

Non-destructive selection of genotypes with better wood properties from morphologically superior genotypes of *Eucalyptus pellita*

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Tree improvement in forestry aims at identifying superior genotypes so as to obtain higher productivity in a shorter period. While selecting superior genotypes, morphological traits like height and girth are given due importance. It is now realized that considering wood quality parameters is essential as it can be highly variable in seemingly identical trees. This would not only reduce the breeding cycle but also enhance the economic value for the growers and ultimately improve the quality of wood-based products. Documenting wood quality traits has always been difficult as they are mostly determined through destructive procedures which are time-consuming and restrictive in terms of a large number of samples. To overcome these limitations, non-destructive tools can be effectively used to obtain information on wood quality parameters in populations and identify superior genotypes. Here we have used non-destructive tools like Pilodyn wood tester and stress wave timer to identify *Eucalyptus pellita* genotypes having superior wood quality (wood density and stiffness) from 52 selected morphologically better genotypes. Considerable variation exists among the morphologically superior genotypes for Pilodyn penetration (10–17 mm) and stress wave velocity (3.36–4.42 km/s). Ultimately, 26 genotypes have been identified which are superior both in terms of morphology as well as wood quality traits. These genotypes can be used for further propagation and improvement studies in *E. pellita*.

Keywords: *Eucalyptus pellita*, nondestructive selection, superior genotypes, tree improvement, wood properties.

TREE improvement in forestry research is a continuous long-term programme having twin objectives of enhancing the productivity and also helping in conservation. Selecting superior genotypes is the first step for increasing productivity. Various aspects are considered during the selection process and traits that are normally preferred till recently during selection were height, girth,

stem straightness, branch angle and tree health status. The first two traits are quantitative, indicating primary and secondary growth traits, while the last three traits are mostly subjective and qualitatively assessed. There has been success in tree improvement programmes by selecting superior genotypes based on morphological traits; however, a major drawback in this process of selection not considering quantifiable wood quality traits¹. It has been a general practice that while documenting variability on various wood traits for any species, information is obtained from a few samples. This is mainly because almost all the standardized testing methods used to assess the wood properties are, to a large extent, destructive in nature. Using wood quality traits and their proper documentation always remained a concern in tree improvement research. Therefore, wood quality did not form the basic component while selecting superior genotypes, be it from the natural forests or plantations. In the plantation forestry, wood quality is important along with growth as it defines the process consistency and product quality. Recently, objectives in tree improvement programmes are oriented not merely targeting volume per unit area, but greater emphasis is on including wood properties. This can directly impact the end-products suitable for industrial applications². Among the wood traits, wood density is important because it is highly heritable and an ideal trait for genetic improvement. It has been widely used in the selection of superior genotypes, families or clones in many plantation species such as *Eucalyptus*³, *Acacia melanoxylon*⁴ and *Tectona grandis*⁵. However, density is only one of the wood quality criteria and may not be enough to describe other wood properties. In softwood species like radiata pine, the microfibril angle which is the angle of cellulose microfibril with the cell wall axis is the determinant of modulus of elasticity (wood stiffness) and stability⁶. To incorporate wood traits in tree improvement, it is essential to have tools and methods capable of determining the traits in standing trees rapidly and reliably with no or minimal damage to the trees. Assessing various wood quality traits in standing trees through non-destructive tools has been one

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of the missions of foresters and wood scientists world over⁷.

With the advancement in technologies, non-destructive tools like penetrometer, acoustic tools and near-infrared spectroscopy are now popular. These tools provide sufficiently reliable information about the wood quality traits in standing trees in quick time without damaging the trees, and most of them are hand-held and easy to operate⁸. These tools have already become an integral part in tree improvement activities in many temperate species. However, their potential in the selection of superior genotypes in India's forestry research is still not explored fully. The present study was taken up to identify a sub-population with better wood quality using non-destructive tools from already selected superior genotypes based on morphological traits like tree height and girth.

Material and methods

A plantation of *Eucalyptus pellita* (commonly known as red mahogany) was established by the Karnataka Forest Development Corporation (KFDC) in 2005 at 3 × 3 m spacing, with an aim to obtain wood material for pulp and paper industries. The plantation was raised in 10.88 ha area at Asu III-22 (long. 15°22'44.6N, lat. 74°28'31.9E) in the Khanapur Range of Dharwad Forest Division, Karnataka, India. In its natural range in Australia, *E. pellita* grows fast, adapting to different environmental conditions with considerable resistance to pests and diseases. As a preferred raw material for pulp and paper industry, wood is also used for making various products⁹. When grown in appropriate site conditions, annually, the tree can grow 2–3 m in height and 2–3 cm diameter at breast height^{10,11}. In the eighth year of the plantation, KFDC decided to select superior trees for initiating further improvement programme in *E. pellita* and after an extensive survey, identified 52 potential trees based on their height and girth. The minimum criteria considered while selecting these genotypes were that the trees must be >20 m tall and have >70 cm girth at breast height (GBH). To have a general idea about the growth variability in the plantation, a sample plot of 25 × 25 m² was randomly laid, and height and girth of each tree in the sample plot were measured and recorded. Tree height (m) was measured using a hypsometer (Vertex IV Hypsometer; Hagloff, Sweden). GBH (cm) was recorded using a measuring tape. Two non-destructive tools, viz. penetrometer (PilodynTM) and stress wave timer (FakoppTM) were used for wood quality assessment.

Pilodyn wood tester (hereafter referred to as Pilodyn) was used as an indirect estimate for wood density¹². Pilodyn penetration has been reported to exhibit strong negative correlation with wood basic density and is effective in segregating standing trees based on wood density classes¹³. A 6 J Pilodyn (2.0 mm diameter pin) tool was

used to measure Pilodyn pin penetration at the breast height, where J stands for 'joule' which is a measure of the force driving the pin. For Pilodyn measurement, a small window was created by removing the bark at the point of measurement and a single Pilodyn reading, i.e. depth of penetration of the flat-nosed pin into the wood was recorded with an accuracy of 1 mm. To ensure consistent and comprehensive data, Pilodyn readings were obtained from two directions of the stem and the readings were averaged.

The stress wave velocity (V) is fundamentally related to wood density (ρ) at the time of velocity measurement and dynamic modulus of elasticity (MoE) as

$$\text{MoE} = \rho V^2.$$

Since in standing trees the green density of wood within a plantation generally remains uniform, the square of the velocity becomes directly proportional to MoE. This helps to quickly rank trees for wood stiffness. Stress wave velocity in standing trees was measured in two opposite directions of the trees using the Fakopp tool. Two probes were inserted in the tree vertically in-line through the bark at an angle of 45° to the trunk surface in the arrangement. The distance between the probes was 1 m and the lower probe was inserted at 30 cm above the ground. Accurate transit-time measurement requires a stable and firm attachment of the transducers to the wood. It was ensured that the transducer probes (needles) penetrate the bark to reach the wood beneath to give the true transit time of stress wave through the wood. The pin-type probe acts as a wave-guide and also provides good coupling of the transducer with the wood that allows sound to propagate despite the presence of bark. The start probe was gently tapped with a light hammer (about 100 g) to induce stress waves in the wood. The arrival time of the stress wave at the receiver (end) probe was recorded with an accuracy of 1 μs. For each tree, five measurements of stress wave transit time were taken. V was determined using the following equation.

$$V = D/(\text{Transit time}),$$

where D is the distance between the probes (i.e. 1.0 m).

Results

The statistical data on tree height, GBH, Pilodyn penetration and stress wave velocity for the 52 superior trees selected and the sample plot are provided in Tables 1 and 2 respectively.

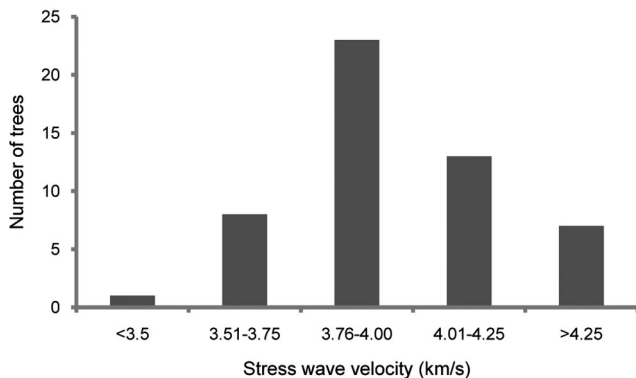
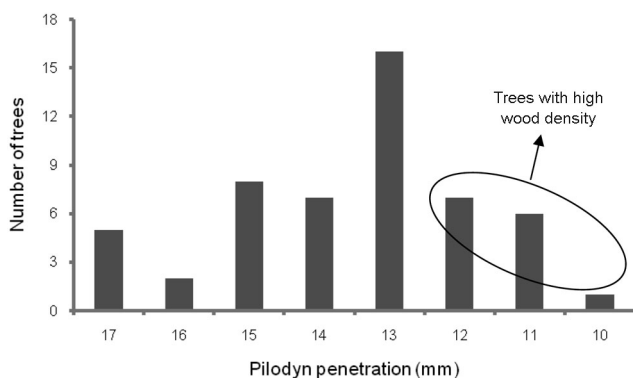
The average girth (86.54 cm) and height (28.10 m) of the superior trees indicated that average annual growth for girth and height was 10.8 cm and 3.51 m respectively. The Pilodyn penetration ranged from 10 to 17 mm while

Table 1. Descriptive statistics of superior trees for various characteristics ($n = 52$)

| Tree characteristics | Average | Coefficient of variation (%) | Minimum | Maximum |
|-----------------------------|---------|------------------------------|---------|---------|
| Tree height (m) | 28.10 | 8.89 | 21.2 | 33.3 |
| Girth over bark (cm) | 86.54 | 6.08 | 77.3 | 99.2 |
| Pilodyn penetration (mm) | 13.60 | 12.86 | 10 | 17 |
| Stress wave velocity (km/s) | 3.93 | 6.18 | 3.36 | 4.42 |

Table 2. Variability for morphological and wood quality traits measured for trees in the sample plot ($n = 60$)

| Tree characteristics | Average | Coefficient of variation (%) | Minimum | Maximum |
|-----------------------------|---------|------------------------------|---------|---------|
| Tree height (m) | 21.62 | 23.08 | 11.4 | 28.7 |
| Girth over bark (cm) | 48.08 | 28.72 | 21.4 | 78.4 |
| Pilodyn penetration (mm) | 13.25 | 11.27 | 10 | 18 |
| Stress wave velocity (km/s) | 3.72 | 7.12 | 3.23 | 4.25 |

**Figure 1.** Frequency distribution of selected trees based on stress wave velocity.**Figure 2.** Frequency distribution of trees based on Pilodyn penetration.

stress wave velocity ranged from 3.36 to 4.42 km/s (Table 1), suggesting wood stiffness variation from 12.42 to 21.50 GPa (assuming green wood density of 1100 kg/m^3). In the sample plot, coefficient of variation (CV) for girth and height is $>23\%$, and the average girth of 48cm indicates that the annual average girth increment

is $\sim 6 \text{ cm}$ while the annual average height increment is $\sim 2.70 \text{ m}$ (Table 2).

In case of the selected trees, stress wave velocity was found to be the least variable ($\text{CV} = 7.12\%$); however it corresponded to nearly 14% variation in MoE. The squared velocity of the best tree was $\sim 72\%$ higher than the worst tree in the sample plot. Though GBH of the selected trees had a smaller CV of 6.08%, Pilodyn penetration had a relatively higher variation ($\text{CV} = 13\%$). This suggests that wood density and MoE of wood are variable even in morphologically identical trees. Figures 1 and 2 show the frequency distribution of selected trees for stress wave velocity and Pilodyn penetration respectively. Out of selected 52 trees, $\sim 37\%$ (21 trees) had stress wave velocity of more than 4 km/s. Pilodyn penetration is known to have a negative relation with wood basic density, i.e. lower the pin penetration better the density. The frequency distribution of Pilodyn penetration suggests that about 14 trees exhibit pin penetration of less than 13 mm, indicating higher wood density.

Pearson's correlation analysis suggests a strong positive association between tree height and GBH (Table 3). The morphological parameters (height and girth) were also positively correlated with stress wave velocity. There was a significant negative association between velocity and Pilodyn measurement, suggesting that trees with high stress wave velocity also have higher wood density. This will have a significant influence on MoE of wood, as it has relation with both density and velocity.

A comparison of the histogram of stress wave velocity among selected trees and those in the sample plot indicates a clear distinction in the two groups (Figure 3). The higher velocity readings clearly demonstrate that the selected trees are superior in wood stiffness compared to those in the sample plot. For the analysis and selection of superior trees within those chosen GBH, Pilodyn penetration and stress wave velocity were normalized with their mean values and subsequently given equal weight to each

of the recorded parameters. By doing so an average score was obtained for each tree. Based on high girth, low Pilodyn penetration and high stress wave velocity, 26 trees having superior wood density and stiffness were selected for further propagation (Table 4).

Discussion

Integrating wood quality traits along with the usually considered growth traits in tree improvement programmes provides an opportunity for the breeders to balance the possible negative impact of growth on wood quality traits¹⁴. Establishing the relationship between girth and wood quality traits helps in developing focused tree improvement programmes. Use of non-destructive tools is gaining considerable importance for documenting variability in wood quality traits and selecting traits for identifying superior genotypes¹⁵. These tools help in rapidly obtaining field data from a large number of samples, thereby strengthening the selection process through its efficiency, better utilization of time, money and resources. Among most of the wood traits, wood basic density has been reported to have high heritability and therefore is an ideal trait for genetic improvement. Wood basic density has a larger implication in tree improvement research as it can influence the chipping properties,

volume of wood, paper quality, sawn wood property, etc.^{16,17}. Moreover, younger trees tend to be in a dynamic stage; thereby some of the important traits also exhibit huge variation. Therefore, these non-destructive methods are ideal for the selection of superior genotypes¹⁸.

In the present study, variability for height and girth in sampled plots as depicted by the CV value (>23%) clearly shows that the plantation has considerable variation. In the sample plot, the average girth of the trees was 48 cm indicating an annual girth increment of 6 cm. Average annual growth increment of *E. pellita* in its native country Australia was 8.29 cm (ref. 19) and it was 7.7 cm in Columbia²⁰, 8.1–10.3 cm in Indonesia¹⁰ and 5.27–6.59 cm in Vietnam²¹. In the present study, the superior genotypes selected based on height and girth had an average annual girth increment of 10.82 cm. A study was carried out in Australia to characterize and evaluate the quality of different families of 12.8-yr-old *E. pellita* using non-destructive tools. The average Pilodyn penetration and acoustic velocity were 13.71 mm and 3.85 km/s respectively²², which are in close agreement with our results. In that study²², the wood density values ranged from 503 to 701 kg/m³. Among the 52 genotypes selected based on primary growth data (tree girth and height), after normalizing the data recorded for Pilodyn penetration (basic density) and stress wave velocity (wood stiffness), 26 genotypes were chosen. The CV for Pilodyn and stress

Table 3. Relationship between girth, height, velocity (stress wave) and Pilodyn penetration

| | Height | Girth | Velocity | Pilodyn |
|----------|--------|--------|----------|---------|
| Height | 1 | | | |
| Girth | 0.88** | 1 | | |
| Velocity | 0.52** | 0.51** | 1 | |
| Pilodyn | -0.21 | -0.20 | -0.56** | 1 |

**Significant at $P < 0.01$.

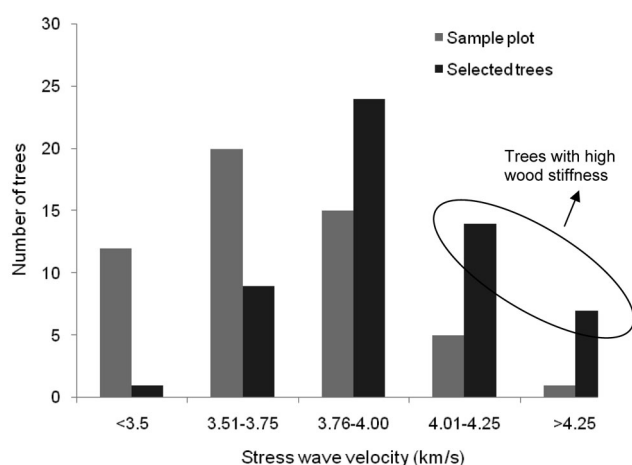


Figure 3. Frequency distribution of stress wave velocity in selected trees and sample plot.

Table 4. Twenty-six trees of *Eucalyptus pellita* selected among 52 superior varieties for further propagation and improvement

| Tree no. | Height (m) | Girth (cm) | Pilodyn (mm) | Stress wave velocity (km/s) |
|----------|------------|------------|--------------|-----------------------------|
| 2 | 33.3 | 88.2 | 12 | 4.31 |
| 3 | 29.6 | 77.3 | 10 | 4.37 |
| 5 | 26.4 | 85.2 | 11 | 4.42 |
| 7 | 33.0 | 91.3 | 11 | 4.20 |
| 8 | 31.2 | 86.5 | 13 | 3.82 |
| 10 | 30.6 | 89.9 | 15 | 4.27 |
| 11 | 31.8 | 96 | 11 | 3.97 |
| 14 | 26.1 | 88.3 | 13 | 3.92 |
| 15 | 27.2 | 84.5 | 12 | 4.12 |
| 17 | 29.3 | 89.6 | 13 | 3.82 |
| 26 | 27.6 | 89.5 | 13 | 4.07 |
| 27 | 28.8 | 93.5 | 13 | 4.15 |
| 28 | 29.6 | 78.8 | 13 | 4.22 |
| 31 | 26.5 | 85.4 | 13 | 3.95 |
| 32 | 25.6 | 99.2 | 11 | 4.26 |
| 33 | 25.1 | 88 | 11.5 | 4.03 |
| 34 | 26.4 | 92 | 12 | 4.31 |
| 38 | 21.2 | 80 | 13 | 4.07 |
| 39 | 29.5 | 80.5 | 12 | 3.77 |
| 40 | 25.3 | 83.5 | 11 | 3.79 |
| 41 | 25.4 | 89 | 12 | 3.66 |
| 42 | 27.8 | 86.8 | 13 | 3.88 |
| 46 | 27.3 | 85 | 13 | 4.02 |
| 48 | 31.1 | 88.5 | 12 | 4.42 |
| 51 | 28.8 | 85.8 | 12 | 4.15 |
| 52 | 28.3 | 85.7 | 13 | 4.15 |

wave velocity for the 26 selected genotypes reduced to 8.58% and 5.23% respectively. The average stress wave velocity of the selected trees increased from 3.93 to 4.08 km/s while the Pilodyn penetration reduced from 13.60 mm to 12.25 mm, indicating superior wood density in the selected trees.

Similar studies using non-destructive tools like Pilodyn and stress wave measurement have been carried out elsewhere for temperate species like hybrid larch²³, Scot pine²⁴, *Pinus pinaster*²⁵, *P. taeda*²⁶, Douglas fir²⁷, Norway spruce¹², and in tropical species such as *Eucalyptus nitens* in New Zealand²⁸, *Eucalyptus* clones in China²⁹, *E. urophylla*³⁰, *Acacia auriculiformis*, *Artocarpus hirsutus*, *A. heterophyllus*, *Swietenia macrophylla*, *Xylia dolabriformis*, *Hevea brasiliensis* and *Tectona grandis*³¹. These studies have emphasized the potential application of the non-destructive tools in tree improvement for better wood properties. The finally selected 26 trees are of superior quality both for wood density and wood stiffness traits. Acoustic velocity provides comparable assessment of stiffness and stability, and could rank the families for intrinsic wood properties in radiata pine⁶. A favourable genetic correlation between acoustic wave velocity and MoE has been reported in *Eucalyptus nitens*, which would assist in identifying genotypes suitable for structural timber and/or engineered wood products³². Acoustic velocity has also been reported to be related with other intrinsic wood characters like fibre length and pulp yield in *Eucalyptus* spp. which are important quality traits for the pulp industry³³.

Conclusion

The present study clearly demonstrates that using non-destructive tools variability in wood quality traits can be assessed in a large number of trees. It can assist in selecting superior genotypes based on wood quality traits during the initial stages of the selection process. Significant variability present in wood quality traits in morphologically identical trees of the studied species emphasizes the need for selection of genotypes based on superior wood properties without compromising on productivity. This would increase the efficiency of tree improvement programmes. Though the results are promising, extensive studies on many other indigenous tropical trees species with a large sampling size is essential so that these tools can become a prerequisite in all tree improvement programmes being carried out in India.

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