Print : ISSN 0970-7662

Journal of Tree Sciences
online available at www.ists.in

Volume 34 No. 1 June, 2015

Suitability of *Leucaena leucocephala* (Lam.) de Wit as a source of pulp and fuelwood in India.

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Key words:

Leucaena leucocephala, fuelwood, pulpwood and proximate analysis

ABSTRACT

The present study was carried out to provide overview on the pulp and fuel properties in the wood of *Leucaena leucocephala* during 2010-2011. The proximate analysis exhibited screened pulp yield of 49.0 % coupled with the kappa number of 20.70, which indicated that the species are suitable for pulping quality and exhibited superiority over the traditional pulpwood species. The fuelwood analysis indicated that the *Leucaena leucocephala* recorded high calorific value (4433.89 kcal kg^{-1}), specific gravity (0.65), fixed carbon (79.57 %) values and low moisture content, ash content (1.15 %) and volatile matter (17.24 %) values. In a holistic perspective, finding of current study indicates that *Leucaena leucocephala* could play a significant role in meeting the demand of paper and energy production.

INTRODUCTION

Wood fiber is used for the manufacture of various kinds of paper, packaging materials, tissues and paper boards etc. The conventional softwoods and hard woods used as raw material by pulp, paper and cellulose based industries are depleting day by day and the wood imports are draining country's foreign exchange. Short rotation industrial agroforestry plantations with the fast growing tree species are potential sources to fill this gap and to make the nation self reliance in pulpwood supply (Prasad et al. 2009). Recent forest utilization policies have curtailed the forest raw material availability to the paper industry. This leaves paper industry to fond largely by itself as far as its raw material requirements are concerned. Hence, the top priority has been accorded to industrial wood forestry. The possible use of Leucaena is likely to reduce the load on the conventional species presently used in pulp and paper industries in the country. This may also partially fill up the demand and supply gap of raw materials for pulp production (Bose et al. 1998). At same time fuelwood requirement of country is increasing at higher pace. Fuelwood accounts for about 50% of the total fuel consumption in rural India. According to the Household Consumer Expenditure Survey conducted by NSSO in the year 2007-08, in rural India, over 77% households depend on fuelwood and wood chips for cooking. India's round wood production in 2006 was estimated to be about 240 million m^3, of which 75% is the estimated share of fuelwood and 15-20 million m^3 industrial round wood, including poles and small lumber for rural households (NFC 2006).

Due to growing demand for pulp by paper industry and fuelwood by rural population is bringing in to being scarcity of cellulosic

fibrous raw material in India, therefore there is a need for high cellulosic plants like Leucaena, which can grow in wide range of climatic and soil conditions. Leucaena is a potential alternative to conventional sources of pulp (Owofadeju and Conclude 2005) and fuelwood. It is promising as a faster growing species for biomass and paper production, and it showed suitable physical characteristics of paper sheet (Lopez et al. 2008). However, such studies attest the pulping quality of Leucaena is desirably modest and warrants investigation. Similarly, the energy requirement in the country is also increasing which demanded identification of energy rich species amenable for short rotation forestry and hence intensive research is needed to identify Leucaena as energy resource crop. Therefore, present study was carried out to characterize pulp and fuelwood properties of *Leucaena leucocephala*.

MATERIALS AND METHODS

The present study was carried out in the Pulpwood laboratory of Forest College and Research Institute, TNAU, Mettupalayam during 2010-2011.The wood samples of *Leucaena leucocephala* were collected from the plantation established at Seshasayee Paper Board Ltd., Erode, Tamil Nadu. In this study, Leucaena was compared with traditional pulp yielding species *viz*., *Eucalyptus hybrid* and *Casuarina equisetifolia* for pulp wood characteristics (Bharati 2007). Similarly, *L. leucocephala* was compared with *Prosopis juliflora* for fuelwood properties (Chauhan 2014).

Pulpwood Characteristics

The physical characteristics such as bulk density, basic density (Haygreen and Bowyer, 1982), moisture content and wood chips classifications (50 mm, 10 mm, 5 mm and 2 mm sieves) (TAPPI methods 1980) were analyzed as per standard methodologies. For chemical analysis, the billets of individual trees were chipped in pilot chipper, followed by air-dried and converted into wood-dust in a laboratory through Wiley disintegrator. The wood-dust retained over 60 meshes was subjected to analysis for moisture, ash content, hot water soluble, 1% NaOH soluble, Alcohol-Benzene extractive, acid insoluble lignin, pentosans and holocellulose following TAPPI (1980). The dryness of the pulp was also determined to quantify pulp yield. Kappa number of each pulp was determined as per the TAPPI method of T236-760.

Fuel wood characterization

The proximate analysis of wood was carried out for fuel properties *viz*., specific gravity (TAPPI 1972) and calorific value (Indian Standard IS-1350-1966; Shanavas 2003). The combustion properties *viz*., percentage of volatile matter, fixed carbon, ash content and heating value were also analyzed. The percentage of volatile matter, fixed carbon and ash contents of four representative samples were determined based on ASTM Standard E711-87 (2004). Some of the derived parameters like Fuelwood Value Index (FVI) and Heating value were calculated based on the energy characteristics *viz*., calorific value, specific gravity, lignin content volatile matter and moisture content (Puri et al. 1994 and Bailey et al. 1982).

The Fuelwood Value Index FVI was calculated based on the energy characteristics *viz*., calorific value, specific gravity, lignin content and moisture content following Puri et al. (1994).

$$FVI = \frac{\text{Calorific Value} \times \text{Specific Gravity} \times \% \text{ lignin}}{\text{Moisture content (\%)}}$$

Heating value was calculated by using this Gouthal formula (Bailey *et al.*, 1982):

$$Hv = 2.326\ (147.6\ C + 144\ V)$$

Where,

Hv is the heating value ($MJkg^{-1}$); C is fixed carbon (%) and V is the volatile matter (%)

RESULTS AND DISCUSSION

Pulp characterization

Physical properties

Properties like basic density and quality of extractives are used by the paper industries as indicators of wood quality for different industrial

processes and final paper products. Basic density is related to the yield, paper resistance, optical properties and surface quality. The physical properties *viz.*, bulk density and basic density of *L. leucocephala* were analyzed along with moisture content and details are presented in Table 1. It is indicated that the bulk density and basic density are superior over the traditional pulpwood species *viz.*, *Eucalyptus hybrid* and *Casuarina equisetifolia*. The *Leucaena leucocephala* recorded basic density of 546 kg m^{-3} which is 1.1 % superior to *Eucalyptus hybrid* and 25.51 % superior to *Casuarina equisetifolia* (Table 1). The higher bulk density (250 kg m^{-3}) and low moisture content (11.01%) were observed in *Leucaena leucocephala.* Similar results were reported among various Eucalyptus species, where basic density ranged between 425-542 kg m^{-3} (Vennila, 2010 and Santosh et al. 2004).

Chips classification results revealed that accepted chips for cooking was around 76.6 % and dust was only 0.5 % (Table 1). This is the standard accepted size of chips for pulping. As compared to *Eucalyptus hybrid* (81.00%), *Leucaena leucocephala* recorded the least values for accepted size of chips. Under the classification of over thick, *Leucaena leucocephala* recorded 5.20% value, which was lower than *Eucalyptus hybrid*.

Chemical properties

The proximate analysis gives an idea of potentiality of raw material for paper making (Rao et al. 1999). Results of proximate analysis are presented in Table 2. Ash contents indicated that silica and foreign materials were present in chips. The ash content of *L. leucocephala* was 0.61% which was maximum as compared to *Eucalyptus hybrid* (0.31%) and *Casuarina equisetifolia* (0.38%). This result is also concomitant with Lopez *et al.* (2008) and Hindi *et al.* (2010) in *L. leucocephala*. It was observed that *L. leucocephala* showed slightly higher ash content than conventional pulp yielding species. High contents of ash may negatively impact on the chemical recovery process that affects the quality of pulp (Khiari 2010).

All the soluble materials belong to the category of extractives, and these are totally undesirable in pulp and paper making. The water and alcohol-benzene soluble substances affect the pulp yield, paper quality and drainage characteristics of paper machine. However, these values were found to be least in *Leucaena leucocephala* as compared to *Eucalyptus hybrid*. Therefore, it will create lesser pitch problems and also proved more homogeneity in paper sheet (Kasiviswanathan 1998). The 1% NaOH solubility measures the low molecular weight carbohydrates in pulp; however, value of 1% NaOH solubility was lower in *L. leucocephala* (10.1 %) as compared to *Eucalyptus hybrids* (13.30 %). It is indicated that the pulp derived from *L. leucocephala* is resistance to degradation by light, heat and fungal decay. Result obtained in the present study is in agreement with the Lopez et al. (2008 and 2011) and Malik et al. (2004) in *Leucaena leucocephala* itself.

Holocellulose content is an important aspect of wood pulp and their percentage in wood states the recovery of pulp. *Leucaena leucocephala* was found to be superior for its holocellulose value (75.5 %). This allows envisaging the valorization of such crop as cellulose derivatives and/or as lignocellulosic fibers for fiber-reinforced composite materials or papermaking applications (Khiari, 2010). The same trend was also observed in the studies conducted by Diaz et al. 2007 and Lopez et al. 2011 in *L. leucocephala.*

The lower acid soluble lignin content was reported in *Leucaena leucocephala* (20.40 %) than traditional pulp yielding species like *Eucalyptus* hybrid *(25.80%)* and *Casuarina equisetifolia* (25.70%). Low lignin content of a lignocellulosic material reduces pulping time and chemical charge compared to those of other non-wood raw materials (Lopez et al. 2008 and Diaz et al. 2007). Furthermore, higher contents of lignin are predicted to consume more chemicals upon the pulp industry (Khristova et al. 2005). The results are in agreement with those of Lopez et al. (2008) and Megahed et al.

Table 1: Physical characteristics of Leucaena leucocephala in comparison to Eucalyptus hybrid[a] and Casuarina equisetifolia[a]

Sl. No.	Parameters	Eucalyptus hybrid	Casuarina equisetifolia	Leucaena leucocephala
1	Moisture (%) as received *	11.25	8.67	11.01
2	Bulk density (OD basis) (kg /m^3)	240.00	191.00	250.00
3	Basic density (OD basis) (kg /m^3)	540.00	435.00	546.00
4.	Chips classification (%)			
	+ 8mm (over thick)	12.60	5.90	5.20
	+ 7 mm (accepts)	81.00	80.40	76.6
	+ 3 mm (pin chips)	6.00	13.20	17.3
	- 3mm (dust)	0.40	0.50	0.50

*Moisture content of wood chips
Source: [a]Bharati (2007)

Table 2: Proximate chemical composition of *Leucaena leucocephala* in comparison to *Eucalyptus* hybrid and *Casuarina equisetifolia*

Sl. No.	Parameters	*Eucalyptus hybrid*	*Casuarina equisetifolia*	*Leucaena leucocephala*
1	Ash	0.35	0.38	0.61
2	Solubility in Hot water	3.80	3.60	4.27
3	Solubility in 1% NaOH	13.30	14.00	10.59
4	Alcohol benzene extractive	3.50	1.20	4.56
5	Acid insoluble lignin	25.80	25.70	20.40
6	Pentosans (ash corrected)	6.80	18.50	15.30
7	Hollo cellulose (ash corrected)	70.90	71.60	75.50
8	Chemical charge as Na_2O (%)	16.00	15.00	20.00
9	Unbleached pulp yield (%)	44.20	48.5	48.20
10	Screen rejects (%)	0.12	0.40	0.08
11	Screened yield (%)	44.10	48.10	49.00
12	Kappa number	21.40	16.50	20.70

Cooking Conditions* TTA and RAA as Na_2O are calculated at 200 gpl total solids basis.
Temp : 170 C; Time : 90 min

Table 3: Fuel characterization of *Leucaena leucocephala* in comparison to *Prosospis juliflora*

Parameters	*Prosopis juliflora**	*Leucaena leucocephala*
Specific Gravity	0.74	0.65
Calorific Value (kcal/kg)	4973.70	4433.89
Moisture Content (%)**	36.26	33.00
Fuelwood Value Index	2661.66	1710.00
Lignin (%)	26.38	19.58
Ash Content (%)	2.25	1.15
Volatile Matter (%)	13.35	17.24
Fixed Carbon (%)	84.39	79.57
Heating value (MJ kg^{-1})	33.45	33.63

* Source: Chauhan (2014) ** Moisture content of green wood

(1998) in *Leucaena leucocephala*.

The amount of pentosan recorded in *Leucaena leucocephala* was 15.30 %, which is higher as compared to *Eucalyptus* hybrid (6.80%) and lower as compared to *Casuarina equisetifolia* (18.50%). Wood contains a certain amount of noncellulosic carbohydrates called hemicelluloses. Hardwood hemicellulos consist of mainly pentosan and it indicates the retention or loss of hemicelluloses in general during pulping and bleaching process, and since hemicelluloses contributes to the strength of paper pulp. The high content of pentosans is always desirable in pulp wood species.

The pulping results like pulp yield, kappa number and screen rejects were analyzed and presented in Table 2. The unbleached pulp yield of *Leucaena leucocephala* was 48.20 %, which is slightly higher than *Eucalyptus* hybrid (44.20%) and equal to *Casuarina equisetifolia*. The kappa number is an indicative of lignin content of pulp and gives an idea of bleaching demand in manufacturing process. The kappa number in *Leucaena leucocephala* was 20.70, which is higher than *Casuarina equisetifolia* (16.50). The kappa number indicated that *Leucaena leucocephala* is 1.71 % superior over the *Eucalyptus* hybrid pulp. Considering these two parameters, *Leucaena leucocephala* recorded 49 % screened yield which is 12.01 and 2.70 % more than *Eucalyptus* hybrid and *Casuarina equisetifolia,* respectively. This value is slightly higher than kraft pulp yield obtained by Khristova et al. (1998), Lopez et al. (2008, 2011) and Oluwadare et al. (2007) in the same species. However the *Leucaena leucocephala* yielded maximum value in terms of pulp wood coupled with low kappa number when compared to *Eucalyptus* hybrid indicating superiority over other pulp species for pulp properties.

Fuelwood properties

Effective planning of energy plantation programme requires adequate information on the energy characteristics of various fast-growing tree species. Anderson et al. (1984) have reported that, the most useful indices of woody biomass quality that influence its suitability for efficient conversion with respect to energy are specific gravity, chemical composition, fuel value and size.

Detailed envisage of fuelwood properties are depicted in table 3. Specific gravity plays an important role in evaluating plant species for fuelwood. High specific gravity makes a desirable

fuelwood species due to its high calorific value per unit volume and slow burning rate. Specific gravity of *Leucaena leucocephala* was found to be lower (0.65) as compared to the standard value of *Prosopos juliflora* (0.71). Many previous workers (Bhatt and Todaria 1992 and Kataki and Konwer, 2002) have inferred that heat of combustion of phytofuels is dependent on its specific gravity. This result is in agreement with the findings of Chow and Lucas (1988) who has reported that wood specific gravity of multipurpose trees ranged from 0.45 to 0.70.

One of the main factors affecting the value of wood for fuel is moisture content. The knowledge of the presence and quantity of wood constituent is important, if it is to be used for fuel, since moisture generally decreases wood calorific value (Erakhrumen 2009).The moisture content of *Leucaena leucocephala* recorded was 33 %, which was lower as compared to *P. juliflora*. In the present study, moisture content recorded was the least. This is in agreement with Jesus and Rossmann (1988) in Subabul, Sugumaran and Seshadri (2009) in *Casuarinas* species.

A high ash content of a plant part makes it less desirable as fuel, because a considerable part of the volume cannot be converted into energy. In present study, the ash content of *L. leucocephala* was found to be 1.5 %. Shanavas and Kumar (2003) recorded ash content in *L. leucocephala* (2.1), *Eucalyptus tereticornis* (1.06) and *Xylia xylocarpa* (1.47). As expected, increasing ash content of fuelwood had a negative effect on heat of combustion.

Lower lignin content (19.58%) was recorded in *L. leucocephala* than standard value of *Prosopis juliflora* (26.38 %). Many previous workers (White1987; Kataki and Konwer 2001) have shown that the higher the concentrations of extractives and lignin in wood, the greater will be the heat of combustion. One of the old report showed that average chemical composition of hardwoods as 22 % for Lignin (Browing 1975). The calorific value of *Leucaena leucocephala* was found to be 4433.89 k Cal kg^{-1} which is lower than *Prosopis juliflora* (4973.20 k Cal kg^{-1}). In fact, these calorific values are close to widely accepted range of 4,000-5000 k Cal kg^{-1}, which is used to screen the species for fuelwood purpose.

Fuel value index (FVI) is an important parameter for screening desirable fuelwood species, which depends upon calorific value, density, moisture and ash content of wood (Bhatt and Todaria 1992). The FVI of studied species (1710.0) was lower compared to *Prosopis juliflora* (2661.6). Previous research showed that high calori c value, high wood density, low ash percentage, low wood moisture and a high biomass/ash ratio are highly desirable fuelwood properties, although the most decisive are calori c value, wood density and ash content (Bhatt and Todaria 1992; Puri et al. 1994).

The heating value is the most important combustion property for determining the suitability of a material as fuel. It gives the indication of the quantity of fuel required to generate a specific amount of energy. The higher heating values for wood can be generally explained based on the lignin and extractive contents relative to cellulose and hemicellulose (Kataki and Konwer 2001). In present study, *L. leucocephala* showed slightly higher heating value (33.63 $MJkg^{-1}$) as compared to *Prosopis juliflora* (33.45$MJkg^{-1}$), which is a good indicator for selection of fuelwood species. The finding of Lhate (2011) was in line with present investigation with values ranged from 19.38 to 21.50 MJ Kg^{-1}.

In a holistic perspective, based on fuel properties *viz.*, calorific value, specific gravity, fuel value index and heating value, *L. leucocephala* can be recommended as fuelwood species.

CONCLUSION

The raw material availability for the various forest based industries is depleting day by day and the recent forest policies have further curtailed it. Therefore, short rotation agroforestry practices and systems with fast growing species like Leucaena has the potential to fill this gap and to make the nation self sufficient in pulpwood and fuelwood production.

The physical and chemical characterization of *Leucaena leucocephala* showed that it can be a potential species for both pulp and fuelwood production in India. However, it is necessary to determine the growth rates and productivity of these tree species under different ecological conditions, their optimum planting tree density and rotation period before including them under plantation programme.

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