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ORIGINAL ARTICLE **LIFE SCIENCE**

SELECTION OF FUELWOOD TREE SPECIES USING FUEL VALUE INDEX IN JHENAIDAH DISTRICT

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Abstract
Four tree species *Acacia nilotica, Samanea saman, Leucaena leucocephala, Tamarindus indica* were collected from different wood vendors of Jhenidah district in Bangladesh to identify the potential fuelwood tree species through fuelwood properties. The calorific value and density of the wood considered as positive characteristics and high moisture and ash content as negative characteristics that helped develop a fuelwood value index (FVI). A 8×2×2 cm^3 of three wood blocks were collected from each tree species in order to determine the fuelwood properties. The highest calorific value and wood density were found in *Acacia nilotica* and *Tamarindus indica* respectively but the ash content was found to be lowest in *Leocoena leucocephala* (1.09%) and highest in *Tamarindus indica* (2.21%). Moreover, the lignin content was the highest in the *Acacia nilotica.* According to FVI, the better quality of fuelwood species in descending order are *Acacia nilotica*> *Leucaena leucocephala*>*Tamarindus indica* >*Samanea saman.* This study also revealed the significant negative correlation between FVI and ash content.

Keywords: Fuelwood, Ash content, Fuel value index, Wood properties

Introduction

According to Arnold and Jongma (1977) fuelwood is considered to be the main source of energy in rural and urban areas of many developing nations such as Africa, extending its use from household to industrial activities. Food and Agricultural Organization (FAO) (2011) reported that the fuel wood percentage of the total wood production for both developing and developed countries where it is 84.2% in case of developing and is 12.3% for developed countries.

Since 1950, fuelwood was regarded as a free commodity particularly in the rural areas of Bangladesh. Different sources like biomass, natural gas, electricity, coal, kerosene, diesel/gas oil and others met the energy requirement of the country. Conventional fuels, such as wood and agricultural residues like paddy husk, straw, jute stick, leaves, cowdung, bran, baggasse and charcoal are widely

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used particularly in the rural area for domestic consumption. But, one report depicts from Forestry Master Plan (FMP) (1993) which is only 13%, of the entire biomass energy consumption in the country comes from fuel wood. (FMP) (1993) also stated that overall, tree and bamboo (48%), agricultural residues (36%), dung (13%) and peat deposits (3%) fulfill the domestic energy demands. In recent times, natural forests as well as the village groves are being over exploited and as a result the fuelwood shortage is severe throughout the country. This has made the fuelwood a marketable product. According to Forestry Master Plan (FMP) (1993) in Bangladesh, fuelwood consumption is lower than any other countries in the world (0.43 m^3/ per capita). FMP estimation of fuelwood demand and supply from 1993 to 2013 portrays that fuelwood deficit is nearly one-third of the overall fuel demands of 2003-2013 which is disappointing. The shortage is likely to be massive in case of the country's failure to protect its forest covers and inadequacy to promote fuelwood plantation all over the country. Therefore, establishing energy plantation on degraded and unoccupied premises is necessary in order to avert this situation. Moreover, in this situation Jungerius (1985) said that indigenous knowledge should be taken under consideration for identifying the tree species because of their intimate knowledge of the local tree species and environment. Fuelwoods are selling according to the preference of the local people.

The choice of fuelwood is generally considered by the availability, the burning duration, the maximum temperature and the ash content (Núñez-Regueira *et al*., 2003). For this reason, people are using hardwoods to fulfill their basic needs of fuelwood that is, in turn responsible for the rapid deforestation of the country.

According to Kataki and Konwer (2001) the physical properties, such as moisture content, chemical composition and wood density are affecting the performance of fuelwood species. For example, increased moisture content in the wood decreases the amount of heat obtained, because more energy is used for evaporating water. Senelwa and Sims (1999) stated that for this reasons combustion efficiency becomes low. So, it is very urgent to evaporate the water present in wood to increase the heating value. Sometimes, moisture of the wood creates the negative effect on its calorific value (Junge, 1980). Structurally, cellulose, hemicelluloses and lignin are the main components of wood cell walls. Moreover, Nasser and Aref (2014) reported that species type and position of wood plays an important role to determine the chemical composition of the wood. According to Fengel and Wengener (2011) wood also consists of small amount of extractives that affect the characteristics of wood and wood products. After hand, Wang *et al*., (1982); Fuwape, (1990); Kataki and Konwar, (2002) stated that these extractives vary greatly in their quantity and chemical characteristics. So according to Wang *et al.,* (1982) to determine the suitability of a species to be considered as fuelwood; extractive, cellulose, hemicelluloses and lignin components are important criteria.

Earlier, fuelwood potentiality was determined either by calorific value or wood density which alone does not reveal the actual preferences of wood for combustion. Therefore, Fuel value index (FVI) was introduced for ranking fuelwood species (Deka *et al*., 2007). This index considers ash content, moisture content, wood density and calorific value of a wood collectively Goel and Behl, (1996); Bhatt and Todaria, (1990); Abbot *et al*., (1997). Recently, FVI value of six mangrove species in Bangladesh has been reported by Islam *et al*., (2019) and Miah and Islam (2020) demonstrated the local preferences of firewood for domestic use with the physical characteristics of firewood species using FVI but there have no data on FVI value with wood physicochemical properties in Bangladesh.

Research work done so far, focuses on the silvicultural aspects and environmental influences the four mentioned tree species in Bangladesh. But till date, no evidential information is found regarding fuel properties and chemical composition of the referred species. Thus, in this study, an attempt has been made to evaluate the fuelwood potentials of these four species for the first time in Bangladesh context and to investigate the relationship between the fuel value index, (FVI) with physiochemical properties of wood, such as, wood density, mc, cellulose, hemicelluloses, lignin, extractives and ash content.

Materials and Methods

Sample collection: Four tree species were selected according to their local use as fuelwood from wood vendors in Jhenaidah district. The species were *Acacia nilotica, Samanea saman, Leucaena leucocephala* and *Tamarindus indica*. Randomly, three logs of each species were sampled among the four species from the wood vendors and 45 cm^3 long and 10-18 cm^3 in diameter were cut from the logs and put into a bag for further conversion in sawmill.

Sample preparation: The logs were converted into 8×2×2 cm^3 wood block for the determination of moisture content, wood density and also into some wood powder for the determination of ash content, calorific value, extractive, cellulose, hemicelluloses and lignin content of the selected wood species. Then the collected samples were transferred to the laboratory for various experiments.

Determination of Moisture content percentage (MC%): The green moisture content of a sample is the trees moisture content that was extracted from a log. The wood blocks taken from log were weighed and dried at 103°C for 24h according to the ASTM-D-4442-16 standard (ASTM) (2016). After that, the wood blocks were weighed again to obtain the dry weight. After that, the moisture content was determined by the following equation-

$$\text{MC}\,\% = \frac{(\text{Green Weight - Oven Dry Weight})}{\text{Oven Dry Weight}} \times 100 \qquad (1)$$

Determination of wood density: According to Chave (2005) the density of a wood is a variable which tells how much carbon the plant uses for their constructing purpose. Wood density varies within the plants. The wood blocks taken from the log were weighed and volumes were estimated according to the ASTM D-143-94 standard (ASTM) (1997). The volume was determined by taking the measurement of the length, wide and height of the wood blocks with the help of slide calipers. After that the density was determined by the following equation-

$$\text{Wood Density (g/cm}^3) = \frac{\text{Oven dry weight}}{\text{Oven dry volume}} \qquad (2)$$

Determination of calorific value: The calorific value was determined on a dry weight basis. Around 1g of oven dry wood powder of per sample was tested by oxygen bomb calorimeter and was estimated using the Dulong's formula from the Laboratory of Mechanical Engineering Department of Khulna University of Engineering and technology (KUET), Bangladesh.

Determination of Extractives, Cellulose, Hemicellulose and Lignin content: Cellulose, hemicellulose and lignin in lingo-cellulosic contents of the biomass samples were calculated as stated in an experimental method reported elsewhere (Mitu *et al*., 2019). In brief, solvent extraction carried out extractives determination experiments (100ml acetone for 1g of dried biomass sample) at 60°C. The biomass sample was dried at 110°C until a constant weight was obtained. After that, the solid residue was cooled in a drier until it reached room temperature and was weighted. Amount of extractives is the weight difference before and after of the extraction. To determine the hemicellulose content, 0.5g of dry biomass sample without the extractives was added in a 150 mL NaOH solution

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(20 g/L) and was boiled with recycled distilled water for 3.5 hours. The residue then went through filtration and was washed in order to remove Na^+. After that, the remaining residue was respectively dried and weighted. The amount of hemicellulose is the difference of the weight before and after the treatment. Lignin determination is carried out by Klason method. In this method, 15 ml of H_2SO_4 (71%) was added to 0.5 g of extractive-less sample of dried biomass. The mixture was then heated and stirred for 2h. This mixture then was diluted to H_2SO_4 (4% concentration) and resulting remains were boiled with the recycled water for 4 hours. After that, the obtained residues were respectively filtered, washed and dried. Lignin is determined by the weight difference before and after this treatment. Lastly, cellulose was measured by calculating the weight difference from lignin, hemicellulose and extractives.

Determination of Ash content percentage: At first, in the laboratory, an appropriate number of small pots were taken, marked using a graphite marker and weighted. Then 1g oven dry weight was taken, ODW wood powder of per sample. After that, they were placed in the muffle furnace at 450°C for four hours according to ASTM standard Method Number E1755-01 (ASTM) (2007). Then, the pots were removed from the furnace and put them into a drier and weighted them. After that, the ash content percentage was determined by following formula-

$$\text{Ash content \%} = \frac{\text{Weight}_{\text{pot plus ash}} - \text{Weight}_{\text{only pot}}}{\text{ODW}_{\text{sample}}} \times 100 \quad (3)$$

Determination of Fuel Value Index, FVI: The fuelwood value index (FVI) was calculated by following method (Purohit and Nautival 1987) –

$$\text{FVI} = \frac{\text{Calorific value}(\text{MJ/kg}) \times \text{Wood Density}(\text{g/cm}^3)}{\text{Ash content}(\text{g/g}) \times \text{Moisture content}(\text{g/g})} \quad (4)$$

Results and discussions

Extractives, Cellulose, Hemicellulose and Lignin content of the species: In the present study, Table1 presents the extractive, cellulose, hemicelluloses and lignin content of the four species. It was demonstrated by Nasser *et al.,* (2014) that, statistically, all of the extractive, cellulose, hemicelluloses and lignin content shows significant differences from each other among the species. In present study, it can be clearly seen that, the selected four different species presented different values in their extractive, cellulose, hemicellulose and lignin content (Table 1). Here, higher extractives content of four tree species was in order of *Leucaena leucocephala* (5.05%) >*Samanea saman* (5.00%)>*Acacia nilotica* (3.34%)>*Tamarindus indica* (1.34%). Cellulose content of four tree species of present studied was in order of *Leucaena leucocephala* (48.45) >*Acacia nilotica* (47.27) > *Tamarindus indica* (41.42) >*Samanea saman* (41.6). Hemicellulose content of four tree species of present studied was in order of *Samanea saman (*29.0)>*Acacia nilotica* (24.9)> *Tamarindus indica* (20) >*Leucaenaleucocephala* (19.35). Lignin content of four tree species of present studied was in order of *Tamarindus indica* (37.25) > *Acacia nilotica* (28.1)>*Leucaena leucocephala* (27.15)>*Samanea saman* (24.5). Fengel and Wengener (2011) stated that, generally, the extractives, cellulose, hemicelluloses and lignin content range from 2- 6%, 45-50%, 15-35% and 23-30 in tree species respectively. But in present study, the extractive, cellulose, hemicelluloses and lignin content of the samples ranged from 1.34-5.05%, 41.6-48.45%, 19.35-29% and 24.5-37.25% respectively. It can be seen that, the *Tamarindus indica* had higher lignin content than normal range of wood species.

Table 1. Extractives, cellulose, hemicellulose and lignin content of the four species

Species	Wood Component %			
	Extractives(%)	Cellulose(%)	Hemicellulose(%)	Lignin(%)
Leucaena leucocephala	5.05	48.45	19.35	27.15
Acacia nilotica	3.34	47.27	24.90	28.10
Samania saman	5.00	41.60	29.00	24.50
Tamarindus indica	1.34	41.42	20.00	37.25

Ash content: For determining fuelwood quality, one of the negative factors is indicated by the highest ash percentage value (Meetei *et al.,* 2014). In general, Panshin and Zeeuw (1980) found that the ash content is usually between 0.1%- 0.5% for the tree species. However, Chow and Lucas (1988) mentioned that wood species in the tropical zone require more mineral components than others for their growth and this may be the logical explanation of the higher value obtained here. Devi *et al.*, (2013) reported that the wood of *Leucaena leucocephala* burns steadily with little smoke, few sparks and produces less than 1% ash . Another study by Puri *et al.*, (1994) reported the ash content of *Acacia nilotica* was 2.1%. Whereas, the ash content of *Tamarindus indica* and *Samanea saman* were found was 2.13% and according to Kumar (2003) 1.56% in heartwood.

Table 2. Fuelwood characteristics of four tree species in Bangladesh

Species	Moisture Content %	Density (g/cm^3)	Ash content %	Calorific value (kJ/g)	FVI
Leucaena leucocephala	57.45	0.65	1.09	19.17	1998.51
Acacia nilotica	48.88	0.75	1.12	19.18	2623.97
Samania saman	47.74	0.63	1.99	17.04	1124.35
Tamarindus indica	40.05	0.82	2.21	16.34	1513.62

In the present study, Table 2 shows that, of all the four selected tree species, exhibited lowest ash content in order to *Leucaena leucocephala* (1.09%)> *Acacia nilotica* (1.12%)>*Samanea saman* (1.99%)> *Tamarindus indica* (2.21%).Thus, higher amount of minerals are absorbed from the soil and are stored into the cell cavities and cell walls in these trees. That's why, they exhibits more ash content percentages than normal range of ash content percentages. But Kataki and Konwer (2001) mentioned that the bark of tree produce higher amount of ash forming materials and relatively lower heating content. So, heating values can be increased by removing the ash contents from the plant parts. Generally, ash content can be considered as an undesirable component and therefore, it is needed to be managed during direct wood combustion (Chow and Lucas, 1988). FAO (1985) revealed that, about 3% of ash content can be found in high quality lump charcoal. Usually, when a species produces a great amount of ash content, it is preferred less (Cardoso 2015). Meetei *et al.*, (2014) found that, in the tree component of 5 distinctive oak tree species, ash percentage demonstrated considerable difference in the biomass components of wood and bark. Ash percentage of the 5 oak species was not only correlated negatively but was also significant with calorific values ($p<0.01$).

Moisture content: According to Abbot *et al.,*(1999) and Bhatt and Tomar (2002) the moisture in wood depends on the seasonal variation, state of the wood and many other factors. Available heat for combustion decreases if the moisture content is high. Kumar (2003) revealed that the moisture content of *Tamarindus indica* was 41.2% and *Samanea saman* was 57.25 in heartwood.

Table 2 showed that, among the four studies tree species, moisture content was highest in *Leucaena leucocephala* (57.45%) followed by *Acacia nilotica* (48.88%), *Samanea saman* (47.74%) and lowest moisture content was observed in *Tamarindus indica* (40.05%). In this study, *Tamarindus indica* has shown high density wood with low MC%.

Wood Density: Another important factor for estimating the quality of a fuelwood is the density of tree species. Kataki and Konwer (2002) and Khoo *et al.,* (1982) said that, due to slow burning rates as well as the high content of energy in per unit of volume, denser species are likely to demonstrate better fuel quality. Moreover, wood density determines a positive factor in fuelwood quality as it has more heating durability. From a study of Meetei *et al.,* (2014), a consequential positive correlation ($p<0.05$) was found between wood density of the 5 oak species and calorific values of the wood samples. High wood density is likely to be subjected to higher lignifications, presence of the lignin and other denser fractions. Another possible explanation given by Kumar (2006) is that complex wood ultrastructure is capable of reiterating a strong linkage between the physical properties of the wood and the chemical substances. Therefore, Cunningham (2001) mentioned that, wood density is one of the most significant factors as it not only identifies the suitable wood for burning but it also gives the wood additional use value. In this study, the highest wood density in g/cm^3 was found for *Tamarindus indica* (0.820)>*Acacia nilotica* (0.749)>*Leucaena leucocephala* (0.653)>*Samanea saman* (0.627). Lowest wood density was noticed in *Samania saman* (0.627).

Calorific value: Calorific values depend on many attributes such as the development type, growth or aging of the different species, seasonal variations and many other factors according to Klasnja *et al.,* (2010). Cardoso *et al*., (2015) reported that, these values coexist with the standard average values of species that maintains other related combustion qualities. The combustion heat of wood is depended mainly on the genetic characteristics of the species and chemical composition of the wood. The species containing a high amount of volatile matter, resin, wax and lignin in general has greater energy content stated by Jain and Singh (1999). From Kataki and Konwer (2001) and Demirbas and Demirbas (2009), it is assumed that calorific values are high when the extractives concentrations as well as lignin contents in wood are high. Along with this, Moya and Tenorio (2013) added that, higher dichloromethane extractives endorse higher calorific values in a tree species. In the present study, all the four selected tree species, exhibited highest calorific values in order of *Acacia nilotica* (19.179 kJ/g)>*Leucaena leucocephala* (19.165 kJ/g)>*Samanea saman* (17.036 kJ/g)> *Tamarindus indica* (16.338 kJ/g).

Ranking based on FVI: For screening desirable fuelwood species, Purohit and Nautiyal (1987) and Jain (1993) emphasized on FVI as it considers major fuel properties that described in Eq. 4. FVI of four tree species of present study was in order of *Acacia nilotica* (2623.97) > *Leucaena leucocephala* (1998.51) >*Tamarindus indica* (1513.62) >*Samanea saman* (1124.35). Among the four observed species, the highest FVI was noticed for *Acacia nilotica* (2623.97) due to higher calorific value in comparison with the other species. So, *Acacia nilotica* (2623.97) is likely to be considered as the best one in terms of being a fuelwood species followed by *Leucaena leucocephala* >*Tamarindus indica* >*Samanea saman* in Jhenaidah district.

Relationship between FVI and Physiochemical properties: Table 3 showed that, cellulose, hemicelluloses, lignin, extractives, wood density, moisture content has no significant effect on FVI. Only ash content showed a highly significant effect on FVI with a negative coefficient ($r= -0.78$). That means, if the value of ash content increases, the value of FVI will decrease. Here, two tailed test of significance is used. In most of the industrial activities, ash is regarded as an undesirable component. The increase of biomass utilization as a fuel may cause an ash disposal problems because it will accumulate in furnaces. This result is in agreement with Nasser *et al.,* (2014). Because, the result of Nasser *et al*., (2014) also showed a highly negative significant effect with heating value ($r= -0.93$).

In present study, species with high ash percentage such as, *Tamarindus indica, Samanea saman* yielded lower heat values than others. Bhatt and Todaria (1990) and Kataki and Konwer (2001) also reported the decreasing heat of combustion with increasing ash percentage in their study.

Table 3. Relation with FVI and other calculated properties

Properties	Pearson correlation coefficient	Significance status*
Cellulose	0.52745	0.17915
Hemicellulose	-0.17436	0.67964
Lignin	-0.02729	0.94886
Extractives	-0.0125	0.97656
Density	-0.06062	0.88661
Moisture content,%	0.16632	0.69386
Ash content,%	-0.78266	0.02166

*at 5% level of significance.

Conclusion

The findings from this study emphasize that, evaluating fuel wood should not solely be subjected to the calorific value, but other factors such as extractive, cellulose, hemicellulose, lignin, ash content and wood density must also be taken into account. Calorific values of the investigated species differ from each other. *Leucaena leucocephala* is the preferred species with regards to low ash content and high extractive and cellulose. In terms of calorific value *Acacia nilotica* seems to be the best option for fuelwood but *Leucaena leucocephala* also have higher calorific value and that is very near to *Acacia nilotica.* Although, the other two species *Tamarindus indica* and *Samanea saman* shown the lowest calorific value, ash content and extractive, but they have a high density and lignin content than other species. On the other hand the *Samanea saman* has exhibited the lowest density, cellulose and lignin content but they have relatively more extractive content than *Acacia nilotica and Tamarindus indica.* Considering the FVI value, in the present study, the preferred wood species are *Acacia nilotica* followed by *Leucaena. leucocephala, Tamarindus indica and Samanea saman.* This study also revealed the highly negative significant correlation between FVI and ash content.

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