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VARIABILITY OF THE MORPHOLOGICAL CHARACTERS OF *BALANITES AEGYPTIACA* (L.) DEL. BASED ON THE CLIMATIC GRADIENT OF ZINDER REGION (EAST-CENTRAL NIGER)

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ABSTRACT

This study, carried out in the centre-east of Niger, aims to analyse the variability in morphological characteristics of *Balanites aegyptiaca*, based on the climatic gradient. Thirteen (13) morphological descriptors were defined and used to characterise the natural populations of *B. aegyptiaca*. They concerned measurements on the morphological aspects of the leaves, thorns and fruits of six (6) spontaneous populations of *Balanites aegyptiaca*. For each population of *B. aegyptiaca*, a random selection of 30 individuals carrying fruits was made. On each individual, measurements were made on 10 fresh leaves, 10 fully developed thorns free from parasites, and 10 ripe fruits showing no signs of physical damage. In total, 1800 fruits, 1800 leaves and 1800 thorns coming from 180 individuals of *Balanites aegyptiaca* were subjected to measurements. The results of the study showed that populations from the sahelo-sudanian zone are characterised by heavy and big fruits, long leaflets and petioles, and thorns with large diameters. Those from the strictly sahelian zone were characterised by large endocarps and a thick pulp. Those from the sahelo-saharian zone were especially characterised by long thorns. This study has demonstrated the morpholoigcal variability of populations of *Balanites aegyptiaca* according to the climatic gradient, confirming the adaptability of the species in relation to the climate's aridity. This ability to adapt explains the wide ecological dispersion of the *Balanites aegyptiaca*. The current study is a contribution to an improved understanding of the different morphotypes of *Balanites aegyptiaca*, and constitutes a step towards the domestication of the species.

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INTRODUCTION

Africa is rich in cultivated and uncultivated plants holding large agronomic and economic potential. However, some of these species remain underutilised due to lack of interest from policy makers and scientists (Kouyaté *et al*., 2011). Additionally, researchers often face difficulties in identifying the origins of certain taxa. To address these challenges, several approaches have been tried, one of which is the evaluation of the morphological and physiological characteristics, which are an essential prerequisite for the study of molecular markers (Nasri *et al*., 2004). Several studies have explored the morphological variation and domestication of native West African species, such as Koura *et al*. (2013) on *Parkia biglobosa*, Diallo *et al*. (2010) on *Tamarindus indica*, Kouyaté *et al*. (2011) on *Adansonia digitata* and Assoumane (2011) on *Acacia senegal*. *B. aegyptiaca*, known under the common name desert date, is a fruit-bearing afro-indian species that also grows in the Arabian Peninsula and in India (Arbonnier, 2000; Eyog *et al*., 2000). It adapts to most types of soils. In the Sahel, it is found on soils that are sandy, rocky, clayey or clay-limish (Arbonnier, 2000). Its various organs are important sources of food for humans and animals, and used in medicine and in handicraft, which makes it an important contributor to local economies. Very few scientific studies have looked into the morphological diversity of this species. In Niger, the only study available offering a morphological description of *B. aegyptiaca* is the work of Abasse *et al*. (2011) that characterised the morphological variation of its fruits and seeds. However, in order use and manage trees and shrubs sustainably, an analysis of the morphological variability of their plant tissues is necessary in order to differentiate individuals (Kouyaté and Van Damme, 2002). Such an analysis of the variability also allows the targeting of morphotypes that are interesting to produce and to discover those that are connected to environmental factors (Zhang, 2002). For this reason, the present study attempts to analyse the variability of some morphological characters of *B. aegyptiaca*, according to the climatic gradient in the Zinder region.

MATERIALS AND METHODS

Study areas: The study was carried out in the Zinder region, in east-central Niger. The analysis of the morphological variation of *B. aegyptiaca* was made from trees of six different origins (municipalities) of the region (Figure 1). The six origins or municipalities are spread out through four departments and three climatic zones in the region. These climatic zones are defined and characterised by Agrhymet (2004). Each of the municipalities included in the study area has been considered representing one population of *B. aegyptiaca*. Table 1 summarizes the study sites' climatic characteristics, geographic locations and administrative zones.

Within each population of *B. aegyptiaca*, 30 individuals carrying fruits were randomly selected. To minimise the risk of sampling closely related individuals, a spacing of 100 m was respected between each sampled tree (Ayadi, 2013). On each individual, measurements were made on 10 fresh leaves, 10 fully developed thorns free from parasites, and 10 ripe fruits showing no signs of physical damage. In total, 1800 fruits, 1800 leaves and 1800 thorns spread across 180 individuals of *B. aegyptiaca* were examined.

Data collection

Measurement of the morphological characteristics of the leaves and thorns: The descriptive measurements on the leaves of *B. aegyptiaca* were carried out on the length of the leaflets, the width of the leaflets and the length of the petioles, all measured in mm by the use of a ruler. The measurements on the thorns concerned their lengths and the diameter of their bases, carried out respectively with a ruler and an electronic caliper.

Measurement of the morphological characteristics of the fruits

The following attributes were measured on the fruits:

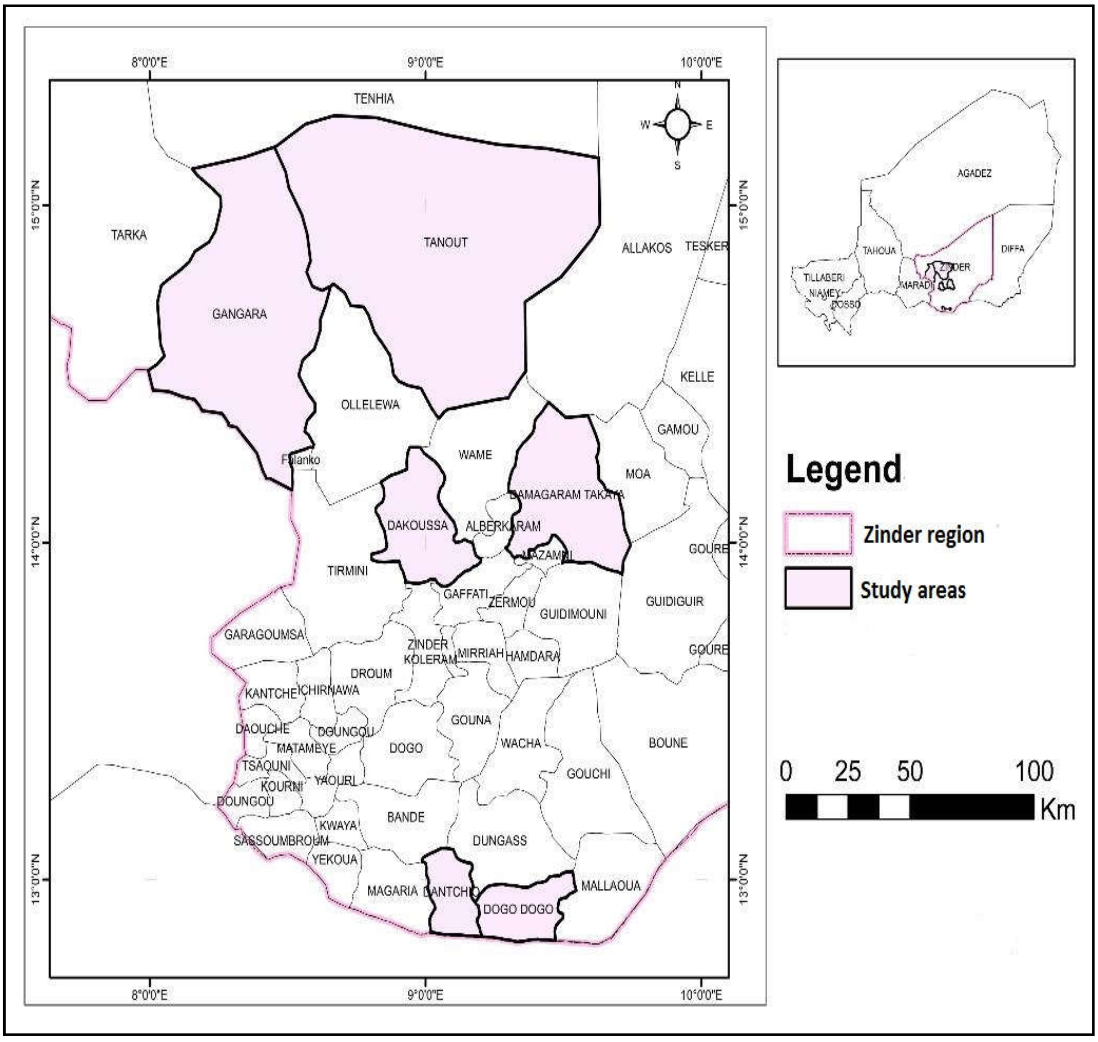

Figure 1. Localisation of the study areas in Zinder region (Niger)

Sampling: In this study, three plant parts of the *B. aegyptiaca* were examined: the leaves, the fruits and the thorns.

- Fruit length (in mm) and fruit width or median diameter (in mm), determined with an electronic caliper.

- Fruit weight (g) determined by weighing on an electronic scale.
- The pulp / mesocarp surrounding the woody endocarp was removed manually using a scalpel, and the weight per unit was measured on a scale (g).
- The length (in mm) and width (in mm) of the woody endocarp were measured after depulping, using a ruler.
- Pulp thickness (Pu.thick) in mm was determined through deduction, using the formula proposed by Ferradous (1995):
  Pu. thick = Fruit thickness – Endocarp thickness.
- Seed weight (g) was also measured after cracking the endocarp and extracting the seed. In the event an endocarp would enclose two seeds, they were measured and counted as a single seed.

Data analysis: The mean and the variation coefficient were calculated for the characters studied per climatic zone. The means of the morphological characters between the climatic zones were compared through a variance analysis (ANOVA) with a significance threshold of 5%. All morphological characters were subjected two by two to Spearman's rank correlation test. A matrix of the studied *B. aegyptiaca* populations and their morphological characters was put through a principal component analysis (PCA). All analyses were made with the help of the software Minitab 17.

RESULTS

Morphological characteristics of the leaves and thorns: A diversity of shapes and sizes were observed for leaves (Figure 2) and thorns (Figure 3) within the studied populations of *B. aegyptiaca*. The comparison of the means of the morphological characters of the leaves and thorns in the different climatic zones revealed a significant difference ($P < 0.05$) (Table 2). The sahelo-sudanian zone shows the highest values for all morphological characters except for the length of thorns, where the highest value was observed in the sahelo-saharian climate (6±0.9 cm). The greatest variation in the studied characters were observed in the sahelo-sudanian zone, and concerned the length of the petioles (CV = 35.4%) followed by the sahelo-saharian zone (CV = 30.2%). The smallest variation coefficient was observed in the sahelo-sudanian zone, and concerned the length of the leaflets (CV = 15.7%).

Table 1. Geographic and ecological characteristics of *B. aegyptiaca* populations studied

Departements	Munncipalities	Agro-ecological zoning	Average rainfall in mm (1998 to 2018)	GPS Coordinates
Magaria	Dan Tchiao	Sahelo-sudanian	593.41±125.12	12°52'N, 9°05'E
Dungass	Dogo Dogo		586.46±113.32	12°53'N, 9°19'E
Takeita	Dakoussa	Sahelian	467.84±108.69	13°59'N, 9°05'E
Damagaram Takaya	Damagaram Takaya		353.01±110.12	14°08'N, 9°29'E
Tanout	Tanout	Sahelo-saharian	250.55±69.87	14°52'N, 8°47'E
	Gangara			14°36'N, 8°30'E

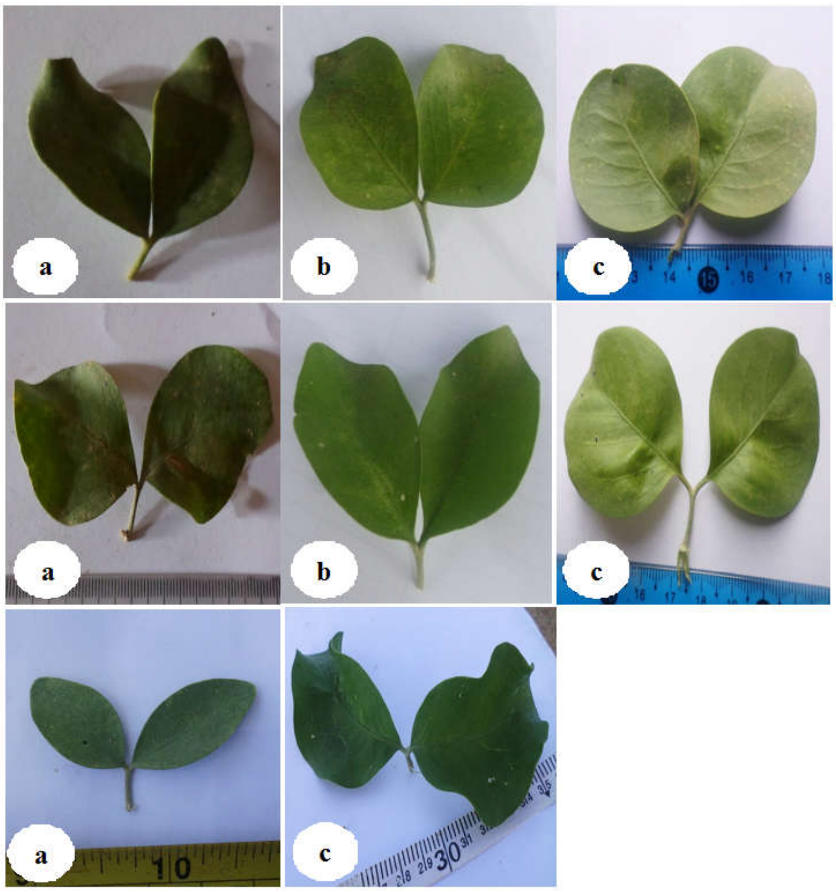

Figure 2. Some forms of leaves of *B. aegyptiaca* observed in the three climatic zones: (a) Sahelo-saharian; (b) Sahelian ; (c) Sahelo-sudanian

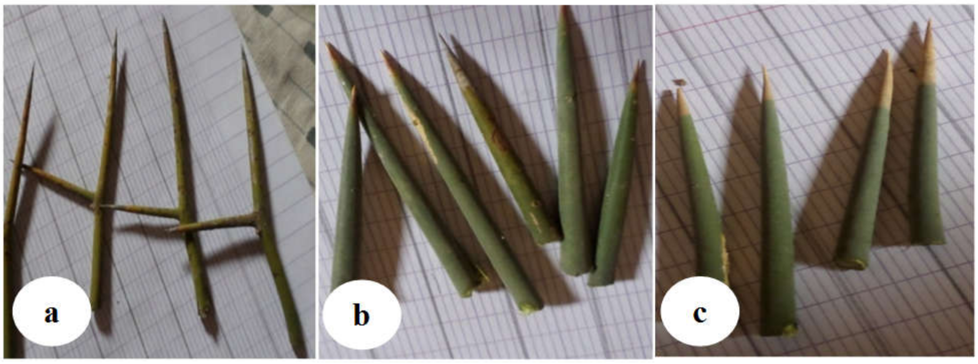

Figure 3. Some forms of thorns of *B. aegyptiaca* observed in the three climatic zones: (a) Sahelo-saharian; (b) Sahelian ; (c) Sahelo-sudanian

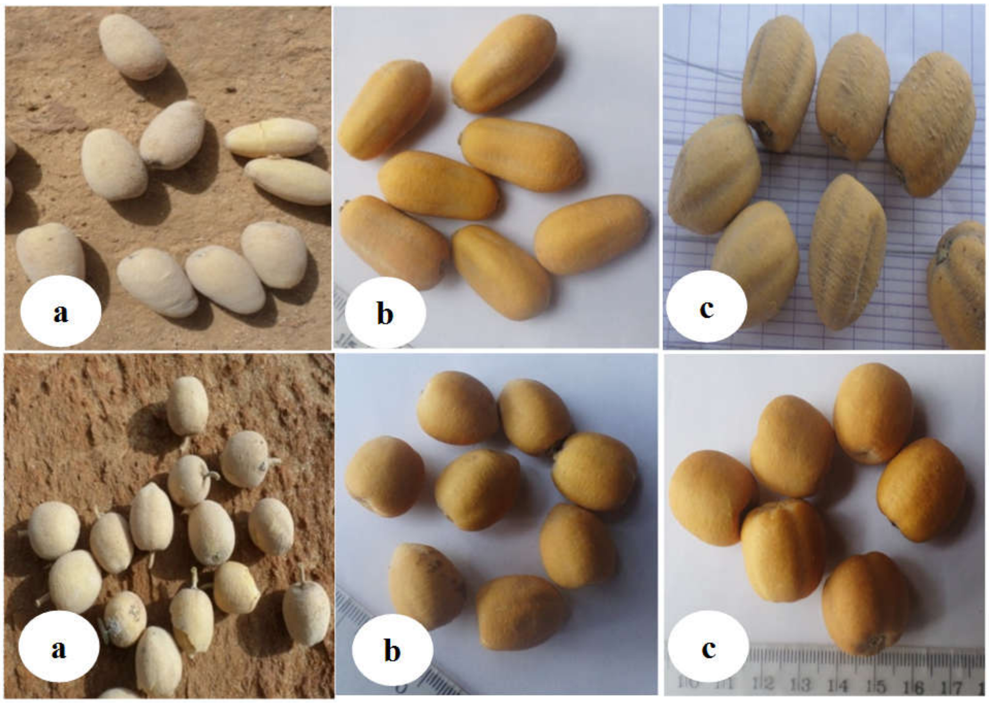

Figure 4. Some forms of fruits of *B. aegyptiaca* observed in the three climatic zones: (a) Sahelo-saharian; (b) Sahelian ; (c) Sahelo-sudanian

Table 2. Average values and coefficients of variation of the morphological characters of the leaves and thorns according the climatic zones

Characters	Sahelo-saharian		Sahelian		Sahelo-sudanian		Probability
	M	CV(%)	M	CV(%)	M	CV(%)	
Leaf.len (mm)	30.8±5.6[a]	18.3	39.2±7.6[b]	19.4	41.3b±6.5[b]	15.7	<0.001
Leaf.wid (mm)	22.3±4.8[a]	21.6	27.7±7.6[b]	27.5	28.4±5.6[b]	19.8	<0.001
Pet.leng (mm)	7.7±2.3[a]	30.2	8.2±2.4[b]	29.4	9.0±3.2[c]	35.4	<0.001
Thor.leng (cm)	6±0.9[a]	15.8	5.6±1.2[b]	21.9	5.7±1.5[b]	26.1	<0.001
Thor.dm (mm)	2.9±0.5[a]	18.0	3.3±0.5[b]	16.1	3.8±0.6[c]	16.5	<0.001

Leaf.len: length of leaflets; Leaf.wid: width of leaflets; Pet.leng: length of petioles; Thor.leng: length of thorns; Thor.dm: diameter of the thorns; M : mean ; CV : coefficient of variation ; the means followed by the same letter on the same line are not significantly different at the 5% threshold.

Table 3. Average values and coefficients of variation of the morphological characters of the fruits according the climatic zones

Characters	Sahelo-saharian		Sahelian		Sahelo-sudanian		Probability
	M	CV (%)	M	CV(%)	M	CV(%)	
Fr.leng (mm)	23.6±3.8[a]	16.3	27.1±5.2[b]	18.1	28.7±5.2[c]	18.3	<0.001
Fr.wid (mm)	18.6±1.8[a]	9.7	20.4±2.7[b]	13.6	19.6±2.7[c]	13.9	<0.001
Fr.weig (g)	3.8±1.1[a]	28.7	5.1±1.6[b]	32.8	5.7±1.6[c]	28.9	<0.001
En.leng (mm)	20.6±3.8[a]	18.7	24.6±5.3[b]	21.8	25.8±5.2[c]	20.4	<0.001
En.wid (mm)	15.5±1.9[a]	12.6	16.8±2.6[b]	15.7	16.1±2.8[c]	17.5	<0.001
Pu.thick (mm)	1.5±0.5[a]	33.6	1.7±0.6[b]	37.9	1.7±0.9[b]	54.5	<0.001
Pu.weig (mm)	1.4±0.4[a]	28.9	1.9±0.6[b]	32.8	2.1±0.6[c]	28.9	<0.001
Seed.weig (g)	1.5±0.4[a]	28.8	2.1±0.6[b]	32.8	2.3±0.6[c]	28.9	<0.001

Fr.leng : fruit length ; Fr.wid: fruit width ; Fr.weig : fruit weight ; En.leng: endocarp length ; En.wid: endocarp width; Pu.thick : pulp thickness; Pu.weig : pulp weigth ; Seed.weig : seed weigth ; M : mean ; CV : coefficient of variation ; the means followed by the same letter on the same line are not significantly different at the 5% threshold

Table 4. Matrix of correlation coefficients of Spearman ranks between the different morphological characters

	Leaf.len	Leaf.wid	Pet.leng	Thor.leng	Thor.dm	Fr.leng	Fr.wid	Fr.weig	Pu.thick	En.leng	En.wid	Pu.weig	Seed.weig
Leaf.len	1.00												
Leaf.wid	0.75**	1.00											
Pet.leng	0.26	0.21	1.00										
Thor.leng	0.03	0.04	0.09	1.00									
Thor.dm	0.36	0.28	0.22	0.15	1.00								
Fr.leng	0.26	0.22	0.14	-0.06	0.30	1.00							
Fr.wid	0.22	0.10	0.02	-0.01	0.28	0.20	1.00						
Fr.weig	0.27	0.24	0.11	-0.00	0.42	0.64*	0.56*	1.00					
Pu.thick	0.13	0.10	0.05	0.05	0.12	0.16	0.34	0.26	1.00				
En.leng	0.26	0.22	0.14	-0.06	0.30	0.99***	0.20	0.64*	0.16	1.00			
En.wid	0.15	0.04	-0.00	-0.05	0.23	0.13	0.82**	0.43	-0.15	0.13	1.00		
Pu.weig	0.28	0.25	0.10	-0.01	0.41	0.25	0.56*	0.043	0.26	0.64*	0.43	1.00	
Seed.weig	0.27	0.25	0.11	-0.00	0.41	0.63*	0.56*	0.99***	0.26	0.63*	0.43	0.9***	1.00

***: Very highly significant; **: Highly significant; *: Significant.

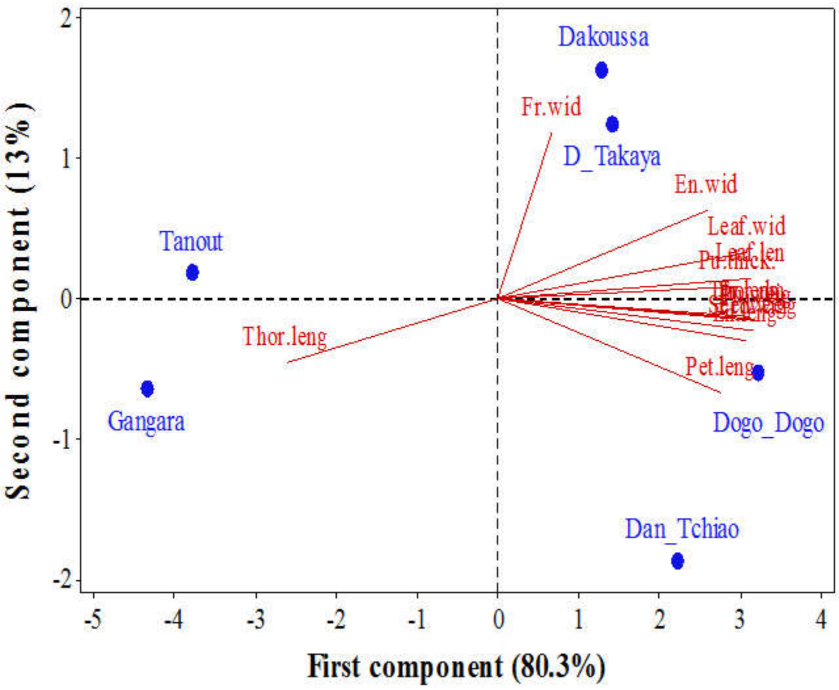

Figure 5. Superimposed representation of morphological characters and populations of *B. aegyptiaca* on the factorial plane of the Principal Component Analysis (PCA)

Morphological characteristics of the fruits: Through the characterisation of the morphological variability, a diversity of fruit shapes could be identified for *B. aegyptiaca* in the three studied climatic zones (Figure 4). The results of the analysis of variance demonstrate that there are statistically significant differences between the climatic zones for all of the fruits morphological characters (Table 3). Therefore, the mean morphological characters, when compared two by two, are significantly different except for the means of the pulp thickness between sahelian and the sahelo-sudanian zones. The intra-zone variability is at its highest for the mean thickness of the pulp in the sahelo-sudanian zone (CV = 54.5%), in the sahelian zone (CV = 37.9%) and in the sahelo-saharian zone (CV = 33.6%). The lowest coefficient of variation was observed on the width of the thickness of the fruits in the sahelo-saharian climate (CV = 9.7%).

Structuring of the studied *B. aegyptiaca* populations: The principal component analysis (PCA) showed that the two first components explained 93.3% of the total variance. Axis 1 taken alone concentrated 80.3% of the information, whilst the second axis held 13% (Figure 5). The analysis of the factorial design revealed the distribution of the *B. aegyptiaca* populations based on their morphological characters.

- The populations of the sahelo-sudanian zone (Dogo Dogo and Dan Tchiao) are characterised not only by heavy fruits, seeds and pulp, but also by the length of their leaflets and petioles, and by thorns with thick diameters.
- The populations of the sahelian zone (Dakoussa and Damagaram Takaya) are characterised by long and wide endocarps, wide fruits, wide leaflets and a thick pulp.
- The populations of the sahelo-saharian zone (Tanout and Gangara) are especially characterised by very long thorns.

Correlation between the morphological characteristics: The correlation matrix between the morphological characters shows that all significant correlations are positive (Table 4). Certain highly significant correlations can be noted within the following characters: length of the fruits and width of the endocarps (r = 0.99), weight of the seeds and weight of the pulp (r = 0.99), weight of the seeds and weight of the fruits (r = 0.99). No significant correlation could be established between two characters relating to different plant parts of the species. The length (Thor.leng) and the diameter (Thor.dm) of the thorns were not significantly correlated to any other characters, and neither where they significantly correlated between themselves.

DISCUSSION

The leaf morphology varies significantly between the climatic zones. This variation might be explained by the fact that leaf loss or reduction in leaf surface are expressions of adaptation among plants to hostile environments (Mahamane and Saadou, 2009; Houari *et al*., 2012). What is more, leafing is the phenological stage in *B. aegyptiaca* that lasts the longest (Saadou, 1990), hence the species needs to reduce its leaf surface in arid environments in order to minimise water losses from transpiration. This leads to the assumption that it is a physiological adaptation to the climatic conditions that causes the morphological changes (Denden *et al*., 2005). These results are in line with those of Kouyaté and Van Damme (2002), who observed that the longest leaves and leaflets of *Detarium microcarpum* were found in the most humid zones of the Sikasso region in Mali. According to Diouf (2003), leaf surface is a very variable character that is strongly influenced by environmental variables. These findings also echo those of Abdoulaye *et al*. (2016), who observed a variation in leaflets length, width and surfaces on the same species in the region of Ouaddaï in Tchad. Likewise, Diouf *et al*. (2019) observed variability among the leaves of *Saba senegalensis* in the different localities studied in Casamance, Senegal.

As for the thorns, the development of their length follows the gradient of climatic aridity. In fact, the longest thorns were encountered in the sahelo-saharian zone, with little variability (CV = 15.8%) compared to the two other zones. This confirms the works of several authors (Mefti *et al*., 2001; Hannani, 2011), according to whom the thorns are forms of adaptation to arid environments. For other authors (Gorneflot, 1998; Benghersallah and Elhadi, 2013), it is the leaves that convert into thorns in order to reduce evapotranspiration. The big fruits of *B. aegyptiaca* observed in the sahelo-sudanian zone could be distinctive traits of provenance or of the climatic zones of the Zinder region. Furthermore, these results reveal an important phenotypic polymorphism between the three climatic zones. The measurements obtained on the fruit characters are in the means reported by Soloviev *et al*. (2004) and Abasse *et al*. (2011) on the same species. These authors also demonstrated that the weight of the fruits varied significantly according to the ecological zones. The morphological variations observed on the fruits between and within the climatic zones also corroborate the results of past studies on other fruit species (Kouyaté and Van Damme, 2002; Maranz and Wiesman, 2003; Diallo *et al*. 2010; Kouyaté *et al*. 2011).

The difference observed on the characters of the fruits from the different climatic zones is likely explained by the differing ecological conditions; the studied populations of *B. aegyptiaca* were selected based on a pre-established climatic subdivision (Agrhymet, 2004). In order to adapt to the climatic conditions, the species reduces or increases the size of its fruits. The better availability of key elements, particularly water, in the wetter sahelo-sudanian zone promotes synthesising activities and consequently charges important reserve quantities into the fruits. Added to these climatic factors are other ones such as the genetics and the micro-variations in the characteristics of the soil and toposequence, which could also explain this difference. Use of the species by local populations is another potentially significant contributor to these variations. In fact, as local populations harvest fruits, they tend to select trees showing good characters, which could over the course of time lead to the decimation or disappearance of the individuals that offer the characters most sought after by the populations. The very strong correlations found between the characters of the fruits confirm the results of Abasse *et al*. (2011). The absence of important correlations between the morphological characters of the different plant parts might indicate an absence of effect between the three organs (leaves, fruits and thorns) studied on the species. This study, although it doesn't take into account characters related to the shape of individuals (stem diameter, crown diameter, crown height), nor qualitative characters (fruit colour, pulp colour, toughness of leaves), could help start the process of selection and domestication of this cherished species. Tests on provenances should be carried out in a controlled environment in order to confirm the heritability of the observed characters, because when environmental conditions are identical, the phenotypical variation is assumed to be an expression of the genetic variation (Westoby *et al*., 2002).

Conclusion

This study on the morphological characterisation of *B. aegyptiaca* from different provenances in the Zinder region has demonstrated a high degree of variability in the studied characters. It has revealed one of the strategies used by *B. aegyptiaca* for adapting itself to arid climate. Specifically, the populations of the sahelo-saharian zone reduce the size of their leaves in order to limit water loss. On the other hand, in the sahelo-sudanian zone (more humid), the climatic conditions facilitates photosynthetic activity and allows the plant to charge important reserves into the fruits and to grow leaf surfaces in order to capture the maximum amount of sun-rays. This research can help improve knowledge of the morphological descriptors and the vegetal materials present in the different agro-ecological zones studied, and help populations identify different morphotypes of the species that appeal to them for future domestication. The study lays the groundwork for identifying *B. aegyptiaca* populations for a future genetic analysis. The genetic analysis of a large number of populations in other regions, supported by molecular markers, could help the development of strategies for improved management of this species' the genetic resources.

Conflict of interests: The authors declare that there is no conflict of interests regarding the publication of this article.

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