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Correlation Analysis among Growth, Wood Density, and Seed Traits in *Gmelina arborea*: A Comprehensive Study

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study explores the intricate relationships among morphological traits, wood properties, and seed characteristics in *Gmelina arborea* across eight natural and planted populations in Madhya Pradesh. The research aims to provide a comprehensive understanding of these interconnections, offering valuable insights for forest management, conservation, and breeding programs. Significant

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positive correlations were observed among several traits, highlighting their interdependence. For instance, crown height was strongly correlated with total tree height and crown width, indicating that trees with larger crowns tend to grow taller and exhibit higher wood density, a critical determinant of timber quality. Similarly, wood density showed positive correlations with girth at breast height (GBH) and branch thickness, suggesting that trees with thicker stems and branches produce denser, more robust wood. Seed traits also displayed notable correlations, with larger fruits associated with heavier seeds, which in turn showed greater viability and potential for seedling vigor—key factors for regeneration and commercial plantations. In contrast, some inverse relationships were identified, such as between crown height and 100-seed weight, indicating possible trade-offs where taller-crowned trees may yield lighter seeds. This integrated analysis emphasizes the importance of selecting key morphological and wood traits as indicators for superior timber quality and enhanced growth performance. The findings demonstrate the practical relevance of morphometric and seed traits in breeding programs and sustainable forestry practices. By using these traits as selection criteria, the study supports the development of more productive *Gmelina arborea* plantations, contributing to improved timber quality and sustainable forest management.

Keywords: Wood density; seed; Gmelina arborea; forest management.

1. INTRODUCTION

Understanding the complex relationships among morphological, physical, and seed traits of tree species is essential for advancing forest management, conservation, and breeding programs. In the context of tropical forestry, species such as *Gmelina arborea* have garnered significant attention due to their rapid growth, adaptability, and valuable timber properties (Kumar, 2020; Singh & Lal, 2021). Often referred to as "white teak," *Gmelina arborea* is recognized for its lightweight, durable wood, which is suitable for a variety of applications, including furniture, construction, and pulp production (Moya, 2004). The correlation analysis of morphological traits, wood properties, and seed characteristics in this species can reveal critical insights into growth performance and wood quality, which are valuable for both natural and plantation forestry.

Morphological traits such as tree height, diameter at breast height (DBH), and canopy spread provide foundational information about growth patterns and biomass accumulation, which are key indicators of ecological fitness and economic viability (Adekunle, 2022). Physical properties of wood, including density, moisture content, and fiber length, influence wood strength, processing efficiency, and end-product quality, directly affecting the economic potential of the species (Zobel & Buijtenen, 2019). Seed traits, including seed weight, size, and viability, are central to understanding the reproductive biology of *Gmelina arborea* and play a crucial role in seedling establishment, survival, and overall forest regeneration (Schmidt, 2018; Garwood & Hartshorn, 2020).

Although several studies have investigated the individual attributes of *Gmelina arborea*, there is limited research exploring the interrelationship among morphological, wood, and seed traits in an integrated framework. Such an approach may reveal underlying trade-offs or synergies among these characteristics, enabling the development of predictive models for growth and wood quality improvement (Sharma et al., 2021; Nanda et al., 2022). Given the ecological and economic significance of *Gmelina arborea*, this study aims to analyze the correlations among its morphological traits, wood physical properties, and seed characteristics, thereby contributing to a more holistic understanding of the species. This research will not only fill gaps in the existing knowledge but also provide actionable insights for forest management, genetic selection, and breeding programs aimed at enhancing the productivity and sustainability of *Gmelina arborea* plantations.

2. MATERIALS AND METHODS

2.1 Site Selection and Tree Sampling

An extensive review of forest flora and vegetation composition in Madhya Pradesh was conducted to select survey locations. These locations encompassed three natural populations (Mandla, Betul, and Jabalpur) and five planted populations (Barha, Saraswahi, Sonaghati, Badhaura, and Neemkheda). A total of 27 trees per population were selected based on their girth at breast height (GBH), which ranged from 50 cm to 125 cm. To minimize age-related variation, trees of similar age were chosen. In natural populations, a minimum spacing of 100 meters was maintained between sampled trees, while in planted populations, 20 meters of spacing was ensured in Plantation for representative sampling. Site selection for the study was based on geographic diversity and phenotypic variation across eight populations. Populations were chosen to encompass a range of climatic and edaphic conditions, capturing the genetic variability in natural and planted *Gmelina arborea* populations.

2.2 Measurement of Morphometric Traits

Morphometric traits were recorded for each tree to assess morphological variation. Total tree height, Clear bole height, Crown height was measured using Ravi's altimeter, as described by Chaturvedi & Khanna (1984). Girth at breast height (GBH)was measured at 1.37 meters above ground level with a measuring tape (Chaturvedi & Khanna, 1984). Crown diameter was calculated by measuring the maximum crown spread in two perpendicular directions (East-West and North-South) using a measuring tape, with the average of the two measurements recorded as the crown diameter, as suggested by Singh (2016).

2.3 Measurement of Fruit and Seed Traits

Fruits were collected from the last week of May to the second week of June, with approximately 100–150 fruits gathered per tree. The collected fruits were manually depulped, and seeds were extracted for further analysis. For each tree, the longest axis (length) and shortest axis (width) of 10 fruits and seeds were measured using a Vernier calliper, and the average measurements were recorded in millimetres (Mehta, 2019). The weight of 100 seeds from each tree was calculated using an electronic balance, to two decimal places (ISTA, 1996).

2.4 Measurement of Physical Properties of Wood

Wood core samples were extracted from each tree at breast height using a Haglöf increment borer, ensuring the removal of outer bark and moss at the sampling point to maintain accuracy, as described by Gerhart & McLauchlan (2014). Bark thickness was measured using a Swedish Bark Gauge, while branch thickness was determined with a measuring tape. The heartwood-to-sapwood ratio was calculated using measurements taken from the wood core samples with a Vernier calliper. Fresh weight of extracted wood core samples was weighed and then oven-dried at 105°C to get dry weight. Moisture content was calculated using the following formula:

$$\text{Moisture Content (\%)} = \frac{\text{Fresh Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

Data collected for morphological, fruit, seed, and wood traits were subjected to pearson correlation analysis in OPSTAT.

3. RESULTS

3.1 Morphometric Traits Correlation

Total Tree Height shows a significant positive correlation with girth at breast height (GBH) (0.187** [1]) and Crown Height (0.312**), suggesting that trees with greater girth at breast height (GBH) and higher crown height also tends to have increased overall height. Crown Height shows strong positive correlations with Total Tree Height (0.312**), Total Bole Height (0.395**), and Crown Width (0.500**), indicating that trees with taller bole heights and wider crowns also have higher crown heights. Crown Width has a strong positive correlation with Crown Height (0.500**), implying that a wider crown is associated with an increased height of the crown, which is expected in trees with balanced, extensive crown structures.

3.2 Wood Property Traits Correlation

Wood Density shows a significant positive correlation with girth at breast height (GBH) (0.194**) and Branch Thickness (0.164*). This suggests that trees with greater girth and thicker branches tend to have denser wood. Branch Thickness is positively correlated with Total Tree Height (0.090NS[2]) and Wood Density (0.164*), indicating that thicker branches may be associated with both taller trees and denser wood, although the relationship with tree height is not statistically significant. Moisture Content shows no significant correlations with most traits, indicating it is relatively independent of the measured morphometric and wood property traits.

[1] *Correlation significance at 0.05 level and **Correlation significance at 0.01 as per Pearson correlation.

[2] NS-Non significant

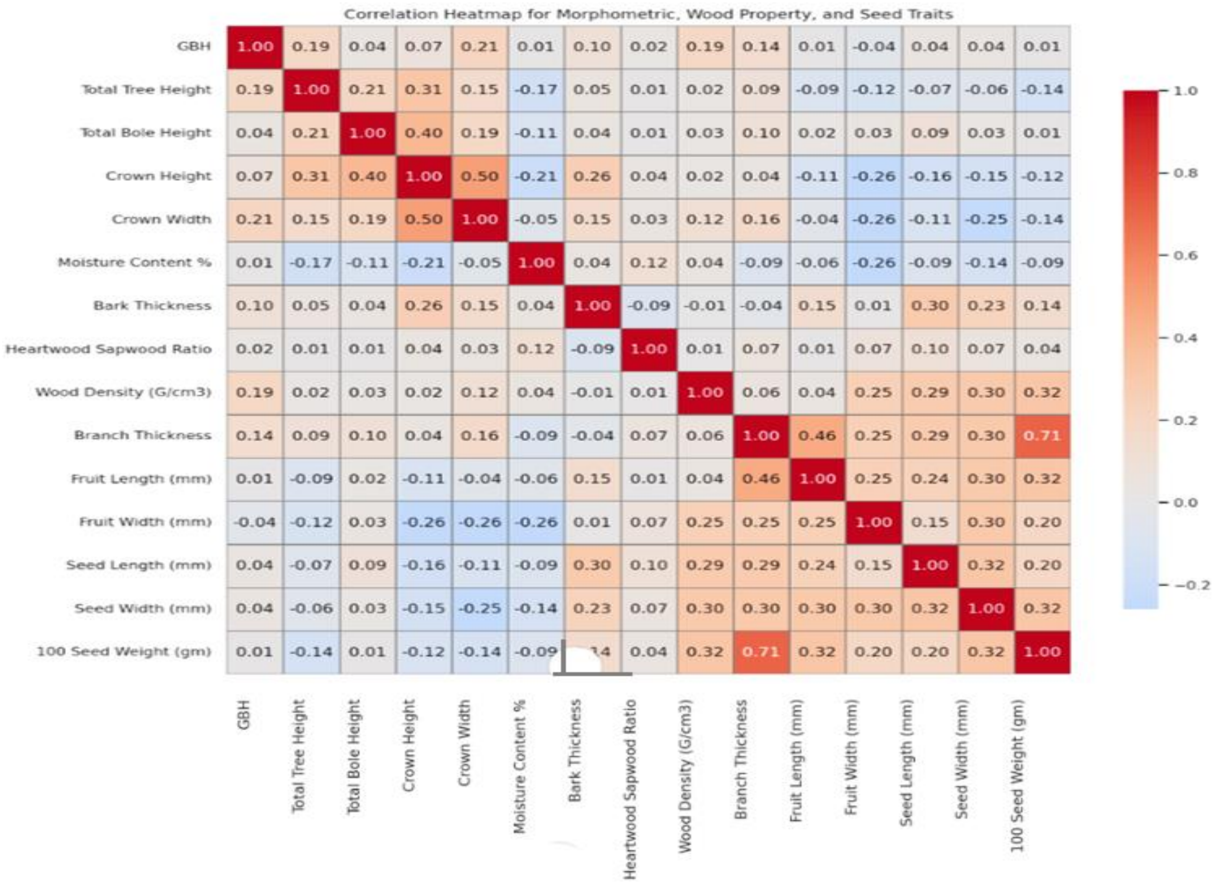

Fig. 1. Pearson correlation matrix for morphometric traits, fruits and seed traits of *Gmelina arborea*

3.3 Fruit and Seed Traits Correlation

Fruit Width shows a significant positive correlation with Fruit Length (0.459**), indicating that longer fruits are also likely to be wider. Seed Length and Seed Width are positively. Correlated with each other (0.301**), which is expected as larger seeds in one dimension are generally larger in the other. 100 Seed Weight has significant positive correlations with Fruit Length (0.320**), Seed Length (0.301**), and Seed Width (0.197*), suggesting that heavier seeds tend to come from larger fruits and have greater length and width

3.4 Interrelations between Morphometric, Wood, and Fruit/Seed Traits

Girth at breast height (GBH) shows a mild positive correlation with Wood Density (0.194**), Branch Thickness (0.139*), and Seed Width (0.036NS), suggesting a complex relationship between tree girth, wood structure, and seed characteristics. Crown Width is positively correlated with Wood Density (0.108NS) and Branch Thickness (0.090NS), suggesting that trees with broader crowns may also tend to have denser wood and thicker branches. Total Bole Height shows a mild, inverse correlation with 100 Seed Weight (-0.142*), indicating that trees with longer boles may have seeds with slightly lower weights. Crown Height shows a significant inverse relationship with 100 Seed Weight (-0.221**), suggesting that trees with higher crowns may tend to produce lighter seeds.

4. DISCUSSION

The findings of the correlation between morphological, wood, and seed traits in *Gmelina arborea* offers critical insights into its utility for sustainable forestry. Morphological characteristics such as bole straightness, crown width, and branch angle significantly influence wood quality, including density and merchantable volume. Iwuoha & Adegbite (2022) highlighted that upright branches and compact crowns contribute to straighter boles and higher wood density, improving timber value. Martínez et al. (2023) similarly found that denser wood correlates with enhanced mechanical strength and greater biomass accumulation in *Gmelina arborea*. Genetic diversity studies have further underscored the importance of provenance in trait expression. Naik et al. (2023) and Murillo-Cruz et al. (2023) demonstrated that seed traits such as weight and size, along with germination success, vary significantly across different populations, emphasizing the need for site-specific genetic selection.

Seed traits also serve as predictors of growth performance and wood quality. Larger seeds have been shown to produce more vigorous seedlings, which correlates with superior growth and higher-quality wood (Chandran et al., 2023). Provenance studies support these findings, revealing that environmental factors and genetic variability play crucial roles in trait interrelations (Lauridsen and Kjaer, 2002) Balancing traits like wood density and growth rate are essential for optimizing plantation productivity and ecological adaptation (Aguirre *et. al,* 2023).

By identifying and leveraging these trait correlations, breeding programs can focus on selecting genotypes with optimal morphometric and reproductive characteristics to enhance *Gmelina arborea*'s performance in plantations and natural forests (Ataguba et al., 2023; Liao et al., 2023). Research shows that morphological characteristics such as height, diameter, and crown spread in *Gmelina arborea* have a direct impact on wood density, an essential factor for wood quality (Olajuyigbe & Adegeye, 2022). These traits influence the mechanical properties of the wood, which are vital for timber use, especially in construction and furniture making. High-density wood correlates positively with mechanical strength, a relationship found in other studies on tropical tree species (Azad et al., 2014). This finding aligns with the work of Rawat (2022) on *Grewia optiva*, where variations in seed morphology were linked to seedling vigor and, consequently, wood density in mature trees.

Seed traits also play a significant role in determining germination rates and seedling growth in *Gmelina arborea*. Seed size, weight, and viability are positively correlated with germination success and early seedling growth, which is crucial for reforestation and commercial plantation programs. Studies by Topwal et al. (2024) on *Cedrus deodara* have shown that larger seeds tend to produce more vigorous seedlings, a trait that translates into better growth performance in field conditions. Similar results were observed in *Tamarindus indica*, where larger, more robust seeds led to higher germination rates and stronger seedlings, suggesting that seed morphology can be an indicator of plant vigor (Azad et al., 2014).

Moreover, geographical provenance has been found to affect morphometric and wood traits significantly, which is also observed in *Gmelina arborea*. Variations in seed and fruit traits based on geographic sources were documented in Dhaka et al. (2017) with *Tectona grandis*, suggesting that local environmental conditions may drive genetic divergence, influencing phenotypic traits. This finding is crucial for conservation strategies, where matching provenances to specific environmental conditions may optimize survival and growth rates.

The relationship between fruit traits and seed quality in *Gmelina arborea* underscores the importance of selecting fruit traits as indirect markers for seed quality, especially in breeding programs. Studies by Azad et al. (2014) demonstrate that seed viability and size positively correlate with wood density, hinting that these traits could serve as proxies in selecting high-quality genotypes. Olajuyigbe & Adegeye (2022) further emphasize that selecting morphometric traits, which exhibit strong correlations with wood properties, can be instrumental in breeding programs aimed at enhancing wood quality and yield.

In conclusion, this study reinforces the importance of morphometric, wood property, fruit, and seed traits as interconnected parameters that influence the overall growth, quality, and productivity of *Gmelina arborea*. These findings align with previous research on various tropical and subtropical trees, validating the use of such traits in selective breeding and forest management strategies. Understanding these correlations provides a foundation for optimizing timber production and ensures the sustainable use of *Gmelina arborea* resources in forestry applications.

4.1 Implications and Significance

- The significant positive correlations among certain morphometric traits (e.g., Total Tree Height, Crown Height, and Crown Width) imply that these dimensions are interdependent and likely related to overall tree growth patterns.

- The correlation of wood density with girth at breast height (GBH) and Branch Thickness suggests a possible link between growth form and wood strength, as trees with larger girths and branch thicknesses tend to have denser wood.
- The associations between fruit and seed dimensions and seed weight imply that larger fruits generally produce larger and heavier seeds, which could impact seed dispersal and germination success.

5. CONCLUSION

The correlation matrix reveals significant relationships among several morphometric, wood, and reproductive traits of *Gmelina arborea*, indicating interdependent growth patterns. These relationships can help in understanding the ecological adaptations of the species and in selecting traits for tree breeding and conservation efforts. The statistically significant correlations, particularly at the 0.01 and 0.05 levels, provide reliable insights that can inform further research and applications in forestry management.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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