Original Research Article

Evaluating Mulberry Clonal Genetic Resources through Chemical Characterization for Pulp and Paper Production

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ABSTRACT

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| **Aims:**  The study aimed to evaluate the chemical characteristics of mulberry clonal genetic resources to assess their suitability as alternative raw materials for the pulp and paper industry in India, addressing the growing demand for wood-based feedstock.  **Study Design:**  A Completely Randomized Design (CRD) was adopted for the experimental layout, with statistical analysis performed using SPSS (version 23).  **Place and Duration of Study:**  The research was conducted at the Department of Sericulture, Forest College and Research Institute, Mettupalayam, Tamil Nadu and the study was carried out during 2023–2024.  **Methodology:**  Seventeen mulberry wood clones including *Morus alba*, *Morus latifolia*, and *Morus laevigata* were analyzed for their chemical composition. Parameters such as ash content, alcohol-benzene extractives, acid-insoluble lignin, holocellulose, 1% NaOH solubility, and hot water solubility were assessed following standard procedures and protocols.  **Results:**  Significant variation (*P*< 0.05) was observed among clones for all chemical traits. Ash content ranged from 0.69% to 2.46%, lignin from 23.48% to 28.41%, and holocellulose from 68.68% to 73.28%. Clones MI-0034, ME-0174, and MI-0145 recorded superior holocellulose content (≥72%), indicating high pulp yield potential. Solubility traits were within acceptable limits, further supporting their industrial suitability.  **Conclusion:**  The findings validate the potential of specific mulberry clones as sustainable raw materials for paper production. These clones offer a promising solution to India's pulpwood shortage and can be strategically deployed in future afforestation and industrial applications. |

*Keywords: Mulberry clones, Pulp and paper industry, Holocellulose content, Lignin content, Raw material characterization, Alternative fiber source, Wood chemical composition, Sustainable paper production*

1. INTRODUCTION

Wood is a naturally diverse and intricate material, with its chemical, physical, and structural characteristics playing a key role in determining its usefulness and market value (Riki *et al.,* 2019). Understanding the chemical makeup of wood is essential for assessing its technical and commercial potential, selecting the right pulping process, and determining the strength and quality of the paper it can produce (Abdul-Khalil *et al.,* 2010). The pulp and paper industry provides a greater contribution to the Indian growing economy. India is estimated to have about 850 to 900 pulp and paper mills, out of which nearly 550 are actively functioning today (CPPRI, 2023-24). Almost 16 million tonnes of paper are produced annually by these paper mills in India.

The primary raw material used to make paper is pulp, which is produced by processing fibers that have been extracted from wood, used paper, agricultural leftovers, etc. By 2025, there will be a 12 million tonnes wood shortage due to the estimated 24 million tonnes demand for paper, of which 22 million tonnes would come from domestic manufacturing (Kulkarni, 2013). The nation's paper industry currently relies primarily on casuarina, eucalyptus and bamboo to supply its raw material needs. At present, paper mills are facing a shortage of raw materials due to the destruction of forest resources and prohibitions on expanding man-made forests. Thus, the paper industry is constantly seeking substitute materials that have a short rotation nature and high yield that can be utilized as a source of feedstock in pulp and paper production (Parthiban *et al.,* 2020). Many different tree species are being encouraged for planting throughout India and among them, the potential of mulberry is clearly demonstrated (Rahman and Jahan, 2014). Mulberry is a long-living, perennial tree primarily grown for its vital role in sericulture, while also serving multiple other purposes, including fruit production and timber use (Tikader & Vijayan, 2017). The fast growing, high yielding and short rotation nature of mulberry make it as a potential candidate to be utilize as a source of feedstock in pulp and paper production in the country like India where paper and paper made products are of great importance in every sector. Walia (2013) further highlighted the value of mulberry wood by demonstrating its suitability for paper production. Lignin and cellulose composition of raw material determines the strength of paper. Pentosan, lignin and cellulose contents in the mulberry tree are moderate (Rahman and Jahan, 2014). In China and Bangladesh, mulberry plants are utilized as a suitable source of pulping to fulfil the raw material requirements of the paper industry. The kraft process can be used to make mulberry plant pulp, which can then be combined with jute fibre pulp up to 50% to create kraft liner. Incorporating up to 50% mulberry pulp into jute pulp considerably enhances the mechanical properties of the resulting paper, as evidenced by the improvements in tensile strength, tear resistance and burst indices (Rahman and Jahan, 2014). However, due to a lack of suitable varieties with better wood qualities, the pulp and paper industries in India have not used mulberry as a raw material resource. Apart from this, the chemical characterization of mulberry wood for pulp and paper production in India are dismally modest. Hence, the current study is conceived and carried out to characterise and profile the wood quality of mulberry clonal genetic resources that can be deployed as alternate candidate species for pulp and paper industries to fulfill the demand of escalating population.

2. material and methods

**2.1Sample preparation**

A total of seventeen lignocellulosic wood samples, representing mulberry clonal genetic resources including- eight clones each of *Morus alba* and *Morus latifolia*, along with one clone of *Morus laevigata* were collected from the Central Sericultural Germplasm Resource Centre, Hosur (Table 1). These clones have been under cultivation since 2016 in the germplasm garden of the Department of Sericulture at the Forest College and Research Institute, Mettupalayam (11°19'37''N to 11°19'39''N latitude, 76°56'09''E longitude, at an elevation of 338 meters, receiving an average annual rainfall of 700–800 mm). The sampling included both native and exotic tree types. One healthy tree with a straight, undamaged bole was selected at random from each clone. From each tree, three discs measuring 5 cm in thickness were extracted, air-dried, ground into fine powder, and later used for analysis of various chemical characters (Fig. 1 A-C).

 **Fig. 1. Sequential Processing of Mulberry Plant Samples for Analysis — (A) Wood discs, (B) Air-dried and shredded wood chips, and (C) Final powdered material stored in labeled containers for further analysis**

**Table 1.Details of mulberry clonal genetic resources**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No** | **Scientific Name** | **Accession number** | **Variety name** | **Origin** |
| 1 | *Morus alba* | MI- 0674 | Khakad- 3 | North India |
| 2 | *Morus latifolia* | MI- 0665 | Naudan- 1 | North West India |
| 3 | *Morus alba* | ME- 0174 | Xuan- 9 | CSR&TI, Mysore |
| 4 | *Morus alba* | MI- 0145 | UP- 8 | CSR&TI, Mysore |
| 5 | *Morus alba* | MI- 0211 | Rajasthan Local | North West India |
| 6 | *Morus latifolia* | ME- 0006 | *M. multicaulis* | RSRS, Kodathi |
| 7 | *Morus laevigata* | MI- 0532 | Querypit | South India |
| 8 | *Morus alba* | MI- 0828 | Hosur- C8 | CSGRC, Hosur |
| 9 | *Morus latifolia* | MI- 0783 | - | - |
| 10 | *Morus latifolia* | ME-0168 | *M. multicaulis* | CSR&TI, Mysore |
| 11 | *Morus alba* | MI- 0300 | White Badana | SGF, Kollegal |
| 12 | *Morus alba* | ME- 0169 | Georgia | CSR&TI, Mysore |
| 13 | *Morus latifolia* | MI- 0549 | C- 1690 | CSR&TI, Berhampur |
| 14 | *Morus latifolia* | MI- 0632 | Chimera | CSR&TI, Berhampur |
| 15 | *Morus alba* | MI- 0034 | Sujanpur- 1 | RSRS, Kodathi |
| 16 | *Morus latifolia* | MI- 0818 | Caranzaleempark | South India |
| 17 | *Morus latifolia* | MI- 0845 | Rajapur- 2 | North East India |

**2.2 Methods for determining chemical characteristics of mulberry clonal genetic resources**

**2.2.1 Ash content (%)**

The ash content in the samples was measured following the ASTM D3174 standard procedure (ASTM International, 2012; Kongprasert *et al.,* 2019). About one gram of each powdered sample was placed in a crucible and gradually heated in a muffle furnace. The temperature was first increased from 450°C to 600°C over the span of an hour. It was then raised to 750°C and held steady for another two hours. After that, the crucibles were left in the furnace for an extra hour to ensure complete combustion (Fig. 2A). The ash content percentage was then calculated using a defined formula.

|  |  |  |
| --- | --- | --- |
| Ash content (%) = | W3 - W1 | × 100 |
| W2 - W1 |

Where,

W1= weight of empty crucible, (g)

W2= weight of empty crucible + original sample, (g) and

W3= weight of empty crucible + ash, (g).

**2.2.2 A-B (Alcohol- Benzene) extractive (%)**

The alcohol-benzene extractive content was assessed using the TAPPI T204 method, as described by Buchanan (2007) and Malakani *et al.,* (2014). Around 7 grams of oven-dried wood powder was placed into a cotton-covered thimble flask and set up in a Soxhlet extractor. The extraction was carried out using 300 ml of an ethanol-benzene solution mixed in a 1:2 ratio, maintained at a temperature range of 70–85°C for six hours. After the process, the extract was collected in a pre-weighed petri dish (W1), dried at 100°C, and weighed again (W2) (Fig. 2B). The percentage of alcohol-benzene extractives was then calculated using a standard formula.

|  |  |  |
| --- | --- | --- |
| AB Extractive (%) = | W2- W1 | × 100 |
| Oven dry weight of the sample |

**2.2.3 Acid insoluble lignin (%)**

The acid-insoluble lignin content was estimated following the TAPPI (2006) standard procedure (Anonymous, 2006). About 1.00 ± 0.01 grams of the alcohol-benzene extracted sample was placed in a 100 ml beaker and moistened with 2 ml of 72% sulfuric acid (H₂SO₄). Then, 130 ml of the same acid was added to the beaker. This setup was kept in a water bath at 20°C for two hours, with occasional stirring to ensure thorough mixing. After digestion, the mixture was filtered through a pre-weighed G2 crucible (W1), thoroughly rinsed with hot water to remove any acid residue, and then the remaining solid was weighed again (W2) (Fig. 2C). The lignin content was calculated using a standard formula based on the weight difference (Malakani *et al.,* 2014).

|  |  |  |
| --- | --- | --- |
| Acid insoluble lignin (%) = | W2- W1 | × 100 |
| Oven dry weight of the sample |

**2.2.4 Hollocellulose (%)**

To determine the holocellulose content, 5.00 ± 0.01 grams of the wood sample was placed into a 250 ml conical flask. The sample was first moistened with 10 ml of distilled water. Then, a solution containing 150 ml of distilled water, 1.5 grams of sodium chloride, and 0.5 ml of acetic acid was added. The flask was sealed using a small inverted flask to minimize evaporation and placed in a water bath maintained at 70°C for one hour. After the heating period, the liquid portion was carefully poured into a pre-weighed crucible (W1). The extraction process was repeated using the same solution to ensure thorough removal of non-cellulosic components. The crucible containing the residue was dried in an oven at 105°C overnight (Fig. 2D). Once cooled, it was reweighed (W2) to determine the amount of holocellulose using a standard calculation. The percentage of holocellulose was calculated using the formula by Ona *et al.* (1995).

|  |  |  |
| --- | --- | --- |
| Holocellulose (%) = | W2- W1 | × 100 |
| Oven dry weight of the sample |

**2.2.5 1% NaOH Solubility (%)**

The 1% NaOH solubility of the samples was evaluated following the TAPPI T 212 om-02 standard (Anonymous, 2002). About 2.00 ± 0.01 grams of finely ground wood powder was placed into a 200 ml beaker, and 100 ml of 1% sodium hydroxide (NaOH) solution was added. The mixture was stirred thoroughly with a glass rod and then placed in a water bath maintained at 97–100°C for one hour. During the heating period, the contents were stirred for about 5 seconds at 10, 15, and 25 minutes to ensure even reaction. After 60 minutes, the mixture was poured into a pre-weighed filtering crucible and rinsed with 100 ml of hot distilled water. Next, 25 ml of 10% acetic acid was added and allowed to sit for a minute before filtering. This acid treatment step was repeated with another 25 ml portion. Finally, the sample was washed repeatedly with hot distilled water until all traces of acid were removed. The crucible with the residue was then dried in an oven at 105 ± 3°C until a constant weight was achieved (Fig. 2E). The one percent NaOH solubility was calculated using a specific formula (Jani & Rushdan, 2014).

|  |  |  |
| --- | --- | --- |
| 1% NaOH solubility (%) = | W1 – W2 | × 100 |
| W1 |

Where,

W1= Oven-dried weight of test specimen before extraction, (g)

W2= Oven-dried weight of test specimen after extraction, (g).

**2.2.6 Hot Water Solubility (%)**

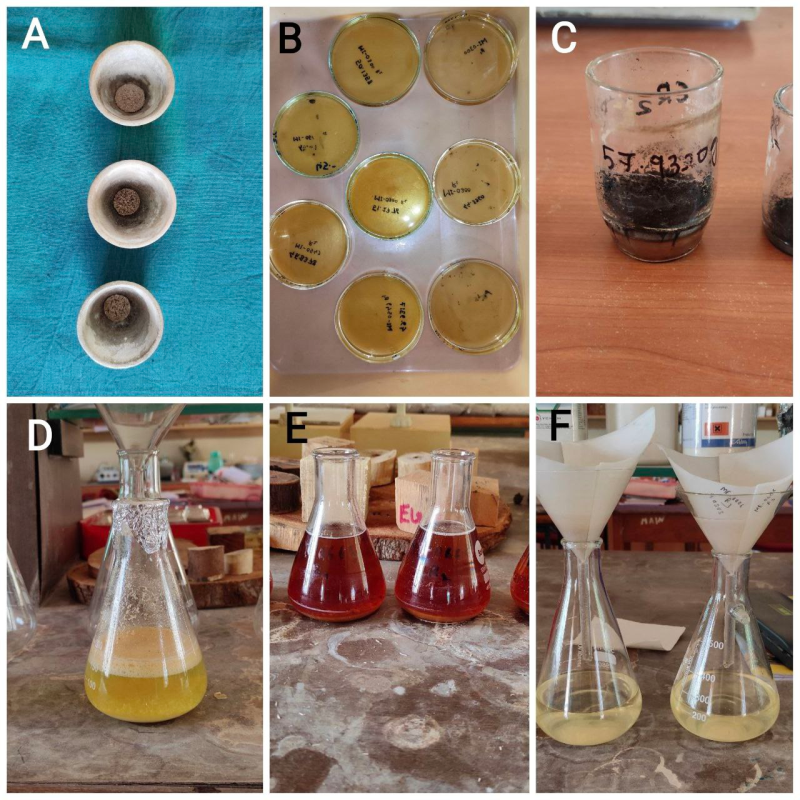
To determine the hot water solubility, 10 ± 0.01grams of finely ground wood powder were measured and placed into a flask, followed by the addition of 100 ml of hot distilled water, as outlined in TAAPI (1999) (Anonymous, 1999). The flask was then heated in a boiling water bath for three hours. After the extraction, the contents were carefully transferred to a pre-weighed filtering crucible, and the liquid was removed using suction. The residue was then rinsed thoroughly with 200 ml of hot distilled water (Fig. 2F). Finally, the amount of material dissolved in hot water was determined using a standard calculation formula (Jani & Rushdan, 2014).

|  |  |  |
| --- | --- | --- |
| Hot water solubility = | W1 – W2 | × 100 |
| W1 |

Where,

W1= Oven-dried weight of test specimen before extraction, (g)

W2= Oven-dried weight of test specimen after extraction, (g).



**Fig. 2. Chemical analysis of mulberry wood samples: A) Ash content (%), B) AB Extractive (%), C) Acid insolube lignin (%), D) Hollocellulose (%), E) 1% NaOH solubility (%), F) Hot water solubility (%)**

**2.3 Experimental design and Statistical Analysis**

The experimental data were analyzed using a Completely Randomized Design (CRD). Statistical analysis was performed with SPSS version 23. To determine the significance of differences among treatment means, analysis of variance (ANOVA) was carried out at a 5% probability level (*P*< 0.05), followed by Duncan’s Multiple Range Test (DMRT) to categorize and compare the means.

3. results and discussion

3.1 Ash content (%)

In evaluating the suitability of mulberry as a raw material for paper production, ash content is a critical factor due to its indication of inorganic compounds present in the material. Typically, hardwoods exhibit an ash content ranging from 1% to 2.5%, while softwoods have lower ash levels of 0.5% to 1% (Sharma *et al.,* 2020). Rahman and Jahan (2014) reported an ash content of approximately 2% for mulberry plants, aligning with the findings of the current study, where ash content ranged from 0.69% (MI-0674) to 2.46% (MI-0632) (Table. 2). Among the 17 mulberry clones examined, four clones had ash content below 1%, twelve clones fell within the 1% to 2% range, and one clone exceeded 2%. High ash content is generally problematic for pulping processes as it impacts alkali consumption, complicates the recovery of cooking liquor and introduces challenges in material handling, pulp washing and beating (Sharma *et al.,* 2011). The majority of clones in this study exhibited ash content within acceptable levels. However, while evaluating the pulp and paper making properties of *Melia azedarach* the ash content was recorded 3.67% (Megra *et al.,* 2022). Which was comparatively higher than the current findings indicating that mulberry could be a promising and viable raw material for paper production.

3.2 A-B (Alcohol- Benzene) extractive (%)

The low molecular weight, non-structural compounds found in wood are called extractives. The majority of them are easily soluble in cold water or neutral organic solvents. They consist of lipids, waxes, alkaloids, proteins, gum, resins, starches, glycosides and essential oils. Chavan *et al.,* (2015) noted that all soluble materials classified as extractives are undesirable in pulp and paper production. The pulp yield, paper quality and drainage properties of the paper machine are impacted by the high extractive content (Mangasha, 2019). Such substances extracted from alcohol-benzene can precipitate during pulping, causing stains on the resulting paper sheets. The acetone extracts of the mulberry plant are approximately 2.5%, which is lower than those found in agricultural residues as reported by Jahan *et al.,* (2004). In the current study, the alcohol-benzene extractives ranged from 2.05% (MI-0300) to 3.79% (MI-0845) (Table. 2), aligning with the values reported by Walia (2013) and Dutt and Tyagi (2011) for mulberry (2.60%) and Eucalyptus species (2.50% - 8.43%) respectively. Vennila and Parthiban (2021) reported the similar range of extractive content when analysed 13 tree species for pulp and paper production which also provide a strong support for the results of the current study.

**Table 2. Chemical characteristics of mulberry clonal genetic resources**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Clones** | **Ash content (%)** | **AB extractive (%)** | **Acid insoluble lignin (%)** | **Holocellulose (%)** | **1% NaOH solubility (%)** | **Hot water solubility (%)** |
| MI- 0674 | 0.69±0.08g | 3.37±0.06abc | 26.71±0.47c | 70.01±0.46defg | 14.50±0.61i | 4.42±0.10cde |
| MI- 0665 | 0.83±0.01fg | 2.80±0.14cdef | 25.23±0.11fgh | 70.40±0.13cde | 22.76±0.46a | 4.27±0.04fgh |
| ME- 0174 | 1.08±0.02cdef | 2.69±0.15ef | 26.12±0.06d | 72.98±0.30a | 20.07±0.22ef | 3.75±0.09k |
| MI- 0145 | 1.76±0.11b | 3.36±0.20abc | 27.31±0.13b | 72.17±0.20ab | 21.60±0.11bc | 4.65±0.06ab |
| MI-0211 | 1.26±0.11cd | 3.53±0.16ab | 24.74±0.12h | 68.99±0.20fgh | 22.65±0.17a | 4.67±0.06a |
| ME- 0006 | 1.01±0.03def | 3.07±0.07bcde | 24.81±0.06gh | 71.39±0.04bc | 17.36±0.51g | 4.28±0.02fg |
| MI- 0532 | 0.98±0.01defg | 2.34±0.03fg | 25.49±1.83ef | 68.68±0.25h | 20.15±0.42def | 4.31±0.04efg |
| MI- 0828 | 1.17±0.09cde | 2.71±0.09def | 25.31±0.24fg | 71.49±0.11bc | 21.37±0.17c | 4.20±0.01ghi |
| MI- 0783 | 1.70±0.27b | 3.41±0.08ab | 25.14±0.32fgh | 69.61±0.96efgh | 21.31±0.38c | 4.54±0.04bc |
| ME- 0168 | 1.03±0.15cdef | 3.49±0.05ab | 26.12±0.21d | 68.82±0.31gh | 21.11±0.27cd | 4.15±0.02hi |
| MI- 0300 | 1.10±0.06cdef | 2.05±0.36g | 25.51±0.11ef | 70.26±0.37cdef | 22.37±0.16ab | 4.33±0.02def |
| ME- 0169 | 1.32±0.02c | 3.27±0.19abcd | 23.71±0.16i | 71.44±0.23bc | 16.65±0.23gh | 4.24±0.02fgh |
| MI- 0549 | 1.14±0.04cde | 3.45±0.08ab | 25.55±0.19ef | 70.64±0.57cde | 20.67±0.46cde | 4.10±0.01i |
| MI- 0632 | 2.46±0.02a | 2.79±0.39def | 25.84±0.11de | 71.30±0.62bcd | 19.49±0.27f | 4.35±0.02def |
| MI- 0034 | 1.73±0.23b | 3.23±0.04abcde | 23.48±0.19i | 73.28±0.19a | 16.76±0.43g | 4.67±0.05a |
| MI- 0818 | 1.15±0.04cde | 2.67±0.18ef | 25.91±0.09de | 69.84±0.96efgh | 21.54±0.17bc | 3.95±0.00j |
| MI- 0845 | 0.87±0.04efg | 3.79±0.42a | 28.41±0.14a | 70.84±0.32h | 15.71±0.20h | 4.44±0.01cd |
| Mean | 1.25 | 3.06 | 25.61 | 70.71 | 19.77 | 4.31 |
| *P* value | *P*< 0.05 | *P* < 0.05 | *P* < 0.05 | *P*< 0.05 | *P* < 0.05 | *P*< 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.

3.3 Acid insoluble lignin (%)

Another key property that plays a crucial role is lignin content. Lignin is a polyphenolic compound that is removed during cooking, aiding in the release of cellulose fibers. The primary goal of pulping and bleaching processes in the paper industry is to eliminate lignin. Typically, wood contains lignin in the range of 20% to 30% (Mithilasri *et al.,* 2024). Lignin content is linked to hardness, bleachability and various other pulp properties (Dutt and Tyagi, 2011). Different pulping and bleaching processes are carried out depending on the amount of lignin present in any raw material, necessitating the measurement of lignin concentration in raw materials (Sharma *et al.,* 2020). In the present study, the clones were analysed for lignin content, which ranged from 23.48% in MI-0034 to 28.41% in MI-0845 (Table. 2). Rahman and Jahan (2014) reported 23% lignin in *Morus* species, while Walia (2013) found 21.42% lignin in *Morus nigra* which was aligning with the current results. The findings of the current study is further strongly supported by the result recorded by Vennila and Parthiban (2021)and Neiva *et al.,* (2015), where similar range of lignin content was observed for different tree species amenable for pulp and paper production. The lignin content recorded in the present analysis was recorded comparatively lower than the lignin content of *Pinus densiflora* (43.24%) and *Eucalyptus globulus* (29.9%) (Lal *et al.,* 2013). These findings highlighted the potentiality of mulberry clones for pulp and paper production and future scope of utilisation of mulberry in paper industry.

3.4 Hollocellulose (%)

Holocellulose is a key and significant component of wood, consisting of both cellulose and hemicellulose. Typically, holocellulose makes up about 65% to 70% of a plant's dry weight. The amount of holocellulose in wood provides insight into its suitability for pulp and paper production. In the present study the clones were analysed for their holocellulose content, which ranged from 68.68% in clone MI-0532 to 73.28% in clone MI-0034 (Table. 2). Among these, 12 clones exhibited holocellulose content exceeding 70%, while 5 clones had holocellulose content above 65%. According to Hatta (2013), a higher holocellulose concentration is a desirable characteristic for the pulp and paper production process since it represents the maximum pulp yield potential. Therefore, the current study indicates that all the clones are suitable for pulp and paper production. However, three mulberry clones MI-0034 (73.28%), MI-0174 (72.98%) and MI-0145 (72.17%) stand out for their superior holocellulose content and are receiving particular attention. Comparable outcomes with a holocellulose content of above 70% were noted in *Morus* species at varying age grades (Rahman and Jahan, 2014), corroborated the present findings. The results of the current study are further supported by the 69% holocellulose content found in *Morus nigra*(Walia, 2013). According to Parthiban and Seenivasan (2017), the pulp and paper industry generally required species with a holocellulose concentration of greater than 65%. Dutta *et al.,* (2009) in their study on *Hibiscus cannabinus* for pulp properties also recorded a similar trend on hollocellulose content of around 71.80% strongly supported the results of the current findings. In light of this, the mulberry clone that was examined for holocellulose in the present study showed that the majority of the clones are suitable for producing paper and provide mulberry as a viable alternative species for pulpwood.

3.5 1% NaOH solubility (%)

NaOH solubility is a key parameter used to assess the microbial decomposition of pulp raw materials and to compare their chemical pulp yields. As noted by Anupam *et al.,* (2014), NaOH solubility is directly correlated with the degree of fungal decay and physical degradation caused by environmental factors such as heat, light and atmospheric oxidation. In the current study, the NaOH solubility of the examined mulberry clones varied from 14.50% in MI-0674 to 22.76% in MI-0665 (Table. 2), indicating differences in their susceptibility to degradation. This range aligns with the findings of Rahman and Jahan (2014), where 23.1% and 21.7% NaOH solubility in 8 month and 12 month old mulberry plants, recorded respectively. Further supporting these results, Dutt *et al.,* (2009) documented NaOH solubility values ranging from 28.5% to 25.80% in *Hibiscus cannabinus* and *Hibiscus sabdariffa*, respectively, which are consistent with the solubility levels observed in the present study. Additionally, the results are strongly corroborated by the work of Mithilasri *et al.,* (2024) and Anusuya (2019), who also reported similar NaOH solubility ranges among various mulberry clones. These findings collectively reinforce the relevance of NaOH solubility as a reliable indicator for evaluating the decomposition and pulp yield potential of mulberry clones.

3.6 Hot water solubility (%)

Hot water solubility plays a crucial role in removing inorganic substances such as tannins, gums, resins, sugars, coloring agents and starch from wood, thereby enhancing the uniformity of the material for paper production. In this study, the hot water solubility of mulberry clonal genetic resources was found to range from 3.75% in ME-0174 to 4.67% in MI-0211 and MI-0034 (Table. 2). The top five mulberry clones with the highest hot water solubility include MI-0211 (4.67%), MI-0034 (4.67%), MI-0145 (4.65%), MI-0783 (4.54%), and MI-0845 (4.44%). These findings are consistent with the results reported by Walia (2013) and Rahman and Jahan (2014), who observed similar hot water solubility levels in mulberry, thereby supporting the current study. The results of the present study was also strongly supported by the findings of Lal *et al.,* (2013) who recorded a hot water solubility percentage of 4.31% in case of *Eucalyptus globulus*. In contrast, Dutt *et al.,* (2009) documented higher hot water solubility values in *Hibiscus cannabinus* (6.42%) and *Hibiscus sabdariffa* (8.24%), which exceed the levels observed in this study. Additionally, the results are further corroborated by Mithilasri *et al.,* (2024) and Anusuya (2019), who reported similar hot water solubility ranges in mulberry genetic resources (3.95% to 4.83% and 4.09% to 4.71%, respectively), establishing a strong correlation with the present findings, further validating the trends observed in this study.

4. Conclusion

The present study successfully characterized the chemical composition of seventeen mulberry clonal genetic resources, highlighting their potential utility in the pulp and paper industry. The analysis revealed that the majority of the clones possessed favorable traits such as low to moderate ash content (0.69%–2.46%), acceptable alcohol-benzene extractives (2.05–3.79%), and moderate lignin levels (23.48%–28.41%), all of which fall within or near the optimal range for pulp production. Notably, holocellulose content, a key determinant of pulp yield was high across most clones, with twelve clones exceeding 70%, indicating a strong promise for high pulp recovery. Clones MI-0034, ME-0174, and MI-0145 demonstrated exceptional holocellulose content (≥72), suggesting their superior suitability for paper making.

Furthermore, 1% NaOH and hot water solubility values aligned well with those reported in established pulpwood species, affirming the structural integrity and chemical stability of mulberry wood under processing conditions. These findings underscore mulberry as a viable, underutilized raw material for pulp and paper manufacturing, especially in light of increasing demand and diminishing availability of conventional pulpwood resources in India.

The study thus provides critical baseline data supporting the strategic selection and deployment of specific mulberry clones particularly MI-0034, ME-0174, and MI-0145 as alternative fiber sources in sustainable paper production systems.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Option 1:

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

**REFERENCES**

1. **Riki, J. T. B., Sotannde, O. A., & Oluwadare, A. O. (2019).** Anatomical and chemical properties of wood and their practical implications in pulp and paper production: A review. Journal of Research in Forestry, Wildlife and Environment*,* **11**(3), 358–368.
2. Khalil, H. A., Yusra, A. I., Bhat, A. H., & Jawaid, M. (2010). Cell wall ultrastructure, anatomy, lignin distribution, and chemical composition of Malaysian cultivated kenaf fiber. Industrial Crops and Products, 31(1), 113–121.<https://doi.org/10.1016/j.indcrop.2009.09.008>
3. Central Pulp & Paper Research Institute (CPPRI). (n.d.). Retrieved July 11, 2025, from <https://cppri.res.in/>
4. Kulkarni, H. D. (2013). Pulp and paper industry raw material scenario—ITC plantation: A case study. IIPTA, 25(1), 79–90.
5. **Parthiban, K. T., Krishnakumar, N., & Devanand, P. S. (2020).**Tree breeding and improvement: Theory and technology (1st ed.). Jodhpur: Scientific Publishers.
6. **Rahman, M. M., & Jahan, M. S. (2014).** Evaluation of mulberry plant as a pulping raw material.Biomass Conversion and Biorefinery*,***4**(1), 53–58.<https://doi.org/10.1007/s13399-013-0095-1>
7. Tikader, A., & Vijayan, K. (2017). Mulberry (Morus spp.) genetic diversity, conservation and management. In Biodiversity and conservation of woody plants (pp. 95-127). Cham: Springer International Publishing. <http://dx.doi.org/10.1007/978-3-319-66426-2_4>
8. **Walia, Y. K. (2013).** Chemical and physical analysis of Morus nigra (black mulberry) for its pulpability. Asian Journal of Advanced Basic Sciences*,***1**(1), 40–44.
9. ASTM International. (2012).*Standard test method for ash in the analysis sample of coal and coke from coal* (ASTM D3174-12). West Conshohocken, PA: ASTM International. <https://www.astm.org/d3174-12.html>
10. **Kongprasert, N., Wangphanich, P., & Jutilarptavorn, A. (2019).** Charcoal briquettes from Madan wood waste as an alternative energy in Thailand. Procedia Manufacturing*,* **30**, 128–135. <https://doi.org/10.1016/j.promfg.2019.02.019>
11. Buchanan, M. T. (2007). 204 cm-97-solvent extractives of wood and pulp (proposed revision of T 204 cm-97). TAPPI-Tech Assoc pulp Pap Ind,
12. **Malakani, M., Khademieslam, H., Hosseinihashemi, S. K., & Zeinaly, F. (2014).** Influence of fungal decay on chemi-mechanical properties of beech wood (Fagus orientalis). Cellulose Chemistry and Technology*,***48**(1–2), 97–103.
13. Anonymous, 2006. Technical Association of the Pulp and Paper Industry: Moisture in pulp, paper and paperboard (TAPPI Standard Test Method T 412 om-06), Atlanta, USA.
14. **Ona, T., Sonoda, T., Shibata, M., & Fukazawa, K. (1995).** Small-scale method to determine the content of wood components from multiple eucalypt samples. TAPPI Journal*,***78**(3), 121–126.
15. Anonymous, 2002. Technical Association of the Pulp and Paper Industry: One percent sodium hydroxide solubility of wood and pulp (TAPPI Standard Test MethodT212 om-02), Atlanta, USA.
16. **Jani, S. M., & Rushdan, I. (2014).** Effect of bleaching on coir fibre pulp and paper properties. Journal of Tropical Agriculture and Food Science, 42(1), 51–61. <https://www.cabdirect.org/cabdirect/abstract/20143268333>
17. Anonymous, 1999. Technical Association of the Pulp and Paper Industry: Water solubility of wood and pulp (TAPPI Standard Test Method T207 cm-99), Atlanta, USA.
18. **Sharma, N., Godiyal, R. D., & Thapliyal, B. P. (2020).** A review on pulping, bleaching and papermaking processes. Journal of Graphic Era University, **8**(1), 95–112.
19. Sharma, A. K., Dutt, D., Upadhyaya, J. S., & Roy, T. K. (2011). Anatomical, morphological, and chemical characterization of *Bambusa tulda*, *Dendrocalamus hamiltonii*, *Bambusa balcooa*, *Melocanna baccifera*, *Bambusa arundinacea*, and *Eucalyptus tereticornis*. BioResources, 6(4), 5062–5073. <https://doi.org/10.15376/biores.6.4.5062-5073>
20. **Megra, M. B., Bachheti, R. K., Tadesse, M. G., & Worku, L. A. (2022).** Evaluation of pulp and papermaking properties of Melia azedarach. Forests*,* **13**(2), 263. <https://doi.org/10.3390/f13020263>
21. **Chavan, S. B., Uthappa, A. R., Keerthika, A., Parthiban, K. T., Vennila, S., Kumar, P., Anbu, P. V., Newaj, R., & Sridhar, K. B. (2015).** Suitability of Leucaena leucocephala (Lam.) de Wit as a source of pulp and fuelwood in India. Journal of Tree Sciences*,* **34**(1), 30–38.
22. **Mangasha, L. A. (2019).** Review on effect of some selected wood properties on pulp and paper properties. Journal of Forestry and Environment*,* **1**(2), 16–22.
23. **Jahan, M. S., Mun, S. P., & Rashid, M. (2004).** Fiber dimensions and chemical properties of various nonwood materials and their suitability for paper production. Journal of Korea Technical Association of the Pulp and Paper Industry*,* **36**(5), 29–35.
24. **Dutt, D., & Tyagi, C. H. (2011).**Comparison of various Eucalyptus species for their morphological, chemical, pulp and paper making characteristics. Indian Journal of Chemical Technology*,* **18**(2), 145–151.
25. **Vennila, S., & Parthiban, K. T. (2021).** Screening of indigenous pulpwood for paper production. International Journal of Chemical Studies, **9**(2), 1059–1064.
26. Mithilashri, M., Parthiban, K. T., & Shankar, S. M. (2024). Screening of mulberry clones for pulp and paper production. International Journal of Agriculture Extension and Social Development*,* 7(9), 473-479. <https://doi.org/10.33545/26180723.2024.v7.i9g.1103>
27. **Neiva, D. M., Fernandes, L., Araújo, S., Lourenço, A., Gominho, J., Simões, R., & Pereira, H. (2015).** Pulping potential of young eucalypts: A comparative study of wood and pulp properties of 12 Eucalyptus species. Proceedings of the 7th International Colloquium on Eucalyptus Pulp, 26–29 May, Vitória, Espírito Santo, Brazil.<https://www.eucalyptus.com.br/artigos/2015_Young_eucalyptus.pdf>
28. **Lal, P. S., Sharma, A., & Bist, V. (2013).** Pine needle—An evaluation of pulp and paper making potential. Journal of Forest Products & Industries*,* **2**(3), 42–47.
29. **Hatta, Z. M. (2013).** Chemical composition and morphological characteristics of cocoa pod husk and cassava peels for pulp and paper production. Australian Journal of Basic and Applied Sciences, **7**(9), 406–411.
30. **Parthiban, K. T., & Seenivasan, R. (2017).**Forestry technologies: A complete value chain approach (1st ed.). Jodhpur: Scientific Publishers.
31. Dutt, D., Upadhyay, J. S., Singh, B., & Tyagi, C. H. (2009). Studies on Hibiscus cannabinus and Hibiscus sabdariffa as an alternative pulp blend for softwood: An optimization of kraft delignification process. Industrial Crops and Products, 29(1), 16–26.
32. **Anupam, K., Lal, P. S., Bist, V., Sharma, A. K., & Swaroop, V. (2014).** Raw material selection for pulping and papermaking using TOPSIS multiple criteria decision making design. Environmental Progress & Sustainable Energy*,* **33**(3), 1034–1041.<https://doi.org/10.1002/ep.11851>
33. **Anusuya, G. (2019).** Characterization of alternate mulberry genetic resources for wood and leaf quality (M.Sc. thesis). Tamil Nadu Agricultural University, Coimbatore, India.