



Mechanical Characterization of Clonal Mulberry (*Morus spp.*) Genotypes for Multifarious Industrial Timber Applications

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Authors' contributions

This work was carried out in collaboration among all authors. Author PLD conceived and designed the study, conducted the experiments, and analysed the data, performed the statistical analysis and contributed to data interpretation. Author KTP contributed to the design of the study, provided essential materials, and assisted with data interpretation. Author IN assisted with laboratory work, data collection, and manuscript preparation. Author MHA contributed to drafting and revising the manuscript, provided critical feedback, and approved the final version of the manuscript for submission. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed to assess the mechanical properties of five mulberry (*Morus spp.*) clonal genetic resources to identify superior candidates for diverse timber-based industrial applications.

Study Design: The investigation employed a Completely Randomized Design (CRD) with replicates, and statistical analyses were performed using ANOVA and Duncan's Multiple Range Test (DMRT) at a 5% significance level.

Place and Duration of Study: Wood samples were collected from a 7-year-old plantation at the Forest College and Research Institute, Mettupalayam, and tests were conducted at the Central Wood Testing Laboratory, Rubber Board, Kottayam during 2023–2024.

Methodology: Five mulberry clones were subjected to destructive mechanical testing based on IS 1708 (1986) standards. Tests included modulus of rupture (MOR), modulus of elasticity (MOE), compressive strength (parallel and perpendicular to grain), shear strength, tensile strength, hardness, and nail and screw withdrawal strength. Samples were processed to specified dimensions and tested using a Universal Testing Machine under standardized environmental conditions.

Results: Clone ME-0168 exhibited the highest mechanical strength across multiple parameters: MOR (819.85 kgcm⁻²), MOE (82.89×10³ kgcm⁻²), compressive strength parallel and perpendicular to grain (420.42 kg cm⁻² and 152.57 kgcm⁻²), shear strength (104.10 kgcm⁻²), and nail and screw holding power (Radial, Tangential, and End- 157.72kg, 149.71kg, 93.71kg and 301.72kg, 329.92kg, 272.22kg respectively). These properties strongly correlate with industrial requirements: high MOR and MOE make it ideal for beams and planks, high compressive and tensile strengths support use in sports gear, and superior nail and screw holding capacity suits furniture and cabinet work.

Conclusion: Mulberry, particularly clone ME-0168, demonstrates strong potential for use in timber-based industries such as furniture, cabinet work, and sports equipment. Its favorable mechanical properties and fast growth make it a sustainable alternative in agroforestry and plantation programs addressing India's rising wood demand.

Keywords: *Mulberry Clones; mechanical properties; timber utility; Modulus of Rupture (MOR); Modulus of Elasticity (MOE); agroforestry; sustainable wood resources; industrial applications.*

1. INTRODUCTION

Wood is a renewable, versatile material valued for its favorable strength-to-weight ratio and diverse mechanical properties, including elasticity, tensile and compressive strength, and shear resistance. Its anisotropic structure and species-specific hardness contribute to durability and functional performance in applications like construction and furniture. With rising demand for sustainable, high-performance materials, understanding the mechanical behavior of different wood species has become increasingly important for industrial use. The rising global population, rapid urban expansion, and shifting policy frameworks have collectively contributed to a significant surge in the demand for wood and wood-based products (Parthiban and Fernandez, 2017). Historically, forests have been the main source of wood for domestic and industrial purposes. However, legal restrictions following the Forest Conservation Act (1980) and Supreme Court directives have significantly limited tree felling in natural forests, reducing wood

availability and prompting the search for alternative land-use strategies (Parthiban et al., 2021). India's wood demand is projected to exceed 80 million m³, with the timber requirement for plywood and related industries expected to surge from 15 million m³ in 2021 to over 57 million m³ by 2030, contributing to a total estimated demand of 98 million m³ (ICFRE, 2021; Kant & Nautiyal, 2021). Since the implementation of the Forest Conservation Act in 1980, limited wood supply from natural forests combined with growing demand has led to a significant gap between wood availability and market needs (Parthiban & Seenivasan, 2017). To address these issues, the Indian government introduced the National Agroforestry Policy in 2014, providing a framework to promote agroforestry practices (Chavan et al., 2015). The policy encourages the identification and integration of promising tree species into plantation and agroforestry systems to help bridge the growing gap between wood demand and supply. In light of this, mulberry has been recognised as a potentially useful alternative

species for agroforestry as well as for many wood based industries because of its multiutility nature. Accordingly, the current study has been designed to identify the superior clones amenable for timber based industries based on their mechanical properties.

Mulberry is a multipurpose tree with applications in sericulture, horticulture, industry, silviculture, and traditional medicine (Biasiolo *et al.*, 2004). It holds major economic value in sericulture, primarily for its leaves, which serve as the main feed for silkworms. Owing to its fast growth and multifarious utility, it is often referred to as the "Kalpavriksha". The wood derived from mulberry trees holds immense potential for multifarious industrial applications, ranging from traditional uses to modern, innovative sectors. Mulberry wood is lightweight and robust enough to be used in furniture manufacturing because of its moderate to high density. It is also used in crafting sports equipment such as cricket bats, hockey sticks, and tennis rackets, as well as in Indian handicrafts and cabinet work (Sánchez, 2000). Although its durability varies by species, mulberry wood is mainly preferred for indoor use due to its limited resistance to environmental

exposure. However, the studies pertaining to Mulberry clonal genetic resources grown in India are scant. Hence, the present study is designed to explore the potential opportunities of mulberry clonal genetic resources for multifarious timber utility based on their primary mechanical properties.

2. MATERIALS AND METHODS

2.1 Sample preparation

A destructive sampling approach was used to collect wood samples from five mulberry clonal genetic resources (Table 1) obtained from the Central Sericultural Germplasm Resource Centre, Hosur. These clones have been grown since 2016 in the germplasm garden of the Department of Sericulture, Forest College and Research Institute, Mettupalayam (11°19'37"N to 11°19'39"N latitude and 76°56'09"E longitude, elevation 338 metre with an average annual rainfall ranging from 700-800 millimetre). Trees were felled and cut into one-meter logs, which were further processed into test samples (40 × 5 × 5 cm) for mechanical property analysis (Fig.1) (Table 2).

Table 1. Details of mulberry clonal genetic resources

S. No	Scientific Name	Accession number	Variety name	Origin
1	<i>Morus alba</i>	MI- 0674	Khakad- 3	North India
2	<i>Morus alba</i>	MI- 0145	UP- 8	CSR&TI, Mysore
3	<i>Morus latifolia</i>	ME- 0168	<i>M. multicaulis</i>	CSR&TI, Mysore
4	<i>Morus latifolia</i>	ME- 0006	<i>M. multicaulis</i>	RSRS, Kodathi
5	<i>Morus latifolia</i>	MI- 0845	Rajapur- 2	North East India



Fig. 1. Prepared Mulberry wood Samples

2.2 Methods of Testing

Mechanical tests were performed following the Indian Standard Specification IS 1708 (Part 5): BIS (1986) guidelines for testing small clear timber specimens (Second Revision). These tests were carried out using a Universal Testing Machine at the Central Wood Testing Laboratory, Rubber Board, Kottayam (IS, 1986).

2.3 Conditioning of the Samples

Before testing, the seasoned wood material was maintained at a nearly constant weight by storing it at a temperature of $27 \pm 2^\circ\text{C}$ and a relative humidity of $65 \pm 5\%$ (IS, 1986).

2.4 Static Bending Test (Modulus of Rupture and Modulus of Elasticity): IS: 1708 (Part 5) - 1986 (Sample size – $30 \times 2 \times 2 \text{ cm}$)

Static bending tests were conducted to assess the stiffness and strength of the wood samples. The load was gradually increased until each specimen fractured, and the resulting stress-strain curves indicated the proportional limit and corresponding deflection. Key parameters measured included maximum load, modulus of rupture (MOR), and modulus of elasticity (MOE). This test helps determine the suitability of the wood for various applications such as beams, planks, furniture, packing cases, and other structural or utility purposes (IS, 1986).

$$\text{Modulus of Rupture (MOR)} = \frac{3 \times P_{\max} \times l}{2 \times b \times h^2}$$

$$\text{Modulus of Elasticity (MOE)} = \frac{P \times l^3}{4 \times D \times b \times h^3}$$

Where,

P = load at the limit of proportionality (kg);

P max = maximum load (kg),

l = span of the test specimen (cm),

b = breadth of the test specimen (cm),

h = depth of the test specimen (cm)

D = deflection at the limit of proportionality (cm),

Rate of Loading - During the entire test, the load was applied continuously. The moving head of the testing machine moves at a constant rate of 1.0 mm per minute.

2.5 Compressive strength (Parallel and Perpendicular to grain) test: IS: 1708 (Part 8 and 9) 1986 (Sample size (Parallel – $8 \times 2 \times 2 \text{ cm}$) (Perpendicular – $10 \times 2 \times 2 \text{ cm}$))

Timber's usefulness was evident in applications where loads act either along or across the grain, such as in furniture legs and sports gear. For each wood sample, compressive stress at maximum load, modulus of elasticity, and compressive stress at the proportional limit were measured in both parallel and perpendicular grain orientations (Fig. 2A) (IS, 1986).

$$\text{Maximum Crushing Strength (MCS)} = \frac{P_{\max}}{A}$$

Where,

Pmax = maximum crushing load at break point (Kg)

A = area of cross section of the specimen on which force was applied (cm^2).

Rate of Loading - The moveable head of the testing device moves at a constant speed of 0.6 millimetres per minute while a constant load is applied.

2.6 Determination of hardness under Static Indentation: IS: 1708 (Part 10) - 1986 (Sample size – $15 \times 5 \times 5 \text{ cm}$)

The required load in kilograms was recorded to pierce a steel ball with a diameter of 1.128 cm to half its size, or 0.564 cm, at the radial, tangential and end surfaces of the sample (Fig.2B) (IS, 1986).

Rate of Loading: A continuous load was applied at a constant speed of 6 mm per minute.

2.7 Shear strength Parallel to Grain: IS: 1708 (Part 11) - 1986 (Sample size $6 \times 5 \times 5 \text{ cm}$)

This method evaluates the shear strength of timber along the grain, reflecting how the material responds to forces that induce sliding between adjacent layers. To facilitate shear failure, specimens were notched at one end, exposing a $5 \times 5 \text{ cm}$ surface in either the tangential or radial plane. This test provides

insight into the wood's structural integrity under shear stress conditions (IS, 1986).

Rate of Loading: The load was applied constantly at a pace of 0.4 mm per minute.

2.8 Tensile Strength Parallel to grain: IS: 1708 (Part 12) - 1986 (Sample size 32.5 x 5 x 1.5 cm)

By utilising forces and reactions that pull away from one another along the grain, the tensile strength parallel to the grain was calculated. At the period of testing, the length of the gauge was maintained at 5 cm (IS, 1986). Both the tensile stress at the maximum load and the proportional limit were measured (Fig.2D).

$$\text{Tensile stress at Maximum Load (TS at ML)} = \frac{P_{\max}}{A}$$

Where,

P_{\max} = maximum load required for failure perpendicular to grain (Kg)

A = area of the specimen on which force was applied (cm²).

Rate of Loading: The load was applied uniformly throughout the test at a constant speed of 1 mm per minute.

2.9 Tensile Strength Perpendicular to Grain: IS: 1708 (Part 13) - 1986 (Sample size 5.6 x 5 x 5 cm)

Tensile strength perpendicular to the grain was evaluated by measuring the load required to cause failure in the sample (Fig.2D). The material's resistance to splitting in the radial or tangential plane was determined by dividing the

maximum load by the cross-sectional area, as per IS (1986) guidelines.

Notches measuring 2.4 x 0.6 cm were created to induce failure in a 50 x 20 mm area.

Rate of Loading: Throughout the test, the load was continuously added at a constant rate of 2.5 mm per minute until the maximum load was reached.

2.10 Nail and Screw holding Power: IS: 1708 (Part 15)-1986 (Sample size 15x5x5cm)

The maximum force (Kg) needed to withdraw screws and nails was measured across the radial, tangential, and end grain surfaces. For radial and tangential surfaces, average values were used to represent side withdrawal resistance. The nails used were 50 mm long, bright-galvanized with diamond-shaped points, flat heads, and 2.50 mm shanks. Each screw and nail was used only once to ensure consistent and accurate results (IS, 1986) (Fig.2C).

Rate of Loading: The force was applied continuously during the test to ensure that the movable head moved at a constant rate of 2 mm per minute until the screw or nail was pulled out completely.

2.11 Experimental Design and Statistical Analysis

A Completely Randomized Design (CRD) was employed for the study. Data analysis was conducted using SPSS 23 software. An analysis of variance (ANOVA) was conducted to test the statistical significance of the mean values ($P < 0.05$), and DMRT analysis was used to group the mean values.

Table 2. Required sample size for testing of various mechanical properties

SL. No.	Name of the test	Prepared sample size
1	Modulus of Rupture (MOR)	30 cm x 20 cm x 20 cm
2	Modulus of Elasticity (MOE)	30 cm x 20 cm x 20 cm
3	Compression parallel to grain	8 cm x 2 cm x 2 cm
4	Compression perpendicular to grain	10 cm x 2 cm x 2 cm
5	Hardness	15 cm x 5 cm x 5 cm
6	Shearing strength parallel to grain	6 cm x 5 cm x 5 cm
7	Nail holding power	15 cm x 5 cm x 5 cm
8	Screw holding power	15 cm x 5 cm x 5 cm
9	Tension parallel to grain	32.5 cm x 5 cm x 1.5 cm
10	Tension perpendicular to grain	5.6 cm x 5 cm x 5 cm

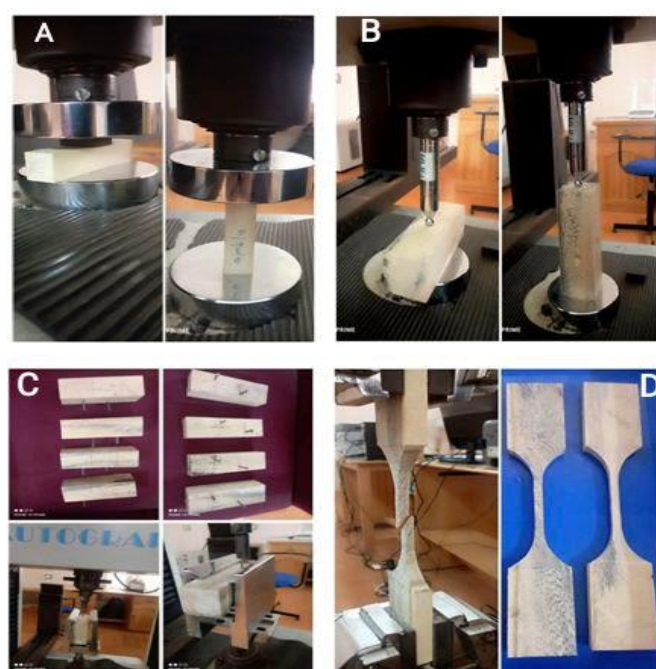


Fig. 2. Mechanical testing of mulberry wood samples under Universal Testing Machine A) Compression strength test B) Hardness test C) Nail Screw Holding test D) Tensile Strength test

3. RESULTS AND DISCUSSION

3.1 Static bending test (Modulus of Rupture and Modulus of Elasticity)

The Modulus of Rupture (MOR) refers to the stress a material can withstand just before it fails in a flexure test. It serves as an indicator of a specimen's strength prior to breaking. In this study, the average Modulus of Rupture (MOR) among the five selected mulberry clonal genetic resources was recorded at $749.59 \text{ Kg cm}^{-2}$. The highest MOR value was observed in ME-0168, reaching $819.87 \text{ Kg cm}^{-2}$, while the lowest was in MI-0674, with a value of $804.55 \text{ Kg cm}^{-2}$ (Table 3). The results of this study align with the findings of Ogunsanwo and Akinlade (2011), where a MOR range of 472.13 to $1063.56 \text{ Kg cm}^{-2}$ for *Gmelina arborea* had been reported. Additionally, the MOR range observed in this study falls within the range reported by Baillères and Durand (2000) for teak wood (81.0 – 135.9 N/mm^2), further corroborating the present findings. The results were also in strong agreement with the MOR range of 63.9 MPa to 118.8 MPa for mulberry wood as recorded by Yu et al., (2015). However, the MOR values for timber species such as *Gmelina arborea* ($202.31 \text{ Kg cm}^{-2}$), *Swietenia macrophylla* ($337.73 \text{ Kg cm}^{-2}$), and *Mangifera indica* ($307.75 \text{ Kg cm}^{-2}$), as reported by Alam et

al., (2022), were significantly lower when compared to the MOR values of mulberry wood in the current study. This indicates the superior strength properties of mulberry wood underscoring its potential as a robust material for various industrial applications.

The Modulus of Elasticity (MOE) assesses the stiffness of wood by measuring the ratio of the applied stress to the resulting strain (deformation) along its length. The average Modulus of Elasticity (MOE) for the mulberry clonal genetic resources was found to be $74.43 \times 10^3 \text{ Kg cm}^{-2}$. Among the five samples, ME-0168 had the highest MOE value at $82.89 \times 10^3 \text{ Kg cm}^{-2}$, while ME-0006 had the lowest MOE at $66.27 \times 10^3 \text{ Kg cm}^{-2}$ (Table 3). The results of the current study was supported by the findings of Carrillo et al., (2011), where MOE range was reported as $6.42 \text{ GPa} \pm 1.23$ to $15.13 \text{ GPa} \pm 2.72$, in *Diospyros texana* and *Acacia schaffneri*, respectively. The result obtained by Bjurhager et al., (2008) for juvenile European aspen (*Populus tremula*) and hybrid aspen (*Populus tremula* × *tremuloides*) also supported the present study. The result of the current study build a strong agreement with the findings of Yu et al., (2015), where MOE for mulberry was recorded as 8650 MPa to 14780 MPa . Further, the result of the present study also corroborated with the findings

by Ogunsanwo and Akinlade (2011) in *Gmelina arborea* (70465.96 Kg cm⁻² to 10235.97 Kg cm⁻²), Miri Tari et al., (2015) in *Paulownia fortune* (65751.30 Kg cm⁻²); Alam et al., (2016) in *Gmelina arborea*, *Swietenia macrophylla* and *Mangifera indica* (99783.82 Kg cm⁻², 82714.59 Kg cm⁻² and 78161.25 Kg cm⁻²), respectively. The modulus of elasticity (MOE) of mulberry genetic resources was compared with various timber species, revealing that mulberry wood have significant potential for a wide range of applications.

3.2 Compressive Strength (Parallel and Perpendicular to Grain) Test

Compression strength parallel to the grain and compression strength perpendicular to the grain are critical mechanical properties of wood that significantly influence its suitability for various structural applications. Compression strength parallel to the grain refers to the wood's ability to resist crushing forces applied along the direction of the fibers. This property is essential for load-bearing structures, such as columns and beams, where the wood must support substantial vertical loads without buckling. On the other hand, compression strength perpendicular to the grain measures the wood's resistance to forces applied across the grain. This parameter was used to classify the wood species into strength classes for two distinct groups: dicotyledonous (hardwoods), where materials were divided into four classes (D20, D30, D40 and D60); and coniferous (softwoods) for which three classes (C20, C25 and C30) were established (Dias and Lahr, 2004; de Almeida et al., 2016). Together, these properties help determine the overall performance, durability, and safety of wood in construction, furniture making and other applications, guiding the selection of appropriate wood species for specific purpose. In the current study, significant differences were observed in compression strength parallel and perpendicular to the grain, with average values of 333.82 Kg cm⁻² and 122.78 Kg cm⁻², respectively. The highest recorded values were 420.42 Kg cm⁻² and 152.57 Kg cm⁻² (ME-0168), while the lowest were 292.61 Kg cm⁻² and 69.81 Kg cm⁻² (ME-0006) (Table 3). The results of the present investigation were in line with the findings of Taragon (2000), where it had been stated that the compressive strength perpendicular to the grain ranged from 1 to 20 MPa and the compressive strength parallel to the grain ranged from 25 to 95 MPa. The results of the current study was also supported by the findings of Azmi

et al., (2022), where compression strength parallel and perpendicular to the grain was recorded 26.12 to 63.35 MPa and 3.3 to 17.7 MPa, respectively for nine Malaysian tropical hardwood species. The compression strength results, both parallel and perpendicular to the grain, from the present study were consistent with the values reported for *Acacia auriculiformis*, *Acacia mangium* and *Grevillea robusta* (396.6 Kg cm⁻² and 252.8 Kg cm⁻², 159.5 Kg cm⁻² and 133.01 Kg cm⁻², 77.86 Kg cm⁻² and 33.56 Kg cm⁻²) (Shanavas and Kumar, 2006), as well as for *Fagus sylvatica* and *Fagus orientalis* (565.23 Kg cm⁻² and 121.96 Kg cm⁻²) (Skarvelis and Mantanis, 2013). Moreover, the agreement of these results with those reported by Kretschmann (2010) for hardwood species such as hackberry, slippery elm, and black locust further supported the validity of the current investigation, emphasizing the consistency of compression strength values across different wood species and geographical regions. These correlations affirm the reliability of the current study's findings and reinforce the importance of considering both parallel and perpendicular compression strength in the selection of wood for construction and other structural applications.

3.3 Determination of Hardness Under Static Indentation

Hardness is a key characteristic of solid materials that reflects their resistance to deformation under applied force, is commonly evaluated using indentation techniques. In wood, the assessment of hardness is influenced by factors such as anisotropy, heterogeneity and hygroscopicity with the specific tool used playing a crucial role in determining the measured values (Riggio and Piazza, 2011). In the current study, Radial, tangential and the end hardness were highest in ME-0168 with the value of 382.15 Kg, 442.63 Kg and 487.95 Kg and the lowest was noticed in ME-0006 with a value of 266.47 Kg, 287.11 Kg and 312.45 Kg, respectively (Table 3). Similar result for hardness (Radial, tangential and end) was observed by Shukla et al., (2007) in different age of *Acacia auriculiformis* (8, 12 and 13 years old). However, the hardness values of certain hardwood species, such as *Acacia mangium* (218.00 Kg, 242.60 Kg and 386.30 Kg) and *Grevillea robusta* (208.70 Kg, 217.00 Kg and 325.20 Kg), was reported by Shanavas and Kumar (2006), were comparatively lower than those observed in the current study. Additionally, the findings of Skarvelis and Mantanis (2013) on *Fagus sylvatica* and *Fagus orientalis*, which reported an average hardness value of 476.18

Kg, further endorse the results of the current investigation, underscoring the reliability and relevance of the hardness measurements obtained in this study.

3.4 Shear Strength Parallel to Grain

Shear strength is a relatively underexplored property in most wood species, despite its significance for various structural applications and its relevance in machining processes. It is a vital mechanical property of wood that influences its performance in structural applications. This property measures the wood's ability to resist forces that cause sliding or shear along the direction of the fibers. High shear strength parallel to the grain is essential for the stability and durability of wooden structures. Shear strength is crucial for applications such as dowel joints, nailing and screwing, as well as timber-to-steel connections, including toothed plate joints (Echavarría *et al.*, 2007). In the current study, the clone ME-0168 demonstrated the highest shear strength at 104.10 Kg cm⁻² while the clone ME-0006 exhibited the lowest shear strength at 58.67 Kg cm⁻² (Table 3). This aligns with the findings of Saravanan *et al.*, (2014), where the shear strengths of 96.87 Kg cm⁻² and 108.09 Kg cm⁻² was recorded at the radial and tangential portions of *Tectona grandis*, respectively. Shukla *et al.*, (2007) reported shear strengths of 50.99 Kg cm⁻² and 68.32 Kg cm⁻² at the radial and tangential positions for *Acacia auriculiformis*, also corroborates with the findings of the current study. However the results of the current study was contrast with the results of Skarvelis and Mantanis (2013), where a mean shear strength value of 151.33 Kg cm⁻² in *Fagus sylvatica* and *Fagus orientalis* had been recorded, suggesting variability in shear strength across different wood species. Further the results of the present findings shows strong agreement with the result of Yu *et al.*, (2015), where shear strength (parallel to grain) of 8.67 MPa to 14.42 MPa has been recorded for mulberry wood.

3.5 Tensile Strength Parallel and Perpendicular to Grain

Tensile strength defined as the stress at which wood fractures under tension, is a critical property influenced by several factors, including species, grade and moisture content (Burgert and Eckstein, 2001). This study measured the tensile strength of timber in relation to its grain direction, revealing that wood exhibits maximum strength when the force is applied parallel to the grain. The highest tensile strength in this study

was observed in the clone ME-0168, with values of 377.79 Kg cm⁻² parallel to the grain and 68.05 Kg cm⁻² perpendicular to the grain (Table 3). Conversely, the clone ME-0006 exhibited the lowest tensile strength, with values of 229.36 Kg cm⁻² in the parallel direction and 39.03 Kg cm⁻² in the perpendicular direction. These findings were consistent with the findings of Shukla *et al.*, (2007), who reported tensile strengths of 32.63 Kg cm⁻² and 35.69 Kg cm⁻² for *Acacia auriculiformis* in radial and tangential positions, respectively. Similarly, Saravanan *et al.*, (2014) found tensile strengths of 293.50 Kg cm⁻² and 48.30 Kg cm⁻² in *Melia dubia*, while Korkut and Hiziroglu (2009) reported 381.06 Kg cm⁻² and 89.91 Kg cm⁻² in *Corylus colurna*. However, these results contrast with Pollet *et al.*, (2012), who documented a significantly higher tensile strength of 1407.21 Kg cm⁻² for *Robinia pseudoacacia*. The increase in tensile strength with tree age, both parallel and perpendicular to the grain, is likely due to higher wood density, improved alignment of wood fibers and the development of stronger intercellular bonds (Saravanan *et al.*, 2014).

3.6 Nail and Screw Holding Power

Nail holding power is a vital mechanical property that significantly influences the structural integrity and longevity of wooden assemblies, particularly in the applications involving fastening and joining process. This property measures the wood's ability to retain nails under load, ensuring that connections in structures like framing, flooring and cabinetry remain secure over time, even under dynamic conditions. In the present study, nail holding power varied considerably among the mulberry clones, with the highest values observed in clone ME-0168 (157.72 Kg in the radial position, 149.71 Kg in the tangential position and 93.71 Kg in the end position) and the lowest in clone ME-0006 (81.68 Kg in the radial position, 83.34 Kg in the tangential position and 55.10 Kg in the end position) (Table 3). These findings were consistent with the results obtained by Neimsuwan and Laemsak (2010) for *Anthocephalus chinensis* (142.35 Kg), Shukla *et al.*, (2007) for *Acacia auriculiformis* (93.81 Kg at the side and 34.67 Kg at the end) and Saravanan *et al.*, (2014) for *Tectona grandis*, which recorded average values of 93.00 Kg at both the radial and tangential positions and 85.00 Kg at the end surface. This comparison highlights the superior nail holding power of the mulberry clones, underscoring their potential suitability for structural applications requiring strong fastening capabilities.

Table 3. Mechanical properties of mulberry genetic resources

Clones		MI- 0674	MI- 0145	ME- 0168	ME- 0006	MI- 0845	Mean	P value
MOR(Kg cm-2)		804.55±6.96 ^a	750.51±12.40 ^b	819.85±7.96 ^a	647.52±12.20 ^d	695.54±20.30 ^c	743.59	<i>P</i> <0.05
MOE× 10³(Kg cm-2)		78.79±1.37 ^{ab}	74.22±1.44 ^{bc}	82.89±0.89 ^a	66.27±1.78 ^d	69.99±1.65 ^{cd}	74.43	<i>P</i> <0.05
Compression parallel to grain (Kg cm-2)		337.10±21.49 ^b	315.62±13.32 ^b	420.42±11.91 ^a	292.61±13.76 ^b	303.34±10.01 ^b	333.82	<i>P</i> <0.05
Compression perpendicular to grain (Kg cm-2)		141.53±14.02 ^{ab}	130.47±10.43 ^{ab}	152.57±2.92 ^a	69.81±3.10 ^c	119.53±5.26 ^b	122.78	<i>P</i> <0.05
	Radial	362.25±3.65 ^b	339.16±4.14 ^c	382.15±2.30 ^a	266.47±2.18 ^d	329.65±4.84 ^c	335.94	<i>P</i> <0.05
	Tangential	398.51±6.58 ^b	326.36±5.85 ^c	442.63±5.64 ^a	287.11±2.07 ^d	304.17±9.10 ^d	351.76	<i>P</i> <0.05
Hardness (Kg)	End	450.69±5.79 ^b	443.08±1.15 ^b	487.95±5.75 ^a	312.45±0.52 ^d	382.79±0.75 ^c	415.39	<i>P</i> <0.05
Shearing strength parallel to grain (Kg cm-2)		80.65±0.77 ^b	76.05±2.23 ^b	104.10±3.78 ^a	58.67±0.99 ^d	66.33±2.35 ^c	77.16	<i>P</i> <0.05
	Radial	141.57±3.92 ^b	131.92±0.57 ^c	157.72±0.67 ^a	81.68±2.62 ^e	94.57±2.57 ^d	121.49	<i>P</i> <0.05
Nail holding power(Kg)	Tangential	134.68±2.66 ^b	101.85±4.27 ^c	149.71±2.35 ^a	83.34±2.87 ^d	90.84±1.64 ^d	112.08	<i>P</i> <0.05
	End	85.66±1.96 ^b	77.62±2.10 ^c	93.71±2.68 ^a	55.10±2.25 ^e	69.45±1.96 ^d	76.31	<i>P</i> <0.05
	Radial	286.12±4.64 ^b	261.94±2.81 ^c	301.72±4.29 ^a	212.63±3.61 ^e	246.8±4.78 ^d	261.84	<i>P</i> <0.05
Screw holding power(Kg)	Tangential	276.91±3.48 ^b	253.74±3.38 ^c	329.92±4.36 ^a	244.13±2.87 ^c	249.23±1.78 ^c	270.79	<i>P</i> <0.05
	End	223.13±2.23 ^b	180.95±2.81 ^c	272.22±1.48 ^a	155.13±5.83 ^d	160.81±1.55 ^d	198.45	<i>P</i> <0.05
Tension parallel to grain (Kg cm-2)		377.79±26.7 ^a	346.31±9.07 ^{ab}	387.62±17.26 ^a	229.36±10.02 ^c	298.12±12.09 ^b	327.84	<i>P</i> <0.05
Tension perpendicular to grain (Kg cm-2)		68.05±2.44 ^a	56.74±3.72 ^b	72.23±2.34 ^a	39.03±3.29 ^c	44.75±2.77 ^c	56.16	<i>P</i> <0.05

*Data expressed as Mean ± S.E. values within the same column with different superscript are significant at *P*<0.05 levels of probability

Screw holding power is an integral mechanical property that plays a significant role in determining the overall performance and durability of wood in various structural applications. It reflects the wood's ability to securely hold screws, which is essential for the integrity of joints and connections in wooden structures. High screw holding power ensures that fasteners remain tightly secured, preventing loosening over time, which is crucial for maintaining the structural stability, particularly in furniture making, construction and other load-bearing applications. In this study, the clone ME-0168 demonstrated the maximum screw holding power across radial, tangential and end positions, with values of 301.72 Kg, 329.92 Kg and 272.22 Kg, respectively, while the clone ME-0006 exhibited the minimum values of 212.63 Kg, 244.13 Kg and 155.13 Kg (Table 3). Shukla *et al.*, (2007) recorded screw holding powers of 253.91 Kg and 133.58 Kg at radial and tangential positions for *Acacia auriculiformis*, corroborating the findings of the present study. Saravanan *et al.*, (2014) reported screw holding power in *Tectona grandis* at radial, tangential and end positions, with average values of 388.00 Kg, 410.00 Kg and 283.00 Kg, respectively, also supporting the findings of this study.

4. CONCLUSION

This study comprehensively evaluated the mechanical properties of five mulberry clonal genetic resources to assess their potential for diverse industrial applications. The results demonstrated considerable variation in key parameters such as modulus of rupture (MOR), modulus of elasticity (MOE), compressive strength (both parallel and perpendicular to the grain), shear strength, hardness, tensile strength, and fastener holding capacity (nail and screw withdrawal). Among the tested clones, ME-0168 consistently exhibited superior mechanical performance across multiple traits, making it a strong candidate for value-added uses such as furniture manufacturing, sports goods, cabinet work, and light structural applications.

Given the increasing demand for sustainable wood sources amid restrictions on natural forest exploitation, mulberry emerges as a viable alternative due to its fast growth, multipurpose utility, and promising mechanical characteristics. The findings support the promotion of selected mulberry clones, especially ME-0168, in agroforestry and plantation programs aimed at bridging the growing gap between wood demand

and supply in India. Future research may focus on long-term field evaluations, durability testing, and wood modification techniques to further expand the industrial applicability of mulberry wood.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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