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Provenance-Based Variation in Tree Height and Leaf Traits of *Hydnocarpus kurzii* (King) Warb. in Northeast India

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ABSTRACT: *Hydnocarpus kurzii* (King) Warb., commonly referred to as Chaulmoogra, is a medicinally important tropical forest tree species widely valued for its therapeutic seed oil and ecological significance. The present study was conducted to evaluate the extent of morphological variability among different seed sources of *Hydnocarpus kurzii* collected from eight geographical locations in Mizoram, Northeast India. Ten superior phenotypic trees were selected from each location while maintaining adequate spacing to minimize the possibility of relatedness among sampled individuals. Quantitative traits such as tree height and leaf area, along with qualitative characteristics including crown architecture, foliage density, leaf morphology, and trunk colour, were assessed. Statistical analyses involving Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT) were employed to determine the significance of variation among seed sources. Considerable variability was observed for quantitative traits across the studied populations. Tree height varied from 20.41 ± 2.17 m to 24.68 ± 1.22 m, whereas leaf area ranged from 173.62 ± 0.61 cm² to 199.59 ± 0.67 cm². Seed sources from Mamit and Lawngtlai consistently exhibited superior vegetative growth performance. ANOVA results revealed highly significant differences for tree height and significant variation for leaf area among the provenances. In contrast, qualitative traits exhibited relatively stable expression across locations.

The findings indicate substantial provenance influence on vegetative growth and adaptive performance in *H. kurzii*. The superior seed sources identified during the present investigation may serve as promising genetic resources for future domestication, plantation establishment, conservation programmes, and tree improvement strategies.

Keywords: *Hydnocarpus kurzii*, provenance variation, medicinal tree species, morphological variability, forest genetics, tree improvement, ex-situ conservation.

INTRODUCTION

Hydnocarpus kurzii (King) Warb. (Achariaceae), commonly known as chaulmoogra, is a valuable medicinal forest tree indigenous to the tropical forests of India, Bangladesh, Myanmar, and parts of Southeast Asia. In India, its natural distribution is largely confined to the north eastern region, particularly the states of Mizoram, Assam, and Tripura (Das *et al.*, 2018). The species is well known for its seed oil, which is rich in cyclopentenyl fatty acids and has been traditionally used in the treatment of leprosy and several chronic dermatological disorders, including eczema, psoriasis, and ringworm (Joseph and Rao 2011). In recent years, increasing interest in plant-based therapeutics has renewed scientific attention towards *Hydnocarpus* species because of their pharmacological potential and conservation value (Grady and Axelsson 2023; FAO, 2025).

Natural populations of *Hydnocarpus kurzii* are increasingly threatened by habitat degradation, forest fragmentation, and indiscriminate harvesting, resulting in a gradual decline in population size and genetic resources. These pressures highlight the need for effective conservation strategies based on the identification and utilization of superior genetic resources. Morphological characterization of natural populations remains an essential approach for evaluating phenotypic diversity, identifying adaptive traits, and supporting provenance selection for conservation, domestication, and genetic improvement programmes (Zobel and Talbert 1984). Recent studies have further emphasized that integrating provenance evaluation with conservation planning can substantially improve the long-term management of forest genetic resources under changing environmental conditions (Leites & Benito Garzón 2023; FAO, 2023).

Morphological traits of forest trees are governed by both genetic factors and environmental influences. Tree height, leaf dimensions, and canopy characteristics are particularly responsive to variations in rainfall, temperature, altitude, soil properties, and moisture availability. Consequently, geographically distinct populations often exhibit considerable phenotypic differentiation as an adaptive response to local environmental conditions. Provenance trials therefore provide an effective means of identifying populations with superior growth performance, wider ecological adaptability, and greater potential for plantation establishment and tree improvement programmes (White *et al.,* 2007). Recent advances in forest genetics have also demonstrated that provenance-specific variation contributes significantly to climate resilience and adaptive capacity in long-lived tree species (Kurjak *et al.*, 2024; Leites & Benito Garzón, 2023).

Leaf traits constitute reliable indicators of plant growth, resource-use efficiency, and environmental adaptation because they directly influence photosynthetic capacity, water-use efficiency, and biomass accumulation. Likewise, tree height serves as an important measure of site suitability, growth vigour, and competitive ability. Variation in these attributes reflects the combined effects of genotype, environmental conditions, and genotype × environment interactions, thereby providing useful information for selecting superior planting materials and developing sustainable forest management strategies (Pandey and Shukla 2015; Rawat *et al.*, 2018; Bhat *et al.*, 2019). Recent ecological studies have further highlighted the value of leaf functional traits as indicators of adaptive responses to environmental heterogeneity and climate variability (Xu *et al.,* 2023**;** Wang *et al*., 2024).

Despite its medicinal importance and ecological significance, comprehensive information on provenance-based morphological variation in *Hydnocarpus kurzii* remains scarce, particularly across the natural populations of northeastern India. Such information is fundamental for identifying elite seed sources and formulating evidence-based strategies for conservation, domestication, and genetic improvement. Therefore, the present study was undertaken to evaluate variation in tree height and leaf morphological traits among different provenances of *Hydnocarpus kurzii* collected from Mizoram, with the objective of identifying superior seed sources for future breeding, plantation development, and long-term conservation.

MATERIALS AND METHODS

Study Area and Selection of Seed Sources

The present study was conducted using seed sources of *Hydnocarpus kurzii* collected from eight different geographical locations of Northeast India, namely Lawngtlai, Serchhip, Lunglei, Hnahthial, Mamit, Behliangchhip, Zion, and Upper Hapzan.

Ten phenotypically superior trees were selected randomly from each location based on desirable growth characteristics. A minimum distance of 100 m was maintained between selected trees to minimize the probability of selecting closely related individuals and to reduce potential inbreeding effects.

Recording of Morphological Traits

Morphological Trait Assessment

Morphological characterization was conducted based on both quantitative and qualitative parameters across selected provenances. Quantitative observations included tree height (m) and leaf area (cm²). Tree height was determined using a Spiegal relaskope, whereas leaf area was measured with a standard measuring scale.

Qualitative descriptors such as tree shape, foliage density, leaf shape, leaf apex characteristics, leaf surface texture, and trunk colour were evaluated through visual assessment. Trunk colour classification was performed using the Royal Horticultural Society (RHS) colour chart.

Statistical Analysis

The recorded morphological data were subjected to descriptive and inferential statistical analyses to assess variability among the seed sources of *Hydnocarpus kurzii*. Quantitative traits were expressed as Mean ± Standard Error (SE). Analysis of Variance (ANOVA) was performed to determine the significance of variation among seed sources. Duncan's Multiple Range Test (DMRT) at 5% probability level was employed for mean separation and identification of statistically homogeneous groups. Statistical analyses were performed using IBM SPSS Statistics software.

RESULTS

Quantitative Morphological Variation

Substantial variability was observed among the studied seed sources for quantitative morphological traits of *Hydnocarpus kurzii* (Table 1). Tree height ranged from 20.41 ± 2.17 m in Zion to 24.68 ± 1.22 m in Mamit, indicating considerable differences in vegetative vigour among populations. Similarly, leaf area varied from 173.62 ± 0.61 cm² in Lunglei to 199.59 ± 0.67 cm² in Mamit.

Among the evaluated locations, Mamit and Lawngtlai consistently exhibited comparatively superior performance for both tree height and leaf area. Intermediate growth performance was recorded in Hnahthial, Serchhip, and Upper Hapzan, whereas comparatively lower values were observed in Lunglei, Zion, and Behliangchhip.

The observed variation among seed sources indicates the influence of geographical origin and environmental conditions on vegetative growth characteristics in *Hydnocarpus kurzii*.

Table 1: Mean ± standard deviation of the Quantitative morphological traits of *Hydnocarpus kurzii* seed sources.

Source	Tree Height (m)	Leaf Area (cm^2)
Lawngtlai	24.52 ± 1.57	192.10 ± 0.72
Hnahthial	22.19 ± 1.83	181.10 ± 0.35
Mamit	24.68 ± 1.22	199.59 ± 0.67
Lunglei	20.79 ± 1.53	173.62 ± 0.61
Serchhip	21.51 ± 2.40	176.93 ± 0.52
Zion	20.41 ± 2.17	173.81 ± 0.44
Behliangchhip	21.02 ± 1.70	174.77 ± 0.26
Upper Hapzan	21.09 ± 1.36	176.52 ± 0.48

Qualitative Morphological Variation

Qualitative morphological traits exhibited comparatively limited variation among the studied seed sources (Table 2). All populations displayed semi-spreading growth habit with narrow crown architecture and dense foliage distribution. Leaf morphology was predominantly oblong to elliptic-oblong across all locations.

Similarly, all seed sources exhibited acuminate leaf apex and glabrescent leaf surface characteristics. Trunk colour remained relatively uniform among the studied populations and corresponded to dark greyish-yellowish brown according to the RHS colour chart. The limited variation observed for qualitative traits suggests relatively stable phenotypic expression and comparatively lower environmental influence on these characters.

Table 2: Qualitative Morphological Characteristics.

Seed Source	Tree Shape	Foliage Density	Leaf Shape	Leaf Apex	Leaf Surface	Trunk Colour
Lawngtlai	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Hnahthial	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Mamit	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Lunglei	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Serchhip	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Zion	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Behliangchhip	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)
Upper Hapzan	Semi-spreading narrow crown	Dense	Oblong to elliptic-oblong	Acuminate	Glabrescent	Dark greyish-yellowish brown N199(B)

ANOVA Analysis

Analysis of variance (ANOVA) revealed significant differences among seed sources for both quantitative morphological traits (Table 3). Tree height exhibited highly significant variation among populations (F = 9.050, P < 0.001), while leaf area also differed significantly (F = 3.453, P = 0.003), indicating substantial phenotypic variability across the studied seed sources.

Table 3: ANOVA for quantitative morphological traits of *Hydnocarpus kurzii.*

Trait	Source of Variation	Df	Sum of Squares	Mean Square	F-value	Significance
Leaf Area	Between Groups	7	6518.498	931.214	3.453	0.003**
	Within Groups	72	19415.552	269.660	-	-
Tree Height	Between Groups	7	195.842	27.977	9.050	0.000***
	Within Groups	72	222.573	3.091	-	-

Values are significant at P < 0.01**; P < 0.001** (*).

Duncan's Multiple Range Test (DMRT)

DMRT analysis further confirmed significant variation among seed sources for both quantitative traits (Table 4). Mamit and Lawngtlai formed the highest statistical groups for tree height and leaf area, indicating superior vegetative performance.

Table 4: DMRT grouping for quantitative morphological traits of *Hydnocarpus kurzii.*

Source	Leaf Area (cm^2)	Tree Height (m)
Mamit	199.59^{a}	24.68^{a}
Lawngtlai	192.10^{ab}	24.52^{a}
Hnahthial	181.10^{bc}	22.19^{b}
Serchhip	176.93^{bc}	21.51^{bc}
Upper Hapzan	176.52^{bc}	21.09^{bc}
Behliangchhip	174.77^{c}	21.02^{bc}
Zion	173.81^{c}	20.41^{c}
Lunglei	173.62^{c}	20.79^{c}

Means followed by the same letter within a column are not significantly different at 5% probability level according to DMRT. Values sharing multiple letters (e.g., "bc") are not significantly different from groups labelled with either letter

DISCUSSION

The present investigation revealed considerable morphological variability among different seed sources of *Hydnocarpus kurzii*, particularly for quantitative growth traits such as tree height and leaf area. The significant variation detected through ANOVA indicates that both provenance origin and environmental conditions strongly influence vegetative growth performance in this species. Similar provenance-related variation has been reported in several tropical forest tree species, where geographical origin, climatic conditions, and local ecological factors regulate phenotypic expression and adaptive potential (White *et al.,* 2007; Bhat *et al*., 2019). The present findings are further supported by recent studies demonstrating that provenance origin plays a critical role in determining growth stability, phenotypic plasticity, and long-term adaptation of forest tree populations under contrasting environmental conditions (Di Fabio *et al.,* 2024; Aspalter *et al.,* 2025).

Among the studied populations, Mamit and Lawngtlai consistently exhibited superior vegetative growth characteristics. Their enhanced performance may be attributed to favourable ecological conditions, including higher rainfall, adequate soil moisture, fertile soils, and a humid tropical climate. Environmental variables such as altitude, soil nutrient availability, and temperature regime are well known to influence physiological efficiency, biomass accumulation, and vegetative vigour in tropical forest trees (Pandey and Shukla 2015). Recent studies further indicate that site quality and functional trait plasticity jointly regulate growth performance and adaptive capacity across different forest environments, emphasizing the importance of selecting superior provenances for plantation and restoration programmes (Di Fabio *et al.,* 2026).

The larger leaf area recorded in superior seed sources may provide adaptive advantages by increasing the photosynthetic surface area and improving light interception efficiency. Enhanced photosynthetic activity promotes greater carbohydrate production, biomass accumulation, and overall growth under favourable environmental conditions (Rawat *et al.,* 2018). Likewise, increased tree height reflects greater resource-use efficiency and ecological adaptability. Recent investigations have also demonstrated that variation in leaf morphological traits is closely associated with environmental adaptation, light acquisition strategies, and growth performance across tropical and subtropical forest ecosystems (Wang *et al.,* 2025; Schimel *et al.,* 2025).

In contrast, the comparatively lower growth performance observed in Behliangchhip, Zion, and Lunglei may be associated with less favourable site conditions or reduced adaptive potential. Ecological stress factors such as nutrient limitation, fluctuations in soil moisture, and microclimatic variability may adversely affect vegetative growth and phenotypic expression. Similar reductions in growth under variable environmental conditions have been reported in several medicinal and tropical forest tree species (Singh *et al*., 2014). Furthermore, climatic variability has been shown to influence the expression of functional traits and adaptive strategies in tropical forest trees, thereby affecting growth performance across contrasting environments (Andrés-Hernández & Rodríguez-Ramírez 2025).

The qualitative morphological traits exhibited relatively low variability among the populations. Uniformity in crown architecture, foliage density, leaf apex, and trunk colour suggests stable expression of these characters and comparatively lower environmental sensitivity. Such traits are generally considered to be under stronger genetic control than quantitative growth characters, which exhibit greater phenotypic plasticity (Ginwal *et al*., 2005).

The findings of the present study have important implications for provenance selection, domestication, and conservation of *H. kurzii*. Identification of superior seed sources such as Mamit and Lawngtlai may facilitate the development of elite planting material for plantation establishment and future breeding programmes. The observed variability among populations also indicates considerable potential for genetic improvement, sustainable utilization, and long-term conservation planning.

From an ecological perspective, provenance differentiation among the studied populations reflects adaptive responses to local environmental conditions. Such adaptive variation is likely to become increasingly important for selecting climate-resilient planting materials under changing environmental conditions. The superior provenances identified in the present investigation may therefore contribute significantly to ex situ conservation, ecological restoration, genetic improvement, and the sustainable management of this valuable medicinal forest tree species. These observations are consistent with recent evidence emphasizing the importance of intraspecific trait variation and provenance-based selection in enhancing the adaptive capacity of forest trees under future climate scenarios (Aspalter *et al.,* 2025).

Implications

The present findings provide valuable insights into provenance-based variability in *Hydnocarpus kurzii* and highlight the importance of geographical origin in determining vegetative growth performance. Superior seed sources identified from Mamit and Lawngtlai may serve as potential genetic resources for domestication, plantation establishment, conservation programmes, and future tree improvement initiatives. The observed adaptive variability may further contribute to the selection of climate-resilient planting materials for sustainable forest management and ecological restoration in Northeast India.

Limitations

The present investigation was primarily based on morphological characterization under natural field conditions and did not include molecular or biochemical analyses. Environmental heterogeneity among study locations may also have influenced phenotypic expression of quantitative traits. Therefore, further studies integrating genetic, physiological, and long-term field evaluations are necessary to validate provenance performance and adaptive potential in *Hydnocarpus kurzii*.

CONCLUSION

The present study demonstrated substantial provenance variation among seed sources of *Hydnocarpus kurzii* collected from different geographical locations of Northeast. Significant differences were observed for quantitative morphological traits, particularly tree height and leaf area, whereas qualitative traits exhibited comparatively stable expression across populations. Among the evaluated provenances, Mamit and Lawngtlai consistently recorded superior vegetative growth performance, indicating their potential suitability for plantation establishment, domestication, and tree improvement programmes. The findings suggest that environmental conditions and geographical origin exert considerable influence on the growth behaviour and adaptive performance of the species. The superior seed sources identified during the present investigation may serve as valuable genetic resources for future breeding strategies, ex-situ conservation initiatives, ecological restoration programmes, and sustainable utilization of *Hydnocarpus kurzii* in north eastern India. The study further highlights the importance of provenance evaluation in conserving and improving medicinal forest tree species under changing environmental conditions.

FUTURE SCOPE

The superior provenances identified in the present study, particularly Mamit and Lawngtlai, should be further evaluated through multi-location field trials and molecular characterization to confirm their genetic superiority and adaptive stability. Future research integrating physiological, biochemical, and genomic approaches will provide a better understanding of provenance-specific adaptation and growth performance. Such investigations will support the development of improved planting materials, breeding programmes, climate-resilient germplasm, and effective conservation strategies for *Hydnocarpus kurzii*, thereby promoting its sustainable utilization, ecological restoration, and long-term genetic conservation in Northeast India.

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Conflict of Interest. None.

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