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Rethinking Iconic Species Reforestation in West Africa: Seed Shape Harnessing Is Strategic for Enhanced Germination and Vigorous Growth in *Khaya senegalensis* and *Parkia biglobosa*

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Abstract: Seed size is a critical factor that can impact the regeneration process of plant populations. The objective of this study is to identify optimal seeds for the cultivation of two overexploited native forest species in Côte d'Ivoire, namely *Khaya senegalensis* (Desr.) A.Juss., 1830 and *Parkia biglobosa* (Jacq.) R.BR. ex G. Don, 1830. A total of 1080 seeds per species were evaluated for germination and seedling vigour in two distinct environments (dry and humid) in Côte d'Ivoire. The results demonstrated that, for *Khaya senegalensis*, larger seeds exhibited higher germination rates, whereas for *Parkia biglobosa*, smaller and medium-sized seeds showed better germination performance. However, regardless of species and study site, larger seeds consistently produced more vigorous seedlings. In this case, pretreatment tests on large seeds of *Parkia biglobosa* can potentially enhance their germination performance. Large seeds, ranging from 0.25–0.37 g in *Khaya senegalensis* and 0.2–0.32 g in *Parkia biglobosa*, appear to be the most suitable and best candidates for high-quality, high-performance seeds to optimise the cultivation of these species in Côte d'Ivoire. Distributing such seeds to farmers can contribute to the success of reforestation and agroforestry programs involving these target species in Côte d'Ivoire. These findings contribute to the sustainable management of the target species and can serve as a basis for restructuring forest regeneration policies in Côte d'Ivoire.

Keywords: seed quality; reforestation; *Khaya senegalensis*; *Parkia biglobosa*; Côte d'Ivoire

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1. Introduction

In Côte d'Ivoire, deforestation due to unreasonable agriculture is a serious threat to biodiversity and the environment [1]. This threat used to be localised in the dense forest zone in the south of the country. Today, it is spreading and increasing in the open savannah in the north of the country. This obviously causes climatic disruption and a drastic loss of plant genetic resources. Furthermore, the preservation of forest species and commercial trees is a major concern in Côte d'Ivoire, which has banned the exploitation of trees north of the 8th parallel. In addition, the country committed at the Bonn Summit [2] to restore about 5000 hectares of forest by 2030.

In the search for a strategy and important support tools for the restructuring of the forest regeneration policy in Côte d'Ivoire, the Ivorian government is asking the structures in charge of forest management and the rural populations to practice intensive reforestation and agroforestry based on local pioneer species. In this context, it was observed after investigation that some indigenous agroforestry species have a major economic development potential for rural populations living in the north of Côte d'Ivoire. These species include *Khaya senegalensis* and *Parkia biglobosa*. These two species were specifically selected among numerous others due to their significant exploitation by rural communities for various purposes such as traditional medicine, food, timber, firewood, rituals and more. According to the World Conservation Monitoring Centre [3], *K. senegalensis* is Vulnerable (VU), while *P. biglobosa* is listed as a species of least concern [4].

Current seed germination is low and this limits afforestation with the two species in question. Furthermore, seed germination and seedling vigour could be an obstacle to successful regeneration with these two species. A study of these factors would therefore seem to be necessary in order to target trajectories for decision support tools. Seed size is a good vector for plant generation renewal. Some studies have already established relationships between seed size, germination, seedling vigour and successful regeneration [5]. Thus, it would seem that plant survival and subsequent growth are influenced by initial seedling vigour. Testing this hypothesis on overexploited species could provide another scientific viewpoint on ecosystem conservation and plant regeneration, while, at the same time, it is recognised that large seeds are not suitable for wind-dispersed species and are probably a restriction of the dispersal distance of seeds. Such a study could be a reliable source and a reference for the rapid artificial regeneration of endangered species.

Even though these two native tree species are often found in field crops or open dry forests in the central and northern parts of the country [6], they are still overexploited for their multiple uses and exposed to a loss of diversity that may eventually lead to their extinction [7,8]. This high pressure is a real threat to their diversity and survival [9]. It is, therefore, necessary to develop new strategies for their conservation and sustainable use. But how? What are the strategies that can optimise the success of their pure cultivation (reforestation) and/or crop association (agroforestry)? What are the trajectories for obtaining high-performance seeds that can guarantee good germination dynamics and make it possible to obtain genotypes that are adapted, vigorous and resilient to a changing climate? To all these questions, we think that the first answer could be domestication and the search for quality seeds. These quality seeds could optimise the success of reforestation and agroforestry based on these species in Côte d'Ivoire and West Africa.

Furthermore, in some studies, seed size is reported to affect germination rate and seedlings' growth performance in some tree species [10,11] but not others [12,13]. Thus, one important step toward producing marketable seeds for forestation and afforestation programmes is to gain knowledge about the relationship between seed size, germination rate and seedling growth. The efficient availability of vigorous seedlings and adapted genotypes from germination studies of sorted seeds is a major asset for the above problem.

In this context, the selection of the best seeds and the monitoring of the seedlings are crucial for plant establishment and recruitment in the field [14]. In some tree species, viz. *Gmelina arborea* and *Afzelia quanzensis* [13,15], the appropriate seed size for producing vigorous seedlings is well known. In contrast, for most of the Ivorian tree species such knowledge is still lacking. In this study, we analyse the effect of seed size on germination rate and growth performance of young trees of *Khaya senegalensis* and *Parkia biglobosa* in order to optimise their reforestation success.

2. Material and Methods

2.1. Plant Material

The analyses were carried out on two forest tree species *Khaya senegalensis* (Desr.) A.Juss. 1830 and *Parkia biglobosa* (Jacq.) R.Br. ex G.Don. 1830. Two types of plant material were used in this study; the first comprised 1080 shelled seeds of *Khaya senegalensis* and

Parkia biglobosa collected from ripe fruits of seed trees in good physiological condition from four locations in Côte d'Ivoire (Table 1). The second type of material comprised 360 four-month-old and 90 twelve-month-old seedlings by species, resulting from the germination of the seeds we collected. These seedlings were reared in a nursery in two different locations in Côte d'Ivoire. The dendrometric characteristics, the number of seed trees and the number of healthy seeds selected after hulling according to their provenance are listed in Table 1. The plant material used is the property of the village communities whose plots we surveyed at each location. Authorisations to use this plant material were given to us orally by these rural populations as part of this study.

Table 1. Dendrometric characteristics and provenance of *Khaya senegalensis* and *Parkia biglobosa* seed trees used.

Species	Provenances	GPS Coordinates		Number of Seed Trees	DBH (cm)			Height (m)			Number of Healthy Seeds
		Longitude	Latitude		Min	Max	Mean	Min	Max	Mean	
Khaya senegalensis	Katiola	5°7′35.814″ W	8°13′53.94″ N	7	43.12	87.6	63.6 ± 22.1 b	13.5	35	22.64 ± 6.8 b	426.61 ± 58.3 b
	Niakara	5°18′40.735″ W	8°40′47.97″ N	10	57.34	108.65	72.34 ± 19.3 ab	16.3	28.5	18.31 ± 7.42 b	793.4 ± 78.6 a
	Korhogo	5°36′12.316″ W	9°33′24.69″ N	10	55.93	98.22	69.91 ± 20.5 ab	24.5	39.5	28.94 ± 8.78 a	804 ± 104.53 a
	Ferké	5°23′43.396″ W	9°36′1.87″ N	9	47.69	126.77	88.3 ± 48.4 a	21.6	42.5	31.52 ± 11.2 a	856.11 ± 153.5 a
	Pr > *F*						0.0131			0.021	0.001
Parkia biglobosa	Katiola	5°7′35.814″ W	8°13′53.94″ N	15	18.4	47.23	21.84 ± 5.1 b	6.5	23.6	12.54 ± 3.3 b	434 ± 87.5 b
	Niakara	5°18′40.735″ W	8°40′47.97″ N	14	20.6	55.81	26.7 ± 7.34 ab	8.5	27.5	20.1 ± 6.5 a	1026 ± 209.6 a
	Korhogo	5°36′12.316″ W	9°33′24.69″ N	20	19.7	63.33	33.4 ± 11.3 a	11.5	26.5	18.77 ± 6.2 a	1009 ± 303.7 a
	Ferké	5°23′43.396″ W	9°36′1.87″ N	12	23.56	38.11	28.7 ± 8.6 a	13.7	21.6	17.64 ± 8.32 ab	579.34 ± 179.82 b
	Pr > *F*						0.016			0.037	0.001

Min = minimum; Max = maximum. In the same column, values with identical letters are statistically identical, while values with different letters are significantly different at the 5% threshold.

2.2. Methods

2.2.1. Experimental Sites

The experiments took place from March 2020 to May 2021 in nurseries at two sites with different climatic characteristics (Daloa and Korhogo) in Côte d'Ivoire (Figure 1). Daloa, with a humid climate, is located in a dense forest zone in the west of the country; while Korhogo, with an arid climate, is located in a savannah zone in the north of the country. The characteristics of the two study sites are listed in Table 2.

2.2.2. Collecting and Grading Seeds

For each species, seeds were collected from seed trees that were chosen for their good physiological condition in the four (4) localities mentioned above: Katiola, Niakara, Korhogo and Ferké (Table 1). The sampled seeds from all provenances were mixed in a tray. A random and repetitive batch of 100 seeds was drawn from the tray for size measurements. For each seed, mass, length, width and thickness were measured.

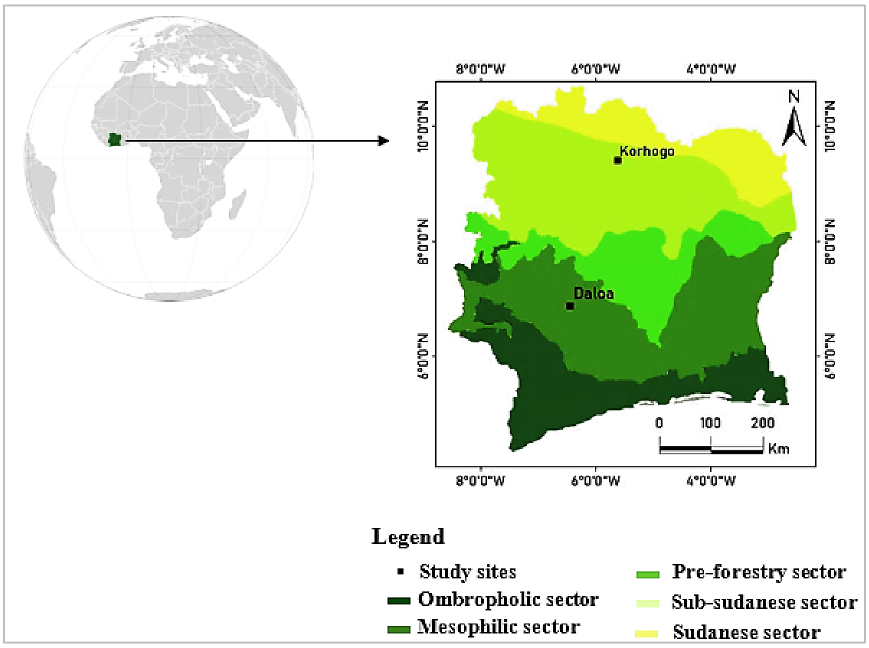


Figure 1. Geographical location and environmental characteristics of the study sites.

Table 2. Location and pedoclimatic characteristics of study sites [5,6,16,17].

Study Sites	Coordinates	Vegetation	Climate	Temperature (°C)	Rainfall (mm/y)	RH (%)	Soil Type
Korhogo	9°570′80556″ N; 5°542′88889″ W	Clear open forest (wooded and grassy savannah)	Tropical dry (Sudano-dry zone)	26.6–35.7	817–1216	20–80	Ferruginous (80%) and ferralitic (20%); superficial gravelly acidic soil, deep gravel with a heavy texture (sandy loamy clay), low in organic matter, highly desaturated, low in calcium, magnesium, potassium and phosphorus
Daloa	6°909′6363″ N 6°438′1157″ W	Dense rain forest (Dense humid vegetation)	Wet tropical (subequatorial; Guinean-humid zone)	21.0–27.2	1000–1900	42–95	Ferralitic, deep, acidic and desaturated in exchangeable bases, rich in organic matter (calcium, magnesium, potassium and phosphorus)

RH = relative humidity.

In this way, for *Khaya senegalensis*, 29 lots of 100 seeds were obtained and measured (427 in Katiola + 793 in Niakara + 804 in Korhogo + 856 in Ferké = 2880 seeds); while a total of 31 lots of 100 seeds were obtained and measured for the species *Parkia biglobosa* (434 in Katiola + 1026 in Niakara + 1009 in Korhogo + 579 in Ferké = 3048 seeds).

The seeds were divided into three size categories—large, medium and small (Figure 2)—according to their morphometric characteristics (mass, length, width and thickness) using an analysis of variance (ANOVA) test (Table 3). In addition to seed mass, morphometric characteristics such as seed length, width and thickness were considered in order to distinguish, differentiate and separate seeds by size category. The distribution of the number of seeds collected by seed size category is presented in Figure 3. This distribution follows a normal distribution. The small and large seeds (two ends of the curves) are low in number, while the average number of seeds is much higher. In a seed collection, the probability of finding medium-sized seeds is higher than that of finding small and large seeds (Figure 3).

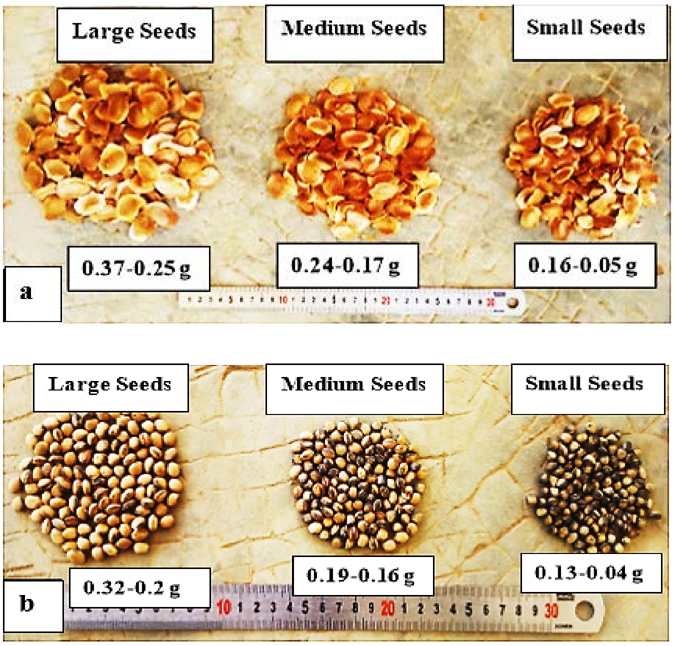


Figure 2. Classification of seeds by size category after dimension measurement for *Khaya senegalensis* (**a**) and *Parkia biglobosa* (**b**).

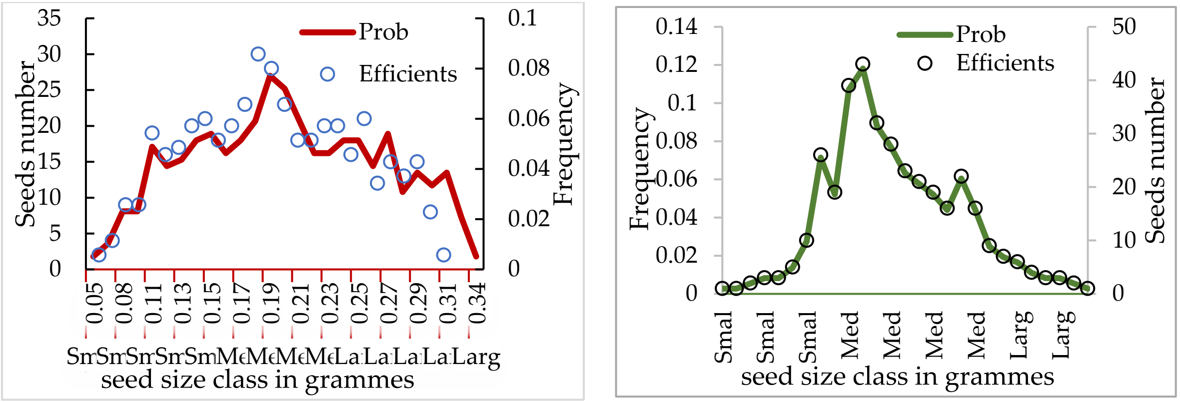
Table 3. Morphometry (Means ± SE) of seeds in different classes sorted by species.

Species	Seed Size	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)
Khaya senegalensis	Large Min-Maxi	0.31 ± 0.03 a (0.25–0.37)	30.7 ± 3.2 a (23–36)	21.2 ± 2.3 a (17–25)	2.6 ± 0.38 a (1.79–3.2)
	Medium Min-Maxi	0.21 ± 0.02 b (0.17–0.24)	23.7 ± 3.6 b (18–32)	17.3 ± 2.4 b (14–22)	2.37 ± 0.43 a (1.61–3.59)
	Small Min-Maxi	0.1 ± 0.03 c (0.05–0.16)	19.4 ± 2.4 c (14–24)	14.6 ± 3.1 c (11–22)	1.95 ± 0.55 a (0.7–2.97)
	Pr* > *F	**0.001**	**0.001**	**0.02**	**0.194**
Parkia biglobosa	Large Min-Maxi	0.27 ± 0.03 a (0.2–0.32)	11.1 ± 0.9 a (10–13)	7.9 ± 0.9 a (6–11)	5.54 ± 0.42 a (4.88–6.4)
	Medium Min-Maxi	0.17 ± 0.01 b (0.16–0.19)	9 ± 0.8 a b (8–11)	6.7 ± 0.7 a b (5–8)	5.13 ± 0.34 a (4.61–5.99)
	Small Min-Maxi	0.12 ± 0.05 c (0.04–0.13)	7.2 ± 0.8 c (5–9)	5.5 ± 0.9 c (4–7)	4.71 ± 0.62 a (3.42–5.89)
	Pr* > *F	**0.002**	**0.031**	**0.004**	**0.182**

Within a column, values with identical letters are statistically identical at the 5% level. If the value of the probability (*Pr* > *F*) is less than 0.05 (5%) then the individuals compared are different for each evaluated variable (different letter in same column). Otherwise, individuals are statistically identical (same letter in same column).

2.2.3. Setting up Trials and Sowing

Black polythene bags, 20 × 10 cm in size, were filled with local potting soil and then grouped into two blocks representative of the two target species. Each block consists of three sub-blocks, one for each size category (large, medium and small), containing 90 bags each. Then, 180 seeds per category were randomly selected, soaked in water (for about one hour), and immediately sown to a depth of 2 cm, with two seeds per bag. This gave: 2 seeds × 90 bags × 3 categories of seeds = 540 seeds (180 large seeds + 180 medium seeds + 180 small seeds) per species and site. The seeds were treated with granulated FURADAN against rodents. Maintenance in the nurseries consisted of daily watering and manual weeding.



(**a**) (**b**)

Figure 3. Distribution of seed number and frequency according to size for *Khaya senegalensis* (**a**) and *Parkia biglobosa* (**b**).

2.2.4. Measurements

The germinated (appearance of hypocotyl) seeds were counted every day. These measures allow the following variables to be assessed [5]:

- Waiting, or latency, time: this is the time in days needed for the first seed to germinate in a batch set (number of days needed for the first germination);
- Germination delay: the time in days between sowing and germination for a given seed in a set of lots (number of days needed for germination of each seed sown);
- Germination speed: the average time in days until 50% of the seeds in a batch germinate (number of days needed for half the seeds sown to germinate);
- Germination duration or spread: the time in days between the first and last germination of a batch (number of days between the first and last germination);
- Germination rate: the proportion of germinated seeds versus the total number of seeds sown. This is expressed as a percentage (ratio of the number of germinated seeds over the number of sown seeds, as a percentage).

2.2.5. Seedling Growth and Mortality

After seedling emergence, the pre-leaves were treated with DECIS to limit insect and larval attacks. The growth of the seedlings was monitored for up to 1 year.

In the first part of the study, we randomly selected 60 seedlings four months after emergence in each seed category and on each site (Daloa and Korhogo). These were destructively measured to assess seedling vigour: total seedling height, seedling crown diameter, number of single and compound leaves and root length and diameter. The dry weights of each compartment were also measured: total seedling dry weight; total leaf dry weight; stem dry weight; and root dry weight.

The dry mass of the organs was obtained after oven drying at 60 °C for 72 h. After drying, the organs were kept in silica gel until measurements were made. All parameters were measured using a ruler graduated in centimetres, electronic calipers graduated in millimetres, a 0.001 g precision balance, an oven and a 45-megapixel Nikon Coolpix 4500 digital camera.

In the second part of the study, 30 closely-monitored 12-month-old seedlings originating from each seed category (30 large + 30 medium + 30 small seeds = 90 seedlings total) were randomly selected from the population of each species in Daloa for a mortality study. For each seedling, provenance (large, medium and small seeds) and, per species, height, diameter and mortality rate (quotient of the number of dead seedlings at 12 months over the number of seedlings selected and monitored at baseline after germination, expressed as a percentage) were measured.

2.2.6. Statistical Analyses

Statistical analyses were first performed using one-dimensional descriptive statistics. All variable influences were compared using analysis of variance in SAS version 9.4 (SAS Institute, Cary, NC, USA). Student–Newman–Keuls and LSD tests at the 5% threshold were used for post hoc comparison. XLSTAT was used to perform linkage analyses (linear and nonlinear regressions) between the variables.

3. Results

3.1. Seed Germination or Emergence

3.1.1. Germination in Khaya Senegalensis

The influence of seed size and experimental sites on the germination rate are presented in Figure 4. As can be seen, the seed category has a significant effect, with large seeds exhibiting the best germination rate irrespective of the site. In addition, the Korhogo site recorded better germination rate performances than the Daloa site.

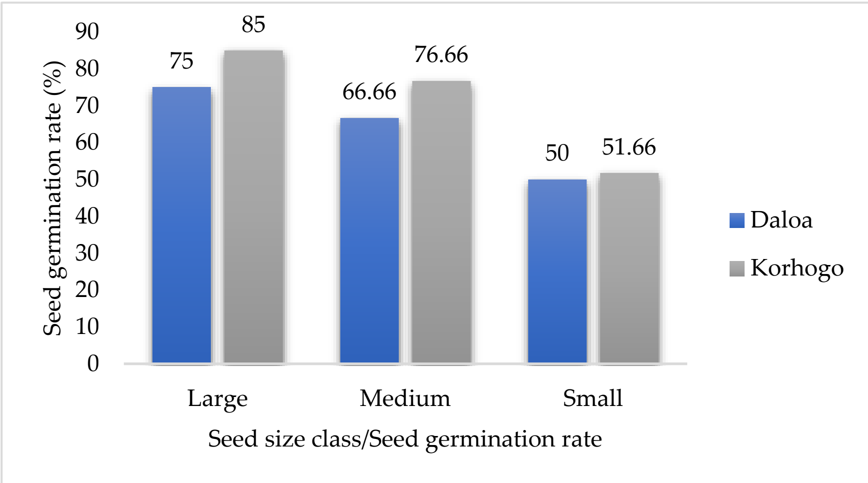


Figure 4. Effect of seed size and study site on germination rate of three sizes of seeds for *Khaya senegalensis*.

Figure 5 shows the daily germination dynamics by seed category in Daloa (Figure 5a) and Korhogo (Figure 5b). The number of seeds germinating every 5 days increases exponentially from day 10 to day 50 in Daloa and from day 15 to day 40 in Korhogo. No seed germinated after these dates in Daloa (day 50) and Korhogo (day 35). Regardless of the site, large seeds have higher dynamics than the other two seed size categories (Figure 5).

For large seeds, the latency time was 16 days in Korhogo against 10 days in Daloa; the germination delay of large seeds varied from 16 to 40 days with an average of 22.25 ± 5.59 days in Korhogo, and from 10 to 41 days with an average of 18.84 ± 9.08 days in Daloa; the germination speed was 22 days in Korhogo against 17 days in Daloa; the total duration of germination was 24 days in Korhogo against 31 days in Daloa; and the germination rate was 85% in Korhogo against 75% in Daloa.

For medium seeds, the waiting time for germination was 14 days in Korhogo against 8 days in Daloa; the germination delay of medium seeds varied from 14 to 40 days with an average of 22.85 ± 7.1 days in Korhogo, and from 8 to 44 days with an average of 19.02 ± 7.75 days in Daloa; The germination speed was 24 days in Korhogo against 23 days in Daloa; the total duration of germination was 26 days in Korhogo against 36 days in Daloa; and the germination rate was 76.66% in Korhogo against 66.66% in Daloa.

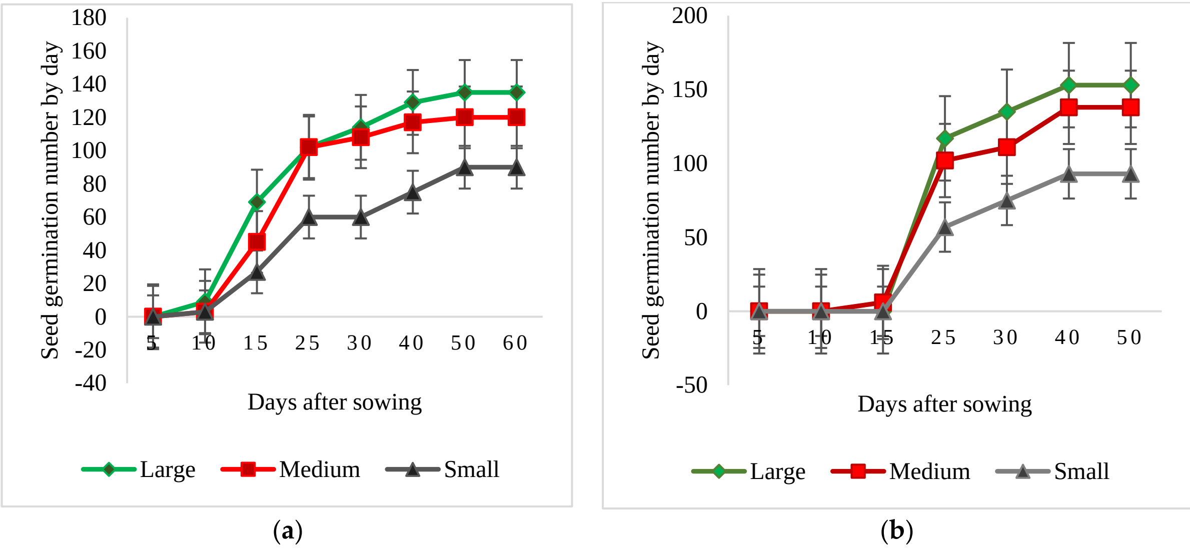


Figure 5. Germination dynamics of seed categories in Daloa (**a**) and Korhogo (**b**) for *Khaya senegalensis*. On each curve, the bars represent the uncertainties (standard error).

For small seeds, the waiting time for germination was 16 days in Korhogo against 7 days in Daloa; the germination delay of small seeds varied from 16 to 37 days with an average of 23.93 ± 5.58 days in Korhogo, and from 7 to 49 days with an average of 24.97 ± 13.05 days in Daloa; the germination speed was 37 days in Korhogo against 49 days in Daloa; the total duration of germination was 21 days in Korhogo against 42 days in Daloa; and the germination rate was 51.66% in Korhogo against 50% in Daloa.

3.1.2. Germination in Parkia Biglobosa

In *Parkia biglobosa*, the results also showed that seed size and study site had a significant influence on seed germination (Figure 6).

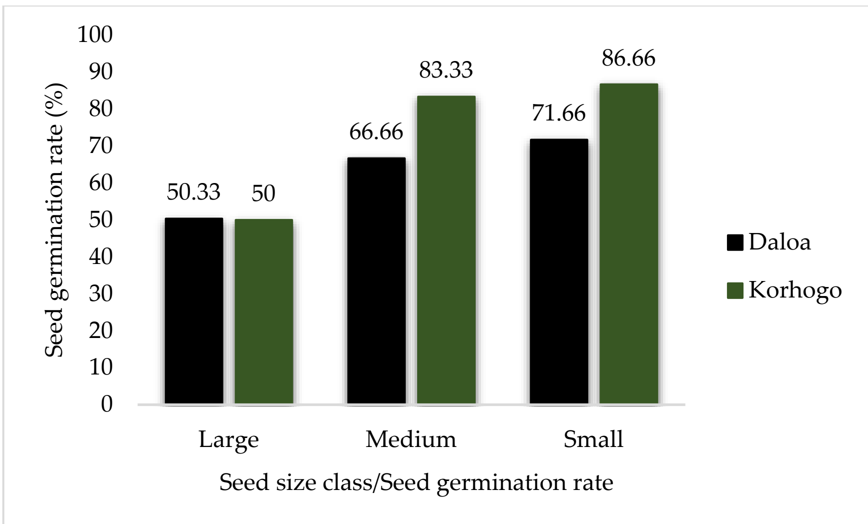


Figure 6. Effect of seed size and study site on germination rate of three sizes of seeds for *Parkia biglobosa*.

In large seeds, the latency to germination was 17 days in Korhogo against 11 days in Daloa; the germination delay of large seeds varied from 17 to 56 days with an average of 39.93 ± 10.62 days in Korhogo, and from 11 to 39 days with an average of 22.81 ± 7.57 days in Daloa; The germination speed was 56 days in Korhogo against 34 days in Daloa; the total duration of germination was 39 days in Korhogo against 28 days in Daloa; and the germination rate was 50% in Korhogo against 50.33% in Daloa.

For medium seeds, the waiting time for germination was 10 days in Korhogo against 4 days in Daloa; the germination delay of each medium seed varied from 10 to 51 days with an average of 19.82 ± 8.20 days in Korhogo, and from 4 to 27 days with an average of 14.57 ± 4.29 days in Daloa; The germination speed was 23 days in Korhogo against 19 days in Daloa; the total duration of germination was 41 days in Korhogo against 23 days in Daloa; and the germination rate was 83.33% in Korhogo against 66.66% in Daloa.

For small seeds, the waiting time was 10 days in Korhogo against 6 days in Daloa; the germination delay varied from 10 to 29 days with an average of 17.55 ± 4.12 days in Korhogo, and from 6 to 24 days with an average of 14.64 ± 4.66 days in Daloa; the germination speed was 24 days in Korhogo and 21 days in Daloa; the total duration of germination was 19 days in Korhogo against 18 days in Daloa; and the germination rate was 86.66% in Korhogo compared to 71.66% in Daloa (Figure 6).

Figure 7 shows the daily germination dynamics by seed category in Daloa (Figure 7a) and Korhogo (Figure 7b). The number of seeds germinating per day is higher and germination stabilises more quickly for small and medium seeds than for large seeds (Figure 7). Regardless of the medium, small and medium-sized seeds have a higher number of germinated seeds per day than large seeds. In Daloa, seed germination stabilises on the 25th, 30th and 40th day, respectively, in large, medium and small seeds (Figure 7a). In Korhogo, seed germination stabilises on the 30th, 30th and 60th day, respectively, in large, medium and small seeds (Figure 7b). After these dates, the seeds no longer germinate.

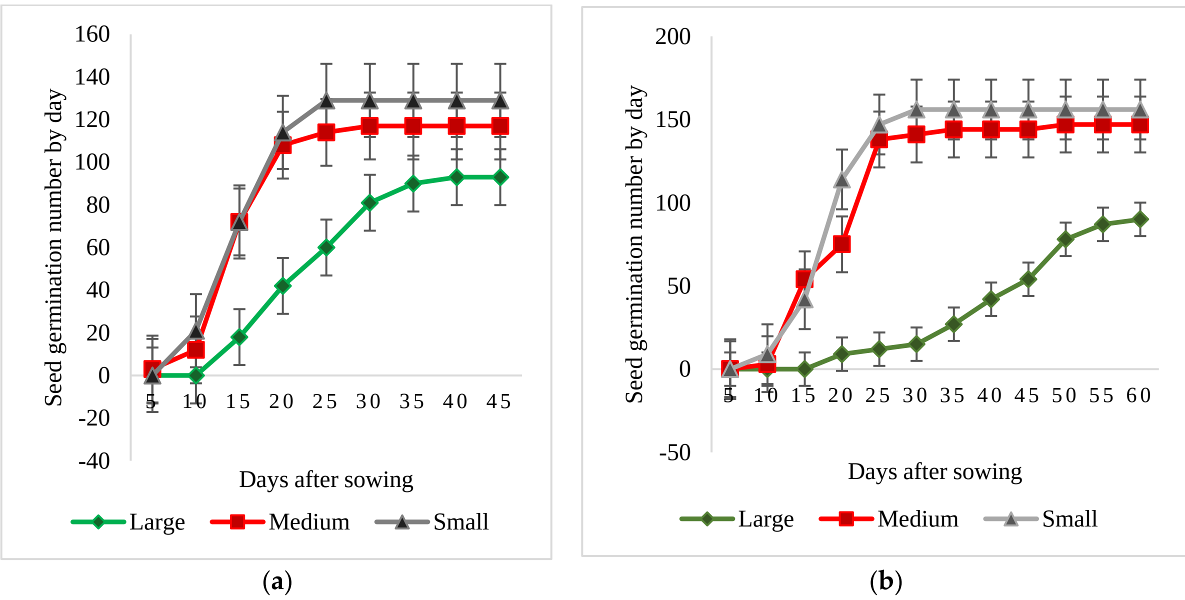


Figure 7. Germination dynamics of seed categories in Daloa (**a**) and Korhogo (**b**) for *Parkia biglobosa*. On each curve, the bars represent the uncertainties (standard error).

3.2. Seedling Growth

3.2.1. Effect of Seed Size and Site on Seedling Growth in Khaya Senegalensis

A comparison of seedling vigour variables by seed category (Table 4 and Figure 8), showed a significant difference in seedling growth by seed category ($p < 0.05$). Seedlings from small seeds did not develop compound leaves. The seedlings resulting from the germination of large seeds were completely different from the rest with high vigour.

Table 4 shows the analysis of variance of seedling biomass parameters by seed category origin. The results show that the parameters evaluated differed from one seed category to another ($p < 0.05$). Large seeds had seedlings with higher average dry biomass than medium and small seeds for all parameters observed (total seedling dry biomass, total leaf dry mass, stem dry mass and root dry mass).

Table 4. Seedling development parameters according to seed category and dry biomass of young plants in *Khaya senegalensis*.

Development Parameters	Height (cm)	Diameter (mm)	Number of Single Leaves	Number of Compound Leaves	Root Length (cm)	Root Diameter (mm)
Large	17.77 ± 3.92 a	3.07 ± 2.6 a	7.43 ± 1.66 a	0.4 ± 1.1 a	13.90 ± 2.87 a	2.97 ± 0.52 a
Medium	12.36 ± 2.08 b	2.07 ± 0.33 b	5.67 ± 1.17 b	0.11 ± 0.46 b	11.6 ± 2.38 b	2.23 ± 0.39 b
Small	8.28 ± 2.11 c	1.6 ± 0.35 c	4.43 ± 0.85 c	0 ± 0 c	8.78 ± 2.43 c	1.83 ± 0.44 b
Pr > *F*	0.0001	0.0001	0.0041	0.0007	0.0001	0.0063
Dry Biomass Parameters	**Total Dry Mass of Seedlings (g)**		**Total Dry Mass of Leaves (g)**		**Stem Dry Mass (g)**	**Root Dry Mass (g)**
Large	0.71 ± 0.25 a		0.32 ± 0.11 a		0.48 ± 0.19 a	0.14 ± 0.05 a
Medium	0.41 ± 0.12 b		0.20 ± 0.06 b		0.32 ± 1.52 b	0.09 ± 0.04 b
Small	0.22 ± 0.11 c		0.1 ± 0.05 c		0.04 ± 0.02 c	0.05 ± 0.02 c
Pr > *F*	0.0001		0.0001		0.0001	0.0001

Within a column, values with identical letters are statistically identical at the 5% level. If the value of the probability (*Pr* > *F*) is less than 0.05 (5%) then the individuals compared are different for each evaluated variable (different letter in same column). Otherwise, individuals are statistically identical (same letter in same column).

Figure 8 shows the influence of seed size on the morphology of four-month-old seedlings in *Khaya senegalensis*. The larger the seed, the larger and better developed the resulting seedling.

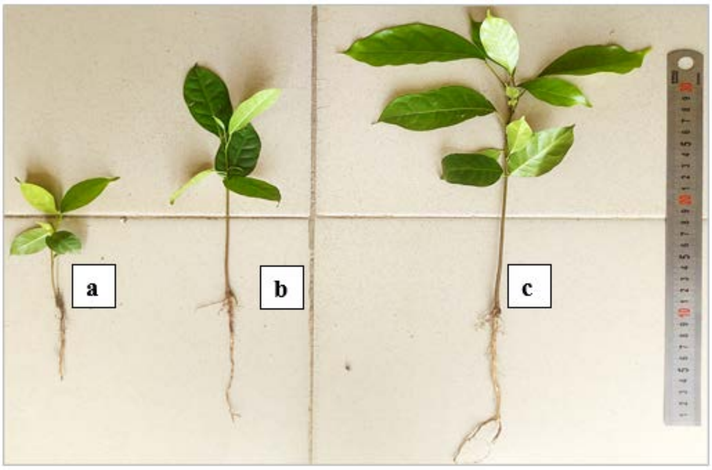


Figure 8. Vigour of 4-month-old seedlings from germination of small (**a**), medium (**b**) and large (**c**) seeds of *Khaya senegalensis*.

Concerning the influence of the study site, the results showed that, with the exception of root diameter, the seedlings obtained in the Daloa nursery were more vigorous than those in the Korhogo nursery (Table 5 and Figure 9).

The seedlings obtained in Daloa showed higher dry biomasses (Table 5) than in Korhogo ($p < 0.05$) for the variables total seedling dry mass, total leaf dry mass, stem dry mass and root dry mass.

Figure 9 illustrates the detailed influence of seed category on seedling vigour for each experimental site. Regardless of seed category, the Daloa site produced larger seedlings.

Table 5. Developmental and dry biomass parameters of young plants according to the experimental site in *Khaya senegalensis*.

Development Parameters	Seedling Height (cm)	Stem Diameter (mm)	Number of Single Leaves	Number of Compound Leaves	Root Length (cm)	Root Diameter (mm)
Daloa	15.85 ± 5.07 [a]	2.76 ± 2.39 [a]	6.88 ± 1.87 [a]	0.35 ± 1.02 [a]	12.78 ± 3.71 [a]	2.74 ± 0.64 [a]
Korhogo	10.93 ± 3.12 [b]	1.91 ± 0.44 [b]	5.18 ± 1.25 [b]	0.04 ± 0.26 [b]	10.7 ± 2.48 [b]	2.09 ± 0.51 [a]
Pr > F	0.0001	0.0002	0.0075	0.0001	0.0069	0.076
Dry Biomass Parameters	**Total Dry Mass of Seedlings (g)**		**Total Dry Mass of Le aves (g)**		**Stem Dry Mass (g)**	**Root Dry Mass (g)**
Daloa	0.61 ± 0.29 [a]		0.26 ± 0.13 [a]		0.29 ± 1.25 [a]	0.12 ± 0.06 [a]
Korhogo	0.24 ± 0.16 [b]		0.18 ± 0.09 [b]		0.08 ± 0.04 [b]	0.08 ± 0.04 [b]
Pr > F	0.0001		0.0001		0.0001	0.0001

Within a column, values with identical letters are statistically identical at the 5% level. If the value of the probability (*Pr > F*) is less than 0.05 (5%) then the individuals compared are different for each evaluated variable (different letter in same column). Otherwise, individuals are statistically identical (same letter in same column).

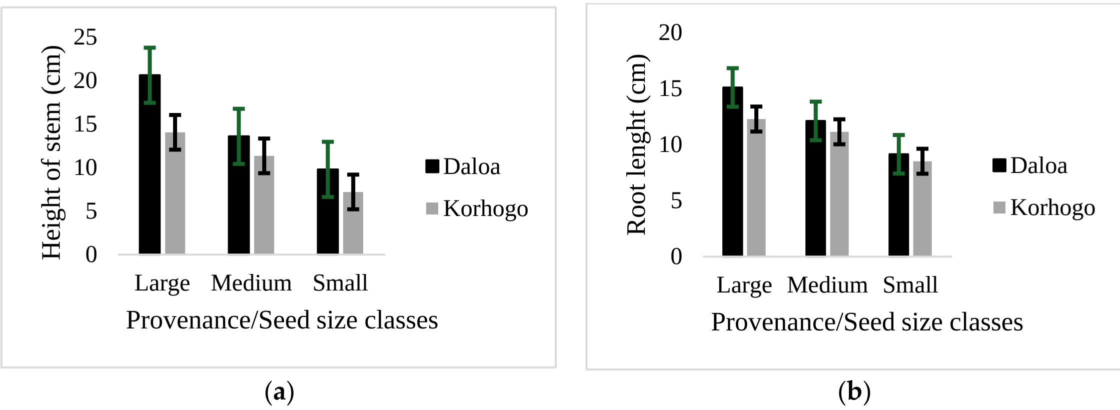


Figure 9. Average stem height (**a**) and average root length (**b**) of seedlings by seed size category and study site for *Khaya senegalensis*. On each band, the bars represent uncertainties (Standard Error).

Figure 10 shows the relationships and regressions between the parameters assessed in *Khaya senegalensis*. Figure 10a shows that seed germination time is independent of seed size. There is a strong dependency between seed size and the height growth (Figure 10b) and total biomass of 4-month-old seedlings (Figure 10c). The larger the seed, the larger the resulting seedlings with high aboveground biomass. The shorter the germination time, the greater the growth of the seedling (Figure 10d). Figure 10f shows that seeds with larger aspect ratios (width/length) generate larger seedlings.

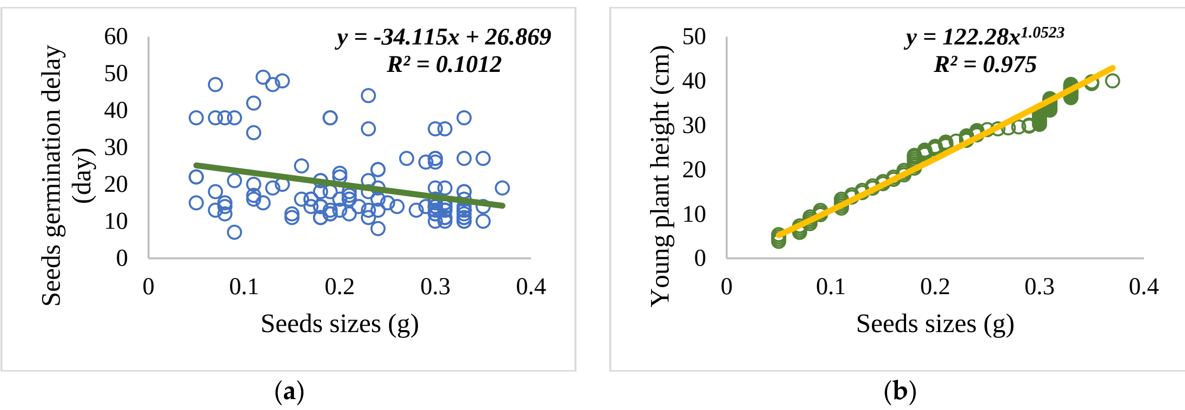


Figure 10. *Cont.*

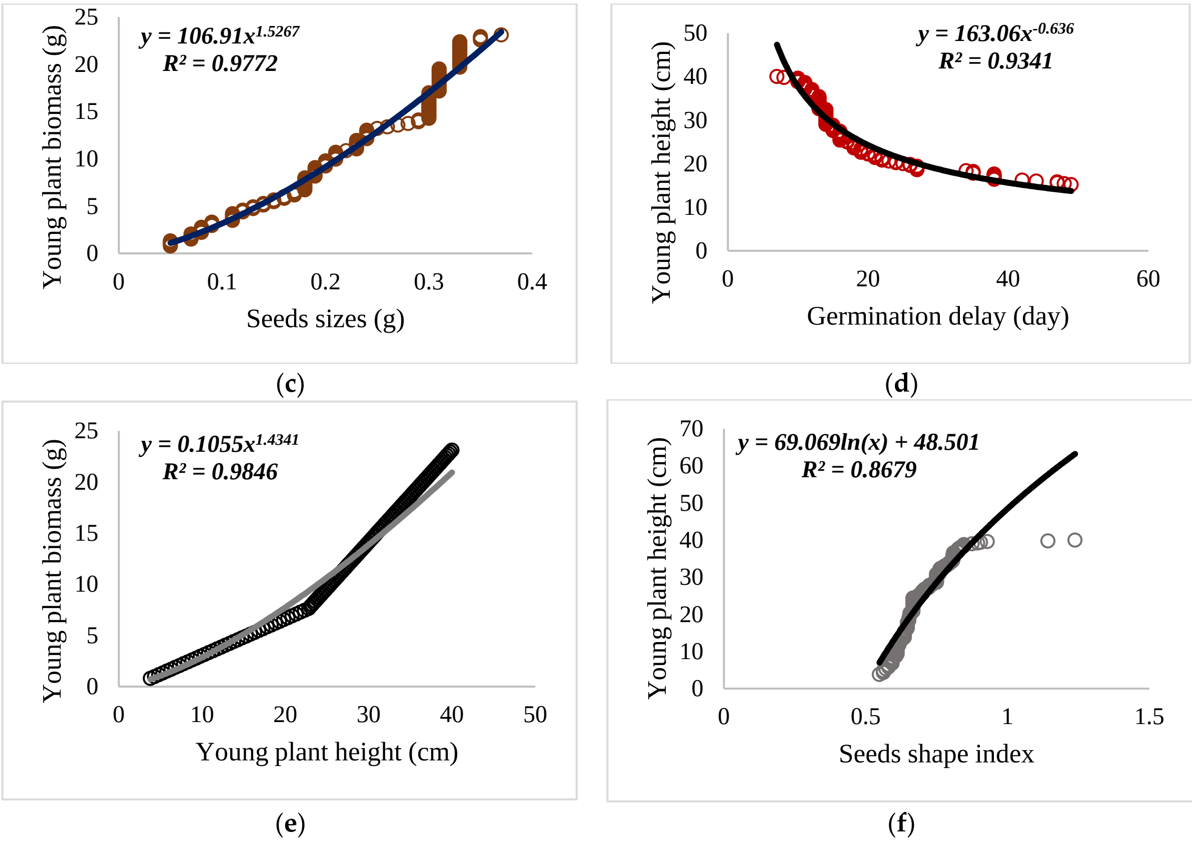


Figure 10. Relationships and regressions between seed size and the parameters assessed in *Khaya senegalensis*. (**a**): relationship between seed size and germination time; (**b**): seed size—plant height; (**c**): seed size—plant biomass; (**d**): germination delay—plant height; (**e**): plant biomass—plant height; (**f**): seed shape index—plant height.

3.2.2. Effect of Seed Size and Site on Seedling Growth in Parkia Biglobosa

In *Parkia biglobosa*, the results showed a significant difference in the majority of the vigour parameters of the young plants evaluated as a function of seed size ($p < 0.05$). Seedlings germinating from larger seeds were more vigorous (Figure 11). The number of leaves and root diameter were statistically identical between seed categories ($p > 0.05$).

Figure 11. Vigour of seedlings from germination of large (**a**), medium (**b**) and small (**c**) seeds of *Parkia biglobosa*.

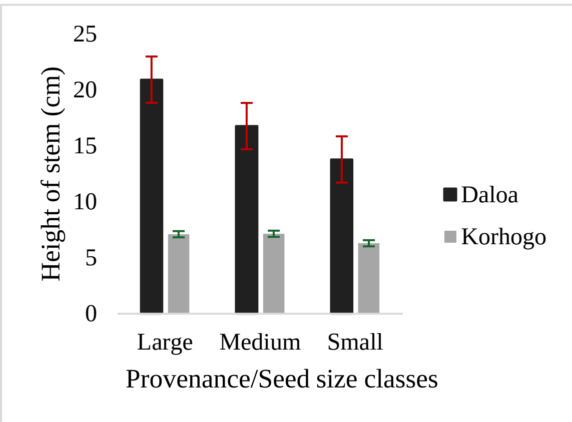
A comparison of young plant vigour parameters evaluated by seed size category shows that stem heights were 13.18 ± 7.13 cm, 11.53 ± 5.14 cm and 10.09 ± 4.24 cm, respectively, for seedlings from large, medium and small seeds. The results for stem diameters were 3.22 ± 0.65 mm, 2.47 ± 0.42 mm and 2.25 ± 0.31 mm for seedlings from large, medium and small seeds, respectively. For the number of compound leaves, the results were 3.9 ± 1.54, 3.98 ± 1.34 and 4.06 ± 1.5 for seedlings from large, medium and small seeds, respectively. For root length, the results were 11.51 ± 7.38 cm, 12.22 ± 4.52 cm and 10.63 ± 4.41 cm, respectively, for seedlings from large, medium and small seeds. For the root diameters, the results were 2.28 ± 0.89 mm, 2.31 ± 0.53 mm and 2.05 ± 0.5 mm for seedlings from large, medium and small seeds, respectively.

The results also show that seedlings germinated from large seeds had the highest dry biomass compared to those from medium and small seeds. For total dry mass, the values of the observed parameters were 0.46 ± 0.39 g, 0.38 ± 0.3 g and 0.33 ± 0.19 g for the seedlings from large, medium and small seeds, respectively. For the total dry mass of the leaves, the results were 0.26 ± 0.22 g, 0.21 ± 0.20 g and 0.18 ± 0.12 g for the seedlings from large, medium and small seeds, respectively. For the stem dry mass, the results were 0.09 ± 0.05 g, 0.08 ± 0.04 g and 0.06 ± 0.02 g for the seedlings from large, medium and small seeds, respectively. For root dry mass, the results were 0.11 ± 0.1 g, 0.10 ± 0.08 g and 0.09 ± 0.06 g for the seedlings from large, medium and small seeds, respectively.

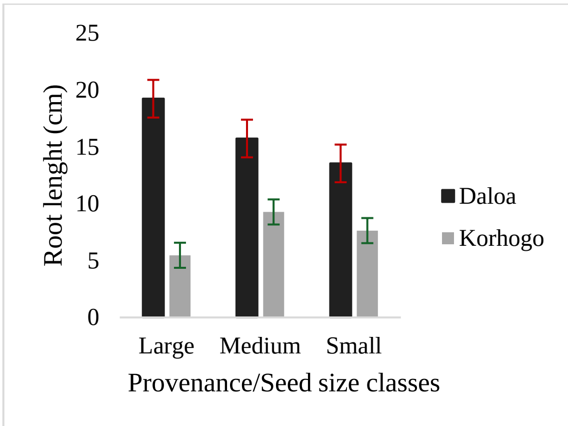
The results showed that the study site influences seedling vigour. Seedlings obtained in Daloa were found to be more vigorous than those obtained in Korhogo. All parameters differed statistically between sites ($p < 0.05$). The results showed that the height of the seedlings was 16.21 ± 3.6 cm in Daloa and 6.79 ± 1.17 cm in Korhogo; the stem diameter was 2.26 ± 0.37 mm in Daloa and 2.78 ± 0.61 mm in Korhogo; the number of compound leaves was 5.02 ± 1.39 in Daloa and 3.08 ± 0.69 in Korhogo; the root length was 15.42 ± 3.87 cm in Daloa and 7.73 ± 3.28 cm in Korhogo; and the root diameter was 2.58 ± 0.57 mm in Daloa and 1.84 ± 0.44 mm in Korhogo.

The biomass parameters evaluated showed a significant difference in parameters according to the study site ($p < 0.05$). The seedlings obtained in Daloa had higher biomass values than in Korhogo with total dry mass values of 0.6 ± 0.26 g compared to 0.17 ± 0.08 g, total leaf dry mass of 0.34 ± 0.17 g compared to 0.08 ± 0.04 g, stem dry mass of 0.1 ± 0.04 g compared to 0.05 ± 0.02 g and root dry mass of 0.15 ± 0.08 g compared to 0.04 ± 0.03 g.

Figure 12 shows the variation in the vigour of seedlings according to seed category and experimental site. This figure confirms that the seedlings are more well-developed in Daloa than in Korhogo with significantly greater stem height and root length.



(**a**)



(**b**)

Figure 12. Average stem height (**a**) and average root length (**b**) of seedlings by seed size category and study site for *Parkia biglobosa*. On each band, the bars represent uncertainties (Standard Error).

Figure 13 shows the different relationships between seed size and 4-month-old seedlings in *Parkia biglobosa*. As with *Khaya senegalensis*, Figure 13a shows that there is no significant relationship between seed size and time to seed germination. However,

Figure 13b,c show that seedling height and total biomass depend on seed size. The larger the seed size, the more vigorous the germination of the seedlings. Figure 13d shows that the shorter the germination time, the greater the height of the seedlings. Figure 13f shows that the larger the shape index (width/length) of the seed, the larger the seedlings that are produced.

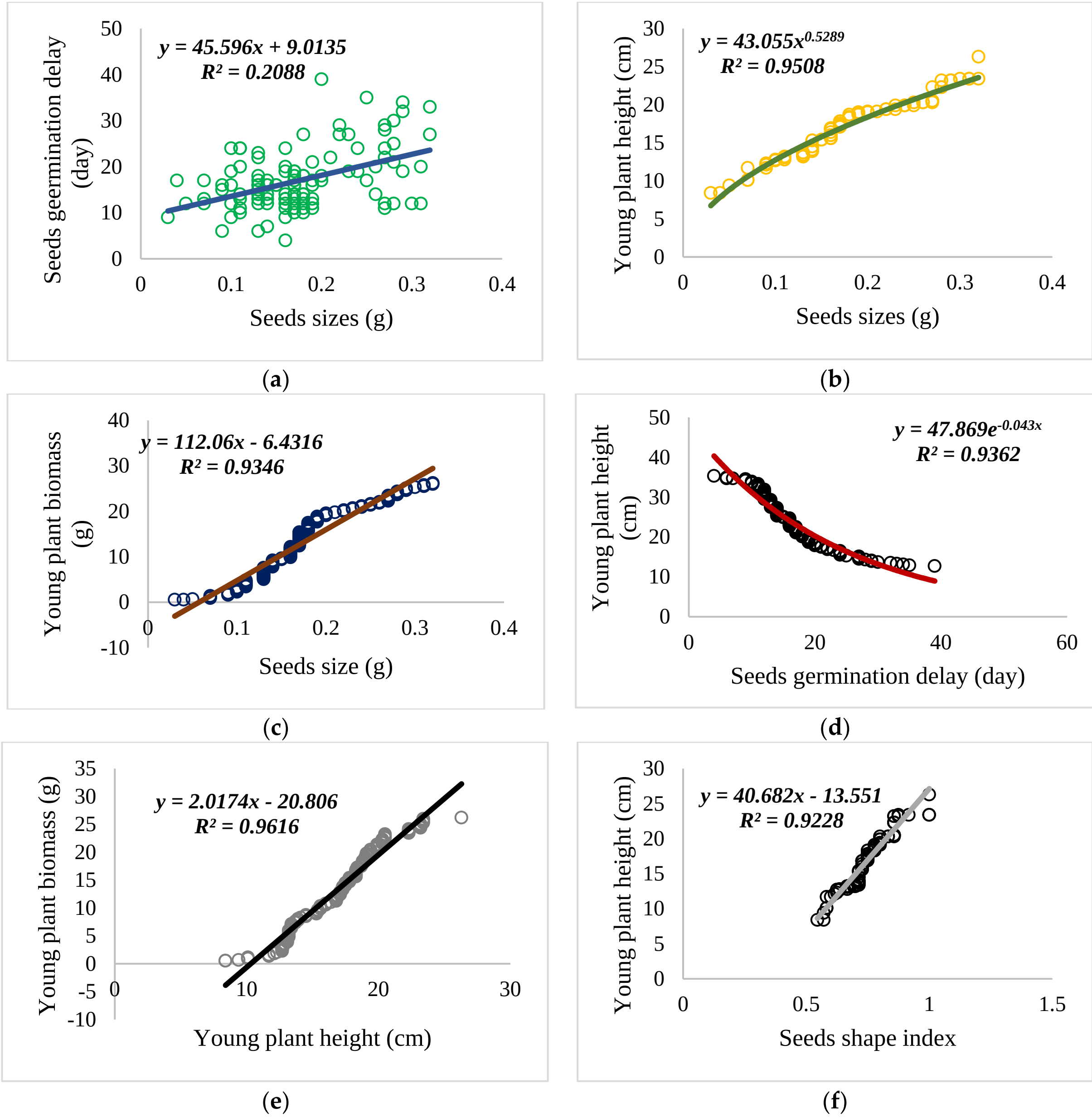


Figure 13. Relationships and regressions between seed size and the parameters assessed in *Parkia biglobosa*. (**a**): relationship between seed size and germination time; (**b**): seed size—plant height; (**c**): seed size—plant biomass; (**d**): germination delay—plant height; (**e**): plant biomass—plant height; (**f**): seed shape index—plant height.

3.2.3. Assessment of Mortality in 12-Month-Old Seedlings

Table 6 shows that after 12 months of monitoring, the number of living seedlings is higher for the seedlings from large seeds. No mortality of 12-month-old plants from large seeds was observed in *Khaya senegalensis* (0%), while a higher rate (up to 72%) of plants from small seeds die during development and do not reach 12 months. However, it should be noted that the morphology of the plants is affected by environmental conditions.

Individuals lose their capacity for increasing vigour according to the seed size category (from the largest to the smallest seeds). Table 6 shows that individuals have almost the same size at 12 months (height and diameter), regardless of seed size category ($p > 0.05$).

Table 6. Vigour and mortality of 12-month-old plants of *Khaya senegalensis* and *Parkia biglobosa*.

Species	Seed Size Sources	Height (cm)	Collar Diameter (cm)	Death Rate (%)
Khaya senegalensis	Larges	167.11 ± 18.3 a	3.3 ± 0.2 a	0
	Mediums	142.7 ± 79.1 a	2.07 ± 0.53 a	47.2
	Small	89.52 ± 56.66 a	2.02 ± 1.37 a	72
	Pr > F	**0.603**	**0.83**	-
Parkia biglobosa	Larges	61.25 ± 23.8 a	0.7 ± 0.41 a	32.5
	Mediums	56.57 ± 17.1 a	0.68 ± 0.39 a	53.33
	Small	54.1 ± 33.3 a	0.66 ± 0.51 a	64.8
	Pr > F	**0.874**	**0.711**	-

Within a column, values with identical letters are statistically identical at the 5% level. If the value of the probability ($Pr > F$) is less than 0.05 (5%) then the individuals compared are different for each evaluated variable (different letter in same column). Otherwise, individuals are statistically identical (same letter in same column).

4. Discussion

We investigated seed germination and seedling growth in *Khaya senegalensis* and *Parkia biglobosa*, two local forest tree species that are highly exploited and threatened. The gained knowledge will be helpful for forestation and afforestation programmes in Côte d'Ivoire. In general, the lipid content of seeds is an important factor for the study of seed dormancy. Unfortunately, it was not considered in this study for a chemical screening of seeds. These species showed a short time to begin germination, generally less than 20 days. In addition, the germination was not greatly spread out, being fewer than 60 days. These results were similar to those previously found in *Terminalia superba*, *Mansonia altissima* and *Pterygota macrocarpa* [18] and in *Pterocarpus erinaceus* [5]. By contrast, for some other trees species, such as *Sideroxylon contrerasii* and *Elaeocarpus prunifolus*, the germination was long, since 434 days and 146 days were required to reach maximum or mean germination, respectively [19,20].

Elsewhere, seed germination dynamics and rate were significantly influenced by both seed size and the experimental site. For *Khaya senegalensis*, large and medium seeds showed faster germination and reached maximum germination earlier than small seeds. They also yield the highest germination rate. Conversely, for *Parkia biglobosa*, small and medium seeds exhibited earlier and faster germination and gave the best germination rate. Larger seeds generally have more nutrient reserves to establish themselves, however, this may be an obstacle for wind dispersal, where lighter seeds generally travel further. Smaller seeds in *Parkia biglobosa*, for example, could be correlated with a lower number of seed infections. However, the fact that small seeds of *Parkia biglobosa* have better germination calls for interest in this seed size category for this species, as seedling vigour based on seed mass is most often altered over time. Indeed, in most species, vigour varies according to the amount of seed reserve up to a limited point in time. This vigour disappears later; thus, the distinction between large, medium and small seedlings is confused.

Our results did not support those of the authors of [12,13], who found no effect of seeds weight on germination rate in *Terminalia superba*, *Terminalia ivorensis*, *Gmelina arborea* and *Afzelia quanzensis*. In contrast, our findings were consistent with those of the authors of [21,22], who reported fast and better germination in large seeds in three and four tropical tree species, respectively. This result was also found by the authors of [11,20,23,24], in *Pinus thunbergii*, *Elaeocarpus prunifilius* and *Terminalia bellerica*. In addition, the results obtained for *Parkia biglobosa* agreed with those published for *Copaifera langsdorffii* by the authors of [25], who reported that smaller seeds showed faster and greater germination than larger seeds. Hence, our results are not surprising. This contrasting behaviour depending on species is well known in tree species and has been attributed to species' strategies for their regeneration and early colonisation of an area [21].

In general, it seems that performance is better in terms of germination and vigour parameters in the south, which is probably not surprising given the higher rainfall and favourable temperatures. The high germination rate obtained at Korhogo than at Daloa could be due to slightly warmer temperatures close to 30 °C since this temperature is reported to be optimal for seed germination in tree species [26,27].

Finally, the best germination rates, found for large seeds in *Khaya senegalensis* and small seeds in *Parkia biglobosa*, were high, ranging between 71% and 86% on average. These rates were similar to those obtained in *Mansonia altissima*, *Pterygota macrocarpa*, *Terminalia superba* [18] and *Pterocarpus erinaceus* [5]; while they are more than two times superior to those recorded in others trees species, viz. *Ceiba pentadra*, *Delonix regia*, *Sterculia urens*, *Albizia lebbeck* and *Leucaena leucocphala*, for which germination rates are very poor (≤30%) [28].

The growth analysis revealed that seedlings germinating from large seeds in both *Khaya senegalensis* and *Parkia biglobosa*, showed the best growth performance. This result conforms with the findings of the authors of [29,30]. These authors argued that the superior growth of seedlings germinating from large seeds is likely due to the efficient use of the greater resources stored in these seeds.

Because in *Parkia biglobosa*, the best growth performance was recorded for seedlings germinating from large seeds, but these seedlings exhibited a feeble germination rate (50%), research to increase their germination is required. Therefore, presoaking treatments in warm or hot water could be applied as done by the authors of [31].

The better growth performance reported at Daloa compared to Korhogo could be attributed to the favourable climatic conditions prevailing in the former experimental site, viz. more rainfall (1300 mm vs. 1000 mm) and a lower average temperature (26 °C vs. 30 °C).

This study showed that seedling mortality is lower up to the age of 12 months in the target species. This fact clarifies, demonstrates and proves that large seeds can be recommended to farmers, agroforesters and forestry management structures as quality seeds for the successful and optimised cultivation of the target species. The results also show that the individuals have statistically the same dimensions regardless of their origin at the age of 12 months, which was not the case at 4 months. Indeed, seedlings at the seedling stage are not yet independent. They, therefore, continue to use the seed's reserve [30]. The larger the seed, the more starch reserves it contains. The seedling, therefore, draws on this reserve, giving it more nutrient reserves and allowing it to develop better than seedlings from small seeds (as development and growth are limited by the quantity of starch available in the seed).

Once the seedling regains its independence through photosynthetic activity, development and growth will depend on environmental conditions (soil fertility, availability of light and water, etc.) [32,33]. Individuals, therefore, lose their vigour, which depends on the seed reserve. They acquire a growth capacity that depends on the environment. An individual resulting from the germination of small seeds under favourable conditions may have the same or greater vigour than an individual resulting from the germination of large seeds. In our study, the plants from the large seeds had slightly larger sizes than the other categories because of the identical environmental conditions. However, statistical analysis showed that these individuals were identical in size.

Even if the individuals tend to be morphologically identical later on, the most important thing is the selection of the right seed type for successful reforestation. In this sense, a mortality study is a priority, and this has shown that large seeds are the best candidates for any species.

5. Conclusions

This study focused on evaluating seed quality based on germination and seedling vigour in *Khaya senegalensis* and *Parkia biglobosa*. The findings indicate that both species demonstrate favourable potential for sexual regeneration, which is influenced by seed size and germination environment. Large seeds of *Khaya senegalensis* consistently exhibited robust germination and produced vigorous seedlings across different environments. Conversely, in *Parkia biglobosa*, small- and medium-sized seeds displayed promising germination potential, but seedlings derived from large seeds demonstrated superior vigour.

These results provide valuable insights, representing the first investigation of its kind for these species. To support agroforestry and reforestation programs in Côte d'Ivoire, we recommend providing farmers with large seeds of *Khaya senegalensis* and exploring the potential of germination tests on diverse provenances to identify optimal sources for such initiatives. Additionally, conducting multi-location or zonal trials categorised by seed size could validate the selection of large seeds as high-quality candidates. Furthermore, implementing pretreatment methods, such as warm or hot water soaking, sulfuric acid treatment, or hull scouring, may effectively break seed dormancy in large seeds of *Parkia biglobosa*, thereby enhancing their germination performance.

By adopting these recommendations, the overall success and efficacy of seed-based interventions can be significantly improved, contributing to the sustainable advancement of agroforestry and reforestation endeavours in Côte d'Ivoire.

Author Contributions: B.I.A. designed the methodology, took the experimental measurements, analysed the data and wrote the paper. V.L. and D.S.A. corrected the article. X.W., M.K., P.D.R., M.J., C.C., K.H.K., J.D. and S.S. supervised the work. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The datasets produced and/or analysed in the current study are available from: Adji, Beda Innocent, 2022, "Quality seed production for optimising the success of reforestation of native forest species: case of *Khaya senegalensis* (Meliaceae), *Pterocarpus erinaceus* (Fabaceae) and *Parkia biglobosa* (Fabaceae)", https://doi.org/10.7910/DVN/AEH9TP, Harvard Dataverse, V1.

Conflicts of Interest: The authors declare no conflict of interest.

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