Assessment of the fuel wood of India: A case study based on fuel characteristics of some indigenous species of Arunachal Pradesh

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ABSTRACT
Biomass in the form of fuelwood has been a source of energy for many centuries all over the world. In rural India, fuelwood remains the first choice of energy source. Arunachal Pradesh is home to many different tree species; so far most of the fuelwoods of Arunachal Pradesh have never been studied for their fuel characteristics. This study is carried out with the following objectives: (i) Identification and selection of indigenous fuelwood species, which are widely distributed throughout Arunachal Pradesh, North East India; (ii) quantitative and qualitative analysis of these fuelwoods; and (iii) to rank these fuelwoods according to their fuel value index.

KEYWORDS
Biochemical; fuel value index; fuelwood; higher heating value; ultimate and proximate

1. Introduction
It is well known that there is a direct relation between a country's living standards and energy consumption. In general higher per capita energy consumption indicates a high living standard. However, increasing consumption of fossil fuels worldwide in the 20th century to meet energy demand, mostly by industrialized nations, suggests that the time is not too distant before depletion begins to adversely affect petroleum and natural gas reserves. This is expected to result in increased usage of alternative energy resources (Klass, 1998; Bhattacharya et al., 2003). The importance of biomass as a future energy supply requires the use of all available resources in a sustainable way without causing negative impacts. Biomass can be used for direct heating in industrial or domestic applications, in the production of steam for electricity generation, or for production of gaseous or liquid fuels.

In India, the demand for energy has increased tremendously in recent years because of its increasing population. The majority of the Indian population lives in rural areas where biomass in the form of fuelwood plays an important role in providing the energy requirement. The increasing population in rural areas has resulted in high fuelwood consumption leading to deforestation. Researchers have indicated that deforestation might have also resulted due to increasing industrial growth which needs new land and agricultural growth, resulting in the cutting of fuelwoods in large numbers. Continuous fuelwood usage is associated with the rapid environmental degradation and energy insecurity among low-income households. The cutting down of a large number of trees without a proper knowledge of fuelwood characteristics might result in an ecological imbalance in a particular region. Therefore, assessment of biomass in the form of fuelwood availability is essential, and determination of fuelwood characteristics is important in order to stop increasing deforestation and environmental disasters. The present study was undertaken to evaluate the characteristics of some indigenous fuelwood species of Arunachal Pradesh, a state in North East India. This study will also assist in identifying the most potential fuelwood among the different species investigated in this study, which might be used for energy plantation in this region.
2. Material and methods

2.1. Sample collection and sample preparation

Twenty fuelwood species, namely, *Castanopsis indica*, *Macaranga pustulata*, *Dysoxylum binecari-ferum*, *Bridelia retusa*, *Myrsine semiserrata*, *Celtis australis*, *Dysoxylum procerum*, *Terminalia myriocarpa*, *Syzygium cerasoids*, *Kydia calycyna*, *Mallotus phillipensis*, *Albizia odoratissima*, *Litsea polyantha*, *Momosops elengi*, *Bauhinia variegate*, *Prema integrifolia*, *Magnoli hodgsonii*, *Pterospermum acerifolium*, *Vitex altissima*, and *Schima wallichii*, which are found in large scale in the forest of Arunachal Pradesh, were selected on the basis of local people’s preference. On the basis of the diameter of the circumference of the branches, the authors selected the branches of tree species all in the age group of 5 to 10 years old, during the months of September and November 2010. The branches were 20 cm in length and 7–10 cm in diameter and were sealed immediately upon collection in an airtight polythene bag and brought to the laboratory within 24 h.

2.2. Fuelwood characterization

The moisture content was determined according to ASTM D4442-07. Density was determined as per ASTM-D2395-93, volume by mercury immersion method. Wood samples were ground separately in a mechanical grinder to pass through a 40-mesh sieve as per TAPPI standard method, T257 Om-85. Ash content was determined as per the TAPPI standard method, T211 om-85. Higher heating value (HHV) was determined using an auto bomb calorimeter (Changsha Kaiyuan Instruments Co., 5E-1AC/ML). An ~1 g oven-dried sample tablet was completely combusted in an adiabatic bomb containing 3.4 MPa of pure oxygen under pressure. The powdered wood samples were free from extractive as per the TAPPI standard method, T264 om-88. Volatile matter was determined by the method described in ASTM Test No. D-271-48, and the fixed carbon content was obtained by subtracting the sum of volatile matter and ash percentage from 100 as per ASTM Test No. D-271-48. Carbon, hydrogen, and nitrogen of the wood samples were determined by using an elemental analyzer (PE 2400 C, H, N analyzer, Perkin Elmer). Cellulose, hemicellulose, and lignin were determined by using the Fibertec I and M systems (Foss AB, Denmark) as described by Van Soest (1987). The Fuel Value Index (FVI) was calculated according to the method reported by Purohit and Nautiyal (1987).

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\text{FVI} = \frac{\text{Calorific value (MJ/kg)} \times \text{Density (g/cc)}}{\text{Ash content (g/g)} \times \text{Moisture content (g/g)}}.
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3. Results

3.1. Ultimate analysis

The results obtained for ultimate analysis in this study are presented in Table 1. From Table 1 it is clear that these biomass fuels contain a higher proportion of carbon compared with hydrogen and oxygen. The high carbon content indicates that the selected samples might have a high energy value. During combustion, nitrogen is converted to gaseous N\(_2\) and its oxides, which are harmful to the environment. Therefore, low nitrogen content in a biomass favors the importance of the species selected in the investigation. As can be seen from the table, all of the samples in the present case have a nitrogen content of <3% and it varies between 1.65% (*Vitex altissima*) to 2.90% (*Litsea polyantha, Terminalia myriocarpa*).

3.2. Proximate analysis

The results for proximate analysis are depicted in Table 1. A maximum ash content of 6.13% was obtained for *Bauhinia variegate* and minimum ash content of 0.70% was observed for *Dysoxylum procerum*. The value of fixed carbon obtained in the authors’ study varies from 05.42% (*Kydia*...
calcyna) to 16.60% (Momosops elengi). In the same study maximum volatile matter was observed for Kydia calcyna (83.40%) while the lowest volatile matter of 71.40% was observed for Momosops elengi.

3.3. Extractive analysis

In this study the alcohol benzene extractive contents were <7% and hot water extractives were <13% while the total extractive content is less than 16%. The findings of extractive analysis are presented in Table 2. These findings are in agreement with the literature (Rowe and Conner, 1979; Kataki and Konwer, 2001).

3.4. Biochemical analysis (lignin, hemicellulose, cellulose determination)

The results for the biochemical composition of the wood species are presented in Table 2. It could be seen from the table that the values obtained for lignin content in the authors’ study are in close agreement with the literature values (Rowell, 2005; Klyosov, 2007) and it varied in the range of 21.96% (Dysoxylum procerum) to 17.09% (Bauhinia variegate). On the other hand, the cellulose content varied between 32.54 (Bauhinia variegate) and 46.82 (Dysoxylum procerum), while the hemicellulose was observed to vary between 19.06 (Castanopsis indica) and 31.55 (Bauhinia variegate).

3.5. Density, gross calorific value (GCV), or HHV

The densities for the studied wood species are presented in Table 3. The density of the tree species was observed to be <1. Momosops elengi has the highest density of 0.82 g/cc and Litsea polyantha has the lowest density of 0.43 g/cc. Calorific value is the thermochemical property of fuel and is defined as the amount of heat available in a fuel (MJ/kg), including the energy contained in the water vapor in the exhaust gases. The HHV of the studied samples are depicted in Table 3. The HHV in the selected samples were observed to be <21 MJ/kg. The highest HHV was recorded for Dysoxylum procerum while Bauhinia variegate has the lowest HHV.
4. Discussion

The different parameters investigated in the previous section have a significant effect on the HHV of wood species, which in turn influences the FVI of the wood species. Both the chemical and the physical composition of the fuel are an important factor, which determines the amount of heat generated by a fuel.
The literature suggests that the heat content is related to the oxidation state of the natural fuels in which carbon atoms generally dominate and overshadow small variations of hydrogen content. It was observed that the wood species with the highest carbon content has the highest heating value and vice versa. The HHV of *Dysoxylum procerum* was \( \approx 20 \) MJ/kg and it has the highest carbon content of 47.44%. On the other hand, *Bauhinia variegata* has the lowest carbon content of 42.33% and its HHV is 16.83 MJ/kg. This linear relationship between HHV and carbon content of a fuel observed in this study is in agreement with those of Tillman (1978) who reported a similar observation. The linear relationship between HHV and carbon content of the wood species is depicted in Figure 1. Parameters investigated under proximate analysis are also observed to influence the HHV of the studied species. The high ash content and moisture content are reported to decrease the HHV of the fuel. In the current study the high ash content was observed for *Bauhinia variegata* while it was lowest in the case of *Litsea polyantha*. The decrease in HHV with high ash content is also reported elsewhere in the literature (Jenkins et al., 1998; Sheng and Azevedo, 2005). Moisture in biomass is stored in spaces within the dead cells and cell walls. Moisture percentage of the wood species generally is observed to vary between 41.27 to 70.20%. For the studied wood species this was observed to be varied between 36.78 to 51.84%. It is reported that moisture does not contribute to the HHV but reduces the heat available from the fuel in different ways such as by lowering the initial gross calorific value. The combustion efficiency of the fuel is also reduced since heat is absorbed in the evaporation of water in the initial stages of combustion. Hence, for *Bauhinia variegata*, the high ash content and moisture content results into low HHV of about 16.83 MJ/kg. Sheng and Azevedo (2005) reported that no direct relation exists between the HHV and the volatile matter despite observing a trend, and no correlation was observed between HHV and fixed carbon. However, according to Demirbas (2004), HHV of fuels increases with increasing fixed carbon content. In another study reported by Gominho et al. (2012) it was observed that content in volatile is inversely proportional to the content in fixed carbon, which was also observed in the authors’ study. According to the literature, extractive content is an important parameter directly affecting the heating value and high extractive content of a plant part makes it desirable as fuel. In general, a high amount of extractives indicates high HHV of the fuelwood. The wood extractives contain about twice the energy of cellulose or hemicelluloses, which is around 35 MJ/kg; therefore, the extractive content is an important parameter in the context of HHV of a fuelwood (White, 1987; Demirbas, 2003; Vargas-Moreno et al., 2012). Wood extractive compositions vary with different fuelwood species. White (1987) and Demirbas (2007)
reported that HHV of the wood species increases with extractive content. However, it is reported that its effect on HHV was not directly related (Senelwa and Sim, 1999). Rather it was observed that the highest contribution to the HHV comes from the resinous fraction of the total extractive content (White, 1987).

In this study the extractive content was highest for *Terminalia myriocarpa* and lowest for *Schima wallichii*. This indicates that, apart from extractive contents, the contribution from other factors also plays an important role in final HHV of the fuelwood, which is in accordance with the literature. Therefore, the high HHV of *Dysoxylum procerum* despite having less extractive content is attributed to the probable presence of a high amount of resinous fraction in extractive, which has the highest contribution on HHV among the other extractive constituents. The other most important factor affecting the HHV of the fuel is its biochemical constituents, which were comprised of cellulose, hemicelluloses, and lignin. Researchers have reported that there is no direct relationship between HHV and the holocellulose of the biopolymeric fuels; rather it is directly related to lignin. In general, the HHVs of lignocellulosic fuels increase with an increase of their lignin contents. The high HHV due to the presence of high lignin content is because of the fact that the lignin has a HHV from 23.26 to 26.58 MJ/kg (White, 1987; Vargas-Moreno et al., 2012). In addition, lignin is richer in carbon and hydrogen, which are the main heat-producing elements. In the authors’ study *Dysoxylum procerum* has the highest lignin content of 21.96% and it has the highest HHV of 20.09 MJ/kg, while *Bauhinia variegata* (HHV = 16.83 MJ/Kg) has the lowest lignin content of 17.09%. The linear relationship between HHV and lignin of the studied wood species are depicted in Figure 2. Montes et al. (2011) reported that there is no direct relation between HHV and density. However, wood with high density and high ash content could result in low HHV. This is inconsistent with the current study. It could be seen from Table 3 that the density among the selected species was observed to vary within 0.43–0.82 g/cc. It was observed that *Dysoxylum procerum* has a low density as well as lowest ash content, which ultimately contributed to its high HHV.

5. Fuel Value Index (FVI)

FVI is the most commonly used parameter to compare the different fuelwoods. In the present investigation, the most preferred species according to the FVI is *Dysoxylum procerum* while *Bauhinia variegata* scored poorly on the FVI (Table 3).
6. Conclusion

In Arunachal Pradesh, people have traditionally been relying on fuelwood as a primary source of energy, which in turn is responsible for rapid deforestation in the state. To avert this situation it is highly necessary to establish a large-scale energy plantation on unused, degraded lands and forest lands. However, while selecting the tree species for energy plantation special attention should be given to the indigenous tree species, which are traditionally preferred for fuel by the local rural people. Fuel value index (FVI) is an important parameter for screening desirable fuelwood species. On the basis of FVI and other physicochemical characteristics studied, it can be concluded that firewood species, such as Dysoxylum procerum, Dysoxylum binectariferum, Macarange pustulata, Litsea polyantha, Momosops elengi, Schima wallichii, and Vitex altissima possess better fuelwood qualities and could be selected for further plantation in this region.

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