

Effect of Substrate and Inorganic Fertiliser on Seed Germination and Growth of *Parkia biglobosa* (Jacq).

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Abstract

Parkia biglobosa is a well-known agroforestry tree species of significant socio-economic importance. However, its propagation in the nursery is a major challenge to production. The study evaluated the effect of different substrates (S1 = 50% potting soil + 50% bokashi compost (fermented compost rich in micro-organisms), S2 = 75% potting soil + 25% bokashi compost and S3 = 100% potting soil) and inorganic fertiliser [$N_{13}P_{17}K_{17}S_6B_{0.5}Zn_{1.5}$] application rates (0, 5 and 10 g/ pot) on the germination and growth of *Parkia biglobosa* in a split-plot designed experiment replicated three times. The substrate served as the main treatment while the rate of inorganic fertiliser application served as the sub-treatment. Data on germination was subjected to survival analyses, while seedling growth (seedling height, root collar diameter, number of leaves, number of branches, length and width of seedling leaves) was analysed using linear and generalised mixed-effects models. The germination results, analyzed using the Kaplan-Meier method, showed a maximum rate of 13.25% with the substrate containing 75% black earth and 25% bokashi, although the differences between substrates were not significant ($p = 0.8$). Despite pre-sowing treatments (scarification and soaking), dormancy was only partially broken, suggesting the need for more effective pre-sowing techniques. In terms of post-germination growth, morphological parameters (height, collar diameter, number of leaves and branches, leaf size) increased overall with time. The best results were obtained with substrates enriched with bokashi compost (25 to 50%) and low doses of mineral fertiliser (0 to 5 g). Analysis of the relationships between the parameters revealed significant correlations: seedling height was strongly associated with leaf length, while collar diameter was associated with leaf width and branching. A principal component analysis (PCA) revealed two opposing morphological strategies: one favouring robustness (collar diameter, wide leaves), the other vertical growth and branching. These findings suggest that the use of bokashi, alone or in combination with a low dose of mineral fertiliser, promotes balanced seedling growth by optimising structural parameters. However, germination efficacy remains limited, calling for further research into the pre-sowing treatments of *P. biglobosa* seeds. These findings will guide conservation strategies and agroforestry programs for *Parkia biglobosa*. It is envisaged that this study will be expanded to other endangered species to

preserve biodiversity.

Keywords: Compost bokashi; central Benin; potting soil; food security; seed germination.

Effet du Substrat et de L'engrais Minéral sur la Germination et la Croissance de *Parkia biglobosa* (Jacq.).

Résumé

Parkia biglobosa est une espèce agroforestière bien connue et d'une grande importance socio-économique. Toutefois, sa propagation en pépinière constitue un défi majeur pour la production. Cette étude a évalué l'effet de différents substrats (S1 = 50 % terreau + 50 % compost bokashi — compost fermenté riche en micro-organismes; S2 = 75 % terreau + 25 % bokashi; et S3 = 100 % terreau) ainsi que de doses d'engrais minéral [$N_{13}P_{17}K_{17}S_6B_{0.5}Zn_{1.5}$] (0, 5 et 10 g/pot) sur la germination et la croissance de *Parkia biglobosa*, dans un dispositif expérimental en split-plot répété trois fois. Le substrat constituait le traitement principal, tandis que la dose d'engrais minéral servait de sous-traitement. Les données de germination ont été analysées par des méthodes de survie, tandis que la croissance des plants (hauteur, diamètre au collet, nombre de feuilles, nombre de branches, longueur et largeur des feuilles) a été analysée à l'aide de modèles linéaires et généralisés à effets mixtes. Les résultats de germination, analysés selon la méthode de Kaplan-Meier, ont montré un taux maximal de 13,25 % avec le substrat contenant 75 % de terre noire et 25 % de bokashi, bien que les différences entre substrats n'aient pas été significatives ($p = 0,8$). Malgré les prétraitements appliqués aux semences (scarification et trempage), la dormance n'a été que partiellement levée, ce qui suggère la nécessité de techniques de pré-germination plus efficaces. Concernant la croissance post-germination, les paramètres morphologiques (hauteur, diamètre du collet, nombre de feuilles et de branches, taille des feuilles) ont globalement augmenté avec le temps. Les meilleurs résultats ont été obtenus avec les substrats enrichis en bokashi (25 à 50 %) et les faibles doses d'engrais minéral (0 à 5 g). L'analyse des relations entre paramètres a révélé des corrélations significatives : la hauteur des plants était fortement associée à la longueur des feuilles, tandis que le diamètre du collet était lié à la largeur des feuilles et au nombre de branches. Une analyse en composantes principales (ACP) a mis en évidence deux stratégies morphologiques opposées : l'une privilégiant la robustesse (diamètre du collet, larges feuilles), l'autre la croissance verticale et le branchage. Ces résultats suggèrent que l'utilisation du bokashi, seul ou combiné à une faible dose d'engrais minéral, favorise une croissance équilibrée des plants en optimisant les paramètres structurels. Toutefois, l'efficacité de la germination demeure limitée, ce qui appelle à des recherches supplémentaires sur les traitements pré-germinatifs des graines de *P. biglobosa*. Ces résultats contribueront à orienter les stratégies de conservation et les programmes agroforestiers impliquant *Parkia biglobosa*. Il est envisagé d'étendre cette étude à d'autres espèces menacées afin de préserver la biodiversité.

Mots-clés: Compost bokashi; centre Bénin; terreau; sécurité alimentaire; germination des semences.

Introduction

Parkia biglobosa (Jacq) (nééré), commonly known as “African locust bean”, is one of the few tropical plant species extensively studied for its biology and use (Abdou *et al.*, 2021). Utilised extensively by local communities in the Sahelian zones of Africa, this multipurpose fruit tree species is highly valued for its non-timber value and ability to ensure food security (Ayanrinde *et al.*, 2023; Nyadanu *et al.*, 2016; Okoye *et al.*, 2014; Koura *et al.*, 2011). Known as "afitin" in Benin, "iru" in Nigeria, "dawadawa" in Ghana, "soumbala" in Burkina Faso, Mali and Guinea, "soumbara" in Côte d'Ivoire, "nététu" in Senegal, and "Kinda" in Sierra Leone (Abdou *et al.*, 2021), *P. biglobosa*'s considerable socio-economic importance and local farming organisations deserve as much attention as initiatives to improve production (PROTA4).

Interestingly, *P. biglobosa* ranks third among the first 10 priority agroforestry woody species in Benin (Assogbadjo *et al.*, 2017) and among the top 10 agroforestry trees in Ghana (Owusu Danquah *et al.*, 2011). *P. biglobosa* is an important plant that provides enormous services (e.g., food, medicine, soil protection and improvement, cultural rites, habits and customs) to rural populations and is a source of income and an effective means of fighting poverty. It is a valuable plant that significantly raises socio-economic standards in sub-Saharan Africa (Kakpo *et al.*, 2023; Ayanrinde *et al.*, 2023). Due to its overexploitation and climate change, hard seed coat and slow growth, *P. biglobosa* faces difficulty in germination and regeneration like many other endogenous agroforestry species (Kakpo *et al.*, 2023; Fingesi, 2023; Abdou *et al.*, 2015; Niang-Diop *et al.*, 2010). According to Koura *et al.*, (2013), *P. biglobosa* parks are characterised by a high presence of old trees and show poor regeneration of stands and regression of the

species' range. In Nigeria, Kareem (2022) reported that this kind of plant grows slowly, has a low density, and is difficult to find processed seeds even at a high cost. *P. biglobosa* faces major production constraints, and if not addressed, could become extinct (Kakpo *et al.*, 2023; Fingesi, 2023). Although the significance of this species has been established, its ability to regenerate is limited. Creating innovative ways for conservation and regeneration methods becomes essential (Froumsia *et al.*, 2019).

Producing quality seedlings of *P. biglobosa* in nursery would enhance the seedling establishment of plantations leading to increased productivity (Tokore Orou Mere *et al.*, 2021). Seed coat dormancy is a major constraint to the regeneration of many hard-seeded fruit tree species (N'danikou *et al.*, 2014; Niang-Diop *et al.*, 2010). Thus, pre-sowing seed pretreatments are necessary for obtaining higher germination rates (Hounsou-Dindin *et al.*, 2021; Douma *et al.*, 2019; N'Danikou *et al.*, 2015). Grafting and other forms of vegetative propagation have been recommended to producers for adoption (N'Danikou *et al.*, 2015). However, such propagation methods require skills that are not available to farmers. Hence, developing simple, effective and efficient methods for propagating *P. biglobosa* seedlings in the nursery will be important for resource conservation and benefit to the local population (Nguema *et al.*, 2014).

Even though recent studies have shown that fertilising endogenous agroforestry species with inorganic fertiliser or organic manure in the nursery could promote their rapid growth (Sodimu *et al.*, 2022; Kareem and Salaudeen 2021; Mukhtar *et al.*, 2021; Tokore Orou Mere *et al.*, 2021; Azongnidé *et al.*, 2019; Oluwalana *et al.*, 2019), few have focused on the rates of inorganic fertiliser (Oluwalana *et al.*, 2019) and combinations of organic and

inorganic fertilizers (Houenou *et al.*, 2021; Tong *et al.*, 2021; Lasmini *et al.*, 2018; Pohan *et al.*, 2018). Furthermore, although macronutrients such as N, P, and K enhance plant growth and development, their availability to the plant is enhanced by the availability of micronutrients (Kakpo 2019; Sanou 2016; Ishikawa *et al.*, 2013; Affokpon *et al.*, 2013; Salih 2013).

Bokashi compost is a product obtained by fermenting organic matter with water, molasses and micro-organisms to reduce food waste, store carbon dioxide in the soil and reduce the use of inorganic fertilisers in agriculture (Xiaohou *et al.*, 2008), and produces humus and vitality for plants (Higa, 2020). Studies have shown the beneficial effects of bokashi or bokashi -NPK on the fruit and biomass yield of some crops such as shallot (*Allium cepa* L. var. aggregatum) (Lasmini *et al.*, 2018), tomato (*Lycopersicon Esculentum* Mill.) (Pohan *et al.*, 2018), Bell Peppers (*Capsicum annum*, L.) (Houenou *et al.*, 2021) and *Amaranthus hybridus* (Tong *et al.*, 2021). These results confirm the hypothesis that bokashi compost, a natural fertiliser, can improve soil structure, boost plant development, and raise soil water content (Anhar *et al.*, 2018; Barajas-Aceves 2016). Moreover, it significantly increases N, P, and K content in plants, suggesting higher leaf production, longer and broader leaves, more branches, and taller plants (Hernández *et al.*, 2014; Lasmini *et al.*, 2018). Although the contribution of bokashi compost is widely recognised, few studies have analysed its effectiveness in Benin. This study aimed to assess the effect of substrate (potting soil mixed with bokashi compost) and rate of $N_{13}P_{17}K_{17}S_6B_{0.5}Zn_{1.5}$ on germination and growth of *P. biglobosa* in Central Benin.

Material and methods

Study area

The study was conducted under the Smallholder Agricultural Productivity Enhancement Program (SAPEP) within the agroecological zone V, a high cotton production area in Collines district, Central Benin. The trial was conducted at Agoua, Central Benin, between Latitude 08.32568° North and Longitude 001.94952° East (Figure 1). In Central Benin, the dominant soils are tropical ferruginous soils located in the central part and crude mineral soils and erosion soils at the edge of the hills (Azontondé *et al.*, 2016; Igué *et al.*, 2005). The altitude ranges from 242 m to 405 m, with an average (<https://www.google.com/maps/search/Bant%C3%A9%2C%20Bant%C3%A8%2C%20Collines%2C%20B%C3%A9nin>). The climate is Sudano-Guinean, and there has been a trend in recent years towards one growing season instead of two per year. The rainy season starts from April to November, and the annual rainfall varies between 1100 mm and 1200 mm. The vegetation is dominated by herbaceous carpet and dotted with a few large trees such as *Khaya senegalensis* A. Juss, *Vitellaria paradoxa* C.F. Gaertn, *Adansonia digitata* L. and *Parkia biglobosa* (PRODECOM, 2006).

Seed, substrates and fertiliser

Parkia biglobosa seeds was used for the study. Samples of *P. biglobosa* seeds were collected from elite trees (mature trees) following an ethnobotanical survey. Ripened fruits were harvested from selected *P. biglobosa* trees and shelled. The seeds were separated from the fruits by crushing the mealy pulp in water, drying it under ambient air, and weighed using an electronic balance. The average weight of the seeds was (19 ± 1)

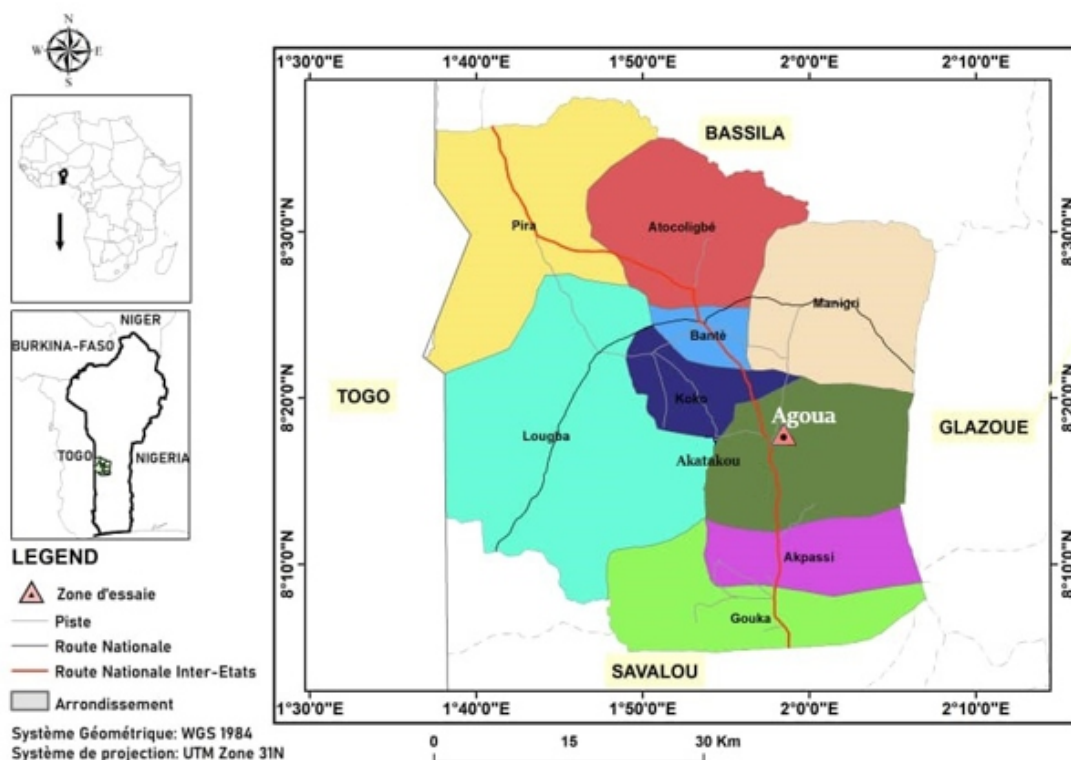


Figure 1. Map showing the study areas

g. The viability of the seeds was tested using the flotation method (Houndonougbo *et al.*, 2020). A total of 135 out of 200 seeds tested were viable and used for the experiment.

The substrate used in the experiment was a combination of potting soil and bokashi. The potting soil (p) was obtained from household waste and sieved before use. The bokashi (b) was made using 40 kg of poultry manure, 20 kg of bran mixture, 20 kg of rice husk, 7.5 l of water, and 0.075 dm³ each of honey and biopesticide solution (EM_s). The physicochemical characteristics of the fresh bokashi was 56.7% dry matter (DM); 78.1% organic matter (OM); pH = 5; C/N ratio = 21.1; 1.27 kg t⁻¹ of ammonium nitrogen (N-NH₄⁺); 12.18 kg t⁻¹ of nitrogen (N); 9.66 kg t⁻¹ of phosphorus (P₂O₅) and 6.89 kg t⁻¹ of

potassium (K₂O) (Houenou *et al.*, 2021). The composition of the substrate was as follows: S₁ = 50%p 50%b; S₂ = 75%p 25%b and S₃ = 100%p. The inorganic fertiliser used in the study was N₁₃P₁₇K₁₇S₆B_{0.5}Zn_{1.5} at 0 g (E₁), 5g (E₂) and 10 g (E₃).

Experimental design and nursery establishment

Two factors namely substrate and inorganic fertiliser treatments were laid in a split-plot designed experiment replicated three times. The main plot treatments consisted of substrates (S₁ = 50%p 50%b; S₂ = 75%p 25%b and S₃ = 100%p) while the subplot treatments consisted of inorganic fertiliser rate (E₁ = 0 g, E₂ = 5 g, E₃ = 10 g). The experiment was set up close to pre-existing water pumps, where water was easily accessible. Pots made of

polyethene, and biodegradable films of 35 cm x 25 cm were filled with different substrates and watered to field capacity under a shed covered with palm leaves to maintain a moderate temperature, with humidity and light intensity favourable to the development of seeds in the nursery. Plaques made of binders with identification numbers were attached to stakes installed in front of each treatment. Seeds were scarified and soaked for 24 h after which they were sown at the rate of 1 seed/pot to a depth of 1.5 cm. The trial involved 09 treatments, each with 27 pots, resulting in a total of 135 pots across all blocks when randomised. Watering was done twice a day at 07h00 and 18h00 (Aho & Kossou, 1997). The initial number of leaves was counted for all seedlings before the inorganic fertiliser application was carried out. The inorganic fertiliser was applied 15 days after germination while keeping it away from the seedling collar.

Data collection

Germination counts were made daily for 30 days from the first germinated seed. A seed is said to germinate if the plumule emerges above the soil surface and has the first two embryonic leaves. Seedling counts were made daily for 30 days from the first germinated seed. A seed was said to have germinated when a plumule emerged from the soil (Amani *et al.*, 2015).

Data on seedling growth parameters (seedling



Figure 2. Seedling measurements, collar diameter (a) and leaf length/width (b) (source : Kakpo, 2021)

height, number of leaves, root collar diameter, number of branches, seedling leaf length, and seedling leaf width) of *P. biglobosa* were collected weekly from August 19, 2021, to November 11, 2021, at five-day intervals. Seedling height was measured with a tape measure and a 30 cm-graduated ruler; the number of leaves and ramifications was counted manually (Fig. 2). The length and width of the leaves were taken on the longest leaf at each time. Using an electronic caliper, the root collar diameter was carefully measured to avoid introducing any stress on the seedlings.

Statistical analysis

To assess the impact of the substrates on the germination rate of *P. biglobosa*, data were subjected to a survival analysis, considering two variables : time to 50% germination. The non-parametric Kaplan-Meier estimator and the log-rank test (McNair *et al.*, 2012) in the library "(survival)" (Therneau, 2021) were used to analyse the germination time. We first ran the global tracking model to determine the time to 50% germination and the maximum time to complete germination. The test was then carried out for the three different substrates. To assess the effect of the inorganic fertiliser on seedling growth, the data collected were modelled using linear mixed-effect models in the 'nlme' library (Pinheiro *et al.*, 2017) and generalised mixed-effect models with the 'glmmTMB' library (Mollie *et al.*, 2017). The modelling procedure consisted of successively testing the effect of the random factor (block) and the effects of time using the unconditional mean model and the unconditional growth model, respectively. The contribution of their effect to total variability was assessed by calculating the intra-class correlation coefficient (ICC) and the variability due to time, respectively. The evaluation of the effect of the inorganic fertiliser led to the selection of the best

structure of variance-covariance matrices for the residuals after a likelihood ratio test. With the best model selected, an analysis of variance (ANOVA) was used to determine the significance of the effect of the inorganic fertiliser and their interactions. Finally, growth curves were constructed to describe the specific features of each treatment. The relationship between the different growth parameters of *P. biglobosa* in nursery under the different treatments 75%p 25%b 5 g, 75%p 25%b 10g, 75%p 25%b 0 g, 50%p 50%b 5 g, 50%p 50%b 0 g, 50%p 50%b 10 g, 100%p 0 g, 100%p 5 g, and 100%p 10 g a principal component analysis was performed. The analyses were carried out using R software version 4.2.1 (R Core Team, 2022).

Results

Main effect of substrate on germination of *Parkia biglobosa* in nursery

Data collected over weeks helped to determine the survival rates and the mean germination time T_{50} of *P. biglobosa* seeds. The results of Kaplan-Meier test on the

germination of *P. biglobosa* are presented in Figure 2. When all the treatments are combined, the germination patterns throughout the days are displayed in Figure 3a. Thus, a total germination rate of 58% is achieved after 5 days of seedling. Yet, in Figure 3b, the substrate, 75%p 25%b, had the highest germination rate (13.25%), the shortest time (6 days) to reach 50% germination, and an average germination time of 8 days, even though the difference in the average germinating time was not significantly different among the substrates ($p = 0.8$) (Figure 3).

Influence of the inorganic fertiliser on early growth of *P. biglobosa*

Seeding height, root collar diameter, number of leaves, and number of branches of *P. biglobosa* were significantly ($p < 0.001$) influenced by the number of days, the inorganic fertiliser, and the number of days inorganic fertiliser (Table 1).

For all the treatments, growth parameters

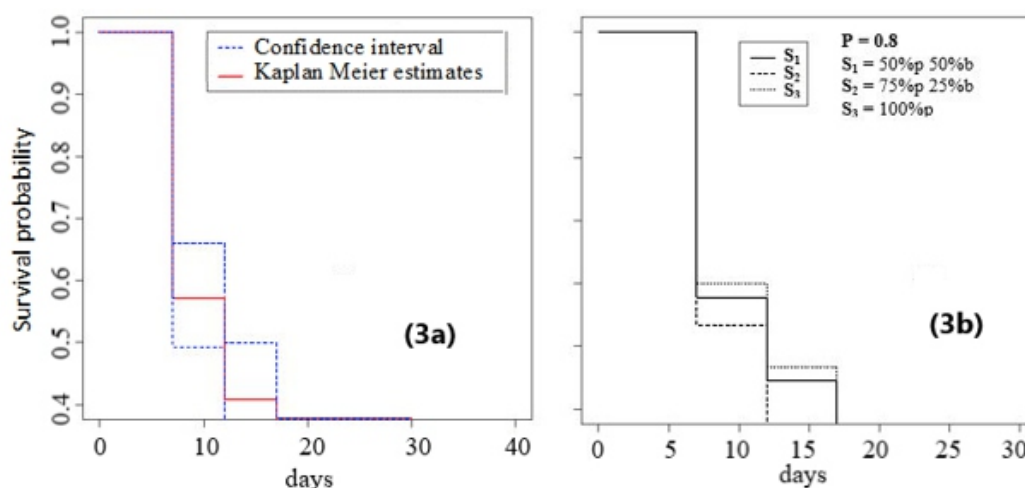


Figure 3. Kaplan Meier curves (a) representing seed germination rates of *P. biglobosa* over time (days from start of the experiment) under each S1, S2 and S3 (b)

Table 1. Linear mixed-effects model

	Factor	numDF	denDF	F-value	p-value
Height	Number of days	1	946	454.769	<0.001
	Inorganic fertiliser	8	946	17.143	<0.001
	Number of days inorganic fertiliser	8	946	7.117	<0.001
	ICC block (%)			1.03	
	ICC Number of days (%)			68.19	
Number leaves	Number of days	1	946	58.0752	<0.001
	Inorganic fertiliser	8	946	16.9249	<0.001
	Number of days inorganic fertiliser	8	946	14.6208	<0.001
	ICC block (%)			4.05	
Root collar diameter				89.67	
	Number of days	1	946	157.679	<0.001
	Inorganic fertiliser	8	946	12.418	<0.001
	Number of days inorganic fertiliser	8	946	3.665	<0.001
	ICC block (%)			0.559	
Number of branches	ICC Number of days (%)			35.98	
	Number of days	1	768	67.603	<0.001
	Inorganic fertiliser	8	768	19.24	<0.001
	Number of days inorganic fertiliser	8	768	9.452	<0.001
	ICC block (%)			6.08	
Leaf length	ICC Number of days (%)			46.57	
	Number of days	1	768	69	<0.001
	Inorganic fertiliser	8	768	2.471	0.011
	Number of days inorganic fertiliser	8	768	2.077	0.035
	ICC block (%)			0.001	
Leaf width	ICC Number of days (%)			28.04	
	Number of days	1	768	12.9	<0.001
	Inorganic fertiliser	8	768	2.762	0.005
	Number of days inorganic fertiliser	8	768	2.211	0.024
	ICC block (%)			0.001	
	ICC Number of days (%)			10.66	

increased with increased duration of seedling growth (Figures 4, 5, 6). Seedlings from treatments 75%p 25%b 10g, 75%p 25%b 0 g and 50%p 50%b 5 g followed the same growth pattern until week 15. However, at week 18, seedling height was highest for

75%p 25%b 10 g, followed by 50%p 50%b 5 g and 75%p 25%b 0 g (Figure 4a). Also, seedling height followed similar growth pattern for seedlings produced from 100%p 5 g and 100%p 10 g until week 13 when 100%p 5 g began to grow taller (Figure 4a). Leaf

production from seedlings produced from 50%p 50%b 0 g and 100%p 0 g followed similar pattern (Figure 4b). Leaf production was much lower during the first 7 weeks in seedlings produced from 50%p 50%b 5 g compared to seedlings produced from 50%p 50%b 0 g and 100%p 0 g. However, leaf production increased much faster between week 7 and week 13 in 50%p 50%b 5 g until week 14 onwards, when leaf production fell below 50%p 50%b 0 g (Figure 4b). The largest collar diameter was observed in seedlings produced from 50%p 50%b 0 g, 100%p 0 g and 50%p 50%b 5 g (Figure 5a). The pattern of growth in collar diameter (Figure 5a) of seedlings from these treatments followed the pattern of leaf production (Figure 5a). At week 18, the treatments could be grouped into three based on the number of branches produced by the treatments. Seedlings produced from 50%p 50%b 0 g, 50%p 50%b 5 g, 75%p 25%b 0 g and 100%p 0 g belonged to group one and had the highest number of branches (~ 8), followed by the second group, 75%p 25%b 5 g, 75%p 25%b 10 g, 100%p 5 g and 50%p 50%b 10 g (<7) followed by the third group 100%p 10 g (~5)

(Figure 6b). Seedling leaf length was higher (>8 cm) among five of the treatments (50%p 50%b 5 g, 75%p 25%b 5 g, 50%p 50%b 10 g, 75%p 25%b 0 g and 100%p 0 g). Interestingly, seedling leaf length declined with increased rate of NPKSBZn application to 100% potting soil (Figure 6a). Seedling leaf width was far larger for seedlings from 75%p 25%b 0 g during the first 10 weeks of seedling growth than the rest of the treatments. However, the rate of growth of seedling leaf width appeared to be similar after the 10 weeks of growth (Fig. 6b).

Relationship between growth parameters of *P. biglobosa* seedlings under different treatments

The results of the principal component analysis showed that the growth parameters of *P. biglobosa* were related (Figure 7). It was observed that leaf length, width and diameter at the collar were positively correlated. However, these parameters were negatively correlated with plant height, number of leaves and number of branches although they positively correlated with each other.

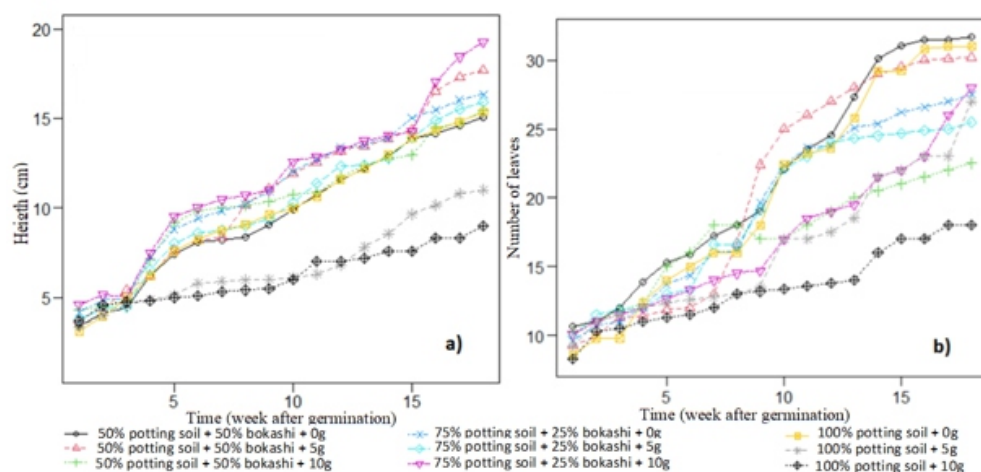


Figure 4. Evolutionary trend of plant height (a) and number of leaves (b) of *Parkia biglobosa* seedlings

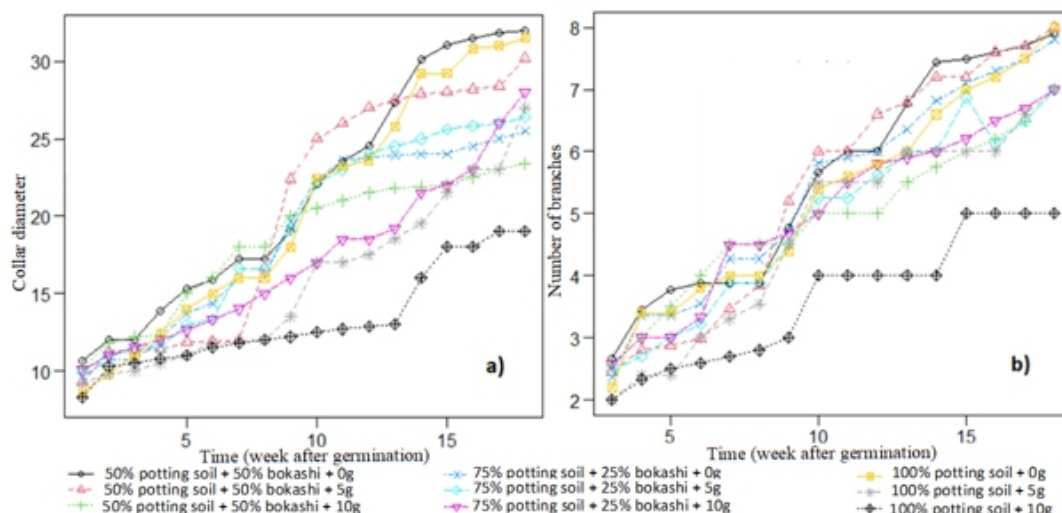


Figure 5. Evolutionary trend of collar diameter (a) and number of branches (b) of *Parkia biglobosa* seedlings

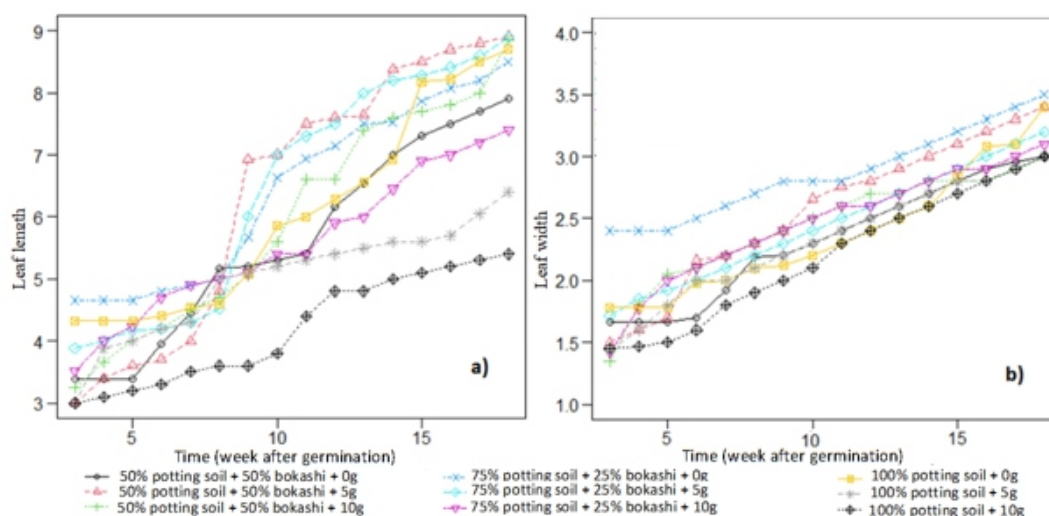


Figure 6. Evolutionary trend of leaf length (a) and leaf width (b) of *Parkia biglobosa* seedlings

Discussion

Effect of potting soil and potting soil-bokashi mixture and they interaction on germination of *P. biglobosa*

The results of this study show that the germination of *P. biglobosa* seeds, although low overall in percentage terms, proceeded rapidly, with a cumulative rate of 58%

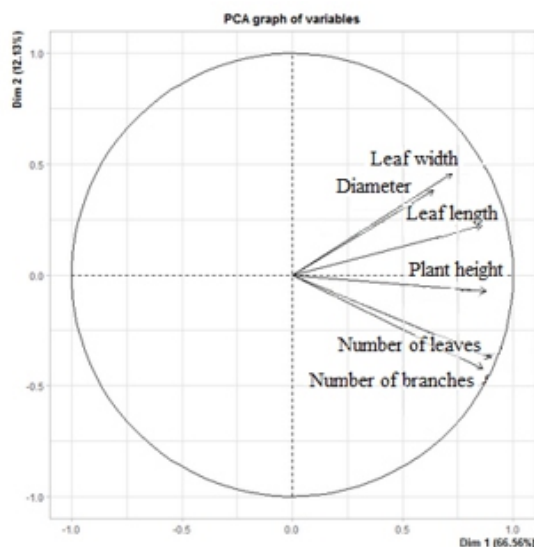


Figure 7. Correlation between growth parameters

reached on the fifth day after sowing, all conditions considered. Using the Kaplan-Meier method, it was possible to accurately monitor emergence and survival dynamics according to the different substrates. The substrate containing 75% black earth and 25% bokashi was the most effective for *P. biglobosa* germination suggesting the stimulating effect of bokashi, a fermented compost rich in micro-organisms (EM), organic acids, enzymes and immediately available nutrients, which promotes early biological processes such as imbibition and the breaking of seed dormancy (Roldán *et al.*, 2005; Teruo, 2001; Higa & Parr, 1994). The findings from the present study have shown that differences in germination of the species among the substrates evaluated were not significant and are consistent with the findings of Goudiaby *et al.* (2021), who also found no significant differences in germination rates of *Leucaena leucocephala* and *Moringa oleifera* across two potting soils

in Kéréwane, Sénégal.

Despite the scarification and soaking of seeds of *P. biglobosa* in water for 24 hours prior to sowing, the highest germination rate observed (13.25%) suggests limited responsiveness to this pre-sowing treatment. This result agrees with Millogo (2014), who reported germination rates ranging between 0.83% and 14.67% from seeds of *P. biglobosa* stored in gene banks in Burkina Faso. In contrast, Adjii *et al.* (2021) observed a 100% germination rate without any pre-sowing treatment when studying *P. biglobosa* under nursery and greenhouse conditions, pointing to the role of environmental conditions and possibly seed provenance in influencing germination success. Other studies reported varied germination outcomes depending on pre-treatment methods. For example, Amonum *et al.* (2016) and Douma *et al.* (2019) used chemical (H_2SO_4) and physical scarification techniques with this species, obtaining germination rates of 16–24% and 58.86%, respectively. Similarly, Hounsou-Dindin *et al.* (2021) achieved between 62.5% and 73.6% germination in *Balanites aegyptiaca* and *Riciodendron heudelotii* using various dormancy-breaking techniques. Comparable germination patterns were observed by Garba *et al.* (2020) in *Tamarindus indica* and by N'danikou *et al.* (2014) in *Vitex doniana*. Thus, the results of the present study confirm that breaking dormancy remains a major physiological obstacle to propagating *P. biglobosa* from seed, even in the presence of a rich substrate such as bokashi, which provided a microbial environment conducive to rapid germination, though germination rates were not high.

Influence of potting soil, compost bokashi and inorganic fertiliser on vegetative development of *P. biglobosa*

Concerning post-germination growth of *P. biglobosa*, the results obtained in this study

reveal the significant influence of substrate composition (potting soil, bokashi) and the dose of inorganic fertiliser (NPKSBZn) on the growth and morphological development of the seedlings. Alo & Aweto (2018) observed that *P. biglobosa* seedlings responded favourably to the application of NPK fertiliser. According to them, one of the major limiting factors affecting the growth of *P. biglobosa* seedlings is nitrogen deficiency. Overall, all treatments favoured a gradual increase in growth parameters over time, particularly in height, crown diameter, number of leaves and branches, and leaf dimensions. However, notable differences emerged depending on the combination of organic and inorganic inputs.

At week 18, the 75%p 25%b 10g treatment stood out as having the greatest height, followed by 50%p 50%b 5g, indicating that the moderate addition of bokashi compost with a supplement of 10g of inorganic fertiliser stimulates greater stem elongation. Bokashi not only improves the availability of nutrients but also stimulates microbial interactions favourable to growth (Marschner, 2012). This result is consistent with the reported effects of bokashi compost on water retention, nutrient availability and improved soil structure (Pascual *et al.*, 2018; Ghanem *et al.*, 2017). Lasmini *et al.* (2018) reported that organic manure reduces soil evaporation and soil temperature fluctuations resulting in the positive effect of bokashi on the growth of tomato (*Lycopersicum Esculentum* Mill) (Pohan *et al.*, 2018) and amaranth (*Amaranthus hybridus*) Houenou *et al.* (2021).

Morphologically, collar diameter growth followed the same pattern as leaf production, showing relationship between apical meristematic activity and basal thickening.

The number of branches at week 18 enabled the treatments to be grouped into three distinct categories. Mixtures with 50% bokashi compost (with or without low inorganic fertiliser input) and potting soil alone without fertilisation (100%p 0g) showed the most intense branching (~8 branches) suggesting that moderate levels of bokashi compost or the absence of inorganic fertiliser in a balanced substrate can encourage branching by reducing nutritional stress and stimulating lateral growth (Anhar *et al.*, 2017 ; Marschner, 2012 ; Steiner *et al.*, 2007). On the other hand, treatments with high NPKSBZn inputs, particularly in pure potting soil (100%p 10g), inhibited several morphological parameters, particularly branching and leaf length of *P. biglobosa*. This phenomenon could be explained by toxicity or nutritional imbalance caused by excess nutrients, particularly in substrates poor in buffering organic matter (Fageria *et al.*, 2002; Chen *et al.*, 2018). Notably, leaf length decreased with increasing inorganic fertiliser in the 100%p treatments, showing sensitivity to mineral concentration. *P. biglobosa* leaf width showed a remarkable early response for the 75%p 25%b 0g treatment, but this difference faded over time, indicating that initial substrate structure benefits may stabilise as seedlings reach a more self-sustaining growth phase (de Sousa Antunes *et al.*, 2022 ; Taiz & Zeiger, 2010).

The interaction between bokashi compost, potting soil and inorganic fertiliser may have a complex influence on the physiology of *P. biglobosa* seedlings. Treatments combining 25-50% bokashi compost and a moderate dose of inorganic fertiliser (≤ 5 g) seem to offer the best treatment for vertical growth, branching and leaf development of *P. biglobosa*. These results suggest that the organic and microbiological richness of

bokashi enables it to limit, or even avoid, excessively high inorganic fertiliser inputs, which can be counter-productive (Fageria *et al.*, 2002). Plants take advantage of nutrient availability for early growth and development; hence, inadequate supply of nutrients could limit seedling growth in a natural and controlled environments (Kareem & Salaudeen, 2021; Saidou *et al.*, 2012). Increased growth resulting from the application of NPK fertiliser and organic manure to *Vitellaria paradoxa* seedlings (Azongnide *et al.*, 2019), and *taaki* (aerobic compost) and bokashi compost to *Anacardium occidentale* seedlings (Tokore Orou Mere *et al.*, 2021), and urea to *Pterocarpus erinaceus* seedlings (Sodimu *et al.*, 2022) suggest the importance of fertiliser application on the seedling growth of agroforestry species in nursery.

Bokashi offers a promising agroecological solution for improving germination and robust growth of *P. biglobosa* seedlings but does not compensate for the biological limitations of dormant seeds on their own. More aggressive pre-treatments may be required to maximise emergence rates.

Relationship between growth parameters of *P. biglobosa* seedlings under different nursery treatments

The positive correlation between leaf length, width and crown diameter indicates morphological vigour linked to leaf expansion and increased structural strength. These characteristics are generally associated with improved photosynthetic efficiency and increased nutrient storage and transport capacity at the crown (Poorter *et al.*, 2012; Marschner, 2012). Such a configuration reflects a functional orientation towards consolidation rather than elongation. Conversely, these three parameters (leaf length, width and crown diameter) are negatively correlated with *P. biglobosa* plant

height, number of leaves and number of branches, although the latter are positively correlated with each other suggesting a morpho-functional compromise in the species' growth strategies. Hence, when the seedling invests more in leaf strength and expansion, height and branching tend to slow down, and vice versa. For example, when plant vigour increases, there is a leaf expansion and thickening of the crown, which works against height, reducing the number of new leaves and branching. This strategy could be beneficial in the context of root competition or moderate light, where optimisation of leaf structure takes precedence over elongation (Valladares *et al.*, 2002).

These results confirm those of Gnanglè *et al.* (2010) and Dossa *et al.* (2020), who also demonstrated synergies and antagonisms between growth parameters in *Vitellaria paradoxa* and *Detarium senegalense* under nursery conditions. In particular, Dossa *et al.*, (2020) observed that *Detarium senegalense* generates more leaves and branches as its size increases, which corroborates the positive correlation between height, number of leaves and branching in our study. However, our results differ from those of Garba *et al.* (2020), who reported a positive correlation between crown diameter and height in *Tamarindus indica* L. This discrepancy may be explained by specific differences in growth dynamics, vegetative architecture or the environmental conditions and substrates used. The contrast observed between strength traits (diameter, broad leaves) and vertical growth traits (height, branches) reflects a classic trade-off in the adaptive strategies of young trees (Reich *et al.*, 2003 ; Li *et al.*, 2021). In constrained environments (light, nutrients), *P. biglobosa* appears to adopt a slow but robust growth strategy, geared towards resilience rather than rapid

establishment. This reinforces the idea that bokashi, by improving the gradual availability of nutrients, encourages slow but morphologically optimised growth.

Conclusion

The study assessed the combined effect of potting soil, bokashi and different doses of inorganic fertiliser (NPKSBZn) on the germination and seedling growth of a woody species, *P. biglobosa*. The results showed that germination remained low despite scarification and soaking pre-sowing treatments. The substrate containing 75% potting soil and 25% bokashi gave the best results in terms of germination speed and rate, although the differences between substrates were not significant. Beyond the germination phase, the effect of bokashi was clearly beneficial for seedling growth of *P. biglobosa*. Treatments containing between 25% and 50% bokashi promoted balanced growth, with good performance in terms of height, branching, leaf length and width. Seedlings given high doses of inorganic fertiliser (notably 100% p 10g) showed signs of stress: reduced height growth, poor branching and limited leaf development of *P. biglobosa*. This study shows that incorporating 25-50% bokashi in the growing medium, combined with a low inorganic fertiliser input, is an effective strategy for improving the performance of *P. biglobosa* seedlings. However, to overcome the constraints of poor germination, further research into seed dormancy treatments is needed.

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