Research article

Influence of morphological characteristics of fruits and provenances on seedling emergence and early growth in *Detarium microcarpum* Guill. & Perr. and *Detarium senegalense* J.F. Gmel. (Fabaceae) in Benin

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HIGHLIGHTS

- Three and two fruit morphotypes were identified for *D. microcarpum* and for *D. senegalense* respectively.
- Morphotypes 2 of both species gave the highest seedling emergence rates and growth parameters.
- The seeds from Borgou-Sud district had given the best seedling emergence performances and the highest values of growth parameters.

ABSTRACT

Detarium microcarpum and *Detarium senegalense* are multipurpose tree species native to Africa. The plant parts of these species are overexploited leading to the decline in their natural populations. This study assessed the possibility for seed-based propagation of these species. Specifically, the aims were to identify their fruit morphotypes in the phytodistricts of Bassila and Borgou-Sud (Sudano-Guinean zone of Benin) and to assess the influence of the fruit morphotypes and their provenances on seedling emergence and early growth parameters. A total of 2400 and 330 fruits were collected for *D. microcarpum* and *D. senegalense* respectively and characterised based on five morphological descriptors. Hierarchical clustering was used to group fruits in morphotypes with similar characteristics. A randomized complete block design with three replicates was used for the trial on seedling emergence and early growth for each species and for 182 days. A linear mixed model on longitudinal data was applied on seedling emergence and early growth data. Three fruit morphotypes were identified for *D. microcarpum* and two morphotypes for *D. senegalense*. Morphotypes 2 of both species were those which gave the highest seedling emergence rates (88.33% for *D. microcarpum*, and 50% for *D. senegalense*). Considering the provenances, the best seedling emergence performances were observed for seeds from the Borgou-Sud district (93.89% in *D. microcarpum* and 39.17% in *D. senegalense*). Also, these seeds were those which gave the highest values of growth parameters. Morphotypes 2 of both species gave the highest values for total height and number of leaves. This study revealed that Borgou-Sud morphotype 2 for each of the two species constitutes potential candidates for domestication programs.

1. Introduction

In a current context of climate change and strong anthropogenic pressure, the capacity for natural regeneration and the resilience of ecosystems are no longer sufficient on their own to restore plant cover (Aronson et al., 1993; Bellefontaine and Monteuuis 2002). This is extremely risky for wild species, as humans limit their dispersal and

evolution in an increasingly harsh physical environment (Vihotogbé et al., 2014). Thus, most of the sustainable management strategies today are focusing on the domestication of resources (N'Danikou et al., 2015). Domestication is a long process which requires substantial data and scientific knowledge on various aspects such as among others morphological and genetic diversity (Frankham et al., 2002; Gaiero et al., 2011), ecology and propagation techniques of the target species

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to inform selection (N'Danikou et al., 2015). Local preferences are important aspects that must be taken into account in conservation and domestication strategies (Assogbadjo et al., 2008; Houndonougbo et al., 2020); since human acts in this process through selective choices based on criteria such as shape, size and taste of plant parts (Abasse et al., 2011). Several wild trees species of great socio-economic importance in Africa, deserve to be domesticated (Hanelt et al., 2001; Salako et al., 2019).

This study focused on *D. microcarpum* Guill. & Perr. and *Detarium senegalense* J.F. Gmel. These species are widespread in savannahs and humid forests in Africa (Kouyate, 2005; Akoègninou et al., 2006), and of great economic importance to local communities. *D. microcarpum*, is a species well known and appreciated by local communities for its food, medicinal and wood-fuel uses (Kouyate 2005; Agbo et al., 2020; Houénon et al., 2021). In Burkina Faso, it is one of the top ten food woody species (Eyog Matig et al., 2002). In Benin, the stems of this species are fully used in the production of wood charcoal (Agbo et al., 2017). As for *D. senegalense*, it is a multipurpose species, making it one of the most important fruit species (Atato et al., 2010). Its fruits are intensively harvested and sold in local and international markets to the point that its survival is threatened (Adomou et al., 2011; Dangbo et al., 2019; Dossa et al., 2020a).

The strong anthropogenic pressures frequently recorded on these species through the intensive cutting of stems and the systematic collection of fruits, associated with the destruction of habitats, constitute potential sources of genetic erosion of plant genetic resources (Angami et al., 2021) such as *Detarium* species. Controlling the best propagation processes for these two species is therefore essential in view of the threats to their natural stands. To accelerate the restoration of natural stands, it essential to ensure the regeneration of species with good quality seeds or propagation materials (Johnson et al., 2020).

The sexual propagation techniques carried out on these two species in West Africa are, for the most part, all devoted to the effect of the pre-treatment of seeds (Kouyaté and Lamien 2011; Sogo et al., 2017; Ambursa et al., 2019; Baatuuwie et al., 2019). In Benin, the scarce work available on seedling emergence of *D. senegalense* has focused on the pre-treatments of seeds with a single area of provenance (Bassila phytodistrict) (Dossa et al., 2020b). However, additional morphological characterization is necessary for all genetic improvement activities and plant variety selection, to target favorable morphological descriptors linked to environmental factors (Sounigo et al., 1997; Zhang, 2002). Also, the success of the restoration of wild species stands necessarily requires control of their morphological characters linked to the fruits (Kouyate, 2005). The identification of fruit morphotypes according to their provenance and the assessment of their effect on seedling establishment is a crucial step for the domestication process. According to Leakey (2019) this is the first step in the domestication of fruit trees. The identification of fruit morphotypes was used to select interesting genotypes for the domestication of *Tamarindus indica* L. (Fandohan et al., 2011). In this context, Salako et al. (2019) recorded different growth and weight responses of *Borassus aethiopum* Mart. hypocotyls based on fruit morphotypes. In addition, Idohou et al. (2015) observed variations in the seedling establishment rate of *Hyphaene thebaica* Mart. according to different fruit morphotypes.

The main objective of the study is to assess the potential for sexual propagation of *D. microcarpum* and *D. senegalense*. Specifically, the study aimed to identify the fruit morphotypes of each of the species in the phytodistricts of Bassila and Borgou-Sud and to assess the influence of the fruit morphotypes and provenances on seedling emergence and early growth parameters.

2. Material and methods

2.1. Study area

The experimental design was implemented on the Campus of Abomey-Calavi in the Guinean zone. However, the fruits used were collected in the phytodistricts of Bassila and Borgou-Sud in the Sudano-Guinean zone (Figure 1). Overall, the annual rainfall varies from 1100 to 1300 mm, while the average annual temperature is 25 °C with an amplitude of 4 °C in the Guinean zone. Relative humidity in this zone varies from 96 to 97% at the end of the rainy season (June July and November) and from 34 to 36% at the end of the dry season (January to February) in the Guinean zone. Soils are either deep ferrallitic or rich in clay, humus and minerals in this zone. The pH of soils in the Guinean zone is between 4.9 and 6 (Igue et al., 2013). The Sudano-Guinean zone records an annual relative humidity of 62%, and monthly averages ranging from 38.65% in February to 81.45% in August. In this zone, the phytodistrict of Bassila is characterized by ferralitics soils with concretions and breastplates while that of Borgou-Sud contains the ferruginous soils on crystalline rocks (Adomou et al., 2006). The pH of soils in the Sudano-Guinean zone is between 6.6 and 7.2. The soils of the Guinean and Sudano-Guinean zones are coarse-textured, derived from sandstone and coastal material with low potassium reserves (Igue et al., 2013).

2.2. Sampling and data collection for fruit morphotypes

The Sudano-Guinean zone is the common distribution area of both species (Akoègninou et al., 2006; Adomou et al., 2011; Dossa et al., 2019). Therefore, this zone was chosen to collect the fruits used for the identification of morphotypes.

In each phytodistrict, two populations of *D. microcarpum* at least 10 km apart from each other were chosen. Twenty (20) adult trees were randomly selected per population. To avoid the selection of genetically closely related individuals, a distance of at least 100 m has been observed between individuals (Turnbull 1975). In total, 80 trees were therefore sampled for *D. microcarpum*. On each tree, 30 fruits were randomly collected, making a total of 2400 fruits collected for this species.

For *D. senegalense*, the same sampling procedure was performed with the difference that only one population was used per phytodistrict. This is because *D. senegalense* is less common in the area compared to *D. microcarpum*. In total, eleven (11) trees including three in Bassila and eight in Borgou-Sud were selected, i.e. a total of 330 fruits collected for this species. The low rate of trees selected for *D. senegalense* is linked to the unavailability of adult fruiting trees. The morphological descriptors collected on the fruits included fruit length, median diameter, thickness, mass and shape index. The measurements were done using a caliper and an electronic balance (OHAUS CL 501 range 500 g × 0.1).

2.3. Experimental design and data collection on seedling emergence and early growth parameters from identified morphotypes

Based on the fruits morphological descriptors, three morphotypes were identified for *D. microcapum* and two for *D. senegalense*. The experiments tested the effect of "provenance" (Bassila *versus* Borgou-sud) and "morphotypes" (three for *D. microcapum* and two for *D. senegalense*), making six and four combinations of levels of both factors for *D. microcapum* and *D. senegalense*, respectively. A randomized complete block design with three replicates was implemented for each of the two species. For each treatment (combination), 20 pots were considered per replicate, making 360 pots (3 blocks × 3 morphotypes × 2 provenances × 20 pots) for *D. microcapum* and 240 pots (3 blocks × 2 morphotypes × 2 provenances × 20 pots) for *D. senegalense*. One fruit was sown per pot. The fruits were sown at a maximum depth of 2 cm. The pots were watered once a day (every morning between 7 a.m. and 8 a.m.) during the period of the experiment. Each treatment received an average of two liters of water. The pots were hand-weeded as needed. Seedling emergence in each pot was recorded daily for 61 days for *D. microcarpum* and 92 days for *D. senegalense*. Seedlings growth parameters (total height, collar diameter and number of leaves), were collected every 10 days for 120 days for *D. microcarpum* and 90 days for *D. senegalense*.
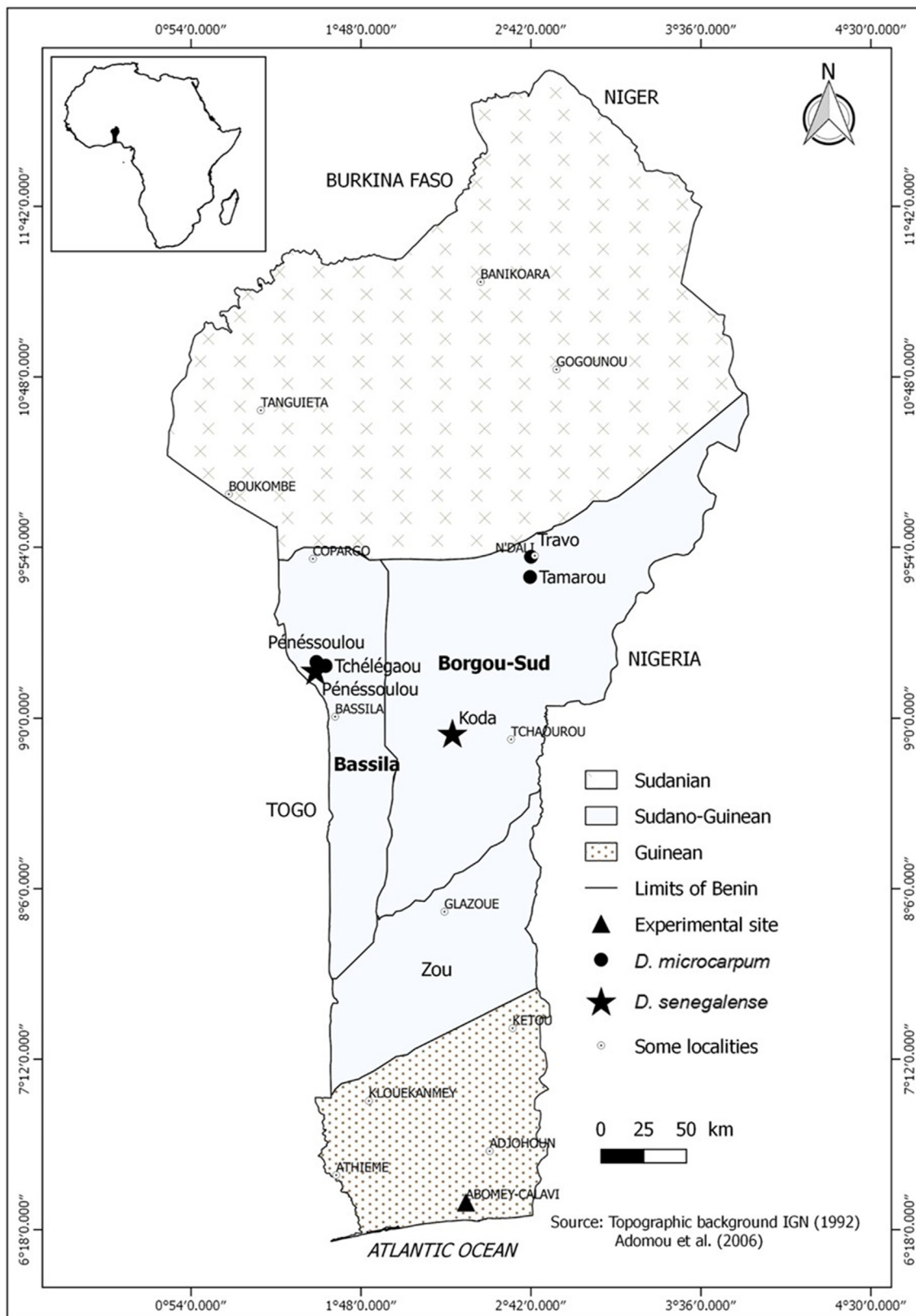
Figure 1. Geographical location of the study area in Benin.

2.4. Data analysis

2.4.1. Morphological variation in fruits of D. microcarpum and D. senegalense

Values of the fruits' morphological traits were averaged per tree. The fruit shape index was adapted from Hounkpèvi et al. (2016):

$$\text{Fruit shape index} = \frac{\text{Fruit length (cm)}}{\text{Fruit median diameter (cm)}},$$

the fruits have an oblong shape when the index >1, round when the index = 1 and oval when the index <1.

The matrix of averaged values of fruit traits by tree were submitted to a hierarchical clustering in the CAP software, version 2.15. The clustering was based on the Ward algorithm (Ward, 1963). This method allows to identify the different fruit morphotypes for each of the two species.

Descriptive statistics (mean, standard error and coefficient of variation) were then applied to the morphological traits for the different morphotypes identified by species. The coefficient of variation (cv) assessment scale proposed by Ouédraogo (1995) was used: (1) small variation (cv = 0–10%); (2) average variation (cv = 10–15%); (3) fairly large variation (cv = 15–44%); and (4) large variation (cv > 44%). One way analysis of variance followed by the Student Newman and Keuls test were used to compare the means between fruit morphotypes of the same species.

2.5. Effect of fruit morphotypes, and provenances on seedling establishment and early growth

The seedling emergence rate (number of seeds germinated/total number of seeds sown) was calculated for each species. The emergence data were treated as time-to-event data (Ritz et al., 2013). To assess the influence of morphotypes and provenances on growth parameters for each species, a linear mixed effects model for longitudinal data with normally distributed errors was used. The model was run with the package *nlme* (Pinheiro et al., 2018). Morphotypes and provenance were included in the model as fixed effects while the block was considered a random factor. Curves showing the trend of emergence rates and growth parameters were constructed to describe the influence of each factor. Statistical analyzes were performed in R software version 3.5.0 (R Core Team 2018).

3. Results

3.1. Identification of fruit morphotypes of D. microcarpum and D. senegalense

3.1.1. Fruit morphotypes of D. microcarpum

The hierarchical clustering carried out on the morphological traits of the fruits of the 80 individuals of *D. microcarpum* revealed, at a dissimilarity threshold of 77.05% (Figure 2), three groups of fruits each corresponding to a morphotype of fruits. The first group encompassed 16 trees, including 7 from Borgou-Sud and 9 from Bassila. The second group is made up of 39 trees, 18 of which come from Borgou-Sud and 21 from Bassila. Finally, the third group includes 25 trees, among which 15 from Borgou-Sud and 10 from Bassila (Figure 2).

Table 1 summarizes the characteristics of the three morphotypes identified for *D. microcarpum*. The morphotype 1 had the highest values for all parameters, except fruit shape index. The morphotype 3 has the lowest values while morphotype 2 had intermediate values for most of the parameters. Except fruit thickness and mass for morphotype 3, all parameters for all morphotypes showed little variation (cv < 10%) within the same morphotype, indicating similar characteristics of fruit traits within each morphotype. The three morphotypes identified in this species have been illustrated in Figure 3.

3.1.2. Fruit morphotypes of D. senegalense

The hierarchical clustering applied on the fruits of 11 trees of *D. senegalense* identified two groups at a dissimilarity threshold of 30%. The first group encompasses 6 trees, 4 of which were from Borgou-Sud and 2 from Bassila. The second group contains 5 trees including 4 from Borgou-Sud and 1 from Bassila (Figure 4).

Morphotype 1 had the highest values for all parameters, and morphotype 2 had the lowest values except fruit thickness which was higher for morphotype 2 (Table 2). However, only fruit mass and shape index differed significantly between the two morphotypes. Variabilities of the morphological traits within morphotypes were weak (cv < 10%). The two morphotypes identified are illustrated in Figure 5.

3.2. Trend in the seedling establishment rates in the two species

Seedling establishment started on the 15th day and ended on the 54th day for *D. microcarpum*. The total seedling establishment rate recorded was 82.77%. Considering the effect of morphotypes, seedling establishment rate was lower (76.67%) for fruits of morphotype 1 than for those of morphotype 2 (88.33%) (Figure 6Ia). Regarding the provenances, the seedling establishment rates were lower for the fruits from Bassila (71.67%) and higher for those of Borgou-Sud (93.89%) (Figure 6Ib).

In *D. senegalense* seedling establishment started on the 23rd day and ended on the 70th day. The total seedling establishment rate recorded was only 32.91%. The trend of the seedling establishment rates in this species showed stepped-like curves with unequal levels, indicating a cohort seedling establishment at irregular time intervals. Seedling establishment rate was lower for morphotype 1 (15%) compared to morphotype 2 (50.33%) (Figure 6IIa). Considering the provenances, seedling establishment rate was also lower for the fruits from Bassila (26.67%) than for the fruits from Borgou-Sud (39.17%) (Figure 6IIb).

The trend of seedling establishment rates according to time in *D. microcarpum* did not reveal any significant variation (p = 0.580) among morphotypes. However, significant time-dependent trend (p < 0.001) was observed between morphotypes for *D. senegalense*. The provenances had a significant influence (p < 0.001) on the seedling establishment of the two species. Likewise, the interaction between the morphotypes and the provenances of both species was significant, indicating that the evolution of the seedling establishment rate was not similar between the morphotypes of the same provenance (p < 0.001; Table 3).

3.3. Early growth in seedlings of the two species

Figure 7 showed the growth trend of *D. microcarpum* seedlings. Morphotype 2 had the highest average total height (25.90 ± 0.18 cm) and the number of leaves (4.51 ± 0.09) while seedlings of morphotype 1 had the largest collar diameter (7.20 ± 0.05 mm) (Figure 7Ia-c). Morphotype 3 showed very low growth performance in terms of total height and collar diameter. Considering the provenances, seedlings of Borgou-Sud had the best performances in total height (24.50 ± 0.15 cm), collar diameter (7.19 ± 0.04 mm) and number of leaves (4.60 ± 0.07) compared to those from Bassila Figure 7IIa-c). An almost ascending trend was observed on the total height and collar diameter curves, while that of the number of leaves revealed an almost sawtooth trend indicating continuous leaf renewal in this species.

Considering *D. senegalense*, morphotype 2 presented the best growth performances in total height (48 ± 0.53 cm) and collar diameter (11.98 ± 0.08 mm) (Figure 8Ia-c). Regarding the provenances, the large values of total height (48 ± 0.65 cm) and number of leaves (14.01 ± 0.23) were recorded in the fruits of Borgou-Sud, unlike the collar diameter for which the highest values (11.99 ± 0.10 mm) were observed for fruits from Bassila (Figure 8IIa-c). The three growth parameters in this species, showed an almost ascending trend as well according to the provenances as the morphotypes.
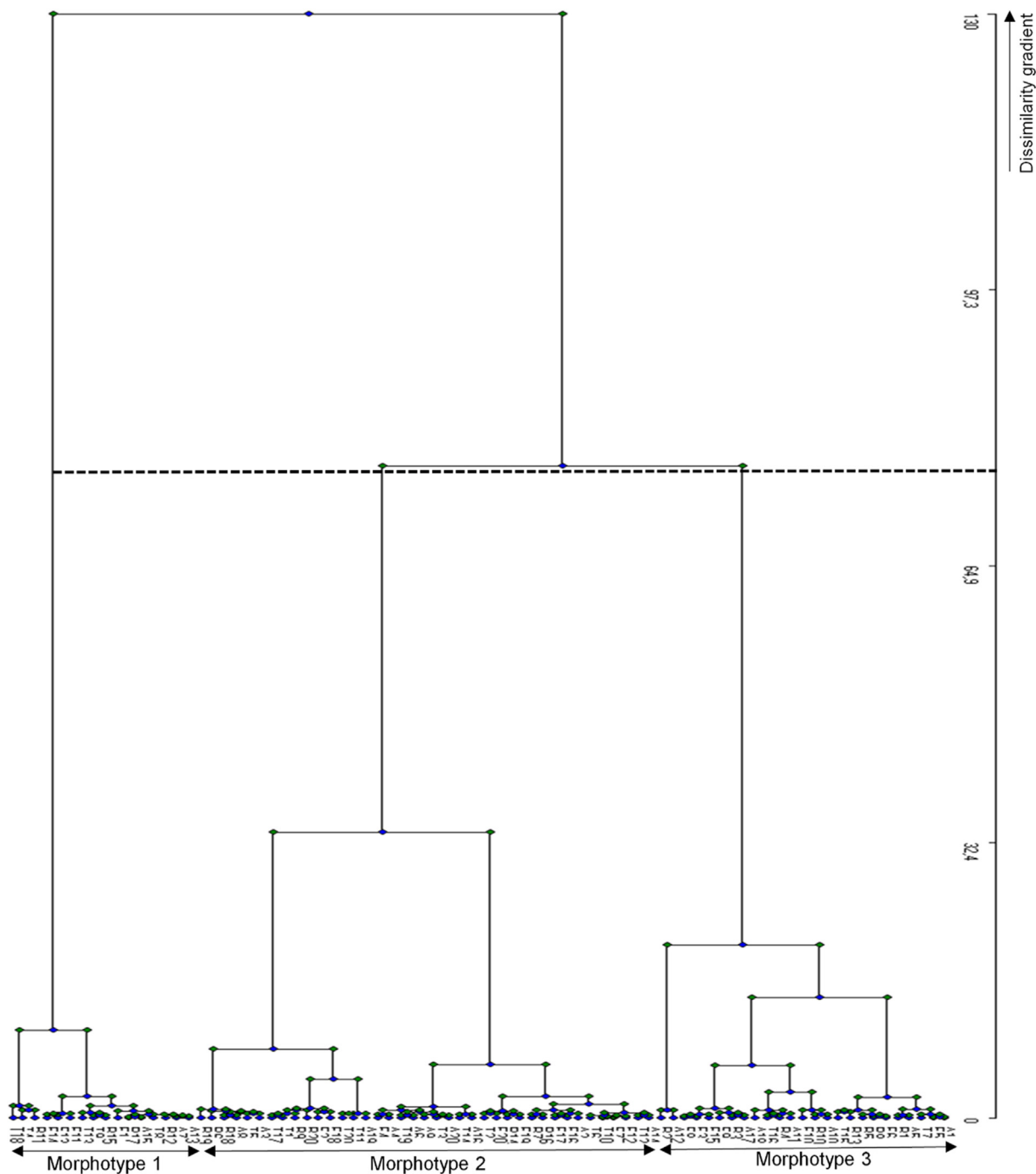
Figure 2. Hierarchical clustering of trees based on morphological traits of *D. microcarpum* fruits.

Table 1. Morphological characteristics of the fruit morphotypes identified in *D. microcarpum*.

Parameters	Morphotype 1		Morphotype 2		Morphotype 3	
	Mean ± SE	cv (%)	Mean ± SE	cv (%)	Mean ± SE	cv (%)
Length (cm)	4.91 ± 0.06 a	4.69	4.52 ± 0.05 b	6.85	4.08 ± 0.06 c	7.84
Median diameter (cm)	4.74 ± 0.07 a	5.80	4.18 ± 0.04 b	6.22	3.82 ± 0.06 c	7.47
Thickness (cm)	2.20 ± 0.04 a	6.67	2.09 ± 0.03 a	9.15	1.92 ± 0.04 b	11.64
Mass (g)	23.81 ± 0.29 a	4.92	18.32 ± 0.26 b	8.77	13.81 ± 0.43 c	15.60
Shape index	1.04 ± 0.01 b	3.66	1.08 ± 0.01 a	3.33	1.07 ± 0.01 a	3.68

SE: standard error; cv: coefficient of variation. In the same row, the values with different letters are significantly different (alpha = 5%, Student Newman and Keuls tests).

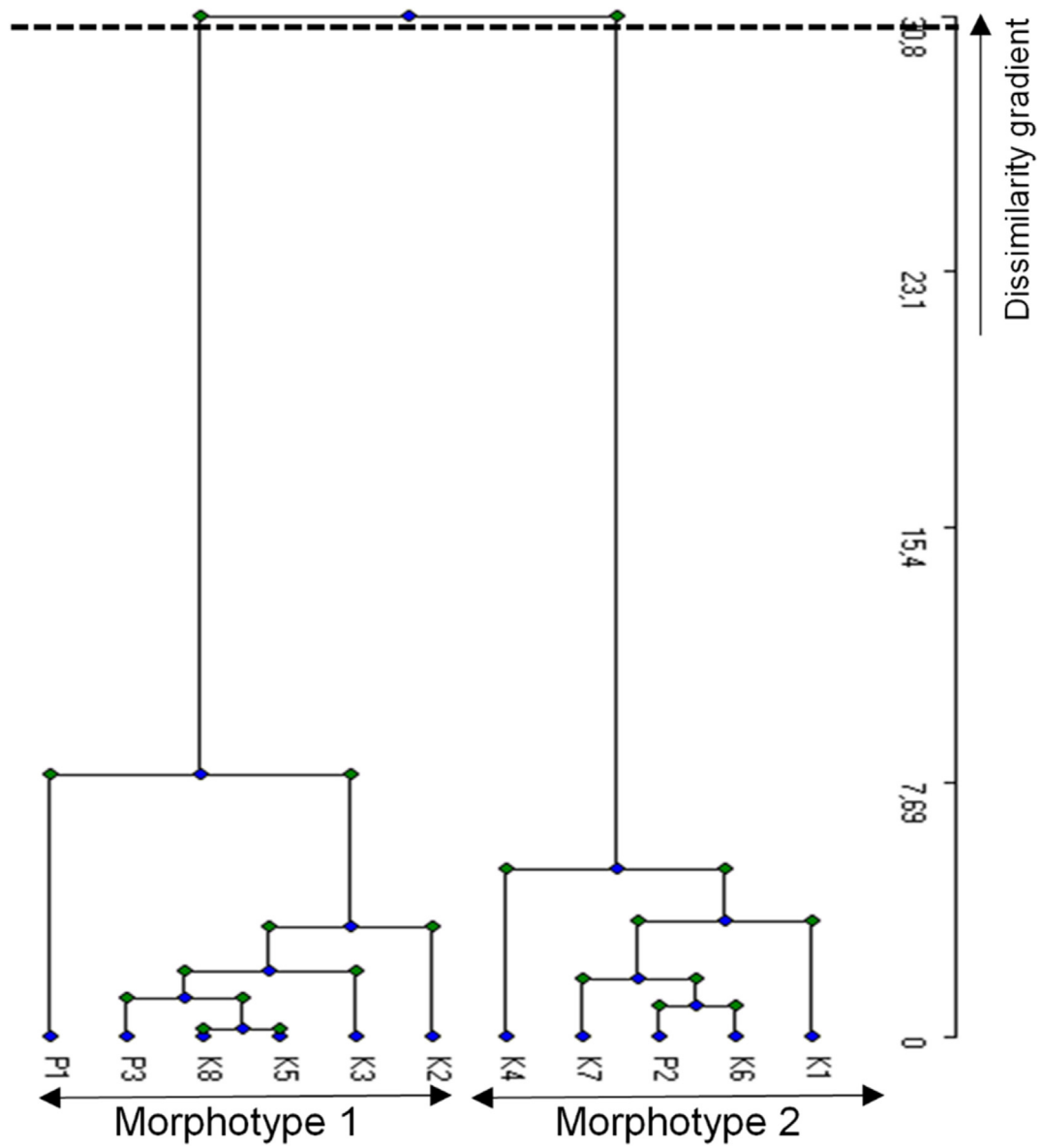**Figure 3.** Illustration of fruit morphotypes of *D. microcarpum* (a morphotype 1, b morphotype 2, c morphotype 3).

Figure 4. Hierarchical clustering of trees based on morphological traits of *D. senegalense* fruits.

Table 2. Morphological characteristics of the morphotypes identified in *D. senegalense*.

Parameters	Morphotype 1		Morphotype 2	
	Mean ± SE	cv (%)	Mean ± SE	cv (%)
Length (cm)	5.68 ± 0.12 a	5.28	5.34 ± 0.10 a	4.12
Median diameter (cm)	4.91 ± 0.10 a	4.79	4.79 ± 0.11 a	5.03
Thickness (cm)	4.02 ± 0.13 a	8.14	4.08 ± 0.14 a	7.70
Mass (g)	31.98 ± 1.00 a	7.66	24.03 ± 0.98 b	9.08
Shape index	1.16 ± 0.01 a	1.87	1.12 ± 0.02 b	3.31

SE: standard error; cv: coefficient of variation. In the same row, the values with different letters are significantly different (alpha = 5%, Student Newman and Keuls tests).

A significant effect of morphotypes and provenances was observed on the growth parameters of *D. microcarpum* ($p < 0.001$; Table 4). The interaction between morphotype and provenance varied significantly ($p < 0.05$) for the total height and the collar diameter, indicating that the trend of these growth parameters is not similar within the morphotypes of each provenance. However, this interaction was not significant for the number of leaves ($p = 0.319$). Regarding *D. senegalense*, a significant variation was also observed for the effect of morphotypes on the three growth parameters ($p < 0.001$; Table 4). The finding was the same about the influence of provenances on the total height and number of leaves ($p < 0.001$). However, provenance did not have a significant influence on collar diameter for this species ($p = 0.099$).

4. Discussion

4.1. Morphological diversity of fruits of D. microcarpum and D. senegalense

A total of three fruit morphotypes were identified for *D. microcarpum* versus two for *D. senegalense*. This result suggests a morphological variability within the fruits of each of these species. Similar observations have already been reported in Benin on *Sclerocarya birrea* (A.Rich.) Hochst. (Gouwakinnou et al., 2011), *Hyphaene thebaica* (L.) Mart. (Idohou et al., 2015) and *Borassus aethiopum* Mart. (Salako et al., 2019) and in Burkina Faso on *Tamarindus indica* L. (Diallo et al., 2008). The existence of such morphological diversity in fruits would be linked to the interaction of several factors including natural selection, selection by humans and animals, gene flow controlled by humans and animals and random genetic drift (Hamrick et al., 1992; Diallo et al., 2008). Indeed, human selection can produce significant differences in fruit size (Assogbadjo et al., 2005; Leakey et al., 2005). The local communities by carrying out the selective multiplication of the fruits of the species, based on the pulp or seed consistency, would induce in the trees the production of fruits of different sizes (Abasse et al., 2011; Boublenza et al., 2019). In addition, the seeds of *Detarium* species being generally dispersed by humans and animals (El-Kamali, 2011; Kouyaté and Lamien 2011), their transport over long distances would tend to increase genetic variation (Hamrick et al., 1992). Furthermore, the variation in fruit size can also be controlled by cross-pollination (Diallo et al., 2008). Thus, environmental factors could not explain the variation in size within the fruits of *Detarium* species due to the appearance of fruits of different morphotypes in the same phytodistrict; such variation could also be controlled by heritability. In fact, heritability is the part of the phenotypic variation in a population, attributable to genetic factors rather than to environmental factors (Wray and Visscher 2008).

Due to the existence of a correlation between the length, the width, and the mass of the fruits with the size of the seeds in some wild species including *Balanites aegyptiaca* (Abasse et al., 2011); upgrading of morphotypes 1 and 2 of the two *Detarium* species would be recommended for pulp and oil needs.

4.2. Variability in seedling establishment and growth dynamics

Seedling establishment started on the 15th day for *D. microcarpum* in the present study. It remains higher than that of 11 days obtained on this species in Nigeria (Ambursa et al., 2019). The delay observed in the present study could be explained by the storage time of the fruits (3 months). Regarding the seedling establishment rate which is 82.77%, this rate is lower than that of 86.67% revealed by the work of Ambursa et al. (2019). Moreover, the seedling establishment rate obtained in the present study remains higher than that of 52.05% mentioned by the work of Baatuuwie et al. (2019) in Ghana. This variability in seedling establishment rates could be governed by the frequency of watering. In fact, only one watering per day was adopted in the present study against twice
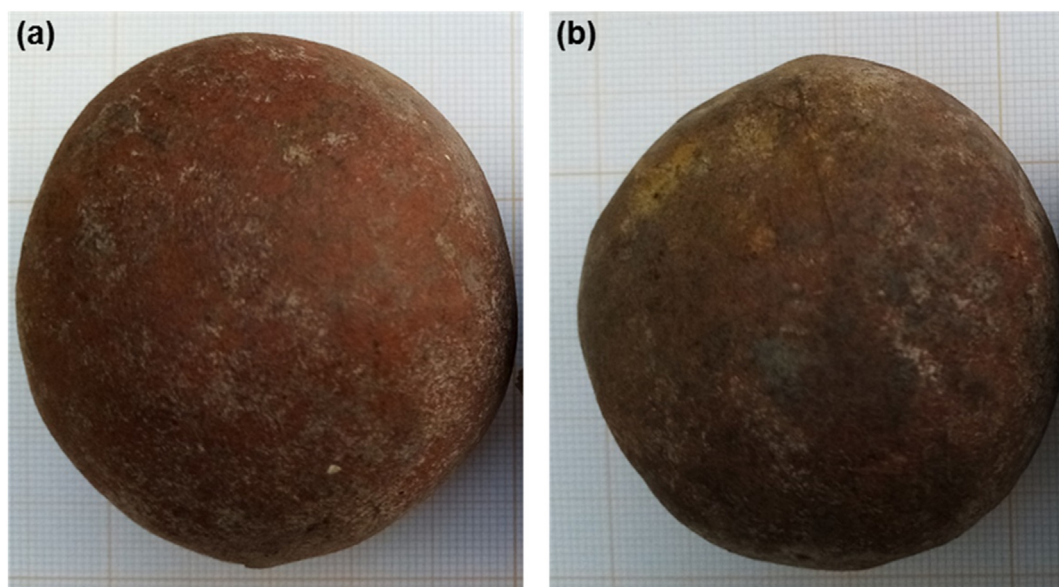

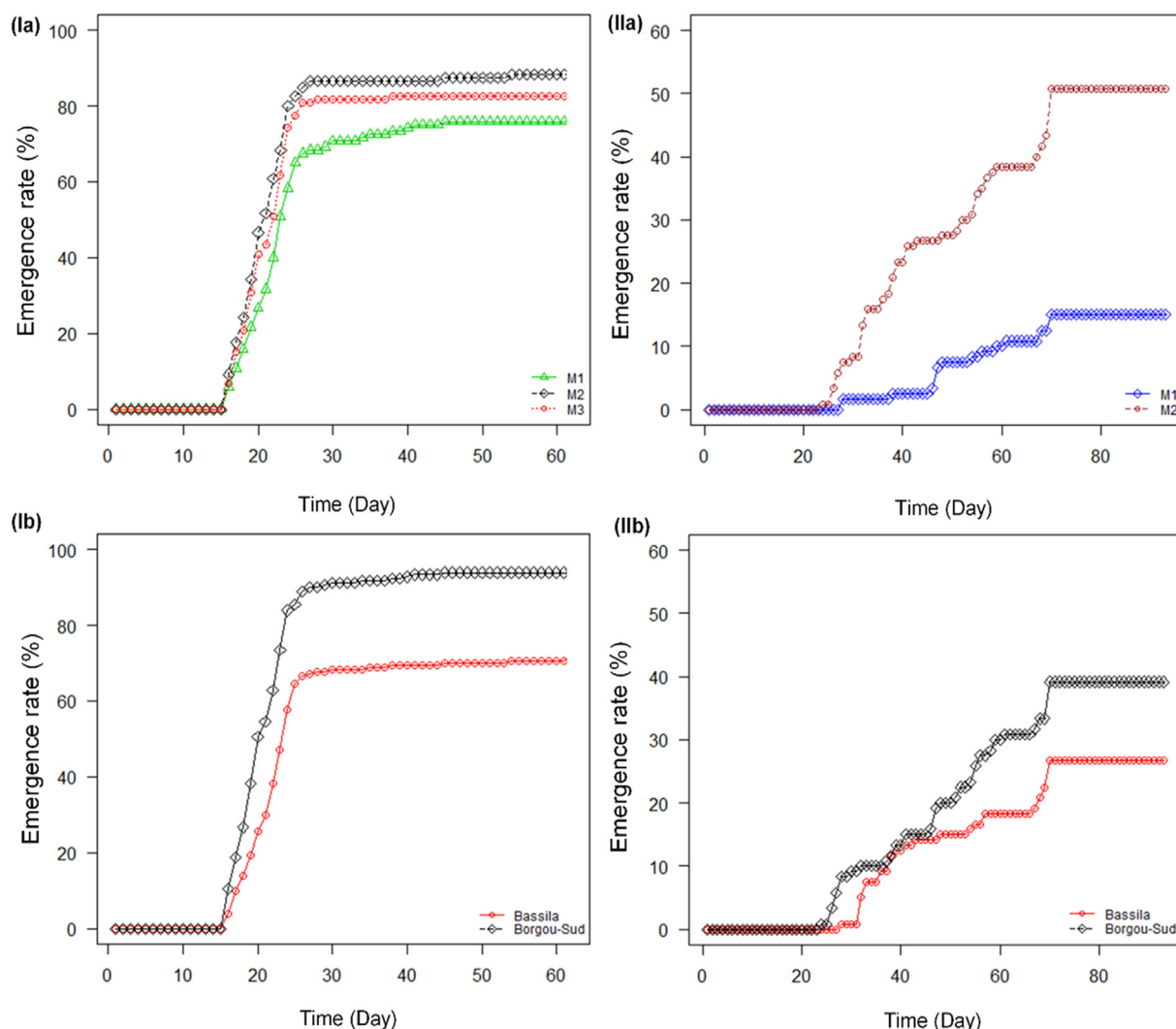**Figure 5.** Illustration of fruit morphotypes of *D. senegalense* (a morphotype 1, b morphotype 2).

Figure 6. Temporal evolution of the emergence rate in *D. microcarpum* and *D. senegalense* (I *D. microcarpum*, II *D. senegalense*, a morphotype, b provenance).

Table 3. Influence of morphotype and provenance on the seedling establishment rate of *D. microcarpum* and *D. senegalense*.

Source of variation	*D. microcarpum*		*D. senegalense*	
	F-value	p-value	F-value	p-value
Time	3.98	0.046	205.81	<0.001
Morphotype	0.54	0.580	3407.60	<0.001
Provenance	1214.08	<0.001	917.61	<0.001
Morphotype:Provenance	36.85	<0.001	432.44	<0.001
Time:Morphotype	0.74	0.477	1729.93	<0.001
Time:Provenance	275.81	<0.001	641.70	<0.001
Time:Morphotype:Provenance	19.64	<0.001	434.38	<0.001

per day mentioned by the work of Baatuuwie et al. (2019). Better still, *D. microcarpum* being a species of the Sudanian and Sahelian zones (Akoègninou et al., 2006; Kouyaté and Lamien 2011), the overflow water could hinder its propagation.

For *D. senegalense*, the seedling establishment started on the 23rd day. This is like the 21 days recorded previously reported by Dossa et al. (2020b). Moreover, in Togo, Sogo et al. (2017) recorded a duration of 6 days after using the seeds directly. Also, a duration of 23 days was recorded by these same authors when they use the whole fruit in the propagation of the species. The long duration recorded would probably be related to the fruits used in the present study. The consistency of the pericarp and in particular the lignified nature of the endocarp of the fruits would have given the seeds a slowing down in the process of seedling establishment. The seedling establishment rate (32.91%) recorded in this species is lower than that of 76% obtained by Dossa et al. (2020b) using fruits from the same study area. The low rate obtained for this species would also be linked to the storage duration (6 months) of the fruits, unlike the fresh fruits used by these authors.

Considering the duration of seedling establishment of both species, that of *D. senegalense* is much greater than that of *D. microcarpum*. This result could be justified by the size of the fruits. Indeed *D. senegalense* produces large fruits unlike *D. microcarpum*. The variability observed in the seedling establishment rates in the two species would be governed by the storage conditions of the fruits. The fruits of *D. microcarpum* underwent three months of conservation against six months for those of *D. senegalense*.

The present study revealed different responses in terms of seedling growth as a function of the fruit morphotypes with morphotypes 1 and 2 as being those which gave the high performance in growth parameters.
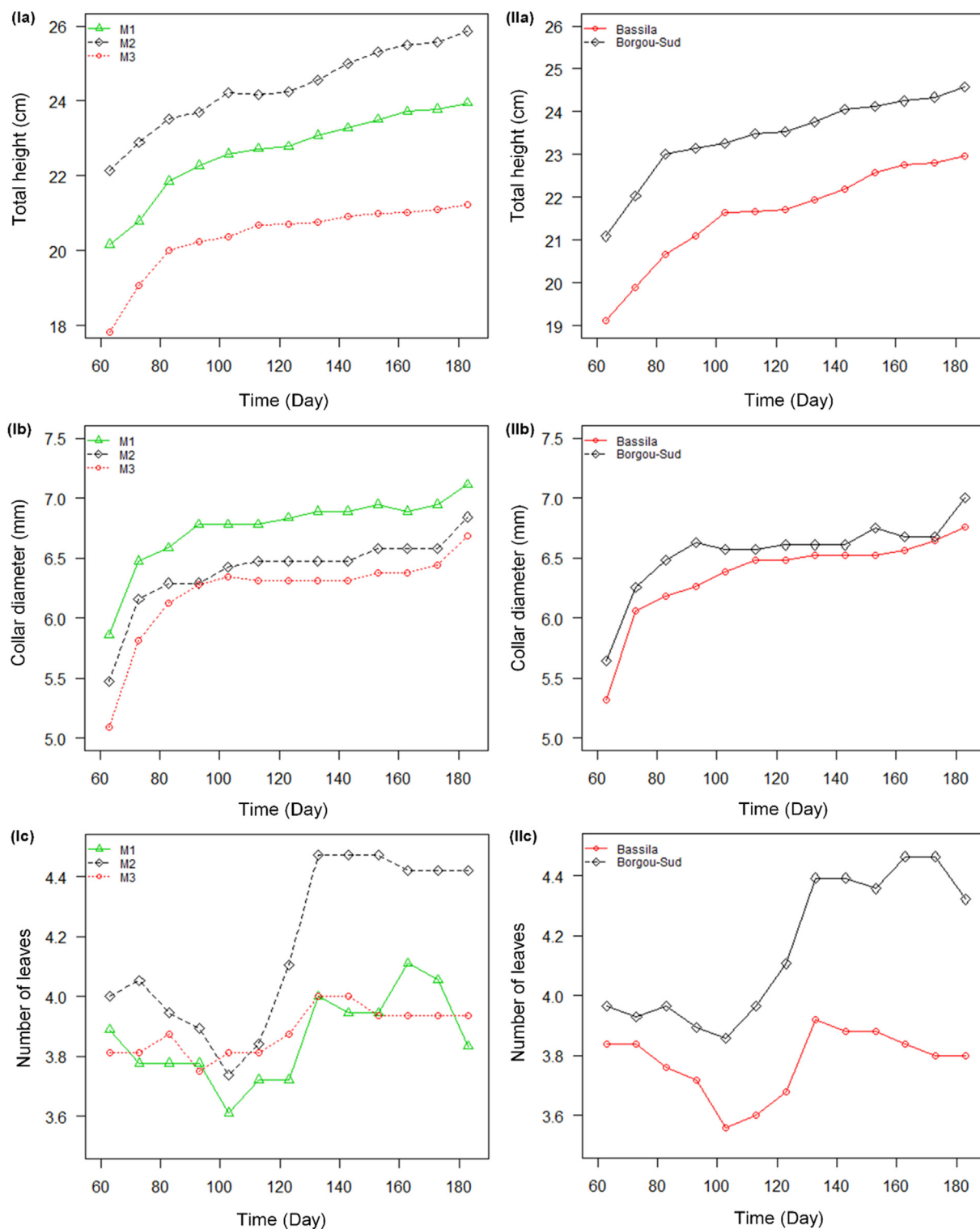
Figure 7. Trend of *D. microcarpum* growth parameters as a function of time (I morphotype, II provenance, a total height, b collar diameter, c number of leaves).

Similar observations have been reported on *Hyphaene thebaica* by Idohou et al. (2015). According to Abasse et al. (2011), the size of fruits and seeds is positively correlated with the early growth of plants which are highly dependent on the material stored in the seed. In addition, a variability of the growth parameters according to the zones of provenance was noted. This result would be under the control of the environmental conditions induced by each phytodistrict on the fruits during their formation.
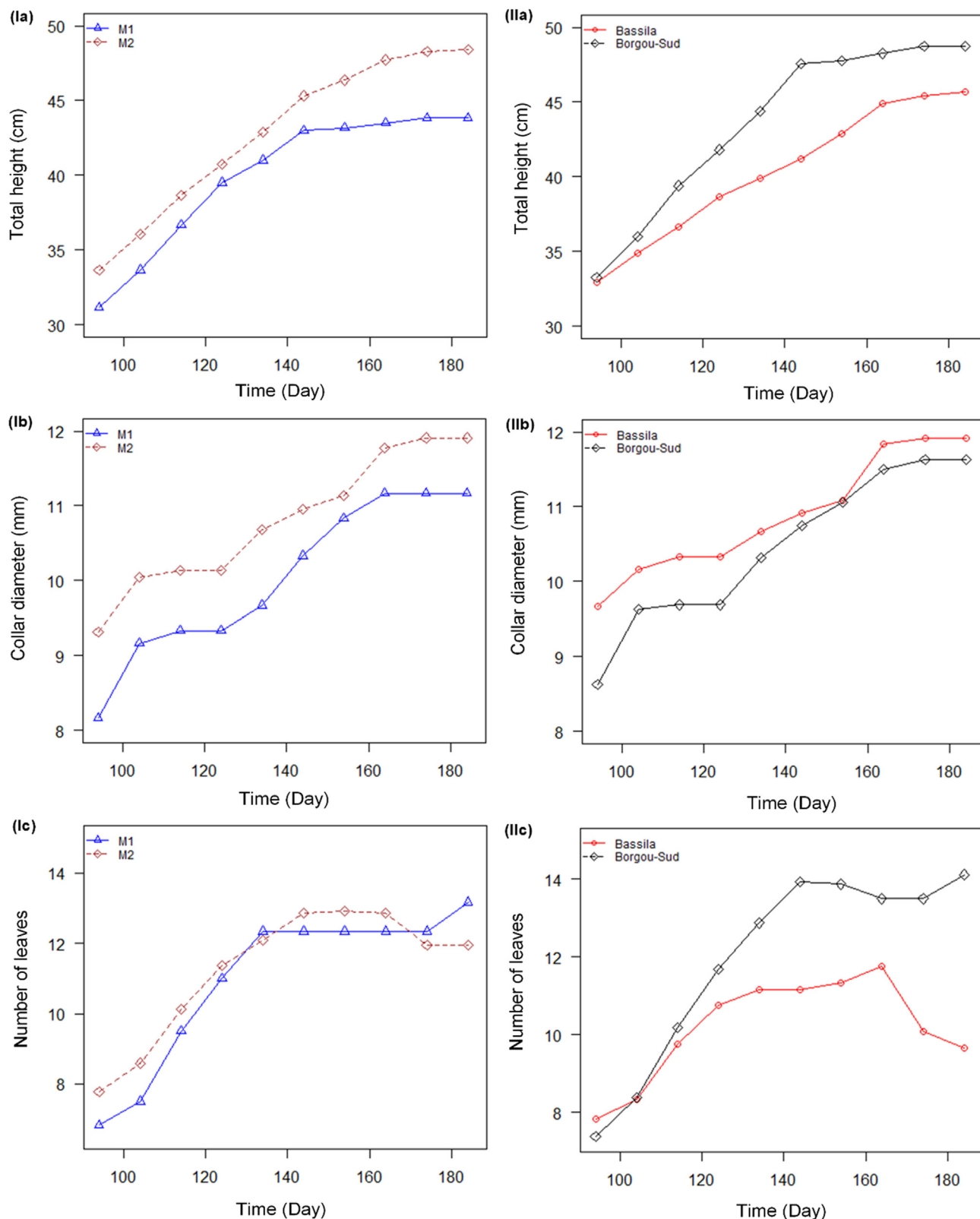
Figure 8. Trend of *D. senegalense* growth parameters as a function of time (I morphotype, II provenance, a total height, b collar diameter, c number of leaves).

4.3. Implications for conservation of the genetic materials

This study revealed significant variability within the fruits of each of the *Detarium* species. Morphotypes 1 and 2 gave the best performance in seedling establishment rate and seedling growth. Therefore, *ex-situ* conservation should target the trees of each of these species producing these elite morphotypes. The establishment of plantations from these morphotypes would be of great interest to fruit traders. Also these morphotypes should be collected and stored in gene banks for genetic improvement purposes.

Table 4. Influence of morphotype and provenance on the growth parameters of *D. microcarpum* and *D. senegalense*.

Source of variation	Total height		Collar diameter		Number of leaves	
	F-value	p-value	F-value	p-value	Chisq	p-value
D. microcarpum						
Time	52.87	<0.001	37.87	<0.001	2.28	0.131
Morphotype	172.46	<0.001	27.75	<0.001	13.17	<0.001
Provenance	109.39	<0.001	18.35	<0.001	25.78	<0.001
Morphotype:Provenance	30.66	<0.001	3.33	0.036	2.29	0.319
Time:Morphotype	1.16	0.314	0.15	0.859	4.88	0.027
Time:Provenance	1.10	0.295	1.23	0.267	57.47	<0.001
Time:Morphotype:Provenance	0.35	0.702	1.63	0.197	10.71	0.005
D. senegalense						
Time	191.73	<0.001	55.62	<0.001	34.55	<0.001
Morphotype	20.02	<0.001	56.06	<0.001	13.54	<0.001
Provenance	57.98	<0.001	2.73	0.099	47.07	<0.001
Time:Morphotype	1.74	0.188	1.85	0.174	0.01	0.957
Time:Provenance	4.47	0.035	4.27	0.039	18.92	<0.001

5. Conclusion

This study revealed morphological differences within fruits of *D. microcarpum* (3 morphotypes) and *D. senegalense* (2 morphotypes). High seedling establishment rates were obtained within the seeds of morphotypes 2 for each of these species. The seeds of Borgou-Sud showed the best seedling establishment performance unlike those of Bassila. Considering the growth parameters, morphotypes 1 and 2 from Borgou-Sud gave high values of total height and collar diameter. Morphotypes 1 and 2 could therefore be considered in restoration strategies. Therefore, to improve the low seedling establishment rate recorded in *D. senegalense*, the use of freshly harvested seeds would be recommended. Although morphotypes 1 and 2 gave very good aptitudes for the propagation of these species, a molecular genetic characterization study is essential to clarify the differences observed within the fruits of these species.

Declarations

Author contribution statement

Gbèdomèdji Hurgues Aristide Houénon; Hélène Fandy: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Aristide Cossi Adomou; Hounnankpon Yédomonhan: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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