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**Title:** A study on ranking of some woody species of southern region in Bangladesh based on Fuel Value Index (FVI)

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**Programme:** Bachelor of Science in Forestry

# A study on Ranking of Some Woody Species of Southern region in Bangladesh Based on Fuel Value Index (FVI).

**Course Title: Project Thesis**

**Course No: FWT-4114**

Project Thesis has been submitted to Forestry and Wood Technology Discipline, Life Science School, Khulna University, Khulna, Bangladesh, for the practical fulfillment of the requirements for the Degree of Bachelor of Science (Hons.) in Forestry and Wood Technology.


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# DECLARATION

I hereby, declare that this project thesis is based on my original work except for quotation and citations which have been duly acknowledged. I also declare that it has not been previously submitted for any other degree at Khulna University or other institutions.


……………………………………
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*Dedicated to*

*My*

*Beloved Parents*

*And Elder Brother*

# APPROVAL

Project Thesis submitted to the Forestry and Wood Technology Discipline, Life Science School, Khulna University, Khulna, Bangladesh, for the partial fulfillment of the requirements for the 4-year professional B.Sc. (Hons.) in Forestry and Wood Technology. I have approved the style and format of the project thesis.

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**Sumona Yeasmin Papri**

# ABSTRACT

Biomass in the form of fuelwood has been a source of energy for many centuries all over the world. Fuelwood meets most of the energy requirements in rural Bangladesh. For this reason selection and identification of better fuelwood is very important in rural areas of Bangladesh. This study therefore aims to identify four fuelwood species commonly used by the communities of southern part of Bangladesh and examine their Fuel Value Index (FVI) from basic properties, namely; moisture content, density, calorific value and ash content. Specifically, four tree species were collected from different wood vendors of Bagerhat district in Bangladesh. These four tree species were *Swietenia macrophylla, Artocarpus heterophyllus, Azadirachta indica* and *Aegle marmelos.* The Fuel Value Index (FVI) was calculated by taking into account the calorific value and density of the wood as positive characteristics, and high moisture content and high ash content as negative characteristics. The ranges of calorific value of this four species varies 16.009 KJ/g to 16.698 KJ/g. Percentage of ash on dry weight basis was found lowest in *Artocarpus heterophyllus* (0.40) and highest in *Azadirachta indica* (1.50). Ash content of tree component gives a significant factor in determining Fuel Value Index (FVI). This study results *Swietenia macrophylla* (2851.46) contains high FVI and *Azadirachta indica* (1584.09) contains lowest FVI. According to Fuel Value Index (FVI), this tree regarded as the best quality fuelwood species followed by *Swietenia macrophylla* > *Aegle marmelos* > *Artocarpus heterophyllus* > *Azadirachta indica.*

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# Introduction

## 1.1 Background and Rationale

Fuel wood is the largest energy source for the three-quarters of the world's population who live in developing countries (Scurlock and Hall, 1990). The demand for fuel wood is likely to continue as the most important energy source for rural areas of many countries in the world. As Bangladesh is a developing country the demand of fuel wood increasing day by day. In case of developed countries they mainly use non forest fuel energy in comparison with developing countries.

An estimate shows that wood fuels contribute 84.2% of total round wood production in the developing countries and 12.3% in the developed country (FAO, 1977). Fuel wood is a dominant domestic fuel in both rural and urban areas of the developing countries. About one half of the wood fuel is used for cooking, about one third for heating the house, boiling water, etc. and the remainder for other domestic purpose

In Bangladesh, the requirement of energy is met from different sources, such as biomass, natural gas, electricity, kerosene, diesel, gas oil, coal and others. In our country, the people of rural areas depend on traditional fuels mainly wood, agricultural residues (paddy husk, bran, straw, bagasse, jute sticks), twigs, leaves and cow dung for their domestic purpose or consumption. Fuel wood contributes 13%, within the whole biomass energy consumption in the country (FMP, 1993). Overall, tree and bamboo provide 48% of the current domestic energy requirement; agricultural residues 36%, dung 13% and 3% are supplied from peat deposits (FMP, 1993).

The majority of the Bangladeshi population lives in rural areas where biomass in the form of fuel wood plays an important role in providing the energy requirement. In earlier, fuel wood was a free product in the rural areas of Bangladesh but the demand for energy has been increased tremendously in recent years due to its increasing population and which has made the fuel wood as market commodity at present time. Nowadays, shortage of fuel wood is severe throughout the country due to overexploitation of natural resources which results in inequality of demand and supply of fuel wood. Forestry Master Plan (FMP, 1993) of Bangladesh states that per capita fuel wood consumption in Bangladesh is lowest (0:043m$^3$) in the world. The projection of fuel wood demand and supply for the years 1993-2013 by the FMP shows a disappointing figure of the fuel wood deficit as almost one-third of the total demand from 2003-2013. This shortage will be severe if the country fails to protect the forest cover and develop the fuel wood plantation throughout the country. To avoid this situation, it is essential to establish energy plantation on degraded and barren lands throughout the country. However, while selecting the tree species for energy plantation, special attention should be given to the indigenous species, which have traditionally been preferred for fuel by the local people. Moreover, local people's choice should be considered for identifying the tree species as they have an intimate knowledge of local environment and the local tree species (Jungerius, 1995).

The choice of fuel wood is generally considered by the availability, the burning duration, the maximum temperature and the ash content (Lisardo N R, Rodriguez A J, Proupin J, Romero G A, 2003). Generally, we prefer hardwoods because of their last linger coals, yield more heat and emits less smoke (Shackleton C M, 2001).

The physical properties which mainly affecting the performance of fuel wood species are moisture content, chemical composition and wood density (Kataki R, Konwer D, 2001). 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 (Senelwa K, Sims R E H, 1999). So, removal of moisture content from wood is very important to determine the total amount of heat. Sometimes, moisture of the wood has been created the negative effect on its calorific value (Junge D C, 1980).

Fuel Value Index (FVI) is an important factor for ranking fuel wood species (Deka D, Saikia P and Konwer D, 2007). FVI, which depends upon calorific value, density, moisture and ash content of wood, is an important parameter for screening desirable fuelwood species (Goel and Beha, 1996; Bhatt and Todaria, 1997; Abbot et al., 1997). Most of the research work done on these four species in Bangladesh has dealt with silvicultural aspects and environmental influences. No information is available on the fuel properties of these species.

Therefore, this study was undertaken to evaluate the fuel wood characteristics of these four species and to investigate the relationship between fuel value index with density, moisture content and ash content.

**1.2 Objectives:**

The main objective of the study is-

1. To determine the best fuelwood species among the four selected species based on Fuel Value Index (FVI).

# Literature Review

## 2.1 Literature Review

Wood is the most important fuel used by humans for thousands of years. Still, it is a major source of energy in both developed and developing countries (Erakhrumen, 2009). Fuelwood constitutes an important source of energy in Bangladesh, supplying almost all of the cooking energy requirements. Nowadays Fuelwood shortage is a severe problem at the national and global levels. Numerous tree species need to be evaluated for their potential to overcome this shortage (Gayer et al., 2008).

Ten indigenous fuelwood species of northeast India was ranked by (Deka et al., 2007).They were ranked by pairwise comparison, a technique used by rural people for selection of fuelwood, and also from their fuel value indexes calculated by using three different formulae. It was found that the ranks of the species obtained from fuel value indexes calculated according to the formula reported by (Goel and Behl, 1996 and Abbot et al., 1992) have sufficient resemblance with those obtained by pair-wise comparison.

A study on fuelwood in Costa Rica. The aim of this study was to investigate the fuel characteristics (calorific value and fuel value index) of 10 fast-growing species in plantations in Costa Rica. The effect of the chemical properties, extractives and moisture content were evaluated. No consistency was observed with regard to which type of wood (sapwood or heartwood) had the highest gross calorific value. Large variations among the species were observed in the case of the fuel value index. For heartwood, the slope gradient of linear correlation was affected by lignin and extractives in sodium hydroxide and dichloromethane solution, whereas in the case of sapwood, only ashes content affected significantly to calorific value. Finally, the fuel value index was affected by the quantity of carbon, the extractives in sodium hydroxide and dichloromethane (Moya et al., 2013).

A study was carried out in India by (Meetei et al., 2014) on five indigenous oak tree species, which were *Castanopsis indica* (Roxb. ex Lindl.) A. D. C., *Lithocarpus fenestratus* (Roxb.)Rehder, *Lithocarpus pachyphyllus* (Kurz)Rehder, *Lithocarpus polystachyus* (Wall. Ex. A. D. C.) Rehder and *Quercus serrata* Murray were estimated for their wood properties such as calorific value, density, moisture content and ash content from a sub-tropical forest of Haraothel hill, Senapati District, Manipur. Wood biomass components were found to have higher calorific value (kJ g (-)) than bark components. The calorific values for tree species were found highest in L. pachyphyllus followed by C. indica L. fenestratus, L. polystachyus and Q. serrata. Calorific values for bole bark, bole wood and branch bark were found significantly different in five oak tree species. Percentage of ash on dry weight basis was found to be highest in Q. serrata and lowest in C. indica. Ash content of tree components gives a singnificant factor in determining fuelwood value index (FVI). Of all the five oak tree species, Q. serrata exhibited highest value of wood density and lowest was observed in C. indica. There was significant correlation between wood densities, ash content with calorific value in oak tree species. Fuelwood value index (FVI) was in the following order: C. indica, pachyphyllus L. polystachyus. fenestratus Q. serrata. Thus, the present study suggests that C. indica may be considered as a fuelwood oak tree species in Manipur.

A research report on quantitative analysis of 32 indigenous mountain fuelwood species of Garhwal Himalayas (Bhatt et al., 1992). Which were of high calorific value, low ash and water content, high density wood and high biomass to ash ratio. Their findings were showed that *Ilex dipyreana, Viburnum grandiflorum*, Cotinifolium V., *Betula utilis, Rhododendron campamdatum* among angiosperms have promising firewood properties. Among gymnosperms, *Juniperus wallichiana* is the most suitable fuelwood species having the highest fuelwood value index. A quantitative study of 32 very good firewood mountain native species from Garhwal in the Himalayas had shown that all species in the temperate zone were the most valuable for fuel because of their high calorific value, their low water and ash content, the high density of wood, and the high ratio of biomass to ash. Their results were showed that *Ilex dipyreana, Viburnum grandifolium*, V. cotinifolium, *Betula utilis. Rhododendron campamdatum*, among the angosperms had good combustible properties. Among the gymnosperms, *Juniperus wallichiana* is the most suitable species of firewood with the highest fuel index.

Another study on quantitative analysis of 19 indigenous fuelwood species of Eastern Himalaya, India was carried out to identify trees with potential for firewood production (Bhatt and Sarangi, 2009). A fuelwood value index was the criteria for screening of the species and defined as the calorific value X density/ash content. Over-all rank sum index of the major firewood species was also assessed on the basis of firewood characteristics, fuelwood production, and availability in the region. The results showed that *Castanopsis indica, Phoebe attenuata, Macropanax undulatum, Ixonanthes khasiana, Morus laevigata, Caryota urens, Lithocarpus elegans*, and *Litsea laeta* are the most preferred firewood species.

Various fuel characteristics, such as moisture, ash, lignin, holocellulose, and extractive contents of different parts of these species, were determined on an ash-free dry weight and extractive-free dry weight (Demirbas et al., 2010). Due to find the relationship, if any, between ash and extractive content with the higher heating value (HHV). The overall HHV among the species were varied from 18.60 to 20.34 MJ/kg and the HHV on an ash-free basis varied from 19.33 to 22.01 MJ/kg.

Wood energy derived from a variety of wood-based sources, the most prominent of which is the fuelwood obtained directly from trees and forests (Nasser et al., 2014). The genus Acacia includes over 1,000 species spread all over the world. Six indigenous acacia species that grow naturally in the southwest region of Saudi Arabia were selected in November 2010 from the Abha and Al-Baha forests to determine the heating values and chemical constituents of their wood on a comparative basis. The results showed that they differed significantly in their chemical components and heating value. The highest heating value was found in the wood of A. tortilis, while A. ehrenbergiana had the lowest although the latter species is the most popular in the Kingdom for firewood.

Fuel wood characteristics of *gleditsia triacanthos* was studied where fuel wood characteristics of *gleditsia triacanthos* variety interims wood were determined with respect to calorific value, wood density, Ash content and moisture content of the samples collected from different sites following standard procedures (Shah et al., 2016). The values for these parameters were substituted in the formula to determine the fuel wood value index (FVI). The pooled mean range values of calorific value (Kcal/kg), wood density (g/cc), Ash Content (%), FVI and wood moisture content (%).The investigation was revealed on the basis of FVI of Gleditsia that the species has the potential to supplement the fuel wood needs of the local populace given the broad gap between demand and supply of fuel wood in the state.

Information about variation and correlations of fuelwood properties and growth is needed in order to recommend species and sites for fuelwood production in a changing climate in Africa (Carmen et al., 2017). They investigated the effects of site variables (land use, soil, terrain), geographical coordinates, and mean annual rainfall on fuelwood properties (volatile matter, fixed carbon, ash content, moisture content, gross calorific value, gross calorific value per cubic metre, and fuel value index) of *Combretum glutinosum* Perr., *Combretum micranthum* G. Don., *Combretum nigricans* Lepr. Ex. Guill. & Perr. *Guiera senegalensis* J.F. Gmel., and *Piliostigma reticulatum* (DC.) Hochst. and correlations of fuelwood properties with wood density and growth (height, stem diameter, and ring width) in Niger. They hypothesized that wood density, fixed carbon, and gross calorific value were positively correlated with one another and that fixed carbon and gross calorific value were positively correlated with growth. Most effects of site variables, geographical coordinate, and mean annual rainfall on fuelwood properties differed among species. Fuel value index was greater on rocky soils than on sandy soils. Wood moisture content of three species was greater in drier locations than in more humid ones. Correlations of fuelwood properties with wood density and growth differed among species. Based on this and previous research, they recommended parkland agroforests and sites with rocky soils and higher mean annual rainfall for fuelwood production.

The fuel potential of six tropical hardwood species were studied namely: *Triplochiton scleroxylon*, *Ceiba pentandra*, *Aningeria robusta*, *Terminalia superba*, *Celtis mildbreadii* and *Piptadenia Africana* (Mitchual et al., 2014). Properties studied included species density, gross calorific value, volatile matter, ash content, organic carbon and elemental composition. Fuel properties were determined using standard laboratory methods. The result indicates that the gross calorific value (GCV) of the species ranged from 20.16 to 22.22 MJ/kg and they slightly varied from each other. Additionally, the GCV of the biomass materials were higher than that of other biomass materials like; wheat straw, rice straw, maize straw and sugar cane. The ash and volatile matter content varied from 0.6075 to 5.0407%, and 75.23% to 83.70% respectively. The overall rating of the properties of the six biomass materials suggested that *Piptadenia africana* has the best fuel property to be used as briquettes and *Aningeria robusta* the worse.

Forest coverage of Bangladesh is decreasing day by day. The production from forest area is continuously declining and most of it used for meeting of the cooking energy needs in Bangladesh (forest resources of Bangladesh, 2000). In Bangladesh, the availability of fuelwood from the forest is continuously declining at an increasing rate due to deforestation and slow regeneration. Most Bangladeshi households in rural areas (99%) as well urban areas (60-66%) use biomass such as wood (Bangladesh energy situation, 2016). In Bangladesh almost all rural households use biomass as their primary source of energy where over 90% of energy supplied from biomass fuel (Hassan et al., 2012). The main concerns are related to over exploitation of tree resources and conversion of woodlands to other non-forestry purpose which potentially have negative impacts not only on climate change but also on local food and fuel production (FRA 1999 and Finco MVA, 2010). Bangladesh has very few amounts of forest resources. The forest area of the country is about 2.52 million ha. The estimated annual depletion of forest rate of the country is 0.2% (FAO, 2011). It has been reported that forest resources of the country is used unsustainably (FAO, 2011). At this rate of depletion, the remaining forest resources are expected to rapidly become exhausted if the plantation programmes are not intensified. Thus the gap between demand and supply could be reduced by increasing the supply of better fuelwood species. This gap between demand and supply of fuelwood creating in indiscriminate feeling of forest, for this reason immediate afforestation of suitable fuelwood species is very necessary in different private and government wastelands. In this study an attempt has been made to identify the suitable fuelwood species from few different vendors of Bagarhat district in Bangladesh.

Wood energy is identified as the major source of energy in rural Bangladesh and this has necessitated the identification of suitable tree species that can be included in energy plantation programme. As a preliminary to a more detailed future study of wood energy plantation, four tree species, namely *Swietenia macrophylla, Artocarpus heterophyllus, Azadirachta indica, Aegle marmelos* were collected for fuelwood characterization studies. Various physico-chemical properties, viz. moisture content, density, ash content and calorific value is determined in this study to identify the best fuelwood species among those four species.

### 2.2 General information about *Swietenia macrophylla*

*Swietenia macrophylla*, commonly known as mahogany, Honduran mahogany, Honduras mahogany (USDA, 2014), big-leaf mahogany (Free et al., 2012), or West Indian mahogany (Elevitch et al., 2000), is a species of plant in the Meliaceae family. It is one of three species that yields genuine mahogany timber, the others being Swietenia mahagoni and Swietenia humilis. It is native to South America and Mexico, but naturalized in Singapore and Hawaii (USDA, 2015), and cultivated in plantations and wind-breaks elsewhere (Elevitch et al., 2000)

Unlike mahogany sourced from its native locations, plantation mahogany grown in Asia is not restricted in trade. The mahogany timber grown in these Asian plantations is the major source of international trade in genuine mahogany today. The Asian countries which grow the majority of *Swietenia macrophylla* are India, Indonesia, Malaysia, Bangladesh, Fiji, Philippines, Singapore, and some others, with India and Fiji being the major world suppliers. The tree is also planted in Laos PDR. Since the 1500s, mahogany has been a prized timber product—a building block for high-quality furniture and musical instruments—valued for its deep reddish color, durability, and beauty (www.thepetitionsite.com, 2017).

**Scientific classification:** *Swietenia macrophylla* King.

**Family:** Meliaceae-Family (rainforest-alliance.org, 2012).

### 2.2.1 Common Name:

Mahoni (all parts of Indonesia); baramahauni, bara-mahagoni, mahagni (Bangladesh); mahogany, big- or large-leaved mahogany, bastard mahogany, Brazilian mahogany tree, Colombian mahogany tree, Dominican mahogany, Honduras mahogany, Mexican mahogany tree, Peruvian mahogany tree, Spanish mahogany, West Indian mahogany (England); acajoudu Honduras, acajou du Venezuela, acajou etranger (France); Echtes mahagoni (Germany); mogano (Italy); cheria mahogany (Malaysia); mahok, mahonie (Netherland); mogno (Portugal); caoba, caoba de Honduras, caoba de Santo, caoba del Atlántico, caobahondureña, domingo, (Spain); mahokkani-baiyani, mahokkani-bailek (Thailand) (Elevitch et al., 2000 and Agroforestry Tree Database, 2013).

### 2.2.2 Distribution:

Native: Belize, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Peru, Venezuela (Orwa et al., 2009).

Exotic: Fiji, Haiti, India, Jamaica, Malaysia, Nigeria, Philippines, Puerto Rico, Sierra Leone, Solomon Islands, Sri Lanka, Trinidad and Tobago (Orwa et al., 2009).

### 2.2.3 Description:

*Swietenia macrophylla* is a very large tree, reaching a height of 30-40 m and a girth of 3-4 m; in favorable conditions it can reach 60 m high and 9 m girth. Trunk straight, cylindrical, with a buttressed base; bark rough, flaking off in small patches.

Leaves paripinnate, up to 60 cm long; leaflets 6-16, ovate, lanceolate, acuminate, slightly oblique, light green or reddish when young, dark green and shining when mature, up to 20 cm long, with 8-12 pale, secondary nerves.

Flowers 8 mm across, in narrow supra-axillary panicles about 8-13 cm long and fragrant; petals greenish-white, oblong, 4 mm long, rigidly pointed.

Fruit a woody capsule resembling a large inverted club, about 12.5 x 7.5 cm, erect.

'Swietenia' commemorates Gerard von Swieten (1700-1772), botanist and physician to Maria Theresa of Austria. The specific name, 'macrophylla', means large leaved and comes from Greek words 'makros' (large) and 'phyllon' (leaf).

Flowering mahogany trees have male and female flowers (about 10 times as many male as female flowers, often only the central flower of a cyme is female), but the flowers of both sexes are similar. Trees are sometimes functionally dioecious. In mixed inflorescences, male flowers open 1st, but self-pollination may occur.

Flowering and fruiting are distinctly seasonal. Fruit may be produced once a year and trees start to produce fruit regularly when about 15 years old. Seeds have a thin, tail like wing that makes them rotate when they fall; they are thus dispersed by wind as far as 500 m from the parent tree.

S. macrophylla is found in all forest types, from the edge of the pine savannah to the climax rainforest, but mostly in mixed hardwood forest belts, along riverbanks, on deep alluvial soils of considerable fertility. It occurs scattered or in small groups, but densities of more than 4-8 trees/ha are rarely encountered. In tropical America, it is among the pioneer species reoccupying degraded agricultural land. It has been shown that teak is outcompeted by S. macrophylla in a mixed stand. In the Philippines, S. macrophylla is reported to be very firm in wind, resistant to cyclones.

The species has some weed potential and may invade native forest communities, especially following disturbance. It should not be planted in close proximity to areas of high nature conservation significance (Orwa et. al., 2009).

### 2.2.4 Fuel Characteristics:

S. macrophylla is an excellent fuelwood species with density of 0.519 g/cm$^3$ and a high calorific value of 16.698 KJ/g. Wood burns steadily with the little smoke, few sparks and produces less than 1% ash. Oil that might be of some commercial value can be extracted from the seed kernels of S. macrophylla (Orwa et. al., 2009).

## 2.3 General information about *Artocarpus heterophyllus*

The jackfruit (*Artocarpus heterophyllus*), also known as jack tree, fenne, jakfruit, or sometimes simply jack or jak (Tropical Biology Association, 2006- *Artocarpus heterophyllus*), is a species of tree in the fig, mulberry, and breadfruit family (Moraceae) native to South India (Love et al., 2011).

The jackfruit tree is well suited to tropical lowlands, and its fruit is the largest tree-borne fruit, reaching as much as 35 kg (80 lb) in weight, 90 cm (35 in) in length, and 50 cm (20 in) in diameter (California Rare Fruit Growers, Inc. 1996). A mature jackfruit tree can produce about 100 to 200 fruits in a year. The jackfruit is a multiple fruit, composed of hundreds to thousands of individual flowers, and it is the fleshy petals that are eaten

The jackfruit tree is a widely cultivated and popular food item throughout the tropical regions of the world. Jackfruit is the national fruit of Bangladesh (Silver et. al, 2014).

**Scientific classification:** *Artocarpus heterophyllus* Lam (Missouri Botanical Garden. Retrieved 2012-11-23).

**Family:** Moraceae-Family.

### 2.3.1 Common Name

Bengali (kanthal); Burmese (khnaôr, peignai); English (jacquir, jackfruit, jack tree); Filipino nancas, langka); French (jacquier); German (jackfruchtßaum); Hindi halasu, kathar, alasa, kanthal, chakki, kathal, panos); Indonesian (nangka,nongko); Javanese nangka,nongko); Khmer (khnaôr); Lao (SinoTibetan) (miiz hnang,miiz); Luganda Yakobo,kifenensi); Malay (tajaka,nangka); Mandinka (jak); Sanskrit (panasa); Sinhala (kos); Spanish (pan de ruta, jacueiro, buen pan, rima, jaca); Swahili (mfenesi, mfenesi mfuu); Tamil (pilla, pilapalam, pilavu); Thai (makmi, khanun, nangka, banun); Vietnamese (mít) (Orwa et al., 2009).

### 2.3.2 Distribution

Native: Bangladesh, India, Malaysia (Orwa et al., 2009).

Exotic: Algeria, Angola, Australia, Benin, Botswana, Brazil, Burkina Faso, Burundi Sao Tome et Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sri Lanka, Sudan, Surinam, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe (Orwa et al., 2009).

### 2.3.3 Description

*Artocarpus heterophyllus* reaches 8-25 m in height; straight stemmed, branching near the base at an angle of 32-88 dig; canopy dense, dome shaped or rarely pyramidal; diameter varies with age, in 5-year-old trees it ranges from 3.5 to 6.7 m; trunk rarely buttressed, with a girth of 30-80 cm and a circumference of 42-96 cm; bark greyish-brown, rough, uneven, somewhat scaly; inner bark thick, ochre; all parts smooth, having either no hairs or minute, white hairs up to 0.5 mm long with tips easily broken, giving twigs and leaves a slightly rough feel; trees produce a long taproot; when injured, all living parts of the tree exude a copious, white gummy latex.

Leaves 4-25 x 2-12 cm, coriaceous, glossy, usually glabrous; top dark green, underside pale green; may be flat, wrinkled or with upcurled sides; arranged alternately on horizontal branches, and spirally on ascending branches with 2/5 phyllotaxis; broadest at or above the mid-portion; pinnately nerved, with 5-12 pairs of veins; those on flower-bearing branches obovate or oblong, those on young shoots oblong, narrow; entire when mature, 2 or 3 lobed when young; apex blunt, short and pointed; base cuneate or pointed; midrib and main veins greenish-white to pale greenish-yellow; at the nodes, stipules fused around stem, leaving an encircling scar after they fall off (Orwa et al., 2009).

### 2.3.4 Fuel Characteristics:

The wood of *Artocarpus heterophyllus* is a very popular fuel both in the urban as well as rural for heating and cooking with a specific gravity of 0.6-0.7 (Orwa et al., 2009). It has a high calorific value of 16.698 KJ/g. It burns steadily with little smoke.

## 2.4 General information about *Azadirachta indica*

*Azadirachta indica*, commonly known as neem, nimtree or Indian lilac (USDA, 2017), is a tree in the mahogany family Meliaceae. It is one of two species in the genus Azadirachta, and is native to the Indian subcontinent, i.e. India, Nepal, Pakistan, Bangladesh, Sri Lanka, and Maldives. It typically is grown in tropical and semi-tropical regions. Neem trees now also grow in islands located in the southern part of Iran. Its fruits and seeds are the source of neem oil.

**Scientific classification:** *Azadirachta indica* A.Juss, 1830 (WCSP, 2016).

**Family:** Moraceae-Family.

### 2.4.1 Common Name

Amharic (kinin); Arabic (nim,neem); Bengali (nimgach,nim); Burmese (bowtamaka, thinboro, tamarkha, tamar, tamaka, tamabin); Cantonese (nimba, kohomba, bevu); Chamorro (sdau); Creole (nim); English (Persian lilac, neem tree, bastard tree, Indian lilac, bead tree, margosa tree, cornucopia, Indian cedar); French (margousier, margosier, neem, nim, azadirac de l'Inde); Hindi (neem, balnimb, nim, veppam, nind, vempu); Indonesian (mind, intaran, membha, imba, mempheuh, mimba); Javanese (mimba, imba); Khmer (sdau); Lao (Sino-Tibetan) (ka dao, kadau); Malay (sadu, baypay, mambu, veppam); Nepali (neem); Sanskrit (nimba); Sinhala (kohomba); Swahili (mwarubaini, mwarubaini kamili, mkilifi); Tamil (vepa, veppu, veppam, vembu); Thai (sadao, kadao, sadao India, khwinin, saliam, cha-tang); Tigrigna (nim); Trade name (neem); Vietnamese (saafu daau) (Orwa et al., 2009).

### 2.4.2 Distribution

Native: India, Indonesia, Malaysia, Myanmar, Pakistan, Senegal, Sri Lanka, Thailand (Orwa et al., 2009).

Exotic: Algeria, Angola, Antigua and Barbuda, Argentina, Australia, Barbados, Benin, Botswana, Brazil, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Congo, Cote d'Ivoire, Cuba, Democratic Republic of Congo, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Fiji, French Guiana, Gabon, Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, Jamaica, Kenya, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mexico, Morocco, Mozambique, Namibia, Nepal, Nicaragua, Nigeria, Panama, Paraguay, Peru, Philippines, Puerto Rico, Rwanda, Sao Tome et Principe, Saudi Arabia, Seychelles, Sierra Leone, Singapore, Somalia, South Africa, St Lucia, St Vincent and the Grenadines, Sudan, Surinam, Swaziland, Tanzania, Togo, Trinidad and Tobago, Tunisia, Uganda, Uruguay, US, Venezuela, Virgin Islands (US), Zambia, Zimbabwe (Orwa et al., 2009).

### 2.4.3 Description

*Azadirachta indica* is a small to medium-sized tree, usually evergreen, up to 15 (30 max.) m tall, with a round, large crown up to 10 (20 max.) m in diameter; branches spreading; bole branchless for up to 7.5 m, up to 90 cm in diameter, sometimes fluted at base; bark moderately thick, with small, scattered tubercles, deeply fissured and flaking in old trees, dark grey outside and reddish inside, with colorless, sticky sap.

Leaves alternate, crowded near the end of branches, simply pinnate, 20- 40 cm long, exstipulate, light green, with 2 pairs of glands at the base. In Africa, it is found in evergreen forest and in dry deciduous forest. Adult *A. indica* tolerates some frost, but seedlings are more sensitive. It quickly dies in waterlogged soils. *A. indica* requires large amounts of light, but it tolerates fairly heavy shade during the 1st few years (Orwa et al., 2009).

### 2.4.4 Fuel Characteristics

The wood makes excellent charcoal (Chaturvedi, 1985). Charcoal made from *A. indica* wood is of excellent quality and the wood has long been used as firewood. Its oil is burned in lamps throughout India (Orwa et al., 2009). It has high calorific value 16.009 KJ/g with density of 0.655.

## 2.5 General information about *Aegle marmelos*

*Aegle marmelos*, commonly known as bael (or bili or bhel), also Bengal quince, golden apple, Japanese bitter orange, stone apple or wood apple, is a species of tree native to India, Nepal, the Andaman and Nicobar Islands and Myanmar. It is present in Sri Lanka, Thailand and Malaysia as a naturalized species. The tree is considered to be sacred by Hindus. Its fruits are used in traditional medicine and as a food throughout its range. [Not verified in body] The common name "wood apple" may also refer to *Limonia acidissima* (Wikipidia- *Aegle marmelos*, 2017).

**Scientific classification:** ***Aegle marmelos*** **L.** (USDA, 2017).

**Family:** Rutaceae-Family.

### 2.5.1 Common Name

Burmese (opesheet,ohshit); English (bael fruit, Indian bael, holy fruit, golden apple, elephant apple, Bengal quince, Indian quince, stone apple); French (oranger du Malabar, cognassier du Bengale, bel indien); German (Belbaum, Schleimapfelbaum, Baelbaum); Gujarati (bili); Hindi (baelputri, bela, sirphal, siri-phal, kooralam); Indonesian (maja batuh, maja); Javanese (modjo); Khmer (bnau); Lao (Sino-Tibetan) (toum); Malay (bilak, bel, bila, maja pahit); Portuguese (marmelos); Thai (matum, mapin, tum); Vietnamese (trai mam, mbau nau) (Orwa et al., 2009).

### 2.5.2 Distribution

Native: India (Orwa et al., 2009).

Exotic: Bangladesh, Egypt, Malaysia, Myanmar, Pakistan, Sri Lanka, Thailand (Orwa et al., 2009).

### 2.5.3 Description

*Aegle marmelos* is a slow-growing, medium sized tree, up to 12-15 m tall with short trunk, thick, soft, flaking bark, and spreading, sometimes spiny branches, the lower ones drooping. Young suckers bear many stiff, straight spines. A clear, gummy sap, resembling gum Arabic, exudes from wounded branches and hangs down in long strands, becoming gradually solid. It is sweet at first taste and then irritating to the throat.

The deciduous, alternate leaves, borne singly or in 2's or 3's, are composed of 3 to 5 oval, pointed, shallowly toothed leaflets, 4-10 cm long, 2-5 cm wide, the terminal one with a long petiole. New foliage is glossy and pinkish-maroon. Mature leaves emit a disagreeable odor when bruised.

Fragrant flowers, in clusters of 4 to 7 along the young branchlets, have 4 recurved, fleshy petals, green outside, yellowish inside, and 50 or more greenish-yellow stamens.

The fruit, round, pyriform, oval, or oblong, 5-20 cm in diameter, may have a thin, hard, woody shell or a more or less soft rind, gray-green until the fruit is fully ripe, when it turns yellowish. It is dotted with aromatic, minute oil glands. Inside, there is a hard central core and 8 to 20 faintly defined triangular segments, with thin, dark-orange walls, filled with aromatic, pale orange, pasty, sweet, resinous, more or less astringent, pulp.

Embedded in the pulp are 10 to 15 seeds, flattened-oblong, about 1 cm long, bearing woolly hairs and each enclosed in a sack of adhesive, transparent mucilage that solidifies on drying (Orwa et al., 2009).

### 2.5.4 Fuel Characteristics

The wood of *Aegle marmelos* produces 16.015 KJ/g calorific values when it burns. It has high density approximately 0.786.

Therefore, this study was undertaken to evaluate the fuelwood characteristics of four selected species and to identify which tree species are better suited as fuelwood species among these four species.

# Materials and Methods

## 3.1 Sample Collection:

Four tree species selected according to its local use as fuelwood from wood vendors in Bagerhat district. The species were *Swietenia macrophylla*, *Artocarpus heterophyllus*, *Azadirachta indica* and *Aegle marmelos*.

Randomly, three logs of each species were sampled among the four species from the wood vendors and 45 $cm^3$ long and 10-I8 $cm^3$ in diameter was cut from the logs and put into a bag. Then the logs were transferred in a saw mill for sizing for the determination of various properties such as-moisture content, density, ash content, calorific value of the wood.

## 3.2 Sample preparation:

Then, in the sawmill, the logs were converted into $8\times2\times2$ $cm^3$ wood block for the determination of moisture content, density and also into some wood powder for the determination of ash content and calorific value of the wood species. Then the collected samples were transferred to the laboratory for their various experiments.

## 3.3 Determination of Moisture content percentage (MC %):

The green moisture content is refers to the moisture content of a sample when it was extracted from a log. Moisture content of wood is the weight of the moisture presence in wood, expressed as a percentage of its oven dry weight (Panshin et al., 1980). The wood blocks taken from log were weighed and dried at 103°c during 24h according to the D-4442 standard. After that, the wood blocks were weighed again to obtain the dry weight. After that, the moisture content was determined ·by the following equation

$$MC\% = \frac{\text{Green Weight} - \text{Oven Dry Weight}}{\text{Oven Dry Weight}} \times 100$$

## 3.4 Determination of wood density:

The density of a wood is a variable which tells how much carbon the plant uses for their constructing purpose (Chave, 2005). Density of wood is the mass of wood per unit of volume (Panshin et al., 1980). Wood density varies within the plants. The wood blocks taken from the log were weighed and estimated the volume according to the D-143 standard. The volume was determined by taking the measurement of the length, wide and height of the wood blocks with the help of slide calipers.

$$\text{Volume} = \text{Length} \times \text{Width} \times \text{Thickness}$$

After that the density was determined by the following equation-

$$\text{Density} = \frac{\text{Oven Dry Weight}}{\text{Oven Dry Volume}}$$

### 3.5 Determination of Calorific value:

To determine the calorific value on a dry weight basis, 1 g of oven dry wood powder of per sample was tested from the laboratory of Khulna University of Engineering Technology (KUET) by following way:

The calorific value of the wood samples was determined using a Gallenkamp autobomb calorimeter (SG96/02/536, Gallenkamp and Company Ltd, London, UK). The method is based on combustion in the 'bomb' chamber. When the sample is burned, the resulting heat is measured by the increase in the temperature of water surrounding the bomb. In this study, 1g of wood sample was pelleted using a briquette press and weighed in a crucible. The pelletwas then connected to the firing wire fitted between the electrodes with the aid of a cotton thread. The circuit was tested and the bomb was filled with oxygen to a pressure of 3,000 Pa (30 bar). The calorimeter vessel was filled with water (total weight 3 kg) at 21°C to 23°C; the prepared bomb was placed inside the calorimeter vessel, and then the calorimeter vessel was placed into the water jacket. The machine was switched on and left for a while (10 to 15 min) to warm up. The initial temperature of the water was recorded before firing and after 10 to 15 minutes, the final temperature reached was recorded. Benzoic acid was used as a standard. Calorific value was then calculated using following formula:

Calorific Value (CV) = [(FT- IT) × 10.82] – 0.086 \ (weight of Sample)

Where 10.82 = heat capacity of the calorimeter in kJ/K, 0.086 = combined energy value of nickel wire and cotton in kJ/g, FT = final temperature, and IT = initial temperature.

### 3.6 Determination of Ash content percentage:

At first, in the laboratory, took an appropriate number of small pots and marked them using a graphite marker and weighted them and also took 1g oven dry weight, ODW wood powder of per sample. Then place them in the muflle furnace at 450°C for four hours according to ASTM standard Method umber E1755-01. Then, removed the pots from the furnace and put them into a drier and weighted them. After that, the ash content percentage was determined by following formula-

$$\text{Ash Content \%} = \frac{\text{Weight}_{\text{pot plus ash}} - \text{Weight}_{\text{only pot}}}{\text{ODW}_{\text{Sample}}} \times 100$$

**3.7 Determination of Fuel Value Index (FVI):**

Fuel value index is an important factor for ranking fuelwood species. FVI values of the fuelwood species were calculated according to (Goel and Behl, 1996) considering density and calorific value as positive characters and moisture and ash content as negative characters. The formula used was as following:

$$\text{FVI} = \frac{\text{Calorific Value}\left(\frac{\text{kJ}}{\text{g}}\right) \times \text{Density}\left(\frac{\text{g}}{\text{cm}^3}\right)}{\text{Ash content}\left(\frac{\text{g}}{\text{g}}\right) \times \text{Water Content}\left(\frac{\text{g}}{\text{g}}\right)}$$

# Result and Discussion

**Table 1: Fuelwood characteristics of four tree species of Bagerhat District in Bangladesh.**

| Species | Moisture Content (%) | Density ($g/cm^3$) | Ash Content (%) | Calorific Value (KJ/g) | Fuel Value Index (FVI) |
|---|---|---|---|---|---|
| *Swietenia macrophylla* | 49.02 | 0.519 | 0.62 | 16.698 | 2851.46 |
| *Artocarpus heterophyllus* | 53.94 | 0.307 | 0.40 | 16.698 | 2375.92 |
| *Azadirachta indica* | 44.13 | 0.655 | 1.50 | 16.009 | 1584.09 |
| *Aegle marmelos* | 43.19 | 0.786 | 1.05 | 16.015 | 2775.73 |

**4.1 Moisture content:**

It has been recorded that the moisture in wood varies with the season and state of the wood, amongst other factors (Abbot et al., 1999 and Bhatt et al., 2002). The higher moisture content reduces combustion ability.

Table- 1 showed that, among the four tree species studied highest percentage of moisture content was recorded in *Artocarpus heterophyllus* (53.94%) followed by *Swietenia macrophylla* (49.02% ) *Azadirachta indica* (44.13%) and lowest moisture content was observed in *Aegle marmelos* (43.19%).

**Table 2: Moisture content of four tree species.**

| Species | Moisture content (%) |
|---|---|
| *Swietenia macrophylla* | 49.02 |
| *Artocarpus heterophyllus* | 53.94 |
| *Azadirachta indica* | 44.13 |
| *Aegle marmelos* | 43.19 |

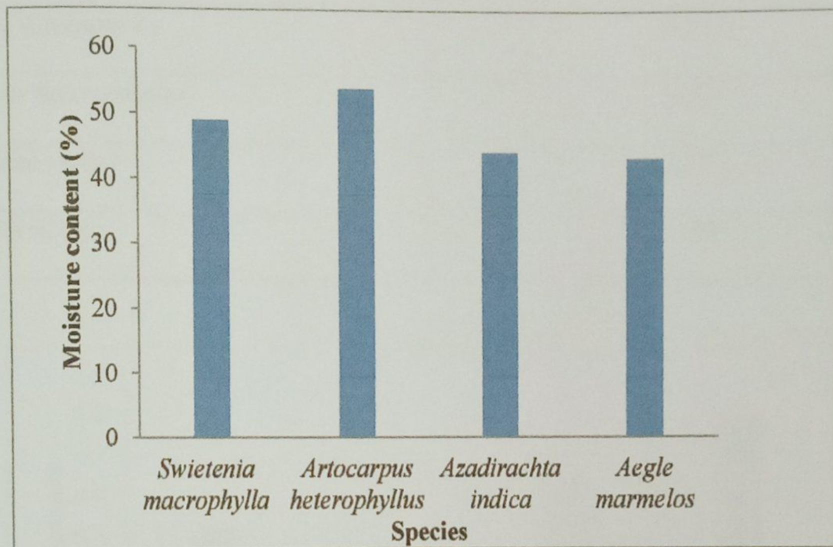


**Figure 1: Moisture content of four tree species.**

### 4.2 Density

Density of a tree species also plays an important role in determining the quality of fuelwood. (Kataki and Konwer, 2002) and (Khoo et al., 1982) said that, denser species are preferable for fuel because of their high energy content per unit volume and slow burning rates. The density of wood also determines a positive factor in fuelwood quality due to its durability on heating. Wood density of five oak tree species showed a significant positive correlation ($p<0.05$) with the calorific values of wood samples (Meetei et al., 2014). High wood density found in wood may be due to high lignification and presence of lignin and other denser fractions or complex wood ultrastructure, apparently enhances wood density, reiterating strong link between chemical constituents of wood and their physical properties (Kumar, 2006). The density of woods is an important attribute not only in the use of the wood for burning, but it also gives the wood additional use value (Cunningham A C. 2001).

In the present study, highest wood density was observed in *Aegle marmelos* (0.786g/cm3)> *Azadirachta indica* (0.655g/cm3) > *Swietenia macrophylla* (O.519g/cm3) > *Artocarpus heterophyllus* (.307g/cm3). Lowest wood density was noticed in *Artocarpus heterophyllus* (0.307g/cm3) (Table 1)

**Table 3: Density of four tree species**

| Species | Density(g/cm$^3$) |
|---|---|
| *Swietenia macrophylla* | 0.519 |
| *Artocarpus heterophyllus* | 0.307 |
| *Azadirachta indica* | 0.655 |
| *Aegle marmelos* | 0.786 |

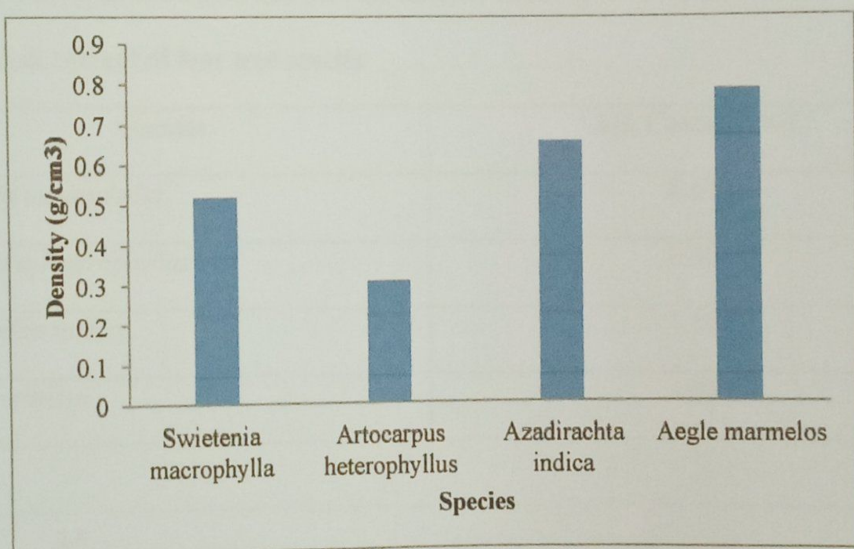


**Figure 2: Density of four tree species**

**4.3 Ash Content**

The highest value of ash percentage for determining fuelwood quality was indicates a negative factor to fuelwood quality (Meetei et al., 2014). Normally the ash content for wood ranges from .01% to 0.5% in tree species (panshin et al., 1980). The higher values obtained here could be explained by the fact that tropical wood species need more mineral elements for growth than there wood species (Chow and Lucas, 1988).

In the present study, highest Ash Content was observed in *Azadirachta indica* (1.5%), *Aegle marmelos* (1.05%) > *Swietenia macrophylla* (O.62%) and *Artocarpus heterophyllus* (0.40%). Lowest Ash Content was noticed in *Artocarpus heterophyllus* (0.40%).) (Table 1)

The bark of tree produce higher amount of ash forming materials and relatively lower heating content (Kataki and Konwer, 2001). So, removing the ash from the plant parts was found to increase their heating values. Generally, ash content is an unfavorable factor that needs to be controlled during the direct combustion of wood (Chow and Lucas, 1988). High quality lump charcoal typically has an ash content of about 3% (FAO, 1985). In general terms, (Cardoso M B, 2015) reported that, the greater amount of ash produced, are less preferred the species.

Ash percentage in tree components of five oak tree species showed significant difference between bark and wood biomass components and ash percentage of five oak tree species was found to be negatively correlated and significant with the calorific values ($p<0.01$) (Meetei et al., 2014).

**Table 4: Ash content of four tree species**

| Species | Ash Content (%) |
|---|---|
| *Swietenia macrophylla* | 0.62 |
| *Artocarpus heterophyllus* | 0.40 |
| *Azadirachta indica* | 1.50 |
| *Aegle marmelos* | 1.05 |

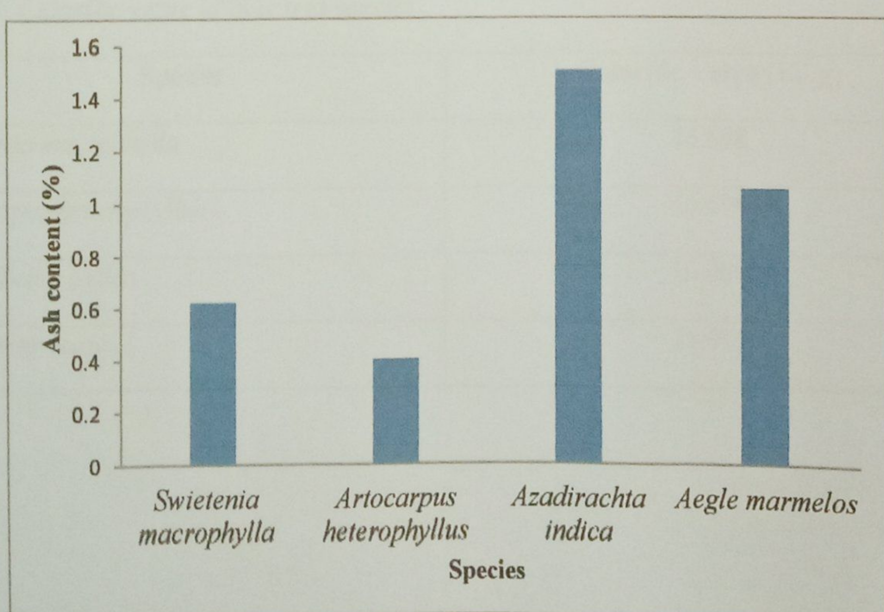

**Figure 3: Ash content of four tree species**

## 4.4 Calorific Value

Calorific values depend on the type of development, growth or age of the different species, as well as seasonal variations, among other factors (Klasnja et al., 2010). We can say that these values coincide with the standard average values of species which possess the relevant combustion qualities (Cardoso et al., 2015). The heat of combustion of wood depends upon the genetic character of the species and chemical composition of the wood. High calorific values may be due to high concentration of extractives and lignin content in wood (Kataki and Konwer, 2001; Demirbas and Demirbas, 2009). However, high content of dichloromethane extractives promote higher calorific values of tree species in addition to the presence of extractives and lignin (Moya and Tenorio, 2013). Bark components showed lower calorific values as compared to wood components. Similar findings were reported by (Senelwa and Sims, 1999) and (Shavanas and Kumar, 2003). Calorific values of bark component were generally lower than that of wood samples due to their higher percentage of ash content (Meetei et al., 2014).

In the present study, highest Calorific value was observed in *Artocarpus heterophyllus* and *Swietenia macrophylla* is 16.698 KJ/g. *Aegle marmelos* and *Azadirachta indica* 16.015 KJ/g and 16.009 KJ/g respectively (Table 1).

**Table 5: Calorific value of four tree species**

| Species | Calorific Value (KJ/g) |
|---|---|
| *Swietenia macrophylla* | 16.698 |
| *Artocarpus heterophyllus* | 16.698 |
| *Azadirachta indica* | 16.009 |
| *Aegle marmelos* | 16.015 |

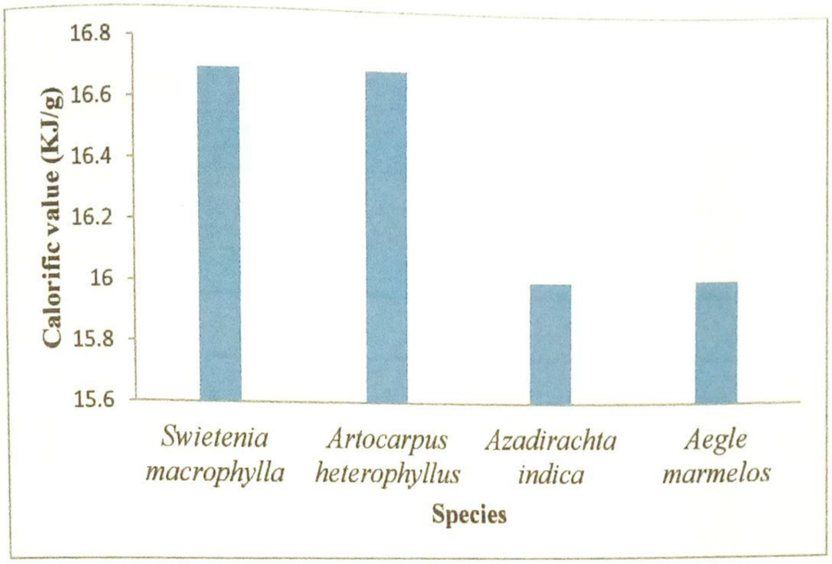


**Figure 4: Calorific value of four tree species**

### 4.5 Ranking based on Fuel Value Index (FVI)

The FVI is an important characteristic for screening desirable fuelwood species (Purohit and • Tautiyal, 1987; Jain, 1993). FVI of four tree species of present studied was in order of *Swietenia macrophylla* (2851.46) > *Aegle marmelos* (2775.73) > *Artocarpus heterophyllus* (2375.92) > *Azadirachta indica* (1584.09). Of all the four observed tree species, highest FVI was recorded in *Swietenia macrophylla* (2851.46) due to higher calorific value as compared to other species.

Therefore, out of four tree species of present study, this tree may be regarded as the best quality of fuelwood species followed by *Swietenia macrophylla* > *Aegle marmelos* > *Artocarpus heterophyllus* > *Azadirachta indica.*

**Table 6: Fuel Value Index (FVI) of four tree species**

| Species | Fuel Value Index (FVI) |
|---|---|
| *Swietenia macrophylla* | 2851.46 |
| *Artocarpus heterophyllus* | 2375.92 |
| *Azadirachta indica* | 1584.09 |
| *Aegle marmelos* | 2775.73 |

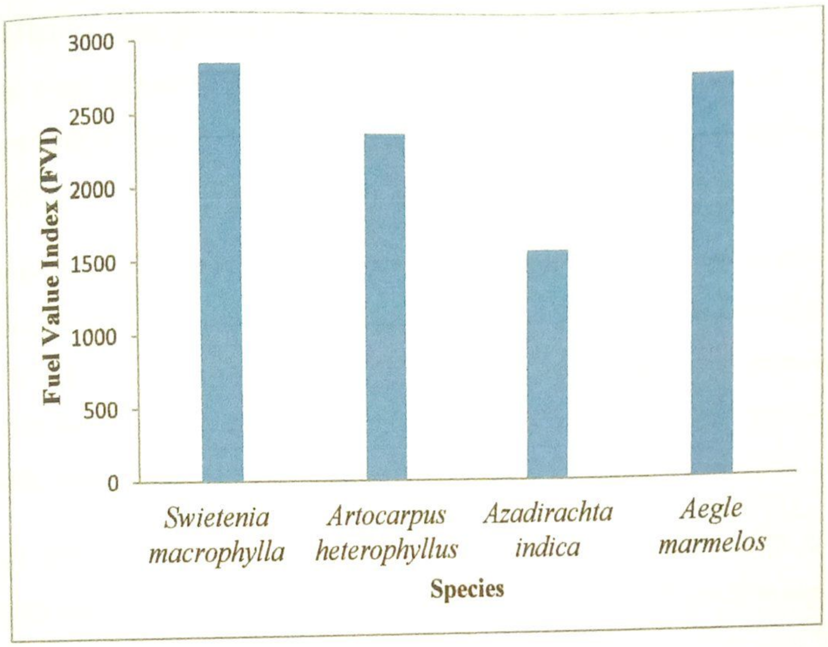


**Figure 5: Fuel Value Index (FVI) of four tree species**

# Conclusion

The result of this study emphasize that, the calorific value should not be the only factor to be taken into account when evaluating fuelwood but moisture content, ash content, density and negative environmental impact should also be considered. Calorific values of the investigated species differ from each other.

*Artocarpus heterophyllus* is the preferred species with regards to low ash content and density but it has relatively high moisture content than other three species. In terms of calorific value *Swietenia macrophylla* and *Artocarpus heterophyllus* are preferable. This two species show same result of calorific value. Moisture content of *Swietenia macrophylla* is lower than *Artocarpus heterophyllus* and it contains higher density than *Artocarpus heterophyllus.*

*Azadirachta indica* contains higher amount of ash content than other three species and comparatively high density and lower moisture content than *Artocarpus heterophyllus* and *Swietenia macrophylla.*

On the other hand, *Aegle marmelos* contains high density and lower moisture content than other three species and higher amount of ash content than *Swietenia macrophylla* and *Artocarpus heterophyllus.*

Considering the Fuel Value Index (FVI), in the present study, the preferred wood species are *Swietenia macrophylla*, followed by *Aegle marmelos, Artocarpus heterophyllus* and *Azadirachta indica* which would constitute a viable wood species to be specifically planted as fuelwood. This study therefore lays an important premise for selection of high fuel potential fuelwood species for possible inclusion into reforestation, afforestation, and agroforestry initiatives currently encouraged by the Government and Civil Society Organizations to address fuelwood shortage in Bangladesh generally. However, before such species prioritization is done, it is recommended that socially defined features that shape local people's perception of acceptable fuelwood species need to be considered which was not undertaken in this study. This will lead to the generation of fuelwood species checklist that is socially acceptable and with high fuel potential in a given area.

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