Original Research Article

Comparative Effect of Biochars on the Growth of *Afzeliaafricana* and *Pterocarpus erinaceus* in Nursery Conditions in Faranah, Guinea

ABSTRACT

Aims: This study aims to assess the effects of various biochar types on the germination, growth, and biomass of two native West African forest species, *Afzelia africana* and *Pterocarpus erinaceus*, under controlled nursery conditions, and to identify suitable biochar treatments for enhancing reforestation practices in Guinea.
Study Design: Experimental design with five treatment groups.
Place and Duration of Study: Nursery trials conducted at Faranah, Guinea, over a six-month period.
Methodology: Five biochar treatments were applied: straw biochar (BP), peanut shell biochar (BCA), corn stalk biochar (BCM), household waste biochar (BDM), and a control with no biochar (D0). Key parameters measured included germination rate, leaf area, leaflet and leaf counts, as well as fresh and dry biomass for each species. Statistical analyses comprised normality tests, ANOVA, and Tukey's post-hoc tests to determine significant differences among treatments.
Results: Significant variations were observed across treatments for several growth parameters. *Afzelia africana* responded favorably to BCA and BDM treatments, exhibiting increased leaf area, number of leaves, number of leaflets, and higher fresh and dry biomass ($p < 0.05$). Conversely, *Pterocarpus erinaceus* showed improved germination rate, germination energy, germination speed, and leaf area with the BCM treatment. Correlations between germination and biomass parameters were particularly strong for *Afzelia africana*, indicating resilience to substrate variation.
Conclusion: Tailoring biochar application to species-specific needs can enhance nursery growth conditions for reforestation purposes. BCA and BDM treatments are most beneficial for *Afzelia africana*, while BCM is optimal for *Pterocarpus erinaceus*. These findings support biochar selection as a practical strategy to improve soil resilience and forest plant growth in Guinea's nursery settings.

Keywords: biochar, Afzeliaafricana, Pterocarpus erinaceus, germination, nursery.

1. INTRODUCTION

The degradation of tropical forests in West Africa is a major environmental issue, exacerbated by the increasing demand for agricultural land and firewood, along with unsustainable management practices (Tyukavina et al., 2018 ; FAO, 2020). These land use changes lead to significant biodiversity loss and ecosystem service decline, underscoring the urgency of reforestation to restore landscapes and combat soil erosion (Chazdon, 2008; Brancalion& Holl, 2020).

Biochars, produced through the pyrolysis of organic matter, are increasingly used as soil amendments in reforestation initiatives. These materials improve soil fertility and water retention, while also contributing to carbon sequestration (Lehmann & Joseph, 2015). In West Africa, where soils are often nutrient-poor and vulnerable to erosion, biochar could offer a sustainable solution to support the growth of young plants in nurseries (Jeffery et al., 2011; Sohi et al., 2010). However, few studies have specifically examined the effects of different types of biochars on local forest species such as *Afzeliaafricana* and *Pterocarpus erinaceus*, two native West African species known for their ecological and economic importance (Louppe et al., 2008; Sanogo et al., 2019).

The application of biochar in nurseries could improve germination rates, growth, and biomass of plants, making the production more vigorous and resilient to environmental stressors (Kammann et al., 2012; Khan et al., 2020). However, the effects of biochars vary depending on the raw materials used for their production, and their effectiveness depends on the specific characteristics of each forest species (Mukherjee et al., 2014; Van Zwieten et al., 2010). A comparative approach using biochars from various sources, such as straw, peanut shells, corn stalks, and organic waste, is thus necessary to identify the most suitable amendments for each species' needs (Schmidt & Wilson, 2014; Nguyen et al., 2021).

The use of biochars as amendments in degraded tropical soils has shown beneficial effects on soil fertility and plant growth (Jeffery et al., 2011). However, the specific adaptation of various biochars to the needs of local forest species remains underexplored, particularly in the African context. This study aims to fill this gap by exploring the interactions between biochar and forest species in nursery conditions, thus providing a scientific basis for improved resource management in reforestation programs (Lehmann & Joseph, 2015; Sohi et al., 2010).

This article aims to evaluate the impact of different biochars on the germination, growth, and biomass of *Afzeliaafricana* and *Pterocarpus erinaceus*. By identifying the most effective type of biochar for each species, this study will contribute to optimizing reforestation practices in West Africa, offering a potential solution to soil degradation and ecosystem conservation challenges (El-Naggar et al., 2019; Anderson et al., 2022).

2. MATERIAL AND METHODS

2.1. Study Area

The study was conducted at the experimental station of the Department of Water, Forests, and Environment of the Valery Giscard d'Estaing Higher Institute of Agronomy and Veterinary Medicine in Faranah (ISAV/F). The station is located between 10°05' North latitude and 10°74' West longitude (Figure 1).

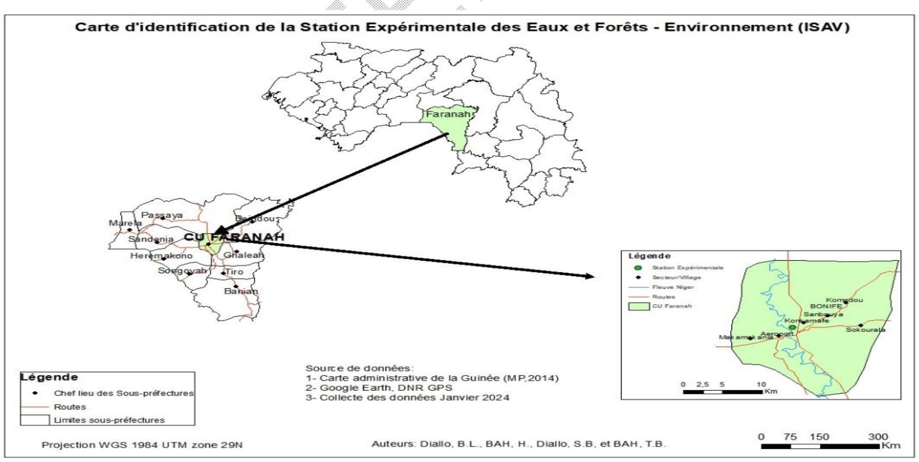

Figure 1: Map of the Study Area

2.2. Plant Material

The plant material consisted of seeds from *Afzeliaafricana* and *Pterocarpus erinaceus*. These seeds were sown in 1 kg-capacity pots with dimensions of 25 cm x 15 cm, containing different substrate mixtures.

2.3. Data Collection Methods

2.3.1. Experimental Design

The experimental design used was a randomized complete block design (RCBD) with two factors: biochar pretreatment and substrate. Biochar was the primary factor of interest. Each pot contained 650 g of forest soil, 300 g of sand, and 50 g of biochar. The biochar types included straw biochar (BP), peanut shell biochar (BCA), corn stalk biochar (BCM), household waste biochar (BDM), and a control with no biochar (D0).

2.3.2. Seed Collection

Seeds of *Afzeliaafricana* and *Pterocarpus erinaceus* were collected from shrubby fallows east of Faranah, near the Faranah-Bantou road, between February and April 2023, from selected seed-producing trees.

2.3.4. Seed Treatment

The outer coverings of *Pterocarpus erinaceus* seeds were trimmed using a pruner, while *Afzeliaafricana* seeds were directly collected beneath seed-bearing trees. After collection, both seed batches were soaked in ordinary borehole water for 24 hours to break dormancy as a pretreatment. Sowing was then conducted in pots containing a mixture of forest soil, sand, and the various biochar types in the proportions described above.

2.3.5. Measured Parameters and Employed Methods

2.3.6. Germination Rate

The germination rate was determined from a test using X seeds, where G represents the number of germinated seeds. It was assessed through three parameters. First, the "latent period" or days to first germination, where (d) represents the time between sowing (tg0) and the first germination (tg1). Second, the "germination spread" or duration, where (e) represents the period from the first germination (tg1) to the final germination (tg2). Finally, the germination rate (T) is calculated as the ratio of germinated seeds to the total number of seeds, given by T = G / N * 100 **(**Camara et al., 2023**).**

2.3.7. Germination Speed (Vg)

The germination speed (Vg) is defined as the number of seeds germinated within one-third of the days allotted for germination, essentially representing one-third of the germination potential or germination rate.

Vg = $\frac{n1/_3}{N}X100$;= où $n^1/_3$ = Number of seeds germinated within one-third of the germination time according to Edondoto et al. (2020)

2.3.8. Average Plant Height (HMP)
The average height and diameter of the plants were measured over eight months, or 210 days. Measurements for growth parameters, specifically height and diameter, were taken every 15 days, starting from the 28th day after sowing, throughout the eight-month period. A measuring tape was used to measure plant height, and a caliper was used to measure the diameter at the plant collar.
2.3.9. Leaf Area

Leaf area was calculated using the MESURIM software.
2.3.10. Number of Leaves and Leaflets

These two parameters were counted manually.
2.3.11. Plant Biomass Evaluation
Biomasses were weighed using a precision scale (0.004 g accuracy) and calculated according to the following formulas: BAH + BRH = BHT; BAS + BRS = BTS.
2.4. Data Analysis Method

To analyze the effects of different types of biochars on the germination, vegetative growth, and biomass of *Afzeliaafricana* and *Pterocarpus erinaceus*, a rigorous statistical approach was employed. Collected data included germination rate, germination speed, vegetative growth measurements (leaf area, number of leaflets and leaves), and both fresh and dry biomass (aerial, root, and total). These measurements were organized according to the five biochar treatment types: straw biochar, peanut shell biochar, corn stalk biochar, household waste biochar, and a control without biochar.
Prior to comparative analyses, a Shapiro-Wilk normality test was conducted on the data to verify their distribution. A Levene’s test was also applied to assess the homogeneity of variances between treatment groups. These preliminary tests ensured that the data met the required conditions for parametric analyses.
A one-way analysis of variance (ANOVA) was performed for each measured parameter to determine whether the different biochar treatments produced significant effects on germination, vegetative growth, and biomass. When ANOVA indicated a significant difference between groups ($p < 0.05$), a Tukey post-hoc test was applied to identify specific pairs of treatments showing significant differences. This post-hoc test allowed for pairwise comparisons of treatment means, precisely identifying biochars with superior or inferior effects on each measured parameter.
To explore potential relationships between growth and biomass parameters, Pearson correlation analyses were conducted. These analyses aimed to evaluate whether certain germination or growth parameters could predict final biomass or other plant performance indicators. The obtained correlation coefficients measured the strength and direction of relationships and determined whether significant trends existed between measured parameters, such as germination rate and total biomass.
Statistical results were synthesized in tables and graphs, with p-values reported for each analysis to indicate the level of significance. Group means were annotated with distinct letters to mark significant differences between treatments.
The results were interpreted in relation to initial hypotheses and previous studies, identifying the most effective types of biochars for each species based on the analyzed parameters. This methodology thus provided a comprehensive analysis of the effects of different biochars, highlighting their potential applications for reforestation programs in West Africa.

3. RESULTS AND DISCUSSION
3.1. Results

3.1.1. Agrochemical Characteristics of Biochars

The different biochars are distinguished by their chemical characteristics, potentially influencing plant growth in nurseries. The pH values range from 7.2 (BCM) to 9.1 (BDM). A higher (alkaline) pH can facilitate the absorption of certain nutrients. For example, household waste biochar (BDM), with a pH of 9.1, may benefit plants tolerant to alkaline conditions, such as certain tropical species. The biochars are particularly high in carbon, especially BCA (39.43% C) and BDM (40.48% C), thus increasing organic matter content in the substrate. This richness can enhance water retention and soil stability, which is beneficial for seed germination and initial plant growth. Electrical conductivity (EC) ranges from 0.53 (BP) to 65.7 (BCA), reflecting the potential salinity of the substrate. High EC levels, such as those found in BCA, may sometimes limit growth if plants are sensitive to salts; however, in this case, it appears to favor certain growth metrics for *Afzeliaafricana* (Table 1)

Table 1: Agrochemical Characteristics of Soil and Applied Biochars

Paramteres	Soil	Biochars			
		BP	BCA	BCM	BDM
pH (eau)	6,1	7,4	7,6	7,2	9,1
Electrical Conductivity (EC, µs/cm)	8,36	0,53	65,7	1,97	33,3
Carbone (C, %)	2,1	39,43	11,03	40,17	40,48
Total Nitrogen (%)	0,15	0,34	0,76	0,42	0,67
C/N ratio (%)	14	117,35	14,60	95,65	60,24

OrganicMatter (%)	3,6	67,82	18,98	69,10	69,63
AvailablePhosphorus (ppm)	55	1,17	1,09	5,96	4,29
Calcium Ca^{2+} ($cmol.kg^{-1}$)	0,769	nd	nd	nd	nd
Magnésium Mg^{2+} (cmol.kg-1)	0,706	nd	nd	nd	nd
Potassium K^{+} (cmol.kg-1)	0,09	nd	nd	nd	nd
Na^{+} (cmol.kg-1)	0,067	nd	nd	nd	nd
CEC ($cmol.kg^{-1}$)	3,16	nd	nd	nd	nd
Ca (ppm)	nd	1,278	0,688	0,671	4,938
Mg (ppm)	nd	0,311	0,239	0,390	0,181
K (ppm)	nd	0,774	1,260	1,192	3,480
Fe (ppm)	15,26	1,458	2,464	1,088	2,425
Mn (ppm)	43,14	4,237	4,817	3,591	4,151
Cu (ppm)	206	44,361	44,761	37,161	42,561
Zn (ppm)	2,18	0,137	0,137	0,082	0,161

Legend:

pH: hydrogen potential; C/N: Carbon-to-nitrogen ratio; CEC: Cation exchange capacity; BP: Straw-based biochar; BCA: Peanut shell-based biochar; BCM: Corn stalk-based biochar; BDM: Household waste-based biochar; nd: not determined.

3.1.2. Germination Rate, Germination Energy, and Germination Speed

For germination rate and germination speed, species-specific differences are observed depending on the type of biochar. Regarding *Afzeliaafricana*, germination rates are high for all treatments (76.67% for D0 to 93.33% for BCM), although there are no significant differences (p=0.323). This suggests that *Afzeliaafricana* is well-tolerant of various substrates and biochars. The germination speed is also slightly higher with BCM, indicating that corn stalk-based biochar (BCM) promotes a quicker start to germination, which may be beneficial for reforestation operations requiring vigorous seedlings. In contrast, *Pterocarpus erinaceus* shows increased sensitivity to biochar types, with significant variations in germination rates (p=0.039) and germination speed (p=0.038). The BCM biochar (83.33%) significantly enhances the germination rate and germination speed compared to other biochars, while the BDM biochar has the lowest effect (56.67%). This demonstrates that *Pterocarpus erinaceus* responds positively to the conditions provided by BCM, possibly due to improved moisture and nutrient retention. (Table 2)

Table 2: Germination Rate, Germination Energy, and Germination Speed

Plant Species	Biochars	Germination Rate (%)	Germination Energy (%)	Germination Speed (%)
Afzeliaafricana	D0	76.67 ± 3.33a	38.33 ± 1.67a	25.56 ± 1.11a
	BP	83.33 ± 3.33a	41.67 ± 1.67a	27.78 ± 1.11a
	BCA	90.00 ± 5.77a	45.00 ± 2.89a	30.00 ± 1.92a
	BCM	93.33 ± 3.33a	46.67 ± 1.67a	31.11 ± 1.11a
	BDM	90.00 ± 10.00a	45.00 ± 5.00a	30.00 ± 3.33a
	P-value	**P=0.323**	**P=0.323**	**P=0.324**
Pterocarpus erinaceus	D0	60.00 ± 5.77b	30.00 ± 2.89b	20.00 ± 1.92b
	BP	60.00 ± 5.77b	30.00 ± 2.89b	20.00 ± 1.92b

Plant Species	Biochars	Germination Rate (%)	Germination Energy (%)	Germination Speed (%)
	BCA	73.33 ± 8.82ab	36.67 ± 4.41ab	24.44 ± 2.94ab
	BCM	83.33 ± 3.33a	41.67 ± 1.67a	27.78 ± 1.11a
	BDM	56.67 ± 3.33b	28.33 ± 1.67b	18.89 ± 1.11b
	P-value	**P=0.039**	**P=0.039**	**P=0.038**

Note: Values are expressed as mean ± standard deviation. Different letters (a, b) within a column indicate significant differences between treatments at $p < 0.05$.

Vegetative Growth: Leaf Area, Number of Leaflets, and Number of Leaves
Biochars significantly influence vegetative growth parameters for both species, although the effects vary by species. For *Afzeliaafricana*, regarding leaf area, BDM promotes the largest leaf area (241.28 cm^2), followed by BCA, indicating that biochars derived from household waste and peanut shells optimize leaf growth. This increase could be linked to better water retention and nutrient availability. For the number of leaves and leaflets, BP and BDM support a high number of leaves, with BP yielding the highest (31 leaves). In contrast, BCA produces the highest number of leaflets (177), suggesting this biochar can enhance leaf development in a more qualitative manner.

For *Pterocarpus erinaceus*, leaf area is significantly influenced (p=0.000), with BCM producing the largest area (75.71 cm^2). Therefore, BCM is most favorable for maximizing light absorption, enhancing photosynthesis. However, the number of leaves and leaflets does not vary significantly, except that BCA promotes a higher number of leaflets. This may indicate that while the number of leaves remains unchanged, the leaf structure is better developed under BCA influence (Table 3).

Table 3: Average Values of Leaf Area, Number of Leaflets, and Number of Leaves

Plant Species	Biochars	Leaf Area (cm^2)	Number of Leaves	Number of Leaflets
Afzeliaafricana	D0	171.66 ± 1.17e	17.00 ± 0.58c	129.33 ± 0.88d
	BP	174.50 ± 0.61d	31.00 ± 0.58a	166.00 ± 0.58b
	BCA	236.35 ± 0.58b	23.00 ± 0.58b	177.00 ± 0.58a
	BCM	177.84 ± 0.59c	22.33 ± 0.67b	119.33 ± 0.88e
	BDM	241.28 ± 1.11a	24.00 ± 0.58b	150.67 ± 0.88c
	P-value	**P=0.000**	**P=0.000**	**P=0.000**
Pterocarpus erinaceus	D0	54.51 ± 1.07c	10.00 ± 1.15a	24.33 ± 1.20c
	BP	46.48 ± 1.33d	6.67 ± 1.20a	28.67 ± 1.20b
	BCA	46.89 ± 0.69d	10.00 ± 1.15a	39.33 ± 1.45a
	BCM	75.71 ± 0.96a	7.33 ± 1.86a	25.67 ± 1.33bc
	BDM	60.65 ± 1.35b	5.67 ± 2.33a	10.67 ± 1.20d
	P-value	**P=0.000**	**P=0.273**	**P=0.000**

3.1.3. Fresh Biomass and Dry Biomass

Biomass accumulation is essential for assessing plant vigor. Results showed that for *Afzeliaafricana*, fresh biomass: BCA is particularly effective in increasing aerial fresh biomass (121.05 g), and BCM boosts root biomass (50.25 g), supporting balanced plant development. For dry biomass, BCA remains the most effective biochar, with a maximum total dry biomass (BTS) of 93.92 g, highlighting its positive impact on long-term growth.

In contrast, for *Pterocarpus erinaceus*, differences in biomass (both fresh and dry) between treatments are not significant. This could suggest that this species is less responsive to the enhancements provided by biochars or that the biochars used do not supply the necessary nutrients for optimal growth (Tables 4 and 5).

Table 4: Average Values of Fresh Biomass

Plant Species	Biochars	Aerial Fresh Biomass (BAH, g)	Root Fresh Biomass (BRH, g)	Total Fresh Biomass (BHT, g)
Afzeliaafricana	D0	54.45 ± 0.95d	34.35 ± 1.18c	88.80 ± 1.09c
	BP	82.87 ± 18.39b	39.95 ± 0.84b	122.82 ± 18.42b
	BCA	121.05 ± 1.41a	38.15 ± 1.01b	159.20 ± 1.26a
	BCM	82.20 ± 1.50b	50.25 ± 1.13a	132.45 ± 1.35ab
	BDM	97.50 ± 0.75ab	52.25 ± 0.20a	149.75 ± 0.67ab
	P-value	**P=0.003**	**P=0.000**	**P=0.001**
Pterocarpus erinaceus	D0	2.93 ± 0.93a	5.97 ± 2.09a	8.90 ± 3.00a
	BP	3.30 ± 0.46a	6.67 ± 0.79a	9.97 ± 1.23a
	BCA	3.20 ± 0.83a	5.97 ± 1.87a	9.17 ± 2.70a
	BCM	4.03 ± 1.39a	6.40 ± 0.62a	10.43 ± 2.01a
	BDM	2.63 ± 1.29a	6.20 ± 1.42a	8.83 ± 2.68a
	P-value	**P=0.900**	**P=0.996**	**P=0.985**

Legend: BAH: Aerial Fresh Biomass, BRH: Root Fresh Biomass, BHT: Total Fresh Biomass

Table 5: Average Values of Dry Biomass

Plant Species	Biochars	Aerial Dry Biomass (BAS, g)	Root Dry Biomass (BRS, g)	Total Dry Biomass (BST, g)
Afzeliaafricana	D0	26.60 ± 0.92d	23.75 ± 1.01b	50.35 ± 0.09d
	BP	56.45 ± 0.55b	31.20 ± 1.10a	87.65 ± 0.55b
	BCA	60.37 ± 1.67a	33.55 ± 1.18a	93.92 ± 0.87a
	BCM	50.30 ± 1.50c	31.30 ± 1.33a	81.60 ± 2.45c
	BDM	55.55 ± 1.33b	29.85 ± 0.95a	85.40 ± 2.08bc
	P-value	**P=0.000**	**P=0.001**	**P=0.000**
Pterocarpus erinaceus	D0	1.57 ± 0.52a	2.73 ± 1.03a	4.30 ± 1.55a
	BP	1.80 ± 0.25a	2.93 ± 0.27a	4.73 ± 0.52a
	BCA	1.87 ± 0.69a	2.93 ± 1.34a	4.80 ± 2.03a
	BCM	2.27 ± 0.88a	4.03 ± 1.08a	6.30 ± 1.96a
	BDM	1.53 ± 0.73a	2.10 ± 0.95a	3.63 ± 1.68a

Plant Species	Biochars	Aerial Dry Biomass (BAS, g)	Root Dry Biomass (BRS, g)	Total Dry Biomass (BST, g)
	P-value	**P=0.930**	**P=0.748**	**P=0.833**

Legend: BAS: Aerial Dry Biomass, BRS: Root Dry Biomass, BST: Total Dry Biomass

3.1.4. Correlations Between Growth Parameters

Correlations between parameters provide insights into the relationships among germination, growth, and final biomass, as shown in Tables 6 and 7.

For *Afzeliaafricana*: (1) The germination rate (TG) is positively correlated with total dry biomass (BST), indicating that a higher germination rate contributes to greater biomass production. (2) Final height (HFinale) and average growth speed (VMC) are also positively correlated with both total fresh and dry biomasses, suggesting that plants growing faster in height also accumulate more biomass. This shows that height can be a good indicator of overall plant health.

For *Pterocarpus erinaceus*: (1) Although correlations are less pronounced for this species, the germination rate is correlated with both total dry biomass (BST) and fresh biomass (BHT), showing a relationship between initial germination success and nursery productivity. (2) Final height and growth speed (VMC) are positively correlated with fresh and dry biomasses, but these relationships are weaker than those for *Afzeliaafricana*, suggesting that other unmeasured factors may influence the growth of *Pterocarpus erinaceus*.

Table 6: Correlation Between Evaluated Parameters of *Afzeliaafricana* in Nursery Conditions Under Different Types of Biochars

	TG	VG	Hi	Hf	VMC	Di	Df	SF	NFO	NFE	BAH	BRH	BHT	BAS	BRS	BTS
TG	1															
VG	1,000**	1														
Hi	0,092	0,092	1													
Hf	0,337	0,337	-,055	1												
VMC	0,198	0,198	-,643**	,764**	1											
Di	-0,058	-0,057	-0,270	0,017	0,098	1										
Df	0,245	0,245	0,118	-,061	-0,102	-0,164	1									
SF	0,315	0,315	0,445	,231	-0,150	-0,353	-0,243	1								
NFO	0,198	0,198	0,075	,056	0,052	-0,159	0,398	-0,030	1							
NFE	0,106	0,106	0,323	,532*	0,317	-0,097	-0,127	0,031	0,267	1						
BAH	0,412	0,412	0,318	,463	0,101	-0,278	-0,218	0,725**	-0,045	0,315	1					
BRH	0,469	0,469	-0,108	,466	0,442	-0,129	0,193	0,322	0,109	0,188	0,213	1				
BHT	0,499	0,499	0,262	,544*	0,209	-0,287	-0,148	0,745**	-0,012	0,33 7	0,966**	0,456	1			
BAS	0,502	0,502	0,366	,701**	0,332	-0,096	-0,149	0,571*	0,142	0,706**	0,757**	0,433	0,803**	1		
BRS	0,509	0,509	0,316	,683**	0,305	,0203	-0,241	0,414	-0,006	0,545*	0,691**	0,350	0,721**	0,840**	1	
BTS	0,519*	0,519*	0,365	,718**	0,336	-0,028	-0,175	0,551*	0,111	0,689**	0,764**	0,426	0,807**	0,992**	0,903**	1

*. Correlation is significant at the 0.05 level (two-tailed), ** correlation is significant at the 0.01 level (two-tailed). TG: Germination Rate, VG: Germination Speed, Hi: Initial Height, Hf: Final Height, VMC: Average Growth Speed, Di: Initial Diameter, Df: Final Diameter, SF: Leaf Area, NFO: Number of Leaflets, NFE: Number of Leaves, BAH: Aerial Fresh Biomass, BRH: Root Fresh Biomass, BHT: Total Fresh Biomass, BAS: Aerial Dry Biomass, BRS: Root Dry Biomass, BTS: Total Dry Biomass.

Table 7: Correlation Between Evaluated Parameters of *Pterocarpus erinaceus* in Nursery Conditions Under Different Types of Biochars

	TG	VG	Hi	Hf	VMC	Di	Df	SF	NFO	NFE	BAH	BRH	BHT	BAS	BRS	BTS
TG	1															
VG	1,00**	1														
Hi	0,08	0,083	1													
Hf	0,18	0,178	0,258	1												
VMC	0,18	0,179	-0,134	,886**	1											
Di	-0,1	-0,102	0,577*	0,018	-0,289	1										
Df	0,3	0,299	0,175	0,305	0,187	0,075	1									
SF	0,43	0,432	-0,023	-0,072	-0,024	0,033	0,253	1								
NFO	0,31	0,31	0	0,418	0,464	-0,389	-0,152	-0,436	1							
NFE	0,01	0,012	-0,508	0,105	0,383	-0,508	-0,229	-0,244	,520*	1						
BAH	0,24	0,237	0,415	0,512	0,333	0,064	0,489	0,172	0,127	-0,028	1					
BRH	0,02	0,019	0,32	0,413	0,281	0,236	0,174	0,01	-0,023	0,009	0,809**	1				
BHT	0,12	0,117	0,378	0,478	0,318	0,171	0,322	0,082	0,042	-0,007	0,934**	,966**	1			
BAS	0,19	0,189	0,44	0,578*	0,386	0,113	0,499	0,159	0,13	-0,009	0,986**	,821**	,935**	1		
BRS	0,22	0,223	0,36	0,5	0,382	0,02	0,365	0,203	0,198	0,113	0,943**	,852**	,935**	,956**	1	
BTS	0,21	0,212	0,395	0,535*	0,388	0,056	0,42	0,188	0,174	0,067	0,970**	,849**	,945**	,983**	,993**	1

*. Correlation is significant at the 0.05 level (two-tailed), ** Correlation is significant at the 0.01 level (two-tailed). TG: Germination Rate, VG: Germination Speed, Hi: Initial Height, Hf: Final Height, VMC: Average Growth Speed, Di: Initial Diameter, Df: Final Diameter, SF: Leaf Area, NFO: Number of Leaflets, NFE: Number of Leaves, BAH: Aerial Fresh Biomass, BRH: Root Fresh Biomass, BHT: Total Fresh Biomass, BAS: Aerial Dry Biomass, BRS: Root Dry Biomass, BTS: Total Dry Biomass

3.2. Discussion

The results of this study highlighted the effect of different types of biochars on the germination, vegetative growth, and biomass of *Afzeliaafricana* and *Pterocarpus erinaceus*. The distinct responses observed between the two species, depending on the applied biochars, underscore the importance of selecting amendments suited to the specific needs of forest species.

3.2.1. Effect of Biochar on Germination Rate

The results showed a significant variation in germination rate for *Pterocarpus erinaceus* depending on the biochars, but not for *Afzeliaafricana*. This difference could be due to the specific substrate requirements of *Pterocarpus erinaceus*. Previous studies have shown that biochars improve germination by increasing nutrient availability and enhancing soil structure (Lehmann & Joseph, 2015; Jeffery et al., 2011). The BCM (corn stalk biochar) and BCA (peanut shell biochar) were particularly effective in promoting germination in this species, suggesting that moisture retention and nutrient availability provided by these biochars played a key role in activating the germination process.

In contrast, for *Afzeliaafricana*, the lack of significant differences between biochar treatments indicated a higher tolerance to substrate variations. This species appeared to benefit from the presence of biochar in general, without requiring a specific type. This tolerance could be advantageous for reforestation programs in diverse environments, allowing the use of various biochars without impacting germination rates (Louppe et al., 2008).

3.2.2. Influence of Biochars on Vegetative Growth (Leaf Area, Number of Leaflets, and Number of Leaves)

Vegetative growth results showed that household waste biochar (BDM) and peanut shell biochar (BCA) had notable positive effects on leaf area and leaf count for Afzeliaafricana. Studies have shown that biochars with high organic matter and carbon content increase leaf area by improving water retention and enhancing the availability of essential nutrients (Zhao et al., 2021; Schmidt & Wilson, 2014).

For *Pterocarpus erinaceus*, only leaf area was significantly influenced by biochars, particularly by BCM. This response could be linked to BCM's ability to provide a soil structure that facilitates nutrient absorption while maintaining adequate moisture (Nguyen et al., 2021). However, leaf count and leaflet count did not vary significantly, suggesting that *Pterocarpus erinaceus* prioritized leaf growth over leaflet density in nutrient-rich substrates.

3.2.3. Biomass Accumulation: Fresh and Dry Biomass

For *Afzeliaafricana*, BCA and BCM biochars were distinguished by their positive effect on total biomass, with high values for both fresh and dry biomass. Studies have shown that biochars improve nutrient retention capacity, particularly for woody species, leading to increased biomass (Lehmann & Joseph, 2015; Anderson et al., 2022). Conversely, for *Pterocarpus erinaceus*, biomass differences between biochars were not significant, suggesting that this species responded less to biochar inputs in terms of biomass production. Some species do not always benefit from biochar amendments, especially if they are adapted to low-nutrient soils (Smith et al., 2020; Meyer et al., 2018). This may also indicate that *Pterocarpus erinaceus* benefited less from carbon inputs and that other specific amendments or nutrients may be required to stimulate biomass production.

3.2.4.Correlations Between Growth Parameters

Correlations showed that, for *Afzeliaafricana*, germination rate and germination speed were positively associated with total biomass. This suggested that high germination rates could be a good indicator of biomass production for this species. Good initial germination often led to optimal growth and biomass accumulation (El-Naggar et al., 2019; Githinji, 2019). For *Pterocarpus erinaceus*, correlations between leaf area and biomass were weak, indicating that this species could develop biomass independently of leaf area, depending on biochar inputs. Some species prioritize root growth and do not show strong correlations between biomass and leaf area (Zwart et al., 2019; Inyang et al., 2020)

4. CONCLUSION

In summary, the studies revealed that *Afzeliaafricana* benefits significantly from BCA biochar in increasing leaf area, aerial and root biomass, and overall growth, making BCA optimal for reforestation projects involving this species. On the other hand, *Pterocarpus erinaceus* showed a more limited response to biochars, but BCM favored germination and leaf area, which could be useful for maximizing initial establishment in nurseries. Thus, the study reveals that biochar selection depends on the plant species and growth objectives. For *Afzeliaafricana*, BCA is recommended to maximize growth and biomass, whereas for *Pterocarpus erinaceus*, BCM is more suitable for seedlings due to its effect on germination and leaf area. These findings could guide nursery practices to improve survival and growth rates of forest species by using suitable biochars.

REFERENCES

1. Anderson, C. J., Groffman, P. M., Kaushal, S. S., & Walter, R. C. (2022). Nitrogen dynamics in restored and degraded urban streams: A review. *Frontiers in Environmental Science, 10*, 837102. https://doi.org/10.3389/fenvs.2022.837102
2. Brancalion, P. H. S., & Holl, K. D. (2020). Guidance for successful tree planting initiatives. *Journal of AppliedEcology, 57*(12), 2349-2361. https://doi.org/10.1111/1365-2664.13725
3. Camara, B., Ndiaye, S., Diédhiou, M. A. A., Goudiaby, A. O. K., Kande, M., Fall, F., &Ngom, D. (2023). Croissance et Développement de Carapa procera DC. sur différents types de terreau en pépinière en Basse Casamance (Sénégal). *International Journal of Biological and Chemical Sciences*, 17(3), 1006-1019. DOI: 10.4314/ijbcs.v17i3.20
4. Chazdon, R. L. (2008). Beyond Deforestation: Restoring Forests and Ecosystem Services on Degraded Lands. *Science, 320*(5882), 1458-1460. https://doi.org/10.1126/science.1155365
5. El-Naggar, A., Lee, S. S., Rinklebe, J., Farooq, M., Song, H., Sarmah, A. K., & Ok, Y. S. (2019). Biochar application to low fertility soils: A review of current status, and future prospects in agriculture. *Environmental International, 122*, 465-478. https://doi.org/10.1016/j.envint.2018.12.058
6. FAO. (2020). *Global Forest Resources Assessment 2020: Main report*. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org
7. Githinji, L. (2019). Effect of biochar application rate on soil physical and hydraulic properties of a sandy soil. *Geoderma, 337*, 1-10. https://doi.org/10.1016/j.geoderma.2018.10.014

8. Githinji, L. (2019). Effect of biochar application rate on soil physical and hydraulic properties of a sandy soil. *Geoderma, 337*, 1-10. https://doi.org/10.1016/j.geoderma.2018.10.014
9. Inyang, M., Gao, B., Pullammanappallil, P., Ding, W., & Zimmerman, A. R. (2010). Biochar from anaerobically digested sugarcane bagasse. *Bioresource Technology, 101*(22), 8868-8872. https://doi.org/10.1016/j.biortech.2010.06.088
10. Jeffery, S., Verheijen, F. G. A., van der Velde, M., & Bastos, A. C. (2011). A quantitative review of the effects of biochar application to soils on crop productivity using meta-analysis. *Agriculture, Ecosystems&Environment, 144*(1), 175-187. https://doi.org/10.1016/j.agee.2011.08.015
11. Jones, D. L., Murphy, D. V., Khalid, M., Ahmad, W., Edwards-Jones, G., & DeLuca, T. H. (2019). Biochar mediated mobilization of native organic nitrogen. *Soil Biology and Biochemistry, 43*(4), 784-787. https://doi.org/10.1016/j.soilbio.2010.04.008
12. Kammann, C., Ratering, S., Eckhard, C., & Müller, C. (2012). Biochar and hydrochar effects on greenhouse gas (carbon dioxide, nitrous oxide, and methane) fluxes from soils. *Journal of EnvironmentalQuality, 41*(4), 1052-1066. https://doi.org/10.2134/jeq2011.0117
13. Khan, S., Chao, C., Waqas, M., Arp, H. P. H., & Zhu, Y. G. (2020). Sewage sludge biochar influence upon rice yield, metal bioaccumulation, and greenhouse gas emissions from acidic paddy soil. *Environmental Science &Technology, 54*(3), 1037-1045. https://doi.org/10.1021/acs.est.9b02782
14. Lehmann, J., & Joseph, S. (2015). *Biochar for Environmental Management: Science, Technology and Implementation* (2nd ed.). Routledge.
15. Louppe, D., Oteng-Amoako, A. A., & Brink, M. (2008). *Plant Resources of Tropical Africa 7(1): Timbers 1*. PROTA Foundation.
16. Meyer, S., Glaser, B., & Quicker, P. (2018). Technical, economical, and climate-related aspects of biochar production technologies: A literature review. *Environmental Science &Technology, 42*(2), 331-338. https://doi.org/10.2134/jeq2017.10.0412
17. Nguyen, T. T. N., Xu, C. Y., Tahmasbian, I., Che, R., Xu, Z., Zhou, X., Wallace, H. M., & Bai, S. H. (2021). Effects of biochar on soil available inorganic nitrogen: A review and meta-analysis. *Geoderma, 312*, 90-102. https://doi.org/10.1016/j.geoderma.2017.10.010
18. Sanogo, K., Traore, D., Camara, A., & Diallo, A. (2019). Characterization of *Afzeliaafricana* and *Pterocarpus erinaceus* stands in Mali. *African Journal of Ecology, 57*(1), 48-56. https://doi.org/10.1111/aje.12565
19. Schmidt, H. P., & Wilson, K. (2014). The 55 uses of biochar. *The Biochar Journal, 1*, 14-16. Retrieved from https://www.biochar-journal.org/en/ct/55-Uses-of-Biochar
20. Smith, P., et al. (2020). How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? *Global Change Biology, 26*(10), 1082-1104. https://doi.org/10.1111/gcb.15218
21. Sohi, S. P., Krull, E., Lopez-Capel, E., & Bol, R. (2010). A review of biochar and its use and function in soil. *Advances in Agronomy, 105*, 47-82. https://doi.org/10.1016/S0065-2113(10)05002-9
22. Solia Edondoto, et al. (2020). Germination study of *Afzeliabipindensis* seeds over an 18-month period. *Agriculture Journal/Conference Proceedings*, Retrieved from https://www.agrimaroc.org/index.php/Actes_IAVH2/article/view/811
23. Tyukavina, A., Hansen, M. C., Potapov, P., Stehman, S. V., Smith-Rodriguez, K., Okpa, C., & Aguilar, R. (2018). Congo Basin forest loss dominated by increasing smallholder clearing. *Science Advances, 4*(11), eaat2993. https://doi.org/10.1126/sciadv.aat2993
24. Van Zwieten, L., Kimber, S., Morris, S., Chan, K. Y., Downie, A., Rust, J., … Cowie, A. (2010). Effects of biochar from slow pyrolysis of papermill waste on agronomic

performance and soil fertility. *Plant and Soil, 327*(1-2), 235-246. https://doi.org/10.1007/s11104-009-0050-x
25. Zwart, K. B., & Kuikman, P. J. (2019). Biochar in climate change mitigation. *Soil Biology and Biochemistry, 52*(6), 85-92. https://doi.org/10.1016/j.soilbio.2019.01.017