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ASSESSMENT OF PROVENANCES AND PHENOTYPIC VARIATION IN PTEROCARPUS ERINACEUS POIR. IN TARABA STATE, NIGERIA

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Abstract

This study evaluated the influence of provenance on the phenotypic traits of Pterocarpus erinaceus mother trees in their selected natural range in Taraba State, Nigeria. Based on the species' natural distribution range in Taraba State, 3 study sites (Bali, Kurmi, and Donga) were randomly selected, and each location was considered a unique population. The study employed standard procedures in provenance study investigation. All mother trees ≥10cm (Diameter at breast height (DBH) 1.3m) and ≤ 100m apart were considered as the same population and were progressively assessed for stocking density and the various phenotypic traits (Total tree height, DBH, crown diameter, height at first branching, and number of primary branches). The stocking density $Ha^{-1}$was determined for each population based on the total land area in m^2. Data were analysed using various statistical tools (ANOVA, SLD post-hoc tests and Pearson correlation). The results revealed very low stocking density (4-5 trees) Ha^{-1} for the three different populations. Provenance had significant effects for some of the phenotypic traits (Total tree height and height to first branching). Kurmi provenance outperformed others, revealing genetic or local adaptive advantages. It may be opined that provenance influenced both stocking density and phenotypic traits. Kurmi provenance demonstrated the most promising for future genetic improvement and seed sourcing study. The overall poor stocking density highlighted the need for a more proactive enrichment planting strategy and sustainable management of the remaining species' natural population.

Keywords: *Pterocarpus erinaceus*, Provenance Evaluation, Phenotypic Traits, Genetic Variation, Taraba State

INTRODUCTION

The implementation of sustainable tree management and conservation strategies cannot be achieved without a knowledge of the phenotypic and genotypic variability of the species, enabling individuals' differentiation (Houetchegnon, 2016). A Morphological variability study is appropriate for overall genetic improvement and tree varietal selection activities. It enables the identification of attractive morphological descriptors, identification of traits linked to the origin of seed sources and possible genetic groups (Zhang, 2012). In Nigeria, the variability among savannah woody species is yet to be fully studied, as ecosystems that support them are highly threatened, and native species are lost with their gene pools (Zhang, 2012). *Pterocarpus erinaceus* (Poir.), commonly known as African rosewood, Senegal rosewood, is a species widespread in the savannahs of Nigeria (Abronnier 2004). This species, endemic to Guineo-Sudanian and Sudano-Sahelian areas and is a multipurpose tree species in its range (Abronnier 2004).

Indeed, it is sought by craftsmen for the manufacture of various musical instruments (balafons, n'goni and djembés) (Silue *et al,* 2014). It is one of the most widely used woody species in the savannah of Nigeria by farmers as forage (Silue *et al,* 2014). The species has several socio-economic values as the bark, leaves and roots are used in pharmacopoeia to treat several illnesses, including anaemia, cough, dysentery, malaria and infant fever (Ouedraogo *et al,* 2017).

However, the recent pressure on the remaining mother trees in its West African range, including Nigeria, makes it one of the most threatened woody species in the savannahs because its timber quality is preferred the especially by Asian countries, counties especially China (Houechanou *et al,* 2013). The African teak provides a high-value timber for export, used in cabinetmaking, building and armaments (Rabiou *et al,* 2017). In Nigeria, stands of *P. erinaceus* are found in various vegetation zones (Guinea-Sudanian savanna; Southern Guinea savanna; Derived/Guinea savanna; and Northern/Southern Guinea savanna) of Nigeria (Kolapo *et al.,* 2023). On a State basis, it has been reported in Kaduna, Kogi, Oyo, Cross River and Taraba (Kolapo *et al.,* 2023). Within Taraba state, *P. erinaceus* is found mostly in central senatorial districts, as high densities have been reported in Ardo Kola, Mutum Biyu, Gassol, Bali, Gashaka, Donga, Kurmi, Ussa and Takum Local Government Areas (LGAs) (Kolapo *et al.,* 2023).

Provenance evaluation is practically aimed at identifying population or seed source which will produce well-adapted and productive forests with particular criteria that include survival, resistance to adverse environmental factors and pest, wood quality, seed production as well as establishing local seed production stands (Akinnagbe and Oni, 2007). Most reported studies on *P. erinaceous* in West Africa have only focused on the Specie's wood quality, botany and ecology as well as ethno-botany (Segla *et al,* 2015). Recently, Kolapo (2023) studied the species germination behaviours with seeds from various sources. However, considering the current threats on this species' remaining mother tree, especially in Taraba State, where there has been a serious depletion of the natural population, there is a need to investigate the existing mother tree population and observe existing variations within and between populations, as well as evaluate the phenotypic traits among the mother trees. It is appropriate to produce reliable data on its morphological variability, as a prerequisite for detecting outstanding phenotypes and the development of optimal valorisation plans and preservation of the species. Though several studies have been carried out on provenance evaluation with reference to some indigenous and exotic species such as *Chrysophyllum albidum*, *Parkia biglobosa* and *Prosopis africana* (Dietrichson, 1969; Willan *et al.,* 1990; Akinnagbe and Oni, 2007), such vital information is lacking among the different natural populations of *P.erinaceus* in Taraba State. The study, therefore investigated the existing variations among the different populations in the form of provenance evaluation, as well as characterized the existing phenotypic traits in mother trees

MATERIALS AND METHODS

Study locations and sampling sites selection

Within the State, *P. erinaceus* occurred mostly in the southern guinea savanna and montane forest of Taraba State Ahmed *et al.,* (2016). However, high densities had been reported in the following locations (Ardo Kola, Mutum Biyu, Gassol, Bali, Gashaka, Donga, Kurmi, Ussa and Takum LGAs (Figure 1) (Ahmed *et al.,*2016). The vegetation of these areas had also been described by Kolapo *et al. (*2023) appropriately as an undisturbed Guinea savannah ecosystem dominated by open savannah woodland (Ahmed *et al.,* 2016). After the preliminary reconnaissance survey, based on the general species distributions and the vegetation types in the

State, 3 Local government Areas (LGAs) found in the southern guinea savanna and montane forest were selected and were treated as suitable representations of the species in its range. Donga (guinea savanna), Bali (guinea savanna) and Kurmi (montane forest)

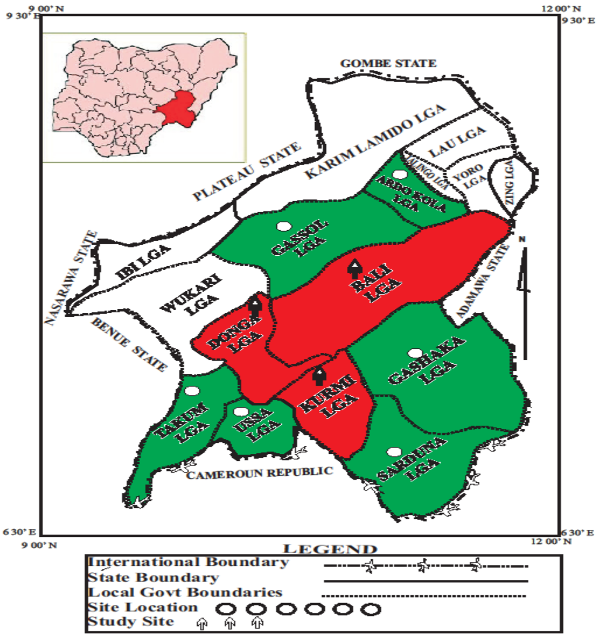

Figure 1: Map of Taraba State showing the 16 Local Governments Areas and the locations where *P. erinaceus* had been reported (Ahmed *et al.,*2016).

KEYNOTE: The green colour indicates the location were *P. erinaceus* had been reported, while the red colors indicated the 3 selected study sites.

Data collection procedure

All the final selected study locations were unique populations of a relatively large number of *P. erinaceus* mother trees of populations and considered to be different from other populations (Ahmed *et al.,*2016). Other factors for consideration in the actual sampling sites selection included field accessibility and terrain. Any other mother tree(s) with ≥100m from the selected population were considered to belong to another population (Ahmed *et al.,*2016). All mother trees ≥10cm in diameter at breast height (1.3m DBH) were considered for inventory. Each mother tree was geo-referenced with its coordinates taken along with other physical and environmental factors recorded. At the end of the inventory total number of mother trees encountered in each provenance was individually counted to estimate stocking density per hectare (Ha^{-1}). Subsequently, all the encountered mother trees were assessed for the following phenotypic traits:

Total tree height (m), Tree diameter (DBH at 1.3m), Number of primary branches, Height at first forking or branching (m), and Crown diameter (m)

Total tree height was determined using the Relascope, while diameter tape was used for measuring the individual mother tree diameter at (DBH). The number of primary branches was physically observed and recorded, while, at first, forking was measured from the base of each mother tree up to the point of branching out. Crown diameter for each mother tree was determined in North-South-West-East directions using the meter tape. Measurement was at the edge of each mother tree crown in the four directions, and the average crown diameter was determined

Data handling and analysis for the provenance study

All the phenotypic traits data were arranged on a provenance basis for each study site. The total land area for each study site was also calculated in m^2 and converted into hectares to determine the species stocking density Ha^{-1}. All the quantitative phenotypic data for all mother trees were subjected to Two-way Analysis of Variance (ANOVA) to test for statistically significant within and between provenances for individual trees for each provenance. Where significant differences were found ($p<0.05$), Standardized Linear Discriminant (SLD) post-hoc test was employed to identify specific group mean differences. To further explore trait interactions, Pearson's correlation coefficient (r) was calculated to assess the strength and direction of relationships among the measured phenotypic variables. Significance was tested at the 5% and 1% levels ($p < 0.05$ and $p < 0.01$)

RESULTS AND DISCUSSION

Physical and vegetation attributes of the sample sites

Provenance I in the Bali Local Government Area had its actual study site in Maigoge (Latitude N7^{0}43’8.11416 and Longitude E10030’11.828.16). The soil type of provenance is clay and sandy-loam, while the geology is basement complex rock with an elevation of 176.5m (Table 1). The vegetation type ranged from mountainous to Guinea savanna. For Provenance II Kurmi, the actual study area was in Gidan Ali (Latitude N7^{0}20’53.3706 and Longitude E10^{0}37’14.49). The soil type is sandy loam, while the geology was also basement complex rock with an elevation of 342.9 m, and the vegetation type ranged from mountainous to Guinea savanna (Table 1). Provenance III, which was Donga, had its actual study in Gayama (Latitude N7^{0}25’6.37212 and Longitude E10^{0}24’27.88812). The soil type is sandy loam, while the geology was basement complex rock with elevation of 232.3 m and the vegetation type also ranged from mountainous to Guinea savanna (Table 1).

Table 1: Physical and vegetation attributes of the sampling sites

Provenance	Ref. Town	Specific pair sample coordinate	Soil types	Geology	Elevation (m)	Vegetation types
1	Maigoge (Bali)	Latitude N7^{0}43’8.11416 Longitude E10^{0}30’11.82816	Sandy-loam	Basement complex rock	176.5	Mountain/ Guinea savanna
2	Gidan Ali (Kurmi)	Latitude N7^{0}20’53.3706 Longitude E10^{0}37’14.490	Sandy-loam and alluvial	Basement complex rock	342.9	Mountain/ Guinea savanna
3	Gayama (Donga)	Latitude N7^{0}25’6..37212 Longitude E10^{0}24’27.88812	Sandy-loam and alluvial	Basement complex rock	232.3	Mountain/ Guinea savanna

Effect of Provenance on *P. erinaceous* mother trees' stocking density

Findings on mother trees stocking density for *P. erinaceus* across the three provenances were low, ranging from 5-6 trees for the mapped provenances. For Provenance 1 (Bali), a total land area of 2.25 Hectares was mapped, and 5 mother trees were encountered, indicating a stocking density of 2.22 Ha trees^{-1} in Provenance II, Kurmi. The total land area mapped was 1.97 Hectares, and 5 mother trees were encountered, giving a stocking density was 2.53 trees Ha^{-1}. In Provenance III, Donga 6 mother trees were encountered in 2.68 Hectares, indicating a stocking density of 2.23 trees Ha¹ (Table 2). From the observed stocking density Ha-1 across the three provenances, provenance had no significant effect on stocking density in the species.

Table 2: *P.erinaceus* stocking density (Ha-1) as influenced by physical attributes of the sample sites

Provenance	Ref. Town	Specific pair sample coordinate	Soil types	Geology	Elevation (m)	Stocking density (Ha^{-1})
1	Maigoge (Bali)	Latitude N7⁰43'8.11416 Longitude E10⁰30'11.82816	Sandy-loam	Basement complex rock	176.5	2.25
2	Gidan Ali (Kurmi)	Latitude N7⁰20'53.3706 Longitude E10⁰37'14.490	Sandy-loam and alluvial	Basement complex rock	342.9	2.22
3	Gayama (Donga)	Latitude N7⁰25'6..37212 Longitude E10⁰24'27.88812	Sandy-loam and alluvial	Basement complex rock	232.3	2.23

Effect of provenance on *P. erinaceus* mother trees' phenotypic traits

The Two-way analysis of variance was conducted for *P. erinaceus* mother trees' phenotypic traits across three provenances: Bali (southern savanna), Kurmi (montane forest), and Donga (southern savanna). revealed significant structural differences, particularly in vertical expansion criteria. Provenance significantly influenced total tree height (F = 6.466, p = 0.021) and height to first branch (F = 5.646, p = 0.030). The results demonstrated significant provenance-level differences in vertical growth parameters (total height, height to first branch), with Kurmi exhibiting the most superior total tree height development (24.3 ± 8.8m) compared with Bali (12.9 ± 2.0 m) and Donga (14.7 ± 3.6 m), respectively (Table 3). This tends to suggest genetic adaptation or local environmental selection favoring taller tree heights in Kurmi, possibly due to competitive light acquisition in dense forest.

However, provenance had no significant effect on other phenotypic traits (stem diameter and primary branches). The non-significant effect of provenance on these traits possibly reflected low genetic variation rather than environmental influence or stronger plasticity in response to micro-site conditions (soil and wind exposure). However marginal significance difference was observed in crown diameter (p= 0.052), thus presenting a potential provenance-level strategy with Donga's provenance having the broadest crowns (4.9 ±2.0 m) compared with Bali's compact crown form (3.0 ± 0.3 m). However, the box plot visualization test conducted for total tree height clearly showed Kurmi's superior growth, with three of the mother trees exceeding 30m height, while all Bali mother trees were generally below 16m (Table 3). Donga provenance was intermediate for this trait except for 1 mother tree that exhibited an outlier with 19.6m (Table 3).

For height at first branching, Kurmi's mother trees were markedly different, with two mother trees branching above 20m, while Bali and Donga provenances' trees all had height at branching below 5m. Crown diameter showed marginal significance (p = 0.052), with Donga (4.9 ± 2.0 m) and Kurmi (4.9 ± 0.9 m) both exceeding Bali's more compact crowns (3.0 ± 0.3 m) Although mother trees diameter and number of primary branches were not influenced by provenance, Bali provenance had slightly more number of primary branches (2.4 ± 0.5) compared with Kurmi and Donga (both 2.2 ±0.4). (Table 3).

Table 3: Phenotypic Trait Comparison of *P. erinaceus* Mother Trees

Traits	Provenance F-value	p-value	Significance (p-5%)
Total tree height	6.466	0.021	*
Height at first branching	5.646	0.030	*
Crown Diameter	4.360	0.052	Ns.
Tree diameter	2.053	0.191	Ns
No of primary branches	0.263	0.775	Ns

*: significance, Ns**:** Not significant

Residual analysis for P. *Erinaceus* mother trees' phenotypic traits

The residual analysis conducted to test for within provenance variations for the different provenances confirmed that individual tree variations exist within provenance (the "Tree" factor in ANOVA) but did not significantly affect any phenotypic traits (p>0.12), suggesting that the observed patterns were indeed provenance-level characteristics rather than individual tree effects These results further demonstrated clearly provenance-specific growth strategies with Kurmi excelling in vertical development while Donga showed more variability for crown architecture but Bali provenance maintained a consistently smaller crown (Figure 2).

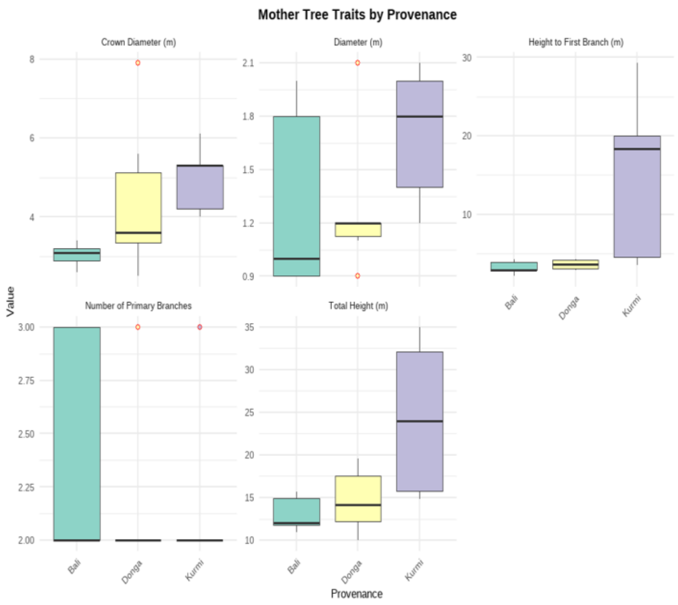

Figure 2: Residual Analysis for phenotypic traits in *P. erinaceus* across the provenances

Phenotypic traits comparison among the three provenances

As shown in Table 4, the post-hoc analysis revealed pronounced differentiation in growth architecture among the three *P. erinaceus* provenances. Provenance had a significant effect on total tree height in Kurmi and Donga provenances. Across the three provenances, provenance had no significant effect on mother trees' diameter, unlike the total three height traits. Crown diameter trait was only influenced by Kurmi provenance, while the interactions among the 3 provenances had no significant effect on the number of primary branches in the species the post-hoc analysis revealed pronounced differentiation in growth architecture among the three *P. erinaceus* provenances. The correlation matrix analysis revealed strong positive correlations among all measured phenotypic traits. Total tree height was strongly correlated with stem diameter, indicating coordinated vertical and radial growth. Similarly, crown diameter maintained significant positive relationships with both total height and stem diameter, suggesting integrated development of above-ground structures (Table 4).

Table 4: SLD Post-Hoc Test for differences among the three provenances for phenotypic traits

Trait	Comparison	Mean Difference (diff)	Lower CI (lwr)	Upper CI (upr)	Adjusted p-value	Significance
Total Height	Donga – Bali	1.623	-7.739	10.986	0.875	Ns
	Kurmi – Bali	11.280	1.501	21.059	0.026	*
	Kurmi – Donga	9.657	0.294	19.019	0.044	*
Diameter	Donga – Bali	-0.037	-0.672	0.599	0.985	Ns
	Kurmi – Bali	0.380	-0.284	1.044	0.286	Ns
	Kurmi – Donga	0.417	-0.219	1.052	0.208	Ns
Height to 1st Branch	Donga – Bali	0.380	-10.788	11.548	0.995	Ns
	Kurmi – Bali	11.900	0.236	23.564	0.046	*
	Kurmi – Donga	11.520	0.352	22.688	0.044	*
Crown Diameter	Donga – Bali	1.377	-0.479	3.232	0.147	Ns
	Kurmi – Bali	1.940	0.002	3.878	0.050	*
	Kurmi – Donga	0.563	-1.292	2.419	0.674	Ns
Primary Branches	Donga – Bali	-0.233	-1.207	0.740	0.779	Ns
	Kurmi – Bali	-0.200	-1.217	0.817	0.843	Ns
	Kurmi – Donga	0.033	-0.940	1.007	0.995	Ns

Key:*Significant at p < 0.05; ns = Not Significant.

Correlation relationships among *P. erinaceous* mother trees' phenotypic traits

As shown in Table 5, the correlation matrix analysis revealed strong positive correlations among all measured phenotypic traits. Total tree height was strongly correlated with stem diameter (r=0.698, p=0.003), indicating coordinated vertical and radial growth. Similarly, crown diameter maintained significant positive relationships with both total height (r=0.603, p=0.013) and stem diameter (r=0.686, p=0.003), suggesting integrated development of above-ground structures (Table 5).

Table 5: Pearson correlation matrix of *P. erinaceus* mother trees' phenotypic traits

Trait pairs	Corr. Coeff. (r)	t-value	p-value	Significance
Total Height × Tree Diameter	0.698	3.650	0.003	**
Total Height × Crown Diam.	0.603	2.830	0.013	*
Tree Diameter × Crown Diameter	0.686	3.531	0.003	**

**Significance codes*:* ** *p<0.01, * p<0.05*

DISCUSSION

Stocking density for *P. erinaceus* across the three provenances

Stocking density for *P. erinaceus* across the three provenances demonstrated a very low number of mother trees, $Ha^{-1,}$ ranging from 2.22 to 2.25 Ha^{-1}. These observed figures further confirmed the continuous anthropogenic pressures on the remaining population of the mother trees in the species' natural range in Taraba State. According to Adjonou *et al.* (2020) and Biaou *et al.* (2023), the species had been under intensive pressure for timber exploitation for export markets as well as looping for animal feed, while land conversion for other economic purposes had equally taken its toll on the remaining mother trees. Nodza *et al.*(2022b) reported that the continuous export of logs by the Chinese to the international timber market had abated. Thus, the combination of these various threats no doubt could be said to be responsible for the disappearance of *P. erinaceus* mother trees in many of its range in Taraba and the rest of its habitats in Nigeria (Nodza *et al.,* 2022b).

Climate change had its own share in most parts of its range (Zhang *et al.* (2017); Erdozain (*et al.* 2023), both reported decreasing annual rainfall, which continues to threaten both the mother trees and natural regeneration in the species range. Based on these findings, *P. erinaceus* was classified as a critically endangered (CR) species (Zhang *et al.* 2017). Observed trends for the phenotypic traits aligned with Liu *et al. (*2022), who reported significant among-population differences in vertical traits such as plant height and height to first branch in *Pinus yunnanensis*, highlighting the role of genetic adaptation to local conditions. Findings from the current study indicated superior vertical growth for Kurmi's provenance and this agreed with Liu *et al. (*2022), who reported that such traits were often shaped by selective pressures and related light competition in dense forests. However, the lack of significant differences in tree diameter and branch numbers across the three provenances in this study suggested a higher degree of phenotypic plasticity or environmental modulation for these traits, a pattern also noted by Liu *et al*. *(*2022).

The analysis of variance for key phenotypic traits in the species revealed significant provenance differentiation, with Kurmi provenance outperforming both Bali and Donga in total height (differences of 11.28m and 9.66m, respectively, $p<0.05$) and height to first branch (differences >11m, $p<0.05$), thus demonstrating superior vertical development consistent with light-competitive strategies. These results are consistent with those obtained by Padmalatha and Prasad (2007) on *P. santalinus* and Kouyaté *et al.* 2011 on Adansonia digitata. While crown diameter showed marginal differences (Kurmi-Bali: 1.94m, $p=0.050$), stem diameter and branch number exhibited no provenance effects ($p>0.19$), suggesting these traits were more environmentally plastic.

Kurmi's architectural advantages-combining exceptional height growth, elevated branching and moderate crown expansion- indicated stronger potential for a timber production system requiring straight boles and efficient light capture. This result is in line with the finding of Sourou (2017) that Phenotypic variability is essential for the selection of attractive genotypes for domestication purposes. The maintained differentiation under common conditions underscores significant genetic control over vertical growth parameters, while the uniform branching patterns across the provenances implied weaker genetic regulation for this trait. It thus suggested that Kurmi provenance constitutes a priority for productivity-focused planting while highlighting the need to conserve diverse architectural strategies represented across all provenances.

The observed significant differences in total height and height to first branch, particularly for Kurmi's provenance, were consistent with Liu *et al.* (2022), who found that provenance-based differentiation in growth traits is genetically driven and can be maintained even under common environmental conditions. The absence of variation in the number of primary branches and diameter across provenances, despite differences in vertical development, tends to agree with the pattern reported in *Pinus yunnanensis* where certain traits exhibited weaker provenance control (Liu *et al.* 2022). Morgenstern (1996) on geographic variation in forest trees further supported the assertion that vertical growth in *P. erinaceus* is a robust marker of genetic superiority for productivity-oriented silviculture, while other traits may be more influenced by local environmental factors or management practices. All correlations exceeded the threshold for moderate strength (r>0.5), with narrow confidence intervals excluding zero, confirming robust linear relationships.

These patterns imply synchronous resource allocation to tree total height, diameter and crown expansion during tree development, thus potentially reflecting common physiological controls over structural growth in *P. erinaceus*. The consistent positive correlations across traits suggest that selection for any one trait, such as height, would likely produce correlated responses in other trees' architectural traits (Liu *et al*., 2022). The strong positive correlations found among total tree height, stem and crown diameter reflect an allometric growth pattern typical of forest trees, thus corroborating the work of Liu *et al*. (2022) who reported high inter-correlation among phenotypic traits in *P. yunnanensis*. Moreover, the strong positive correlations among total tree height, stem diameter and crown diameter in this study agreed with the findings of Schmeddes *et al*. (2024) on *Fagus sylvatica*, who reported coordinated growth patterns in European beech, suggesting traits integration is controlled by shared physiological or genetic factors.

CONCLUSION

The study highlighted the critical role of provenance in shaping stocking density and phenotypic traits variations in *P. erinaceus* populations in Taraba State. Generally, the observed stocking density indicated low density $Ha^{-1,}$ thus highlighting unsustainable harvesting across its range in the studied locations. Phenotypic variations were most pronounced in traits related to vertical growth (height and branching), particularly favouring Kurmi provenance, thus suggesting a genetic advantage that could be harnessed in future tree improvement and selection programs. These outcomes further confirm the importance of integrating provenance-specific ecological understanding into conservation, enrichment planning and plantation design programs in the species.

The poor stocking density in *P. erinaceus* observed in this study suggested the need for proactive, sustainable actions to protect the remaining mother trees, as well as deliberate mass seedling production to initiate an enrichment planting program in its range. Based on superior performance for Kurmi provenance phenotypic trains, Kurmi provenance should be prioritized for future selection and improvement programs for timber and reforestation purposes. By aligning ecological insights with practical forest management, the sustainable use and conservation of the species is implied. However, the fact that *P. erinaceus* exists in other areas apart from those studied, there is a need to extend similar studies to the rest of its range in Taraba State

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