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Research Paper

An assessment of Indian fuelwood with regards to properties and environmental impact

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Abstract

Wood energy is identified as the major source of energy in rural India. The trees commonly used for fuelwood in India are *Acacia nilotica* (L.) Del., *Acacia leucophloea* (Roxb.) Willd, *Prosopis cineraria* (L.) Druce, *Tectona grandis* L.f., *Cassia fistula* L., *Butea monosperma* (Lam.) Taub. and *Sterculia urens* Roxb. Properties, such as wood density, ash content and elemental composition of plants were determined and correlated with the calorific value and evaluated in relation to their properties and environmental impact when burned. It was revealed that the wood with the highest calorific value does not necessarily constitute the best option as fuelwood, if elemental composition is taken into account. The variation of the wood density, calorific value and elemental composition C, N, P, S, Pb, Al, As and Cd and their indirect impact on the environment is discussed in this paper.

Keywords: Ash content, calorific value, element composition, fuel wood, environmental impact.

Introduction

In many third world countries, the majority of the population lives in the rural areas where fuelwood, charcoal, crop residue and animal wastes provide most of the energy requirement. Many people, especially in rural areas of India, use wood for energy purposes rather than for other applications. The contribution of fuelwood to the total energy consumed varies from place to place and is mainly determined by the level of development and availability. In many of the developing countries, it is estimated that wood still accounts for up to 90% of the total energy consumption and that firewood has become a tradable commodity due to unaffordable costs of other energy sources [1]. Factors influencing the extent of wood use as a fuel include availability of electricity, levels of household income, degree of urbanization and cultural factors.

The choice of wood fuel is normally governed by the availability, the burning duration, the maximum temperature and the ash content [2]. Generally hardwoods are preferred, as their coals last longer, yield more heat and emit less smoke and some *Eucalyptus* species are not well regarded as fuelwood within rural communities, [3]. As the commonly used wood species become scarcer, people often begin to use whatever fuelwood is available, without considering sustainability, ecological factors or the environmental effect.

The main physical properties affecting the performance of fuelwood are moisture content, chemical and elemental composition and wood density [4]. Increased moisture in the wood therefore results in a decrease in the obtained amount of heat, as more energy is used to evaporate water, which lowers the combustion efficiency [5]. For complete combustion it is necessary to evaporate the water present in wood. Few attempts have established the negative effect of moisture in wood on its calorific value [6]. Major elements contributing to the calorific value are carbon, hydrogen, nitrogen, oxygen and sulphur. The calorific value of wood can be related to its elemental composition and varies between 17 and 20 MJ/kg for oven dried wood [7]. Elemental analysis can be used to describe biomass fuels, determine their calorific values [8] and their expected impaction on the environment. This study is aiming to determine the best substitute of fuelwood, to evaluate seven different available fuelwood in terms of energy content and elemental composition. In this study, we determined the wood density, ash content, calorific value and the elemental composition of all samples and developed a simple credit system that could help consumers to decide on the best option of fuelwood for their purpose.

Materials and Methods

Samples

All wood species investigated in this study, A*cacia nilotica* and *A. leucophloea* are native and readily available from dry tropical forest, Udaipur and Bhilwara district, Rajasthan Western India. *Prosopis cineraria* (Khejadi), *Tectona grandis* (Sagvan), *Cassia fistula* (Garmal), *Butea monosperma* (Palas), and *Sterculia urens* (Kadava) are commercially utilized species that may be grown in demarcated areas. A*cacia nilotica, A. leucophloea* and *Prosopis cineraria* are harvested as fuelwood and charcoal source and sold to areas as far as the India. *Tectona grandis, Cassia fistula, Butea monosperma* and *Sterculia urens* are the main source for saw timber, but the waste products, such as saw dust, waste wood pieces are increasingly used for fuelwood in the form of briquettes. All of them are equally available in the western India and commonly sold in bags containing 12-17 logs. The prices vary from Rs. 80 to 100 per bag. On average the A*cacia nilotica, A. leucophloea* and *Prosopis cineraria* are the cheapest (about Rs. 6/log), followed by *Tectona grandis, Cassia fistula* and *Butea monosperma* (Rs. 9 to 15/log and finally *Sterculia urens* (Rs. 7 to 10/log).

In the present study, the samples were collected for analysis of wood density, calorific value, ash content, carbon, nitrogen, phosphrous, sulphur, lead, aluminum, arsenic and cadmium: A*cacia nilotica* (Desi babool), *Acacia leucophloea* (Ronjiya), *Prosopis cineraria* (Khejadi), *Tectona grandis* (Sagvan), *Cassia fistula* (Garmal), *Butea monosperma* (Palas) and *Sterculia urens* (Kadava). The common name is given in parenthesis.

Sample preparation

For the determination of the calorific value, samples were cut from seven different pieces of each species. A disc was cut from the centre and from each disc a 0.5 cm3 cube containing both heart- and sapwood. The cubes were oven dried prior to analysis. For the wood density determination larger pieces were cut from the same disc, also containing heart- and sapwood. For the ash content determination and elemental analysis seven wood blocks, as described above, were further comminuted with wood mill to obtain wood particles with a diameter of 180 mm. Smaller and larger particles were discarded. The samples were oven dried prior to analysis.

Wood density

The wood density was determined by Smith method [9], which avoids the need to determine the exact volume of the samples. The samples were subjected to cycles of over- and under-pressure in a water tank for 5 days. Subsequently the saturated weight was determined and after 24 h of drying the oven-dry weight. The wood density can be calculated as follows:

$$\text{Wood density (g/cm}^3) = 1/([(m_{\text{saturated}} - m_{\text{oven dry}})/m_{\text{oven dry}}] + 1/1.53)$$

Calorific value

The calorific value of dried wood samples was determined with a Rajdhani® bomb calorimeter, India, in which about 0.5 g of oven dried wood was completely combusted under a pressurized to 425 psi with pure oxygen, and the rise in temperature of the cylinder allows the calculation of the calorific value when the exact weight of the sample is known. The bomb-calorimeter was calibrated against benzoic acid standards before the analysis of samples [10].

Ash content

The ash content was determined according to TAPPI standard T 211 om-85 [11]. Wood samples were weighed before they were placed in a furnace at 575ºC for 4 h. Subsequently the ash was weighed and the ash content determined according to

$$\text{Ash content} = m_{\text{ash}} \times 100/m_{\text{oven dry}}$$

Whereas m = wood mass.

Elemental analysis

The samples for analytical determinations were prepared by wet digestion using perchloric and nitric acid (1:5, v/v). After digestion, C, N and S were determined; Carbon content was determined by Walkley and Black method; Nitrogen was estimated by micro-Kjeldahl technique, after digestion with mixture ($CuSO_4$+K_2SO_4+H_2SO_4) using Gerhardt (Vap 10) distillation assembly, Germany; sulphur was measured by turbidoimetric method; using standard research methods of plant analysis by Narwal [12]. Trace metal Pb, Al, As and Cd were quantified by ICP-Inductive Coupled Plasma Spectrophotometer, Perkin Elmer, Optima 3300 RL at Sophisticated Instrumentation Center for Applied Research and Training, (SICART), Vallabh Vidya Nagar, Gujarat, India.

Results and Discussion

The wood density, calorific value, ash content, carbon, nitrogen and sulphur content of seven fuelwood species are represented in Table 1. The wood density and calorific value of the seven wood species ranges from 686 to 978 kg/m^3 and 19.7 to 23.4 MJ/kg, respectively. Bhatt and Tomar [13] described the average wood density and calorific value of several indigenous woody species of north east India in detail and obtained similar values, ranging from 638 to 983 kg/m^3 and 20.08 to 22.94 Mj/kg for wood density and calorific value, respectively. A higher wood density increases the calorific value and tends to slow the burning rate [14]. *A. nilotica* has the maximum wood density with highest calorific value, whereas *S. urens* shows the lowest wood density and calorific value. Figure 1 illustrates the calorific value plotted against wood density.

S. urens has the poorest ash content, followed by *C. fistula, B. monosperma, T. grandis, P. cineraria, A. leucophloea* and *A. nilotica.* The ash content is the remaining inorganic part of wood matter that cannot be combusted. 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 [15]. Lisardo *et al* [2] described the softwood species show a lower ash content than the hardwoods despite them possess higher calorific values. The difference in ash content is, however, statistically more significant than the difference in calorific values, which means that the wood with the highest calorific value is not necessarily the best option as fuelwood, especially if used, e.g., in a small scale boiler for heating purposes.

Table 1. Wood density, calorific Value, ash content, carbon, nitrogen and sulphur content of evaluated fuelwood species

Wood Species	Average wood density (kg/m3)	Average calorific value (Mj/kg)	Ash content (%)	Carbon (%)	Nitrogen (%)	Sulphur (%)
Acacia nilotica	978	23.40	2.8	46.6	0.39	0.143
A. leucophloea	967	22.51	2.7	44.4	0.43	0.092
Prosopis cineraria	942	21.93	2.5	43.4	0.38	0.140
Tectona grandis	889	21.68	2.2	41.2	0.41	0.099
Cassia fistula	847	20.64	1.6	39.8	0.37	0.087
Butea monosperma	789	20.49	1.8	38.6	0.40	0.159
Sterculia urens	686	19.70	1.4	37.8	0.47	0.163

Figure 2 shows that the calorific value increased, as expected, with the carbon content. *A. nilotica* has the highest carbon content as well as calorific value, whereas *S. urens* has the lowest carbon content and calorific values. *C. fistula* has the lowest nitrogen content, followed by *P. cineraria*, *A. nilotica*, *B. monosperma, T. grandis,* while sulphur content varied in different wood sample was found to be highest in *S. urens* followed by *B. monosperma, A. nilotica*, *P. cineraria, T. grandis, A. leucophloea* and *C. fistula* (Table 1). The higher the carbon, nitrogen and sulphur content, the more likely is the formation of carbon monoxide, carbon dioxide, nitrogen/sulphur oxides, nitric acid, sulphuric acid which have harmful impact on the environment. Wood after combustion releases water and carbon dioxide into the atmosphere.

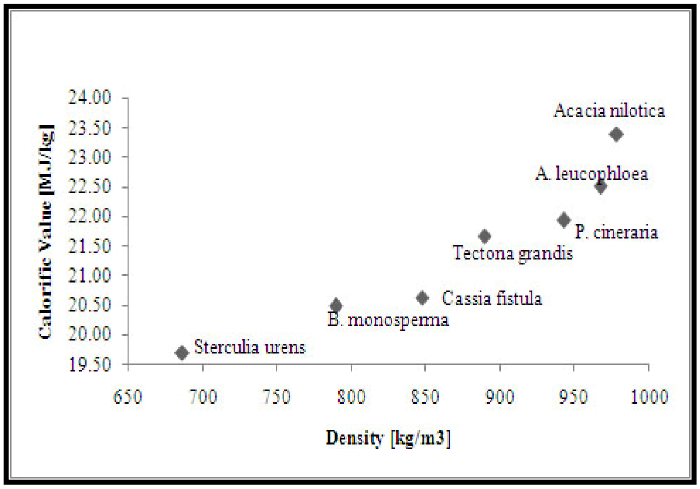

Figure 1. The calorific value as a function of wood density.

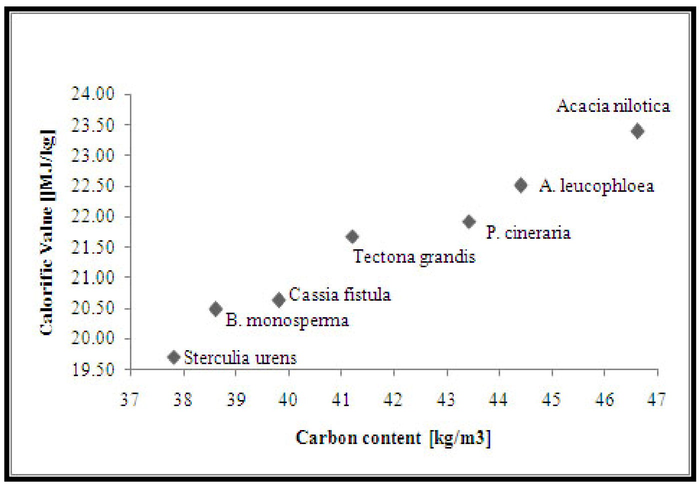

Figure 2. The calorific value as a function of carbon content.

Lyons *et al.* [16] stated that in practice, oxidation of wood is not always complete and small amounts of carbon monoxide, hydrocarbons and other gases, such as nitrogen/sulphur oxides and fumes are also released. Some of these are harmful to health, some to the environment and some to the atmosphere, commonly called greenhouse gases. Pollutants such as carbon monoxide (CO), sulphur dioxide, nitrogen dioxide (NO_2) and particulate matter are of significance because of the effect they have on the environment and human health. Nitrogen oxide gases are produced by combustion, both from nitrogen contained in the wood fuel and from oxidation of atmospheric oxygen at high temperatures and nitrogen is oxidized to various nitrogen oxides (NOx). When NOx and volatile organic compounds (VOCs) react in the presence of sunlight, they form a photochemical smog, which is a significant form of air pollution [17]. Nitrogen oxides also play an important role in the atmospheric reactions creating ozone and acidic rain by the formation of nitric acid. Exposure to nitrogen oxides increases the risk of respiratory infections as it is highly toxic and irritating to the respiratory system. In this study the chemical composition of the waste gas from wood combustion was not directly determined, but the nitrogen content of the wood samples, which is a good indicator of the amount of nitrogen-based toxic components that can be formed.

Apart from the nitrogen content, the amount of metals and other trace elements in the wood samples was determined. In trace amounts, some of the heavy metals such as iron, copper, magnesium and zinc are nutritionally essential for health but large amounts can cause poisoning. Elements like lead, aluminium, arsenic and cadmium are toxic to humans and the environment [18] and it can be seen that of the toxic metals, the greatest concentrations are given by lead and aluminium. Fig. 3 A shows the highest lead concentration can be found in *S. urens*, followed by *T. grandis, B. monosperma, C. fistula, A. leucophloea, P. cineraria* and *A. nilotica.* Lead can damage nervous connections and cause blood and brain disorders. It is considered to be particularly harmful for women's ability to reproduce. The distribution of the toxic metals for the different wood species showed that *S. urens* has by far the largest aluminium concentration, followed by *B. monosperma, T. grandis*, *P. cineraria*, *C. fistula, A. leucophloea* and *A. nilotica* (Fig. 3 A). The large aluminium and lead concentration in *S. urens*, with low poor carbon content suggested that they might have a rather negative impact on health and environment if they are used extensively as fuelwood. Aluminium is a neurotoxin that alters the function of the blood–brain barrier and it has been suggested that aluminium is a cause of Alzheimer's disease. It also has a large contributing factor to the loss of plant production on acid soils. The hardwood species on the other hand have a significantly lower content of aluminium and lead and therefore present a better choice of fuelwood [19].

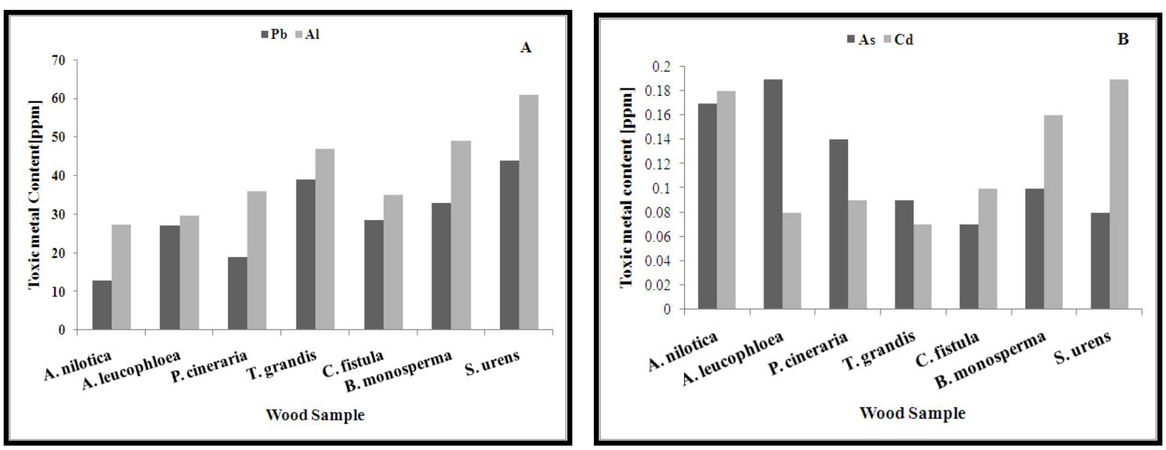

Figure 3. Concentration of toxic metal content in the wood sample. (A) Lead and Aluminium (B) Arsenic and Cadmium.

The highest arsenic concentration found in *A. leucophloea* followed by *A. nilotica, P. cineraria, B. monosperma, T. grandis, S. uren,*and *C. fistula* (Fig.3 B). Arsenic and arsenic compounds are carcinogens and are known to cause multiple system failure. It is still used as wood preservative in the form of chromate copper arsenate (CCA). Cadmium content varied in seven wood samples was found to be highest (0.19 ppm) in *S. urens* and lowest (0.07 ppm) in *T. grandis* (Fig.3 B). Cadmium may lead to pneumonitis, pulmonary edema and eventually death, if too high doses are inhaled. It is also a potential carcinogenic and an environmental hazard. Human exposure to environmental cadmium is primarily the result of the burning of fossil fuels and municipal wastes [19].

Table 2 summarizes the properties of all seven investigated wood species and a rating in terms of energy output and an elemental composition. For each property, the samples were assigned a value between 1 and 7, with 1 being the best and 7 being the worst. The final rating value was determined as the sum of all values divided by the number of measured ten properties [14]. Based on this final rating value, the preferred fuelwood species should be *A. nilotica* (3.20) followed by *C. fistula* (3.44), *A. leucophloea* (3.40), *P. cineraria* (3.40), *T. grandis* (3.90), *B. monosperma* (5.00) and *S. urens* (5.90).

The wood species investigated in this study are commonly used by the pulp and paper or the sawmilling industry and seldom as fuelwood. The main consumer of this wood can probably be found in the middle/upper class of (semi-) urban inhabitants, which use the wood either for recreational purposes or for heating purposes – both are a considerable market in India. The comparison of different wood species with regards to their physical properties could help to decide, which fuelwood constitutes the best choice in terms of energy output and environmental impact. Compared to other energy sources [20], wood combustion also has the lowest acid impact per unit of energy. When all contributions of the components involved in energy production are taken into consideration, wood combustion has the lowest greenhouse gas and acid precipitation impact per unit of heat delivered among the various energy options.

Table 2. Rating of the wood species with all determined properties. 1=best, 7=worst

Property	Species					
	Acacia nilotica	*Acacia leucophloea*	*Prosopis cineraria*	*Tectona grandis*	*Cassia fistula*	*Butea monosperma*	*Sterculia urens*
Wood density	1	2	3	4	5	6	7
Calorific value	1	2	3	4	5	6	7
Ash content	7	6	5	4	3	2	1
Carbon content	1	2	3	4	5	6	7
Nitrogen content	3	6	2	5	1	4	7
Sulphur content	5	2	4	3	1	6	7
Al content	1	2	4	5	3	6	7
As content	6	7	5	3	1	4	2
Cd content	6	2	3	1	4	5	7
Pb content	1	3	2	6	4	5	7
Rating	3.20	3.40	3.40	3.90	3.20	5.00	5.90

Conclusion

The results of this study accentuate that the calorific value should not be the only factor to be taken into account when evaluating fuelwood, but elemental composition and negative environmental impact should also be considered. While the calorific values of the investigated species differ from each other, when the other determined properties vary significantly. *C. fistula* is the preferred species with regards to low nitrogen and ash content, followed by *P. cineraria* which also have low nitrogen content. *S. urens* has low ash content, but the highest nitrogen and sulphur content of all investigated species. The two *Acacia* species also showed high nitrogen and ash contents. Taking the rather low calorific value of *S. urens* into account, *A. nilotica, C. fistula, A. leucophloea* and *P. cineraria* seems to be the best option for fuelwood. In terms of toxic metal content *S. urens* presents the best compromise. Although the two Acacia species shown the lowest aluminum and lead content, they have a fairly high cadmium and arsenic content, while *C. fistula* and *T. grandis* shown low concentrations of cadmium and arsenic. If all determined properties are taken into account, the preferred wood species should be, *A. nilotica* followed by *C. fistula, A. leucophloea*, *P. cineraria, T. grandis*, , *B. monosperma* and *S. urens* which would constitute a viable wood species to be specifically planted as fuelwood.

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