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Physicochemical characterization of Mulberry Genetic Resources and varieties for Generation of sustainable Biomass Energy

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ABSTRACT: Mulberry trees have been recognized for their versatile applications in various industries, including the production of wood for energy purposes. The present study investigated the physicochemical properties of mulberry genetic resources and varieties in relation to their potential as a renewable energy source in the form of wood. This study also emphasizes the need to address challenges in effectively optimizing fuelwood production and utilization for a more sustainable future. The assessed physical properties of these resources revealed a moisture content, bulk density, basic density and specific gravity of 33.96-47.43%, 165.69-210.98 Kgm^{-3}, 566.40-718.65 Kgm^{-3} and 0.40-0.66 respectively. Regarding chemical properties, the analysis unveiled ash content, acid benzene extractive, acid insoluble lignin and holocellulose of 1.10-2.39%, 2.21-3.77%, 20.91-28.45% and 68.59-73.28% respectively. On the basis of physicochemical properties *M. macroura, M. laevigata, M. nigra, M.alba,* G2 and *M. australis* are the most preferred energy plants among the 11species and 4 varieties studied. The physicochemical analysis of mulberry genetic resources and varieties sheds light on the promising potential of mulberry wood as an eco-friendly and renewable energy source. However, further research and development are essential to optimize fuelwood production, utilization, and deployment strategies, paving the way for a greener and more sustainable energy for future.

Keywords: Mulberry tree, woody biomass**,** fuelwood, renewable energy, energy crisis.

INTRODUCTION

India is one of the rapidly developing countries in the world with an ever increasing economy similar to other developing nations. However, it is also facing an energy crisis. The country heavily relies on its coal and oil reserves for energy. According to a report from the Ministry of Statistics, India's energy needs are primarily met by coal and lignite, followed by petroleum (Thomas *et al*., 2017). India, too, is a significant importer of crude oil. 78% of the current crude oil requirement is being imported which has taken heavy toll of the country's exchequer (Parthiban *et al*., 2020). The increasing global population and growing human demands are contributing to the rapid depletion of fossil fuel resources, resulting in environmental challenges like the emission of greenhouse gases and water contamination. The World Energy Forum has made a prediction that the world's fossil-based oil, coal, and gas reserves will be completely depleted within the next 10 decades (Kumar *et al*., 2010). Considering the rapid depletion of our available resources and the escalating environmental hazards, it is crucial to prioritize the consideration and exploitation of cheaper and greener energy sources.

In recent years, biomass has gained significant recognition worldwide as a highly promising and renewable energy source. Currently, approximately 10% of the world's energy demand is fulfilled by bioenergy (Thomas *et al*., 2017). Biomass holds great potential as an excellent alternative to various fossil fuels. According to the World Energy Council reports, the successful implementation of energy policies has the potential to meet 60% of global energy needs through renewable energy sources by 2025. This achievement would lead to a significant reduction in the dependence on fossil fuels, lowering their contribution to the overall energy consumption to 30% (Koh and Hoi, 2003). In India, there is a significant demand for fuelwood. It is estimated that the country consumes approximately 270 million tonnes of fuelwood. Fuelwood plays a crucial role in meeting the energy needs of the population, particularly in rural and tribal areas. In fact, fuelwood satisfies around 40% of the country's total energy requirements. Furthermore, there is an ongoing trend of increasing fuelwood demand, with many people relying on it for their livelihood sustenance. This has led to a rise in both the quantity and intensity of fuelwood use. Unfortunately, this trend indicates that there is a growing gap between the demand for fuelwood and the ability to meet it in the future (Dadile *et al*., 2020).

Currently, the cultivation of short-rotation coppice (SRC) has mainly focused on a limited number of tree species, such as Salix, Populus, and Eucalyptus. However, their cultivation is primarily restricted to developed countries that have specific energy requirements and commercial objectives (Lu *et al.*, 2009). There is now a greater emphasis on identifying and promoting new fast-growing woody tree species that possess favourable characteristics. These species should be easily propagated, adaptable to various agro climatic regions, capable of withstanding intensive coppicing treatments, and able to produce high-quality fuelwood. Additionally, these trees should offer several economic and social benefits (Christersson, 2010).

Mulberry (*Morus* spp. L., *Moraceae*) is a pioneering tree that originated in the temperate Indo-China Himalayan region and has spread worldwide over centuries. It holds significant commercial value and is cultivated perennially for various purposes. Mulberry trees are utilized in sericulture, horticulture, industrial, silviculture, and ornamental applications (Biasiolo *et al.*, 2004). The growth rate of mulberry trees is rapid, and they have the potential to yield up to 45.2 tons per hectare per year of dry biomass. The actual biomass yield can vary depending on factors such as the specific genotype of the tree, the location of the plantation, the density of the plantation, fertilizer applications, and the harvesting technique employed (Sánchez, 1999). The majority of mulberry species exhibit rapid growth during their juvenile stage. Both proleptic and sylleptic shoots display strong growth vigor, leading to the production of significant amounts of woody biomass. The fast growth rate and high biomass yield of mulberry make it an excellent and promising energy crop. Recent studies have revealed that mulberry stem wood has dense composition with high cellulose content, low moisture, and minimal ash content. This composition gives it a high calorific value and excellent combustion characteristics. Thus, the emerging prospect of mulberry as an energy crop seems to have crucial importance in future bioenergy applications (Lu *et al.*, 2009).

The main objective of this study is to assess the physical and chemical properties of fuelwood derived from different mulberry species and varieties. The huge mulberry biomass is currently either unutilized or underutilized. The findings of this research can be particularly beneficial for both rural and urban communities that rely on fuelwood as their primary source of energy. The results of the study will assist these communities in selecting the appropriate types of firewood based on physicochemical properties such as low moisture content, high density, low ash content, and high lignin content, among various other factors.

MATERIAL AND METHODS

A. Location, Climate and Soil

Samples were collected from Department of Sericulture, Forest College and Research Institute, Mettupalayam (between 11°19'37"N and 11°19'39"N latitude and 76°56'09"E longitude; at an elevation of 338m above mean sea level). Mettupalayam experiences a tropical climate with a mean annual rainfall of 700-800 mm, most of which is received during the south west monsoon season (June to September). Mean maximum temperature ranges from 30°C to 35°C and mean minimum temperature from 18°C to 23°C. The dry season usually corresponds to the period from December to February. The soil is red or lateritic with a pHof 6.0-7.5.

B Selection of species

The study focused on examining the significance of eleven mulberry species and four commonly used mulberry varieties, taking into account their local relevance. The selected trees encompassed a range of indigenous species as well as species that are exotic to the region. For each species, one representative tree with a clean bole and that is free from damage was randomly selected. The trees were felled at ground level and three 5-cm thick discs each were cut from each tree. Samples were air dried and made into powder and used for various analyses

C. Determination of physical properties

(i) Moisture content. Moisture content of wood was determined in accordance to ASTM D4442 (ASTM 2016).Representative samples (in triplicate) were collected for analysis. To prevent moisture-related changes, each specimen should be weighed immediately. If immediate weighing is not possible, the specimen should be protected from moisture by placing it in a plastic bag or wrapping it tightly in metal foil until it can be weighed. Once weighed, the specimen should be placed in an oven heated to a temperature of 103 ± 2 °C until there is no significant weight change observed during 3-hour intervals. The constant weight achieved after drying and the original weight of the specimen when it was cut are used in determining the moisture content percentage using a specific formula (Bergman, 2021).

$$\text{Moisture content (\%)} = \frac{\text{Mass when cut} - \text{oven dry mass}}{\text{Oven dry mass}} \times 100$$

(ii) Bulk density. For the bulk wood the weight and dimensions of each individual sample were measured according to a specific equation (Kongprasert *et al.*, 2019).

$$\rho = \frac{m}{v}$$

Where,

ρ = bulk density (g/cm^3)

m = mass of wood sample (g)

v = volume of sample (cm^3)

(iii) Basic density. The initial density of the wood samples was determined through the displacement method (Haygreen and Bowyer, 1982), and the density was subsequently calculated using a specific formula

$$\text{Basic density} = \frac{E_2}{F + G}$$

Where,

E2- Green weight (after soaking in water for 48 hours)

F – Oven dry weight

G – Deflection of the needle in cm due to water displacement.

(iv) Specific gravity. To determine the specific gravity, the weight of an equal volume of water was measured using the water displacement method as outlined in the standard and suggested methods of TAPPI (1972). The specific gravity was calculated by dividing the oven-dry weight of the disc by the weight of an equivalent volume of water (Mainoo and Appiah 1996).

D. Determination of chemical properties

(i) Ash content. The percentage of ash content of the samples was determined in accordance with ASTM D3174 standard (Kongprasert *et al.*, 2019).

$$\text{Ash content (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100$$

Where,

W_1= weight of empty crucible, (g)

W_2= weight of empty crucible + original sample, (g) and

W_3= weight of empty crucible + ashed sample, (g).

(ii) Acid benzene extractive. Alcohol-benzene extractive was calculated in accordance with TAPPI T212 (1993); Malakani *et al.* (2014). Approximately 7g of oven-dried sample was placed in a trimble flask, and the mouth of the trimble flask was covered with cotton. The flask was then placed in a Soxhlet apparatus. A total of 300ml of extraction solvent, which was a mixture of alcohol and benzene (1:2 ratio of ethanol to benzene), was used for the extraction process. The extraction took place for six hours at a temperature range of 70-85°C. After the extraction, the extract was transferred to a petri dish that had been previously weighed (W_1). The extract in the petri dish was then dried at a temperature of 100°C and reweighed (W_2). AB extractives were calculated using the formula.

$$\text{AB Extractive (\%)} = \frac{W_2 - W_1}{\text{Oven dry weight of the sample}} \times 100$$

(iii) Acid insoluble lignin. Acid insoluble lignin was determined in accordance with TAPPI T222 (1998). Each AB extracted sample weighing 1.00 ± 0.01g was placed in a beaker with a volume of 100 ml. The samples were thoroughly wetted by adding 2 ml of a 72% H_2SO_4 solution. Subsequently, 130 ml of 72% H_2SO_4 was poured into the beaker. The beaker containing the samples and H_2SO_4 solution was then placed in a water bath at a temperature of 20°C for a period of two hours. During this time, the contents were stirred using a glass rod. After the two-hour duration, the contents of the beaker were filtered through a tarred G2 crucible (W_1). The crucible containing the residues was then washed with hot water. Finally, the residues in the crucible were weighed (W_2). The percentage lignin content was calculated by the formula (Malakani *et al.*, 2014).

$$\text{Acid insoluble lignin (\%)} = \frac{W_2 - W_1}{\text{Oven dry weight of the sample}} \times 100$$

(iv) Holocellulose. To analyse the holocellulose content, wood sample of 5.00 ± 0.01g was placed in a 250 ml conical flask. The sample was thoroughly wetted by adding 10 ml of distilled water. Next, 150 ml of distilled water, 1.5g of sodium chloride, and 0.5 ml of acetic acid were added to the conical flask. The conical flask was then closed with a small flask positioned in an inverted manner. The contents of the conical flask were placed in a water bath and maintained at a temperature of 70°C for duration of 1 hour. After one hour, the supernatant was transferred to a tarred crucible (W_1). The same treatment process was repeated using water, sodium chloride, and acetic acid. Finally, the contents in the crucible were dried along with the crucible itself in an oven at a temperature of 105°C overnight. The crucible and its contents were then weighed (W_2). The percentage holocellulose was calculated using the formula (Ona *et al*., 1995).

$$\text{Holocellulose (\%)} = \frac{W_2 - W_1}{\text{Oven dry weight of the sample}}$$

E. Statistical analysis

Completely Randomized Design (CRD) was used for entire study and the obtained results are statistically analyzed by using SPSS 16 software. An analysis of variance (ANOVA) was performed for to test the statistical significance of mean values ($p<0.001$). Also, DMRT analysis was used for grouping the mean values.

RESULT AND DISCUSSION

A. Physical properties of mulberry wood

The wood physical properties *viz.*, moisture content, bulk density, basic density and specific gravity were analysed for eleven mulberry species and four varieties and there results are presented in Table 1.

(i) Moisture content (%). Moisture content was ranged from 33.96 to 47.43 per cent. Higher moisture was found in species of *M. indica* (47.43%) and lower in variety V1 (33.96%). The current findings in line with the results made by Baqir *et al.* (2019) where the moisture content of various subtropical species ranged from 38.70 to 58.67 per cent. Generally, wood species with higher moisture content decrease its calorific value and species which are denser with less moisture content are preferred for fuel wood because per unit volume of energy content is higher and rate of burning is slow (Kataki & Konwer 2002). Many studies reported that tropical tree species exhibited comparatively higher Moisture content than temperate species (Bhaat *et al.*, 2010). Moisture content is a critical factor that can have a significant impact on the combustion characteristics of biomass (ASkowuah *et al.*, 2012). The elevated moisture level in biomass not only affects the profitability of biomass combustion due to the process itself but also leads to higher transportation costs due to its low energy density. Moisture significantly influences the lower calorific value of all combustion fuels and plays a vital role in the combustion process. When fuels with high moisture content are burned, they produce a larger volume of exhaust gases, thereby reducing the combustion temperature (Tsai *et al.*, 2018).

(ii) Wood Density. Bulk and basic densities of eleven species and four varieties of mulberry were examined. The bulk densities of the species ranged from 165.69 to 210.98 Kgm^{-3}. *M. laevigata*(210.98Kgm^{-3}) exhibited the highest bulk density while *M. latifolia*(165.69Kgm^{-3}) exhibit lowest bulk density among all the samples analyzed. These bulk density values falls with the findings of Dai *et al*. (2015) who reported that woody biomass fuel species had bulk density in the range of 100-750 Kgm^{-3}. These findings are also in accordance with the results made by Mithilasri (2022) where the bulk densities of mulberry clones ranged from 113.83 (MI-0308) to 245.31 Kgm^{-3} (MI-0807).

Basic densitiy was ranged from 566.40 to 718.65Kgm^{-3}. *M. laevigata* (718.65 Kgm^{-3}) was identified as the woody species with the highest basic density while variety S36 (566.40 Kgm^{-3}) recorded with the lowest basic density among all the samples studied. Similar findings were reported by Mithilasri (2022) where basic density ranged from 341.50 (MI-0308) to 735.95 Kgm^{-3} (MI-0807). Parthiban *et al*. (2020) reported similar trend for basic densities in energy species like Eucalyptus (540 Kg m^{-3}), Casuarina (495 Kgm^{-3}), *Chukrasia tabularis* (467.11 Kgm^{-3}), *Dalbergia sissoo* (610 Kgm^{-3}), *Acacia auriculiformis* (580 Kgm^{-3}), *Leucaena leucocephala* (546 Kgm^{-3}) etc. The fuel value of biomass material is closely influenced by its density. When wood is denser, it possesses a greater amount of heat per unit volume, resulting in longer burning durations (Desta and Ambaye 2020).

(iii) Specific gravity. The specific gravity of analysed species ranged from 0.40 (S36) to 0.66 (*M. macroura*). These findings align with the statement made by Chow and Lucas (1998) that the specific gravity of wood for energy species should typically fall within the range of 0.45 to 0.70. Furthermore, the results obtained are consistent with the findings of Golpayegani *et al*. (2012), who observed a specific gravity range of 0.45 to 0.61 for *Morus alba*. Mainoo and Ulzen Appiah (1996) also reported that the wood specific gravity ranged from 0.43 for *Cassia siamea*, 0.69 for *Leucaena leucocephala* and 0.45-0.75 for *Gliricidia sepium*. The specific gravity of wood is a metric that is closely associated with the quality of wood, including its strength in compression, tension, and other aspects. It also provides insights into how carbon is distributed within a tree (Woodcock and Shier 2002). Many previous workers (Groves *et al*., 1989; Bhatt & Todaria 1992; Kataki & Konwer 2002) have indicated that the heat of combustion of phytofuels is influenced by their specific gravity.

Table 1: Physical properties of mulberry genetic resources.

Species	Moisture content (%)	Bulk density (kg m^{-3})	Basic density (kg m^{-3})	Specific gravity
M. indica	47.43 ± 1.37^{a}	210.47 ± 2.69^{a}	617.75 ± 5.23^{cd}	0.55 ± 0.02^{d}
M. alba	37.63 ± 0.28^{efg}	169.12 ± 2.48^{e}	638.47 ± 14.06^{bcd}	0.58 ± 0.02^{abcd}
M. laevigata	38.60 ± 1.28^{ef}	210.98 ± 1.71^{a}	718.65 ± 14.24^{a}	0.56 ± 0.02^{cd}
M. latifolia	41.12 ± 0.15^{cd}	165.69 ± 0.87^{e}	632.97 ± 17.81^{bcd}	0.52 ± 0.02^{d}
M. australis	35.59 ± 0.41^{hi}	199.79 ± 1.74^{cd}	618.44 ± 20.10^{cd}	0.60 ± 0.03^{abcd}
M. sinensis	34.96 ± 0.12^{hi}	166.96 ± 0.71^{e}	626.40 ± 19.01^{bcd}	0.64 ± 0.03^{ab}
M. cathayana	36.76 ± 0.25^{fgh}	196.23 ± 0.60^{d}	630.17 ± 17.67^{bcd}	0.59 ± 0.02^{abcd}
M. bombycis	37.89 ± 0.80^{efg}	202.22 ± 2.18^{c}	661.53 ± 7.64^{bc}	0.58 ± 0.01^{abcd}
M. nigra	42.84 ± 0.77^{bc}	207.21 ± 2.15^{ab}	672.67 ± 4.97^{ab}	$0.58\pm0.00b^{cd}$
M. macroura	36.03 ± 0.49^{gh}	208.09 ± 1.89^{ab}	668.82 ± 16.57^{b}	0.66 ± 0.04^{a}
M. rotundiloba	35.38 ± 0.64^{hi}	203.82 ± 1.35^{bc}	610.82 ± 21.79^{de}	0.57 ± 0.03^{bcd}
V1	33.96 ± 0.41^{i}	168.19 ± 0.45^{e}	611.36 ± 18.61^{de}	0.59 ± 0.05^{abcd}
S36	43.63 ± 0.42^{b}	168.64 ± 0.30^{e}	566.40 ± 25.98^{e}	0.40 ± 0.02^{e}
G2	36.30 ± 0.72^{gh}	202.39 ± 0.64^{c}	669.10 ± 18.91^{b}	0.63 ± 0.03^{abc}
G4	39.58 ± 0.78^{de}	197.01 ± 0.74^{d}	625.56 ± 17.20^{bcd}	0.54 ± 0.03^{d}
Mean	38.51	191.79	637.94	0.57
P value	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$

Data expressed as Mean ± SE. Values within the same column with different superscript are significant.

B Chemical properties of mulberry wood

Chemical properties of mulberry wood, *viz.,* ash content, AB extractive, acid insoluble lignin and holocellulose were analysed for eleven mulberry species and four varieties and the results are presented in table 2.

(i) Ash content. The ash content ranged between 1.10and 2.39 per cent. Maximum value was found in species *M. latifola* (2.39%), and minimum value was found in *M. alba* (1.10%). The higher value of ash content in fuel makes it less desirable fuel, because maximum part of fuel volume could not be converted into energy (Kumar *et al*., 2011). The current study was in concurrence with the findings of Goswami and Das (2020) in red mulberry (*M. rubra*) calculated as 2.21%. Kataki & Konwer (2001) also reported that ash content of some indigenous species wood was in the range of 0.91 to 1.93per cent. Ash content plays a significant role in the heat transfer to the surface of a fuel and the diffusion of oxygen during char combustion. Since ash is an unburnable impurity, fuels with lower ash content are more suitable for thermal utilization compared to fuels with higher ash content (Kim *et al.*, 2001). The presence of higher ash content in a fuel generally results in increased dust emissions and can impact the combustion volume and efficiency. According to Koppejan and Loo (2012), there is an inverse relationship between a fuel's ash content and its calorific value, meaning that as the ash content increases, the calorific value tends to decrease.

(ii) AB extractive. In this study, the extractive content ranges from 2.21-3.77 per cent. Maximum value was found in variety V1 (3.77%), and minimum value was found in *M. australis* (2.21%). Similar results were reported by Mithilashri (2022) wherein the extractive percentage for different mulberry clones varied from 2.21 to 3.84 per cent which support and confirm the findings of the current study. The current results also align with the findings of Walia (2013) in red mulberry (*M. rubra*), which reported the Acid Benzene extractive percentage to be 2.60 per cent. Extractives are nonstructural and low molecular weight compound present in wood. They include fats, waxes, alkaloid, protein, gum, resins, starch, glycoside, and essential oils, most of which are readily soluble in neutral organic solvents or cold water. The composition and diversity of extractives, as well as their respective quantities, play a crucial role in determining the heating value of biofuels intended for energy purposes (Dadile *et al*., 2020). Extractives functions as intermediates in tree metabolism, as defense mechanism and energy reserve (Telmo & Lousada 2011).

(iii) Acid insoluble lignin. The acid insoluble lignin ranged from 20.91 to 28.45 per cent. *M. laevigata* (28.45%) was identified as the woody species with the highest lignin content while variety S36 (20.91%) recorded the lowest lignin content among all the samples studied. Rahman and Jahan (2014) reported a lignin content of 23 per cent in *Morus* spp, while Walia (2013) found a lignin content of 21.42 per cent in *Morus nigra* which confirms the current study. The current study also aligns with the findings of Mithilashri (2022) wherein the acid insoluble lignin content varied from 20.52 to 28.35 per cent for different mulberry clones. Parthiban *et al*. (2020) also reported similar trend for different energy species where acid insoluble lignin content ranged from 22.00 to 28.31 per cent. Lignin is a complex polyphenolic material arising from enzymatic dehydrogenative polymerization of the phenylpropene units. It plays a crucial role in the combustion process by affecting the chemical composition of wood at both the molecular and atomic levels (Demirbas, 2007). The lignin content of wood significantly influences the heating value of wood. The higher the lignin content, the higher the heating value of the fuelwood species (Dadile *et al*., 2020).

(iv) Holocellulose. Holocellulose content ranged from 68.59 to 73.28per cent. Maximum value was found in species *M. latifolia* (73.28%), and minimum value was found in *M. australis* (68.59%). The current study's results are in agreement with Mithilashri (2022), which reported varying holocellulose content ranging from 67.82 to 73.73 per cent across different mulberry clones which support and confirm the current study. The findings of Parthiban *et al*. (2020) are also consistent with the current study, as they also observed a similar trend among different energy species, with holocellulose content varying from 63.50 to 78 per cent. The composition of biomass, particularly lignin and extractives, plays a significant role in affecting the higher heating value (HHV). This is attributed to their lower oxygen content compared to the polysaccharides found in holocellulose. Polysaccharides in holocellulose have relatively simpler structures, leading to a higher likelihood of thermal degradation (Marques *et al*., 2020).

Table 2: Chemical properties of mulberry genetic resources.

Species	Ash content (%)	AB Extractive (%)	Acid insoluble lignin (%)	Holocellulose (%)
M. indica	1.60±0.05^{cd}	2.37±0.13^{g}	25.79±0.27^{bc}	70.81±0.46^{cde}
M. alba	1.10±0.12^{g}	3.72±0.04^{a}	25.99±0.21^{b}	70.03±0.71^{defg}
M. laevigata	2.00±0.09^{b}	3.04±0.31^{cde}	28.45±0.35^{a}	68.88±0.26^{gh}
M. latifolia	2.39±0.10^{a}	3.37±0.19^{bc}	22.12±0.37^{g}	73.28±0.41^{a}
M. australis	1.26±0.12^{efg}	2.21±0.15^{g}	26.08±0.38^{b}	68.59±0.36^{h}
M. sinensis	1.63±0.12^{cd}	2.72±0.08^{ef}	25.08±0.33^{bcd}	71.05±0.38^{bcd}
M. cathayana	1.44±0.01^{de}	3.15±0.13^{cd}	23.74±0.71^{ef}	71.39±0.33^{bc}
M. bombycis	1.40±0.07^{def}	2.87±0.05^{de}	22.96±0.07^{fg}	72.10±0.31^{ab}
M. nigra	1.23±0.15^{efg}	2.50±0.07^{fg}	27.32±0.31^{a}	69.35±0.70^{fgh}
M. macroura	1.15±0.08^{fg}	3.09±0.07^{cd}	25.94±0.2^{b}	70.18±0.10^{def}
M. rotundiloba	1.86±0.04^{bc}	3.51±0.05^{ab}	23.31±0.43^{fg}	71.88±0.17^{bc}
V1	2.02±0.05^{b}	3.77±0.02^{a}	24.09±0.43^{def}	71.86±0.43^{bc}
S36	1.73±0.07^{c}	2.24±0.06^{g}	20.91±0.10^{h}	71.99±0.36^{bc}
G2	1.30±0.13^{efg}	2.30±0.04^{g}	24.74±0.94^{cde}	69.79±0.21^{efg}
G4	1.47±0.04^{de}	2.28±0.03^{g}	24.92±0.23^{bcde}	70.19±0.45^{def}
Mean	1.57	2.87	24.76	70.75
P value	P<0.001	P<0.001	P<0.001	P<0.001

Data expressed as Mean ± SE. Values within the same column with different superscript are significant

Rating of eleven mulberry species and four varieties on the basis on physical and chemical properties for energy output is presented in Table 3. The species were assigned the value 1–13: Value 1 is for the best and value 13 is for the worst.

Based on final rating, the preferred species for energy should be *M. macroura*>*M. laevigata*>*M. nigra* = *M. alba*>G2>*M. australis*> *M. cathayana*> *M. sinensis*> *M. rotundiloba*> *M. bombycis*> *M. indica* = V1 > G4> *M. latifolia*> S36.

Table 3: Ranking of tree species on the basis of physical and chemical properties.

Species	Moisture content	Bulk density	Basic density	Ash content	AB extractive	Acid insoluble lignin	Holocellulose	Overall Rank[a]
M. indica	15	2	12	9	11	6	8	4.20(10)
M. alba	8	11	6	1	2	4	5	2.47(3)
M. laevigata	10	1	1	13	7	1	2	2.33(2)
M. latifolia	12	15	7	15	4	14	15	5.47(12)
M. australis	4	8	11	4	15	3	1	3.07(5)
M. sinensis	2	14	9	10	9	7	9	4.00(7)
M. cathayana	7	10	8	7	5	11	10	3.87(6)
M. bombycis	9	7	5	6	8	13	14	4.13(9)
M. nigra	13	4	2	3	10	2	3	2.47(3)
M. macroura	5	3	4	2	6	5	6	2.07(1)
M. rotundiloba	3	5	14	12	3	12	12	4.07(8)
V1	1	13	13	14	1	10	11	4.20(10)
S36	14	12	15	11	14	15	13	6.27(13)
G2	6	6	3	5	12	9	4	3.00(4)
G4	11	9	10	8	13	8	7	4.40(11)

For quality criterion of each species the value ranges from 1 to 13and the value 1 is (best) and 13 is (worst)

[a]Values in brackets represents over all ranks, 1 represents best and 13 represent worst

CONCLUSIONS

The physical and chemical composition of fuelwood species has significant influences on the energy value of woody biomass. The results of the current study indicates *M. macroura* is the most preferable species for energy production, followed by *M. laevigata, M. nigra, M. alba,* G2 and *M. australis* respectively. On the other hand, S36 is considered the least suitable species for energy output based on its rating. The promising species and varieties identified in this study can be recommended for inclusion in a fuelwood plantation establishment program for domestic and commercial cooking and heating. By incorporating into the plantation program, it is expected to meet the energy needs of both households and commercial establishments efficiently and sustainably.

FUTURE SCOPE

Further research could focus on developing advanced cultivation techniques that optimize the growth and energy yield of mulberry trees. Additionally, exploring innovative processing methods and conversion technologies could enhance the efficiency of energy extraction from mulberry wood. Collaborative efforts between researchers, policymakers, and industries could lead to the implementation of holistic and sustainable approaches, ensuring the successful integration of mulberry wood-based energy into the broader renewable energy framework.

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REFERENCES

Akowuah, J. O., Kemausuor, F., & Mitchual, S. J. (2012). Physico-chemical characteristics and market potential of sawdust charcoal briquette. *International Journal of Energy and Environmental Engineering*, *3*, 1-6.

Baqir, M., Kothari, R., & Singh, R. P. (2019). Characterization and ranking of subtropical trees in a rural plantation forest of Uttar Pradesh, India, as fuel wood using fuel wood value index (FVI). *Environment, Development and Sustainability*, *21*(2), 763-776.

Bergman, R. (2021). Drying and control of moisture content and dimensional changes. *Chapter 13 in FPL-GTR-282*, 13-1.

Bhatt, B. P., & Todaria, N. P. (1992). Fuelwood characteristics of some Indian mountain species. *Forest Ecology and Management*, *47*(1-4), 363-366.

Bhatt, B. P., Sarangi, S. K., & De, L. C. (2010). Fuelwood characteristics of some firewood trees and shrubs of Eastern Himalaya, India. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *32*(5), 469-474.

Biasiolo, M., Da Canal, M. T., & ornadore, N. (2004). Micromorphological characterization of ten mulberry cultivars (*Morus* spp.). *Economic Botany*, *58*(4), 639-646.

Chow, P., & Lucas, E. B. (1988). Fuel characteristics of selected four-year-old trees in Nigeria. *Wood and fiber science*, 431-437.

Christersson, L. (2010). Wood production potential in poplar plantations in Sweden. *Biomass and Bioenergy*, *34*(9), 1289-1299.

Dadile, A. M., Sotannde, O. A., Zira, B. D., Garba, M., & Yakubu, I. (2020). Evaluation of elemental and chemical compositions of some fuelwood species for energy value. *International Journal of Forestry Research*, *2020*, 1-8.

Dai, J., Saayman, J., Grace, J. R., & Ellis, N. (2015). Gasification of woody biomass. *Annual review of chemical and biomolecular engineering*, *6*, 77-99.

Demirbas, A. (2007). Combustion of biomass. *Energy sources, Part A: Recovery, utilization, and environmental effects*, *29*(6), 549-561.

Desta, H. M., & Ambaye, C. S. (2020). Determination of energy properties of fuelwood from five selected tree species in tropical highlands of southeast Ethiopia. *Journal of Energy*, *2020*, 1-7.

Goswami, R., & Das, R. (2020). Energy cogeneration study of red mulberry (*Morus rubra*)-based biomass. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *42*(8), 979-1000

Groves, K. W., & Chivuya, A. M. (1989). Fuelwood evaluation of four Australian-grown tree species. *ACIAR Monograph*, (10), 159-169.

Haygreen, J. G., & Bowyer, J. L. (1982). Forest product and wood science. *An introduction pub., Iowa State University press, Iowa, USA 495p*.

Kataki, R., & Konwer, D. (2001). Fuelwood characteristics of some indigenous woody species of north-east India. *Biomass and Bioenergy*, *20*(1), 17-23.

Kataki, R., & Konwer, D. (2002). Fuelwood characteristics of indigenous tree species of north-east India. *Biomass and Bioenergy*, *22*(6), 433-437.

Kim, H. J., Lu, G. Q., Naruse, I., Yuan, J., & Ohtake, K. (2001). Modeling on combustion characteristics of biocoal briquettes. *J. Energy Resour. Technol.*, *123*(1), 27-31.

Koh, M. P., & Hoi, W. K. (2003). Sustainable biomass production for energy in Malaysia. *Biomass and Bioenergy*, *25*(5), 517-529.

Kongprasert, N., Wangphanich, P., & Jutilarptavorn, A. (2019). Charcoal briquettes from Madan wood waste as an alternative energy Sin Thailand. *Procedia Manufacturing*, *30*, 128-135.

Koppejan, J., & Van Loo, S. (Eds.). (2012). *The handbook of biomass combustion and co-firing*. Routledge.

Kumar, A., Kumar, K., Kaushik, N., Sharma, S., & Mishra, S. (2010). Renewable energy in India: current status and future potentials. *Renewable and sustainable energy reviews*, *14*(8), 2434-2442.

Kumar, J. N., Patel, K., Kumar, R. N., & Bhoi, R. K. (2011). An evaluation of fuelwood properties of some Aravally mountain tree and shrub species of Western India. *Biomass and Bioenergy*, *35*(1), 411-414.

Lu, L., Tang, Y., Xie, J. S., & Yuan, Y. L. (2009). The role of marginal agricultural land-based mulberry planting in biomass energy production. *Renewable Energy*, *34*(7), 1789-1794.

Mainoo, A.A. & Ulzen-Appiah, Francis. (1996). Growth, wood yield and energy characteristics of *Leucaena leucocephala*, *Gliricidia sepium* and *Senna siamea* at age four years. *Ghana Journal of Forestry*, *3*.

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.

Marques, R. D., Cunha, T. Q. G., Chagas, M. P., Venturoli, F., Belini, G. B., Yamaji, F. M., & Sette Junior, C. R. (2020). Wood quality of five species of the Cerrado for energy purposes. *Scientia Forestalis*, *48*(125), e3225.

Mithilasri, M. (2022). Clonal evaluation, wood and leaf quality characterization of mulberry genetic resources. Ph.D. *(Seri) Thesis*, TNAU, Coimbatore. Pages 1-100.

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.

Parthiban, K. T., Kumar, N. K., Palanikumaran, B., & Kanna, S. U. (2020). Dendro biomass resources for solid and liquid fuel generation--opportunities and challenges. *Madras Agricultural Journal*.

Rahman, M. M., & Jahan, M. S. (2014). Evaluation of mulberry plant as a pulping raw material. *Biomass Conversion and Biorefinery*, *4*, 53-58.

Sánchez, M. D. (1999). Mulberry: an exceptional forage available almost worldwide. *World Animal Review*, 36-46.

Se Golpayegani, A., Brémaud, I., Gril, J., Thevenon, M. F., Arnould, O., & Pourtahmasi, K. (2012). Effect of extractions on dynamic mechanical properties of white mulberry (*Morus alba*). *Journal of wood Science*, *58*(2), 153-162.

TAPPI (US Technical Association of Pulp and Paper Industry), Acid insoluble lignin in wood and pulp, T 222 om-98, 1998.

TAPPI (US Technical Association of Pulp and Paper Industry), Wood extractives in ethanol-benzene mixture, T 204 cm-97, 1997.

Telmo, C., & Lousada, J. (2011). The explained variation by lignin and extractive contents on higher heating value of wood. *Biomass and bioenergy*, *35*(5), 1663-1667.

Thomas, P., Soren, N., Rumjit, N. P., James, J. G., & Saravanakumar, M. P. (2017). Biomass resources and potential of anaerobic digestion in Indian scenario. *Renewable and Sustainable Energy Reviews*, *77*, 718-730.

Tsai, C. H., Tsai, W. T., Liu, S. C., & Lin, Y. Q. (2018). Thermochemical characterization of biochar from cocoa pod husk prepared at low pyrolysis temperature. *Biomass Conversion and Biorefinery*, *8*, 237-243.

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.

Woodcock, D., & Shier, A. (2002). Wood specific gravity and its radial variations: the many ways to make a tree. *Trees*, *16*, 437-443.

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