Comparison of inter-specific wood properties in *Leucaena* species for pulp and bioenergy

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Abstract

Pulp, paper and energy consumption across the globe have increased tremendously. It is necessary to meet future demand by evaluating and identifying alternative sources of raw material for these industries. In this context, this paper describes the growth attributes and wood physico-chemical variability of five different species of *Leucaena,* viz. *Leucaena leucocephala, L. diversifolia, L. collinsii, L. lanceolata* and *L. shanonii*. In each of the species, the growth, biomass, wood fibre morphology, cellulose, holocellulose, total lignin, alcohol-benzene extractives, hot water solubility, NaOH solubility and fuelwood characters such as basic density, moisture, ash content, fixed carbon, volatile matter, and calorific value have been characterised. Our results revealed better pulpwood properties of *L. leucocephala,* while *L. collinsii* had better attributes of being fuelwood. However, the latter had comparable levels of lignocellulosic properties with *L. leucocephala,* suggesting a new source of raw material for pulp and bioenergy. Further, it could be used as a donor parent for interspecific hybridisation to produce superior hybrids for the utilisation of wood-based industries. Finally, *L. collinsii* could be used as an alternative species for minimising the demand for pulp and bioenergy requirements.

Keywords: Bioenergy, Fuelwood, Industries, *Leucaena* species, Pulpwood

Introduction

Wood products are important natural resources as they are eco-friendly, energy-efficient, environmentally safer, and recyclable. The wood-based industries are the major industrial sectors, largely depending on raw material for the processing of pulp and bioenergy (Rajarajan *et al.,* 2023). However, the domestic supply of these raw materials is highly insufficient, which causes imports from foreign countries (Malik *et al.,* 2004). The consumption in India is expected to be doubled in the future due to lifestyle changes and economic factors (Dixon *et al.,* 2012). Considering an alternative source of multipurpose species, which has the potential for pulp and bioenergy, would support more raw materials. This approach will help reduce pressure on natural forests and serve as a substitute for timber imports (Akowuah *et al.,* 2012; Baptista *et al.,* 2014; Owusu and Asumadu-Sarkodie, 2016), especially in the context of the general interim ban on unregulated felling in natural forests (Arunachalam and Kusum, 2012).

Leucaena species have traditionally been used for wood, fodder and fuelwood (López *et al.,* 2008). Among 22 Leucaena species, *L. leucocephala* is widely studied and utilised in pulp industries (Malik *et al.,* 2004; López *et al.,* 2008; Pande *et al.,* 2013). Reportedly, the species, however, has limitations of slow growth during establishment, poor growth on acid soils, susceptibility to cold and psyllid and massive seed dispersal (Raghu *et al.,* 2005; Olckers, 2011). Also, the high seed production of this species is associated with less vegetative growth during seeding (Khanna *et al.,* 2019). These limitations can be overcome by identifying a suitable species. More importantly, the species should support both pulp and bioenergy requirements (Feria *et al.,* 2011). Therefore, it is necessary to identify an alternative species that could be used by the industries in the future for

sustainable production with environmental safety. With this background, this paper describes the potential of five Leucaena species based on their wood properties.

Materials and Methods

Study site and experimental design: Five Leucaena species viz. *L. leucocephala, L. diversifolia, L. collinsii, L. lanceolata* and *L. shanonii* were selected for the present study. Four-year-old trees, raised at 3 x 3 m spacing under a randomised block design (RBD) with three replications and three plants for each replication, were used. The plants were raised on black soil under semi-arid conditions in the research farm of the ICAR-Central Agroforestry Research Institute, Uttar Pradesh, India (25.5040° N, 78.5431° E, 250 msl). Growth, fiber morphology and wood physico-chemical properties were studied under field conditions. The plant height (m) and diameter at breast height (cm) were measured. For biomass yield estimation, four live plants were cut at the tree base, and their fresh weight was measured gravimetrically and expressed in kg.

Physico-chemical properties of fuelwood: The manually cut wood chips (15–20 mm length, 12 mm width and 8 mm thick) were used for physico-chemical properties. Wood blocks (stem disc without bark) were used for fuelwood characterisation. For chemical analysis, [cellulose (%), holocellulose (%), total lignin (%), alcohol-benzene extractives (%), ash content (%), 1% NaOH and hot water soluble (%)], the chips were further ground and passed through a 40 to 60 mesh screen following TAPPI standards (TAPPI, 1991). Fiber length (μm) and diameter (μm) were measured according to Pande *et al.* (2013). For fuelwood characterisation, basic density (kg/m^3) and per cent moisture (drying at 105°C to constant weight), gross calorific values (MJ/kg), volatile matter (%) and fixed carbon (%) of wood samples were determined according to ASTM standards.

Statistical analyses: Duncan's Multiple Range Test at the *p* <0.05 level was used to determine the significance. The principal coordinate analysis (PCA) and the correlation coefficient were carried out using XLSTAT software (2020), Addinsoft, Paris, France. Species ranking has been done based on the mean performances of all the parameters, as desired for pulp and fuelwood efficacy.
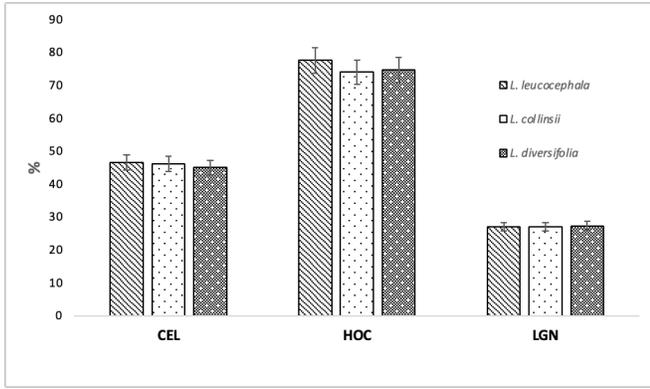
Results and Discussion

Growth, fiber morphology and chemical composition: The mean performance value of five

Table 1. Characterization of growth, wood fiber morphology and chemical composition of five Leucaena species

| Species	PHT	DBH	BMS	FRL	FDM	NaOH	HWS	ABE	HOC	LGN	CEL	Species ranking
L. leucocephala	11.89 [a]	9.80 [a]	73.30 [a]	1042.11 [a]	22.72 [a]	23.0 [c]	1.59 [a]	3.80 [c]	77.54 [a]	27.01 [a]	46.59 [a]	1
L. collinsii	10.77 [ab]	9.27 [a]	55.30 [b]	959.77 [ab]	22.34 [a]	27.07 [b]	1.60 [a]	3.80 [bc]	73.98 [a]	27.01 [a]	46.18 [ab]	2
L. diversifolia	10.05 [b]	8.90 [a]	54.20 [b]	906.90 [bc]	20.21 [ab]	29.67 [ab]	1.64 [a]	4.40 [b]	74.67 [a]	27.25 [a]	45.02 [ab]	3
L. lanceolata	7.75 [c]	7.52 [b]	51.80 [b]	868.79 [bc]	20.91 [ab]	29.00 [ab]	1.64 [a]	5.80 [a]	70.80 [a]	28.30 [a]	40.57 [bc]	4
L. shanonii	6.29 [d]	5.14 [c]	35.10 [c]	785.24 [c]	18.17 [b]	31.20 [a]	1.67 [a]	6.24 [a]	68.06 [a]	28.08 [a]	38.10 [c]	5

PHT: Plant height; **DBH:** Diameter at breast height; **FRL:** Fiber length; **BMS:** Biomass; **NaOH:** NaOH soluble; **HWS:** Hot water soluble; **ABE:** Alcohol-benzene extractive; **HOC:** Holocellulose; **LGN:** Lignin; **CEL:** Cellulose; Values with different letters indicate a significant difference (P<0.05) based on Duncan's test

Fig 1. Comparison of wood properties of *L. leucocephala*, *L. collinsii* and *L. diversifolia* with *L. leucocephala* [CEL: Cellulose; HOC: Holocellulose; LGN: Lignin]

Leucaena species concerning growth, fiber morphology and most physico-chemical composition registered significant variations (Table 1). *L. leucocephala* recorded maximum PHT (11.89 m), DBH (9.80 cm), biomass (73.30 kg), wood fiber length (1.04 mm) and diameter (23.0 μm), followed by *L. collinsii*, *L. diversifolia*, *L. lanceolata* and *L. shanonii* (Table 1). Furthermore, the results revealed that compared to others, *L. leucocephala* had superior growth characteristics, together with good fiber morphology. The growth parameters of *L. collinsii* and *L. diversifolia* were comparable with those of *L. leucocephala*.

L. leucocephala recorded higher values than other Leucaena species for the chemical composition studied
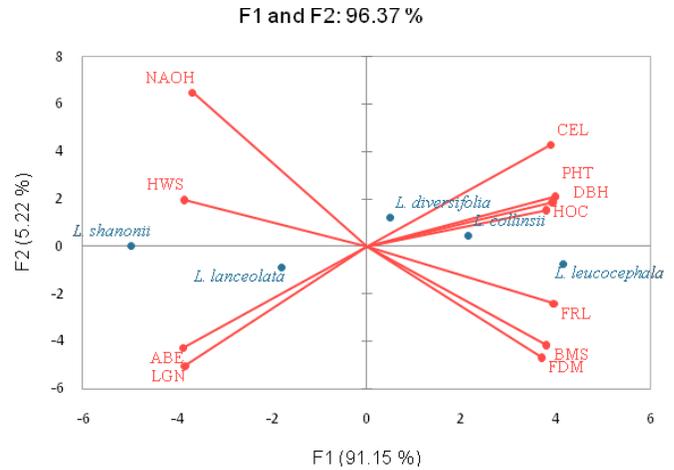

Fig 2. Biplot based on principal component analysis (PCA) for wood chemical composition among five Leucaena species [PHT: Plant height; DBH: Diameter at breast height; FRL: Fiber length; FDM: Fiber diameter; BMS: Biomass; NaOH: NaOH soluble; HWS: Hot water soluble; ABE: Alcohol-benzene extractive; HOC: Holocellulose; LGN: Lignin; CEL: Cellulose; Values with different letters indicate a significant difference (P<0.05) based on Duncan's test]

(Table 1). Its superior ligno-cellulosic properties have been widely reported and are preferred in pulp industries (López *et al.*, 2008; López *et al.*, 2010; Feria *et al.*, 2011). Interestingly, *L. collinsii* and *L. diversifolia* had comparable cellulose and lignin contents, which are crucial chemical

Table 2. Fuelwood properties of *Leucaena* species

Species	BDS	FC	CV	ASH	MC	VLM	Species ranking
L. collinsii	748.08 [a]	95.26 [a]	20.14 [a]	1.14 [b]	5.24 [a]	3.38 [c]	1
L. diversifolia	708.09 [a]	92.95 [a]	19.01 [a]	1.26 [b]	5.34 [a]	3.60 [bc]	2
L. leucocephala	599.03 [b]	89.30 [a]	16.84 [b]	3.38 [a]	5.43 [a]	3.60 [bc]	3
L. lanceolata	584.13 [b]	88.33 [a]	16.73 [b]	3.45 [a]	5.97 [a]	4.03 [b]	4
L. shanonii	581.18 [b]	84.13 [a]	16.64 [b]	3.98 [a]	5.38 [a]	5.58 [a]	5

BDS: Basic density; FC: Fixed carbon; CV: Calorific value; ASH: Ash content; MC: Moisture content; VLM: Volatile matter content; Values with different letters indicate significant differences (P<0.05) based on Duncan's test
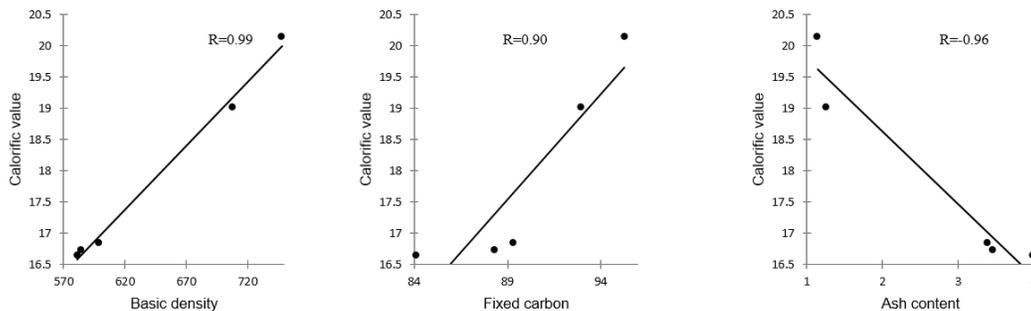
Fig 3. Relationship of fuelwood properties such as calorific value with (a) basic density, (b) fixed carbon, and (c) ash content in *Leucaena* spp

parameters for pulp. Additionally, fiber diameter, hot water-soluble substances, and AB extractives were similar among these three species.

Considering the higher cellulose content and its fraction, along with lower lignin and other extractives, *L. collinsii* and *L. diversifolia* emerge as alternatives to *L. leucocephala* regarding pulp yield and quality, as shown in Fig 1.

The PCA analysis-based biplot also clearly distinguished the species based on their average chemical profiles, supporting the above interpretation, as shown in Fig 2.

Bioenergy properties: Inter-species variations in fuel wood properties were observed among the Leucaena species (Table 2). *L. collinsii* had a high basic density (748.08 kg/m^3), moisture (5.24%), ash (1.14%), volatile matter (3.38%), fixed carbon (95.26%) and calorific value (20.14 MJ/kg) than the other species (Table 2).

The calorific value registered a significant positive correlation with basic density and fixed carbon, and a reverse correlation with ash content shown in Fig 3.

As the basic density increases, the fixed carbon manifests a higher calorific value (Chagunda *et al.,* 2017). Keeping this viewpoint, it could be inferred that *L. collinsii,* for basic density, fixed carbon and calorific value, contributed to greater combustion efficiency in *L. collinsii* has greater combustion efficiency than other species studied. Furthermore, high ash content is less desirable a characteristic as fuelwood because it results in a significant portion of the volume not being converted into energy (Nunes *et al.,* 2017). Eventually, the volatile matter is the portion of biomass as carbon, hydrogen and oxygen that emits volatile gases at 400 to 500°C (Van Loo and Koppejan, 2012). Hence again, *L. collinsii* emerged as a better choice for energy and shall burn with less smoke.

Conclusion

The present study indicates *L. collinsii* as a potential species for fuelwood and pulp utility compared with *L. leucocephala*. For instance, *L. collinsii* exhibits superior growth attributes, viz., higher plant height, DBH and biomass. Also, it has better fuelwood properties, *viz.* basic density, fixed carbon, calorific value, ash content and moisture content than other Leucaena species studied. In addition, upright pulpwood qualities, *viz.,* cellulose and fibre qualities. Thus, it was concluded that *L. collinsii* can be an alternative multipurpose species for both pulp and bioenergy-based industries in the future. Meanwhile, focus on tree improvement will aid inter-specific hybridization for enhanced productivity through QTL identification and gene introgression for wood properties. Overall, *L. collinsii* can be appropriately integrated into farmlands for greater harvest to meet industrial requirements for pulp and bioenergy.

Acknowledgment

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