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Variation in bark thickness among clones of *Eucalyptus tereticornis* across agro climatic zones

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Abstract
This study assessed the variation in bark thickness among three improved clones of *Eucalyptus tereticornis* developed by ITC Bhadrachalam and established by Harihar Polyfibers across five agro climatic zones of Karnataka. Bark thickness was measured using a Vernier caliper, and statistical analyses were performed to evaluate the influence of clones, agro climatic zones, and their interaction. The analysis revealed significant differences among clones and a significant clone × environment interaction, indicating that the performance of each clone varied depending on the site. However, agro climatic zones alone did not exert a statistically significant effect on bark thickness. One clone consistently recorded higher bark thickness across several zones, suggesting superior adaptability. These findings underscore the importance of genotype x environment interactions in optimizing wood quality traits for clonal forestry programs.

Keywords: *Eucalyptus tereticornis*, bark thickness, clonal variation, genotype × environment interaction, agro climatic zones

Introduction

Eucalyptus tereticornis, commonly known as forest red gum, is a key species in both global and Indian forestry due to its fast growth, high adaptability, and wide range of end-uses including timber, pulpwood, and essential oils. Native to Australia, it has been extensively introduced in tropical and subtropical regions worldwide, including India, for afforestation and commercial plantation programs (Eldridge *et al.*, 1993; FAO, 2009) [4, 5]. Its ability to tolerate diverse climatic and edaphic conditions makes it an ideal species for large-scale plantation forestry. In India, *Eucalyptus tereticornis* was introduced during the 19th century and has since played a crucial role in reforesting degraded lands. It is now a major contributor to industrial wood supply, especially in the paper and pulp sector (Lal, 2001) [9]. Its short rotation cycle, allows for rapid turnover and economic returns, positioning it as a sustainable alternative to slow-growing native hardwoods (Sharma *et al.*, 2021) [13].

Genetic variability in growth and wood traits among populations of *Eucalyptus tereticornis* is largely influenced by provenance; the geographical origin of planting material. Provenance-based differences can impact key attributes such as height, diameter, bark thickness, and wood quality, which are crucial for determining suitability for industrial use (Zobel and Talbert, 1984; Hamilton *et al.*, 2017) [16, 6]. Given the wide agro climatic diversity in India, selecting suitable genotypes for specific site conditions is essential for maximizing growth performance and resource use efficiency (Kumar *et al.*, 2003) [7]. Clonal forestry, which involves vegetative propagation of genetically superior trees, has revolutionized plantation management by offering greater uniformity and productivity than seed-based plantations (Libby, 1982) [10]. Clones ensure stable performance and consistent wood traits across planting cycles. In India, ITC Bhadrachalam has developed elite clones of *Eucalyptus tereticornis* such as clones 3, 7, and 316, which are extensively deployed in different agro climatic zones. These clones have been selected for traits like rapid growth, disease resistance, and high wood density, making them ideal for industrial applications (Bhatia, 1984; Kumar *et al.*, 2003) [7].

Among wood and anatomical traits, bark thickness holds increasing importance due to its role in both ecological adaptation and industrial processing. It affects not only wood recovery and debarking efficiency but also contributes to the tree's defense mechanisms and physiological performance. Studies have shown that bark thickness is influenced by genetic constitution and varies with site conditions, age, and management practices (Laasasenaho *et al.*, 2005; Wu *et al.*, 2011) [8, 15]. Berrocal *et al.* (2020) [1] further demonstrated the influence of stand age and density on bark and wood anatomical traits in tropical hardwood species, reinforcing the need for environment-specific evaluations.

Bark also serves several critical physiological and protective functions. It acts as a shield against fire, pathogens, and mechanical injury, while also playing a role in moisture retention and insulation. Rosell *et al.* (2014) [12] highlighted that bark traits are shaped by trade-offs between protection and growth, with significant variation across species and environmental gradients. In fire-prone ecosystems, thicker bark improves cambial protection, enabling post-fire recovery. Pausas (2015) [11] linked bark thickness with fire regime adaptations, making it a relevant trait in plantation forestry, especially in drought-prone and high-risk fire zones. From an industrial standpoint, bark is often removed before pulping to avoid high extractives and ash content but has potential for valorization. It is increasingly used for biomass, mulch, and extractive recovery, Tomasi *et al.* (2023) [14]. This dual nature industrial challenge and value-added resource makes bark an important consideration in clonal selection and wood quality assessments.

From a genetic improvement perspective, bark thickness is gaining recognition as a valuable trait for inclusion in clonal evaluation and breeding programs. When correlated with growth and wood properties, it can serve as a selection indicator for overall vigor and processing suitability (Zobel and Talbert, 1984; Kumar *et al.*, 2003) [16, 7]. Given its moderate heritability and environmental sensitivity, assessing bark traits across multiple environments supports a better understanding of genotype × environment interactions (Wu *et al.*, 2015) [15]. This enhances the ability to develop site-specific clone deployment strategies and refine clonal selections that are well-suited for both ecological resilience and industrial performance.

Materials and Methods

Survey and Selection of Clones

This study was conducted using ITC Bhadrachalam clones of *Eucalyptus tereticornis* from five pure clonal plantations established by Harihar Polyfibers across different agro climatic zones of Karnataka: Central dry zone (Tumkur), Eastern dry zone (Bangalore rural), Southern dry zone (Mandya), Southern transition zone (Mysore), and Northern transition zone (Haveri). These zones represent diverse climatic conditions, enabling the investigation of genotype x environment interactions in bark development. Three operationally important clones; clone 3, clone 7, and clone 316 were selected from plantations of the same age. A total of 18 trees per clone were sampled in each zone. Three plots were laid per clone, and six trees per plot were randomly selected, ensuring replication and minimizing sampling bias. This systematic sampling design allowed for robust statistical analysis of clonal variation and the potential influence of site-specific environmental factors on bark thickness.

Bark Thickness Measurement and Statistical Analysis

Bark thickness was measured on cross-sectional wood discs using a Vernier caliper at both the major and minor axes, following the standard procedure outlined by Chaturvedi and Khanna (1994) [3]. The mean of the two readings was calculated and considered for further analysis. A two-way analysis of variance (ANOVA) was employed to evaluate the effects of clone, agro-climatic zone, and their interaction on bark thickness. Post-hoc comparison of means was conducted using Duncan's Multiple Range Test (DMRT) at a 5% level of significance to determine statistically significant differences among treatments.

Results

The two-way analysis of variance (ANOVA) revealed that (given in table.1.) clonal variation in bark thickness was statistically significant (SS = 0.108; F = 6.097; p = 0.006), indicating a moderate genetic influence on this trait. The interaction between agro climatic zones and clones also showed a statistically significant effect (SS = 0.208; F = 2.929; p = 0.016), suggesting that the performance of individual clones varied depending on the environmental conditions of each zone. In contrast, the main effect of agro climatic zones was not significant (SS = 0.032; F = 0.916; p = 0.468), implying that the zone alone had limited influence on bark thickness. The critical difference (C.D.) for clones was 0.071. For the clone × zone interaction, the C.D. was higher at 0.158.

Duncan's Multiple Range Test (DMRT) results (given in table.2.) indicated that Clone 7 recorded the highest mean bark thickness in the Central Dry Zone (0.733 mm), followed by clone 3 (0.450 mm) and clone 316 (0.433 mm), all of which were statistically grouped under the same subset ('a'), indicating non-significant differences within the zone. In the Eastern dry zone, clone 3 showed the highest mean (0.600 mm), followed by clone 7 (0.483 mm) and clone 316 (0.461 mm). Similar patterns were observed across the Southern dry zone, Southern transition zone, and Northern transition zone, with clone 3 consistently performing well. Despite overlapping groupings, numerical trends consistently favored clone 7, which demonstrated slightly higher mean bark thickness across most zones, followed by clone 3, with clone 316 showing the lowest values. These results reflect moderate variability and indicate potential clonal differences in bark development, although not always statistically distinct within individual zones.

Significant variation in bark thickness among *Eucalyptus tereticornis* clones indicates a moderate genetic influence, as supported by the significant clone effect (p = 0.006). The clone × agro climatic zone interaction (p = 0.016) highlights genotype × environment effects, consistent with findings by Wu *et al.* (2011) [8, 15], who reported similar interactions for bark traits in hybrid Eucalyptus. The non-significant effect of agro climatic zones alone (p = 0.468) suggests that genetic constitution plays a more dominant role, aligning with Laasasenaho *et al.* (2005) [8], who emphasized the influence of intrinsic genetic factors on bark thickness. Berrocal *et al.* (2020) [1] reported variation in bark and wood traits of *Tectona grandis* influenced by plantation age and stand density. Although age was uniform across all clones in the present context, observed interactions effects imply possible environmental modulation of bark traits. These findings support the broader understanding that both genetic makeup and localized site conditions jointly influence the traits of forest tree species. Numerical differences in bark thickness, along with high coefficients of variation in some clone-zone combinations, point to variable adaptability and performance stability. These findings underscore the importance of genotype evaluation across environments for site-specific clonal deployment. These patterns reinforce the importance of genotype screening across diverse environmental gradients and the development of site-specific deployment strategies for optimized wood quality traits in clonal forestry.

Table 1: Two-way ANOVA for bark thickness in *Eucalyptus tereticornis* clones across agro climatic zones.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance (p-value)	Critical Difference (C.D.)
Plots (Replication)	2	0.012	—	—	—	—
Agro climatic Zone	4	0.032	0.008	0.916	0.468	N/A
Clones	2	0.108	0.054	6.097	0.006	0.071
Zone × Clone Interaction	8	0.208	0.026	2.929	0.016	0.158
Error	28	0.248	0.009	—	—	—
Total	44	0.608	—	—	—	—

Table 2: DMRT analysis of bark thickness (mm) in *Eucalyptus tereticornis* clones across five agro climatic zones

Clone	Tumkur	Bangalore Rural	Mandya	Mysore	Haveri
CL.3	0.45[a]	0.60[a]	0.472[a]	0.561[a]	0.439[a]
CL.7	0.733[a]	0.483[a]	0.661[a]	0.528[a]	0.45[a]
CL.316	0.433[a]	0.461[a]	0.45[a]	0.439[a]	0.472[a]

Conclusion

The study revealed significant clonal variation in bark thickness among *Eucalyptus tereticornis* clones, with a clear influence of genetic constitution. While agro climatic zones alone did not significantly affect the trait, the significant clone × zone interaction indicates that clonal performance varied depending on the environment. Clones responded differently to site conditions, emphasizing the importance of genotype × environment interaction in determining bark development. These findings highlight the need for site-specific clonal deployment to optimize bark-related wood properties for industrial applications.

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