV in percentage) of the variables of *P. erinaceus* fruits.

Fruit characteristics		Oti-Kéran (OK)	Fazao-Malfakassa (FM)	Abdoulaye (AB)	Togodo (TO)	Plateau Akposso (AK)	*p* value
Length of fruit (LFr, mm)	Mean ± SD CV (%)	46.47 ± 6.33c (13.64)	48.83 ± 6.92bc (14.17	58.61 ± 8.35a (14.25)	51.92 ± 7.23b (13.93)	51.41 ± 6.82b (13.27)	$4.35.10^{-16}$***
Width of fruit (WiFr, mm)	Mean ± SD CV (%)	5.95 ± 1.44ab (24.2)	6.52 ± 1.48a (22.74)	5.42 ± 1.25bc (23.11)	4.78 ± 2.17c (45.52)	5.62 ± 1.27b (22.58)	$2.5.10^{-9}$***
Weight of fruit (WeFr, mg)	Mean ± SD CV (%)	334 ± 100ab (29.89)	359 ± 89ab (25.39)	372 ± 88a (23.71)	305 ± 87b (28.57)	342 ± 85ab (24.99)	0.0206*
Number of seeds per fruit (NbG)	Mean ± SD CV (%)	1.04 ± 0.19d (19.12)	1.16 ± 0.37c (32.36)	1.25 ± 0.44b (35.41)	1.1 ± 0.31cd (28.24)	1.38 ± 0.50a (36.66)	$2.2.10^{-16}$***

SD: standard deviation; test of Tukey: the values followed by the same letter on one line are not significantly different at the threshold of alpha = 0.05. Codes of significance: * ≤ 0.05, ** ≤ 0.01, and *** = 0.001.

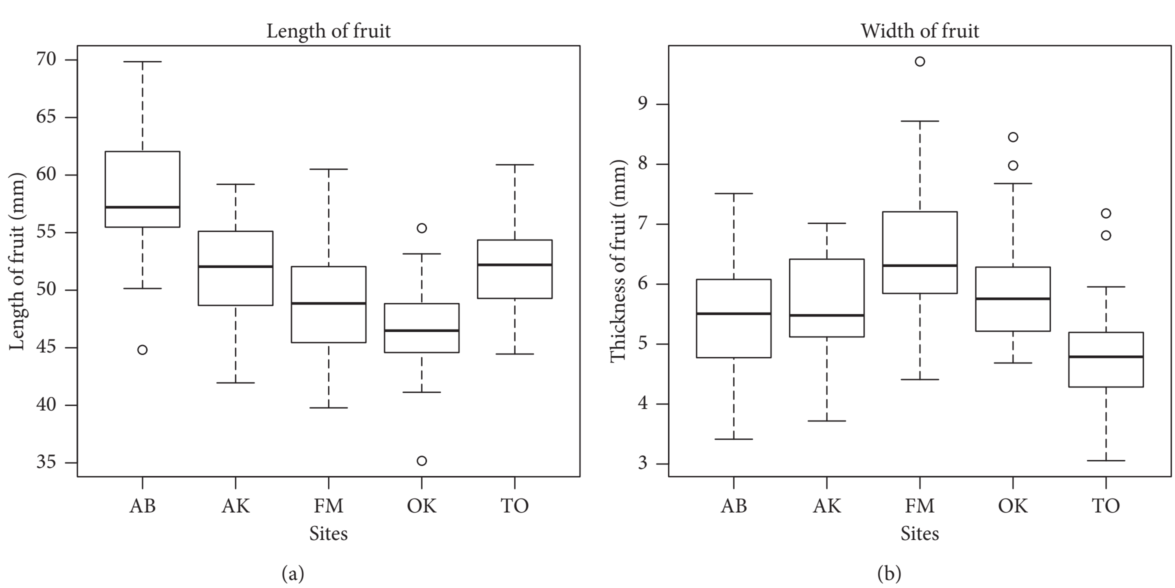
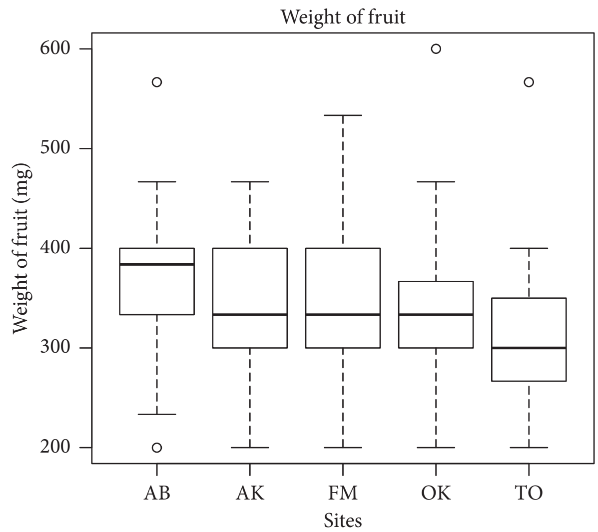


Figure 9: Continued.



(c)

Figure 9: Distribution of trees' fruit characteristics at the five sites.

Table 11: Mean values of the parameters of the fruit according to the climatic zone.

Climatic zone		LFr (mm)	WiFr (mm)	WeFr (mg)
Sudanian (OK, FM)	Mean ± SD	47.76 ± 4.66a	6.27 ± 1.10a	344.85 ± 82.95ab
Transition (AB)	Mean ± SD	58.61 ± 5.75b	5.43 ± 0.89b	372.14 ± 75.46a
Guinean (PA, TO)	Mean ± SD	51.70 ± 4.34c	5.17 ± 0.99b	322.28 ± 76.94b
p value		$<2.2.10^{-16***}$	$1.56.10^{-7***}$	0.02066^{*}

LFr = length fruit, WiFr = width fruit, WeFr = weight fruit. SD: standard deviation; Test of Tukey: the values followed by the same letter on one column are not significantly different at the threshold of alpha = 0.05. Codes of significance: *≤0.05, **≤ 0.01, and ***=0.001.

Table 12: Mean values and coefficients of variation (CV in percentage) of *P. erinaceus* seeds' variables.

Seeds' characteristics		Oti-Kéran (OK)	Fazao-Malfakassa (FM)	Abdoulaye (AB)	Togodo (TO)	Plateau Akposso (AK)	p value
Lenght of seed	Mean ± SD	9.29 ± 1.22b	9.68 ± 1.06a	9.14 ± 1.22b	9.31 ± 1.01b	8.84 ± 1.26c	$9.85.10^{-14***}$
(LS, mm)	CV (%)	(13.13)	(10.95)	(13.34)	(10.84)	(14.25)	
Width of seed	Mean ± SD	2.33 ± 0.57ab	2.27 ± 0.62bc	2.43 ± 0.60a	2.39 ± 0.51ab	2.34 ± 0.74ab	0.039^{*}
(WiS, mm)	CV (%)	(24.26)	(40.66)	(24.69)	(21.33)	(31.62)	
Weight of seed	Mean ± SD	73.26 ± 18.72a	71.63 ± 24.08ab	66.13 ± 22.15c	67.99 ± 13.9bc	65.84 ± 19.42c	$9.52.10^{-6***}$
(WeS, mg)	CV (%)	(24.65)	(33.8)	(33.33)	(19.4)	(29.23)	

SD: standard deviation; test of Tukey: the values followed by the same letter on one line are not significantly different at the threshold of alpha = 0.05. Codes of significance: *≤0.05, **≤0.01, and ***=0.001.

Further analysis of factorial maps and digital classification allowed us to identify three morphotypes of *P. erinaceus* in Togo (Figure 12):

The first morphotype (green, Figure 11) corresponding to Group 1 was mainly composed of trees from OK (36.11%) and FM (33.33%). They were characterized by the widest fruits at 6.81 ± 1.20 mm, the shortest fruit at 48.22 ± 3.22 mm, and heaviest seeds at 83.31 ± 11.37 mg. Their leaves and terminal leaflets measured 11.27 ± 2.13 cm and 36.51 ± 6.27 mm, respectively (Table 14); these are the tallest trees from Figure 7.

The second morphotype (black, Figure 11) corresponding to Group 2 was mainly composed of individuals from TO (56.41%) and AK (25.64%). They were characterized by the leaves and large terminal leaflets measuring 16.38 ± 2.56 cm and 52.33 ± 6.01 mm, respectively. Their fruits measured 51.86 ± 4.78 mm long with a width of 5.12 ± 0.87 mm. Those fruits contained seeds of 9.14 ± 0.66 mm long and weighing 64.87 ± 10.77 mg (Table 14); these are the shortest trees from Figure 7.

The third morphotype (red, Figure 11), Group 3, gathering 35% of individuals in the protected area AB, contained the longest fruits at 58.12 ± 5.94 mm with a width of 5.21 ± 0.88 mm. They have leaves a bit larger (11.68 ± 1.63 cm) with leaflets at 36.52 ± 3.82 mm longer than those of Group 1. Their seeds at 8.85 ± 0.78 mm long and weighing 58.20 ± 15.68 mg were shorter and lighter than those of Groups 1 and 2 (Table 14).

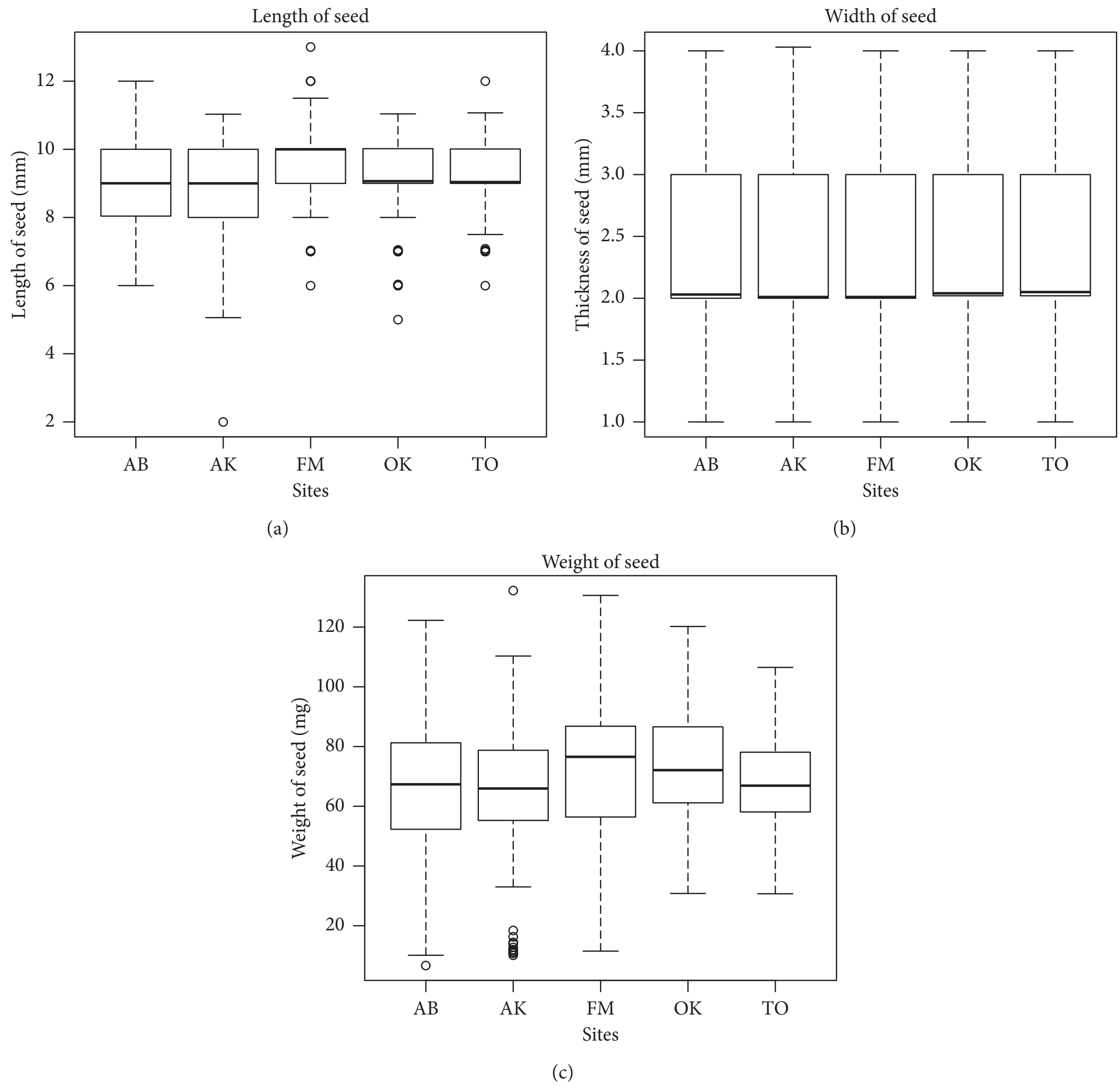


Figure 10: Distribution of trees' seed characteristics at the five sites.

Table 13: Mean values of the seeds' parameters according to the climatic zone.

Climatic zone		LS (mm)	WiS (mm)	WeS (mg)
Sudanian (OK, FM)	Mean ± SD	9.49 ± 1.16a	2.31 ± 0.60a	72.45 ± 21.56a
Transition (AB)	Mean ± SD	9.15 ± 1.23b	2.43 ± 0.61b	66.13 ± 22.19b
Guinean (PA, TO)	Mean ± SD	9.10 ± 1.16b	2.37 ± 0.63ab	67.01 ± 16.67b
p value		$1.784.10^{-7***}$	0.0189^{*}	$2.133.10^{-6***}$

LS = length of seed, WiS = width of seed, WeS = weight of seed. SD: standard deviation; test of Tukey: the values followed by the same letter on one column are not significantly different at the threshold of alpha = 0.05. Codes of significance: *≤0.05, **≤0.01, and ***= 0.001.

4. Discussion

This study allowed us to examine the morphological characteristics (dendrometric parameters, leaves, fruits, and seeds) in five natural stands of *P. erinaceus*. The statistical analysis highlighted three (3) morphologically distinct populations, significantly different from each other. Koura et al. [20] showed that generally, morphological data analysis of plant species leads to the identification and determination of diversity groups in order to precise their constitution. Trees from the protected areas OK, FM, and AB presented the highest mean values of total height (13 to 19 m), merchantable height (5.9 to 6.45 m), and also the diameter (34 to 42 cm). These results indicate that these three sites, situated, respectively, in the ecological zones 1, 2, and 3, seem to be more favourable to the optimal development of *P. erinaceus*

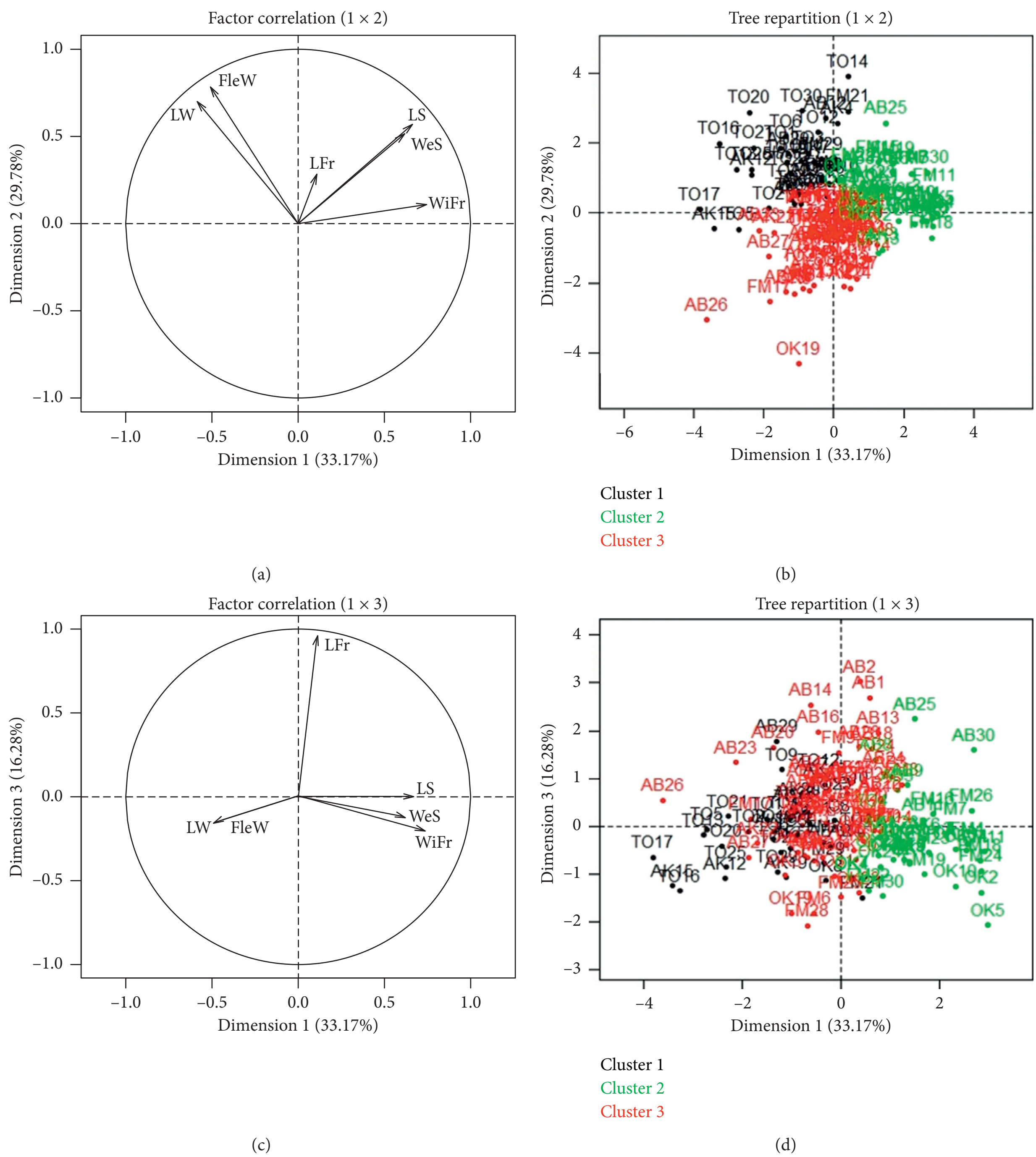


Figure 11: Projection of the trees in the space of axes 1, 2, and 3. Factor correlation for (a) axes 1 and 2 and (c) axes 1 and 3. Tree repartition in the space of (b) axes 1 and 2 and (d) axes 1 and 3.

stands. In fact, these areas, characterized by the Sudanian savannah (Zone 1), dry forest and savannah (Zone 2), and wooded Guinean savannah (Zone 3), are communities where *P. erinaceus* is more present [5, 21, 22]. In contrast, the nonprotected area (e.g., in AK) has the lowest values (total height 11 m, merchantable height 4 m, and diameter 22 cm). These results are consistent with those obtained by Adjonou et al. [9]. Trees of the protected area show better performance than those of the exploited areas. Furthermore, in the nonprotected zones, in addition to exploitation, agriculture is one of the main activities leading to regular clearing of lands for crop's production, reducing available resources. Consequently, the landscape composed of forest fragments [23].

Morphological variability of Togolese populations of *P. erinaceus* is also found at the level of the leaves, fruits, and seeds. This variability could be due to environmental factors (rainfall, types of soils, etc.) resulting from adaptive

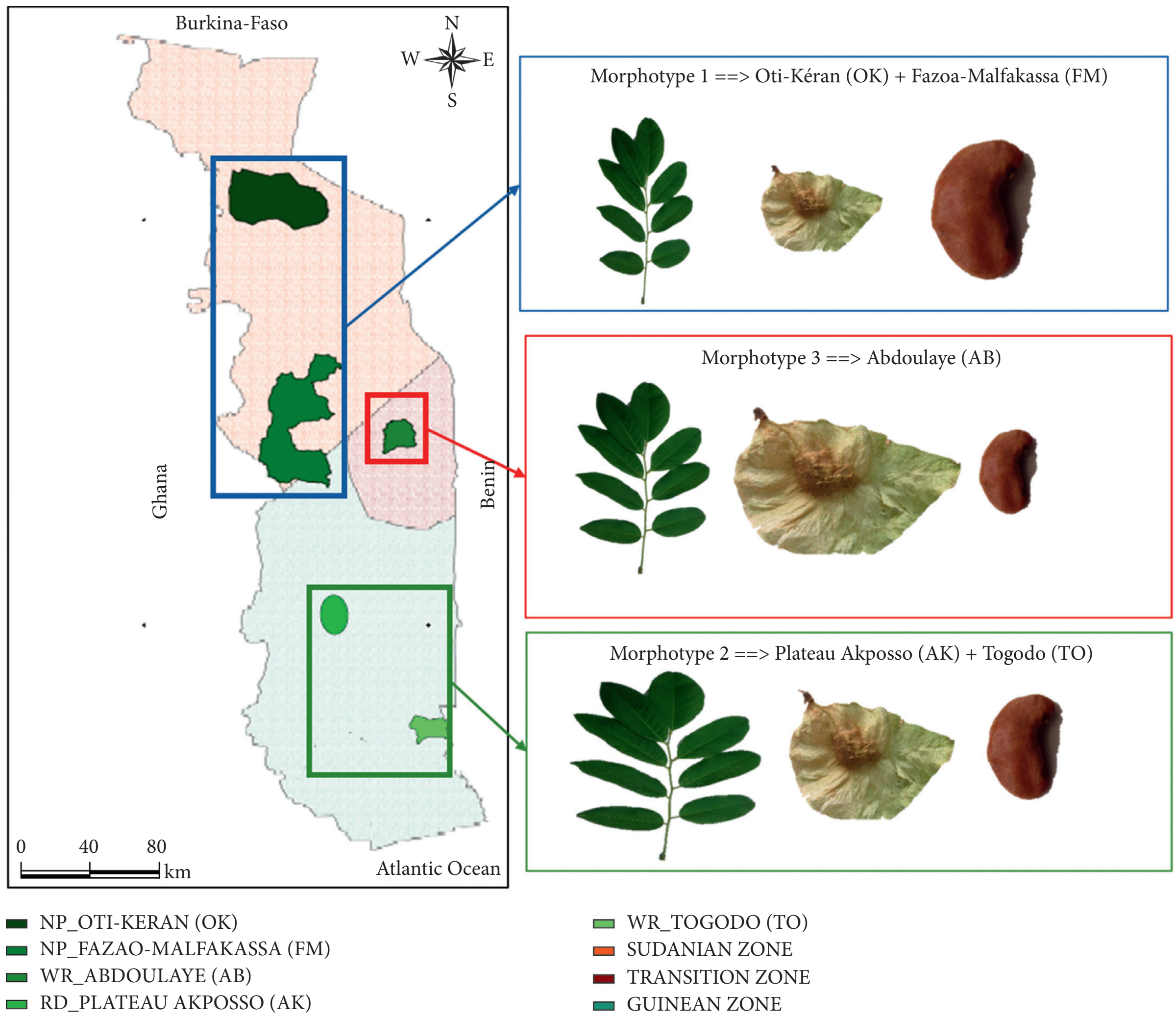


Figure 12: *Pterocarpus erinaceus*' populations identified in Togo.

Table 14: Mean values of the groups' characteristics obtained through the digital classification.

Features		Morphotypes 1	2	3
Percentages of every population (%)	Oti-Kéran (OK)	36.11	2.56	18.33
	Fazao-Malfakassa (FM)	33.33	7.69	20.00
	Abdoulaye (AB)	16.67	7.69	35.00
	Togodo (TO)	11.11	25.64	15.00
	Plateau Akposso (AK)	2.78	56.41	11.67
Leaf width (LW, cm)	Mean ± SD	11.27 ± 2.13	16.38 ± 2.56	11.68 ± 1.63
Final leaflet width (LFle, mm)	Mean ± SD	36.51 ± 6.27	52.33 ± 6.01	36.52 ± 3.82
Length of fruit (LFr, mm)	Mean ± SD	48.22 ± 3.22	51.86 ± 4.78	58.12 ± 5.94
Width of fruit (WiFr, mm)	Mean ± SD	6.81 ± 1.20	5.12 ± 0.87	5.21 ± 0.88
Length of seed (LS, mm)	Mean ± SD	10.00 ± 0.37	9.14 ± 0.66	8.85 ± 0.78
Weight of seed (WeS, mg)	Mean ± SD	83.31 ± 11.37	64.87 ± 10.77	58.20 ± 15.68

SD: standard deviation.

responses to optimize their development [24, 25]. In fact, the majority of the minimal data obtained for the fruits and leaves was collected from the least watered and hottest zone such as OK, whereas the maxima were found in the zones of high rainfall. Environmental effects on morphological characteristics have been observed with other plant species such as *Detarium microcarpum* [11], *Lawsonia inermis* [26, 27], *Medicago truncatula* [28], and *Pistacia atlantica* [29]. The amount of assimilates produced due to photosynthesis in the leaves and the resultant production of organs (fruits and seeds) would be restrained due to lower dimensions of leaves [30]. Fahn [31] states that the decrease in the length of the leaves and the fruits is positively correlated to the increase of the aridity of the climate.

In contrast to fruits and leaves, the seeds in OK possessed high lengths, widths, and weights similar to those of FM. The weak correlation between the features of the seed with those of the leaf and the fruit is most likely due to genetic variation [32, 33].

The discriminating morphological descriptors of width of the leaf and the terminal leaflet, the length and width of the fruit, and the length and weight of the seed made it possible to distinguish 3 groups of individuals. The first group was formed mainly by the trees of Sudanian OK and FM with the widest fruits and longest and heaviest seeds. The second group trees of AK and TO of the Guinean zone had the largest leaves and leaflets. The third group representative of the Transition domain (AB) was composed of the smallest and lightest seeds.

5. Conclusion

Our work focused on the evaluation of the dendrometrical and morphological descriptors of *P. erinaceus* and showed interpopulation differences. The most discriminating characteristics of the leaf (width of the leaf and the terminal leaflet), fruit (length and width), and seed (length and weight) suggest three morphotypes. Our quantitative descriptors helped to distinguish the presence of morphotypes and discerned the most important factors for setting up selection and *P. erinaceus* domestication programs. For example, "Oti-Kéran (OK) + Fazao-Malfakassa (FM)" and "Abdoulaye (AB)" groups' individuals have the best forest characteristics such as long leaves and large fruits containing long and heavy seeds. The knowledge gained from these works could be used, in addition to the information derived from recent studies on the technological qualities of wood species, in the context of the selection of ligneous plants that respond to the concerns of forest stakeholders as well as local communities.

In-depth studies on the phenology of the species, the strategies, and genetic diversity would make it possible to better understand the forestry of the species in order to guarantee its sustainable conservation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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