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A Study on Fuelwood Properties of Four Woody Species of Southwestern Region in Bangladesh

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I, Afrin Sultana, declare that this thesis reports the original research work of the author, except as otherwise stated. The material presented has not been submitted either in whole or in part for a degree from this or any university.

The findings of the research has not been or will not be published anywhere without the concurrence of the concerned supervisor.

Afrin Sultana

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Session: 2015-2016

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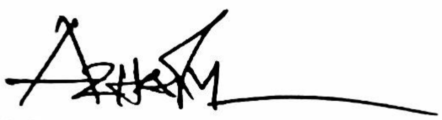
Dedicated to….

My Beloved Parents

And Brothers

Approval

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



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ABSTRACT

Four tree species were collected from different wood vendors of Jhenidah district in Bangladesh and fuelwood properties viz. moisture content, ash content, density, calorific value and fuel value index (FVI) and extractive, cellulose, hemicelluloses and lignin content calculated to screen desirable species for potential production of fuelwood in these areas. Four tree species that we were selected namely *Acacia nilotica, Samanea saman, Leucaena leucocephala, Tamarindus indica.* The present study indicated that, which species posses better fuelwood quality among the selected four tree species according to their Fuel Wood Value Index, FVI and high extractives and lignin content. The The fuelwood value index (FVI) was also worked out, taking into account the calorific value and density of the wood as positive characteristics, and high water content and high ash content as negative characteristics. Percentage of ash on dry weight basis was found to be lowest in *Leocoena leucocephala* (1.09%) and highest in *Tamarindus indica* (2.21%). Ash content of tree components gives a singnificant factor in determining fuelwood value index (FVI). According to FVI, this tree may be regarded as the best quality of fuelwood species followed by *Acacia nilotica* > *Leucaena leucocephala* >*Tamarindus indica* > *Samanea saman*.

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CAHPTER ONE

INTRODUCTION

1.1 Introduction:

The importance of fuelwood as a primary source of energy varies widely among different parts of the world. Developed countries use more non-forest fuel energy than 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).

Fuelwood 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 purposes like agricultural processing and industry (Arnold and Jongma, 1978).

The energy requirement of Bangladesh is met from different sources, such as biomass, electricity, natural gas, kerosene, diesel/gas oil, coal and others. The people of rural areas depend mainly on traditional fuels, namely wood, agricultural residues, such as paddy husk, bran, straw, baggasse, jute stick, twigs, leaves, charcoal and cowdung for their domestic consumption. But, fuelwood contribute 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% and dung 13%. The remaining 3% are supplied from peat deposits (FMP, 1993).

In Bangladesh, fuelwood was indicated a free product in the rural areas in the 1950s. Now, the shortage of fuelwood is severe throughout the whole country due to the over exploitation of natural forests and village groves, which has made the fuelwood as market commodity at present time. Forestry Master Plan (FMP, 1993) of Bangladesh states that per capita fuelwood consumption in Bangladesh is the lowest (0:043m3) in the world. The projection of fuelwood demand and supply for the years 1993–2013 by the FMP shows a disappointing figure of the fuelwood deficit as almost one-third of the total fuel demand from 2003 to 2013. This shortage will also be severe if the country fails to protect the forest cover and develop the fuelwood plantation throughout the country.

To avert this situation, it is highly necessary to establish energy plantation on unused and degraded lands of the region. Moreover, local people's choice should be considered for identifying the tree species as they have an intimate knowledge of the local environment and the local tree species (Jungerius, 1995). The peoples of wood vendors sell fuelwood 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 (Lisardo et al., 2003). Generally, we prefer hardwoods because of their last longer coals, yield more heat and emits less smoke (Shackleton, 2001). For this reason, the peoples are using hardwoods to fulfill their basic needs of fuelwood, which in turn is responsible for rapid deforestation of the country.

The physical properties which mainly affecting the performance of fuelwood species are moisture content, chemical composition and wood density (Kataki and Konwer, 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 and Sims, 1999). So, it is very argent to evaporate the water present in wood for obtaining total amount of heat. Sometimes, moisture of the wood has been created the negative effect on its calorific value (Junge, 1980).

Structurally, wood cell walls are composed of cellulose, hemicelluloses and lignin. The chemical composition of wood varies widely based on species and the position on the tree (Nasser and Aref, 2014). Wood also contains small amount of extractives which have effect on the characteristics of wood and wood products (Fengel and Wengener, 1989). Wood extractives vary greatly in their quantity and their chemical nature (Wang et al., 1981; Fuwape, 1990; Kataki and Konwar, 2002). Extractive, cellulose, hemicelluloses and lignin content are an important criterion for determining the suitability of a certain type of wood as fuelwood (Wang et al., 1981).

Fuel value index (FVI) is an important factor for ranking fuelwood species (Deka et al., 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 Behl, 1996; Bhatt and Todaria, 1992; 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 chemical composition and fuel properties of these species.

Therefore, this study was undertaken to evaluate the fuelwood characteristics of these four species and to investigate the relationship between the fuel value index, FVI with cellulose, hemicelluloses, lignin, extractives, density, moisture content and ash content.

1.2 Objectives of the study:

The main objectives of this study were-

- to determine the fuel value index , FVI of the four selected wood species.
- to determine the extractive, cellulose, hemicellulose and lignin content of all samples from selected wood species.

CHAPTER TWO
LITERATURE REVIEW

2.1 Literature review:

Wood has been 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 shortage is being felt at the national and global levels (Nasser et al., 2014). Numerous tree species need to be evaluated for their potential to overcome this shortage (Geyer et.al, 2008). Use of woody biomass for obtaining heat energy has increased dramatically over the last few decades (Bilandzija et al., 2012).

Like many other developing countries, in Saudi Arabia a study was carried out about fuelwood characteristics *of* six Acacia species by (Nasser and Aref, 2014). That study was undertaken to evaluate the fuelwood characteristics of six Acacia species growing wild in two geographical locations in southeast Saudi Arabia and to investigate the relationship between the heating value and chemical constituents of the various woods. That study reported that, the heating values were highly positively correlated with the contents of lignin (R^2 =0.70) and total extractives (R^2 =0.70).

Another study was carried out in Costa Rica by (Moya et al., 2013) the aim of that 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 in that study. The results revealed that the calorific value and FVI were affected by chemical parameters and by the amount of extractives in wood.

A study was carried out in India by (Meetei et al., 2014) about fuelwood properties of some oak tree species of Manipur, India. The main objective of the present study was to investigate the calorific value (kJ g), wood density (g cm), ash content (%) and moisture content (%) for fuelwood components (bole, branch and twig) of five oak species and estimating their FVI. The results revealed that the, *Castanopsis indica* exhibited highest FVI value due to its lowest value of ash content as compared to other species.

A ranking of ten indigenous fuelwood species by FVI of Northeast India were carried out in India by (Deka et al., 2007). They were ranked by pair-wise 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 formulae reported by (Goel and Behl, 1996) and (Abbot et al., 1992) have sufficient resemblance with those obtained by pair-wise comparison.

Another study was carried out in India by (Kumar et al., 2009) about an assessment of Indian fuelwood with regards to properties and environmental impact. It was showed that the wood with the highest calorific value does not necessarily constitute the best option as fuelwood, if elemental composition is taken into account. The variation of the wood density, calorific value and elemental composition C, N, P, S, Pb, Al, As and Cd and their indirect impact on the environment is discussed in this paper.

A study was carried out by (Shanavas et al., 2002) about Fuelwood characteristics of tree species in homegardens of Kerala in India. In that paper they report a study on heat of combustion and physical properties that determine combustion of important homegarden trees and their tissue types, besides a few other widely used fuel materials. That report showed that, tree species/tissue types with high density, low ash and moisture fractions are favoured as fuelwoods, as they show better combustion characteristics. However, choice of wood for fuel does not depend on its heat value alone; other factors such as drying properties, emission characteristics, ease and completeness of combustion, rapidity of burning etc. are probably important.

A study was dealed about the fuelwood value index in components of ten tree species of arid region in India by (Puri et al., 1994). That study presents the fuelwood characteristics of ten major tree species of the arid region and their variations for tree parts such as stump, stem, branches, foliage and bark. It reaveled that, from highest to lowest calorific values, the order of the component groups was treetop, branches, bark, stem, stump and foliage and also showed that, indigenous tree species are better suited as fuelwood as compared to exotics.

An experiment was conducted by (Cardoso et al., 2015), about preference and calorific value of fuelwood species in rural populations in northwestern Patagonia in Argentina. In that work, therefore, they focus on studying the relationship that exists between the fuelwood species used in three rural communities in the northwest of Patagonia and their combustibility, integrating traditional knowledge with the physical properties of woody plants. It reported that, the species with the highest FVI values are those mostly preferred by local people. In this work, the similarity observed between the empirical data and traditional ecological knowledge seems to revalue local's know how related to the use of these fundamental resources that could be beneficial for sustainable management.

An experiment was conducted with thirty tree species indigenously growing in their natural habitat in subtropical forest of central India by (Jain and Singh, 1998). The species were collected and fuelwood properties viz. moisture, silica, ash, density, carbon, nitrogen, volatile matter, calorific value and fuel value index (FVI) calculated. In this study an attempt has been made to identify the suitable fuelwood species from forest flora of central India. These species could be selected for intensive culture on marginal wastelands in central India to meet the firewood demand and the resulted species were selected according to their highest FVI values.

Bangladesh forests are also surviving under high level of demographic stress. 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 continually declining at an ever increasing rate due to indiscriminate deforestation and slow regeneration and afforestation. Most Bangladeshi households in rural areas (99%) as well as 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 is 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 purposes 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 sparse forest resources. The forest area of the country is about 2.52 million ha. The estimated annual depletion of forests rate of the country is 0.2% (FAO, 2011). It has been reported that the forest resource of the country is used unsustainably (FAO, 2011). At this rate of deforestation, the remaining forest resources are expected to rapidly become exhausted if the plantation programmes are not intensified. Thus the gap between demand and availability could be reduced by increasing the supply of better fuelwood quality. This combination of ecological degradation and scarcity of fuelwood, creating in indiscriminate felling of forest for this reason requires immediate attention for afforestation of suitable species on wastelands. In this study an attempt has been made to identify the suitable fuelwood species from few different vendors of Jhenidah district in Bangladesh.

Although, 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 *Acacia nilotica*, *Leucaena leucocephala*, *Tamarindus indica*, *Samanea saman* were collected for fuelwood characterization studies. Various physico-chemical properties, viz. moisture and ash content, density, cellulose, holocellulose, lignin and extractive contents of different parts of these species were determined on ash-free dry weight basis and extractive-free dry weight basis to find out relationship, if any, between ash and extractive content with the calorific value.

Elimination of ash from the plant parts increased calorific value while extractive-free materials declined in net caloric content in all plant parts, indicating a possible relationship of these two parameters with the heat of combustion (Kataki and Konwer, 2001).

2.2.1 General information about *Leucaena leucocephala*:

Ipil ipil (*Leucaena leucocephala*) is a well known fast growing tree species. It is widely distributed in Asia as well as in the world. It coppicing capability is quite well when young. Ipil ipil is lignocellulosic material which reduces soil erosion and increases soil fertility. It is also a multipurpose tree species. It can be grown in most of the areas of Bangladesh. It required least maintenance and tending operation (Zabala). It is well known mainly as fuelwood because it produces low density, low ash content and low quality timber and furniture (Rahman, 2008).

Scientific classification: *Leucaena leucocephala* (Lam.) de Wit

Family: Fabaceae-Pea family (Orwa et al., 2009).

2.2.2 Common name:

Leuceana (Arabic), wild tamarinds (Corozal, Belize), lead tree (Florida), lamtoro (Indonesia, Malaysia), ipil ipil (Philippines), jumby bean (Bahamas), false koa, koa-haole (Hawaii), lopa Samoa (American Samoa), subabul (India), vaivai (Fiji), kay keo dau (Vietnam), tagarai, nattucavundal (Tamil), lucina (Tigrigna), nito (cook Island), cassis (Vanuatu), pepe (Niue and Samoa), (Rahman, 2008).

2.2.3 Distribution:

Native: Colombia, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Spain, United States of America

Exotic: Antigua and Barbuda, Australia, Bahamas, Barbados, Cambodia, Cote d'Ivoire, Cuba, Democratic Republic of Congo, Dominica, Dominican Republic, Eritrea, Ethiopia, Fiji, Grenada, Haiti, India, Indonesia, Jamaica, Kenya, Laos, Malaysia, Myanmar, Nigeria, Papua New Guinea, Philippines, Puerto Rico, South Africa, Sri Lanka, St Kitts and Nevis, St Lucia, St Vincent and the Grenadines, Sudan, Taiwan, Province of China, Tanzania, Thailand, Trinidad and Tobago, Uganda, Vietnam, Virgin Islands (US), (Orwa et al., 2009).

2.2.4 Description:

Leucaena leucocephala is a small, variably shrubby and highly branched (ssp. leucocephala) to medium-sized tree with a short, clear bole to 5 m, upright angular branching and a narrow open crown (ssp. glabrata), 3-15 (max. 20) m tall, bole diameter 10-50 cm. Bark on young branches smooth, grey-brown, slash salmon pink, darker grey-brown and rougher with shallow, rusty orange-brown vertical fissures and deep red inner bark on older branches and bole. This evergreen plant is deep rooted. It often has a combination of flowers, immature and mature pods present on the tree at the same time.

Leaves with (min. 4) 6-9 pairs pinnae; pinnular rachis 5-10.2 cm long, leaflets 9-16 (max. 21) mm long, 2-4.5 mm wide, 13-21 pairs per pinna, slightly asymmetric, linear-oblong to weakly elliptic, acute at tip, rounded to obtuse at base, glabrous except on margins. Leaves and leaflets fold up with heat, cold or lack of water.

Flower heads 12-21 mm in diameter, 100-180 flowers per head, in groups of 2-6 in leaf axils, arising on actively growing young shoots, flowers white or pale cream-white.

Pods (min. 9) 11-19 cm long, (min. 13) 15-21 mm wide, (min. 3) 5-20 (max. 45) per flower head, linear-oblong, acute or rounded at apex, flat, 8-18 seeded, mid- to orange-brown, glabrous and slightly lustrous or densely covered in white velvety hairs, papery, opening along both margins. Seeds hard, dark brown with a hard, shining testa, 6.7-9.6 mm long, 4-6.3 mm wide, aligned transversely in pod, (Orwa et al., 2009).

2.2.5 Fuel characteristics:

L. leucocephala is an excellent firewood species with a specific gravity of 0.45-0.55 and a high calorific value of 4600 cal/kg. Wood burns steadily with little smoke, few sparks and produces less than 1% ash. The tree makes excellent charcoal with a heating value of 29 MJ/kg and good recovery values (25-30%). Addition of ground L. leucocephala to fuel oil for diesel engines was found to involve no harmful agents in the ash, (Orwa et al., 2009).

2.3.1 General information about *Acacia nilotica*:

Acacia nilotica is multipurpose nitrogen fixing tree legume. *A. nilotica* can play an important role in stabilizing and recovering the degraded sites (Bargali et al., 2009). It is a relatively fast growing, drought resistant multipurpose legume with the ability of biological nitrogen fixation. In addition, its strong tap root system (Toky et al., 1992), long growing period of more than 300 days with four peaks of leaf flush (Beniwal et al., 1992), it can intensively exploit soil column for nutrients and moisture. This species has high potential for nitrogen fixation (Toky et al., 1994), and has been considered as one of the fast growing species of the wastelands, and agro forestry systems throughout India providing strong timber, fodder for goats and sheep, and high quality fuel wood apart from enriching the soil with nitrogen (Bargali et al., 2009).

Scientific classification: *Acacia nilotica* (L.) Willd. ex Del

Family: Fabaceae

2.3.2 Common name:

Acacia nilotica (L.) Willd. ex Del commonly known as babul, kikar or Indian gum Arabic tree, has been recognized worldwide as a multipurpose tree, (National Academy of Sciences, 1980).

2.3.3 Distribution:

A. nilotica (L) Willd Ex Del is a thorny wattle native to India, Pakistan and much of Africa. (Brenan, 1983). *Acacia nilotica* most commonly known as babla, is one of the most important tree species not only in India and Pakistan but also in 'the continent of Africa and many middle Eastern countries. It is probably indigenous to Sind, Uttar Pradesh, Gujarat and the Northern Deccan (Ghose, 2004). The species has also been introduced into the West Indies as an ornamental tree, (National Academy of Sciences, 1980).

In Australia it is regarded as one of the worst weeds because of its invasiveness, potential for spread, and economic and environmental impacts. It is widely distributed throughout arid and semi-arid zones of the world (Bargali et al., 2009).

2.3.4 Description:

Acacia nilotica (family Leguminosae, subfamily Mimosoideae) grows to 15-18 m in height and 2-3 m in diameter. The bark is generally slaty green in young trees or nearly black in mature trees.

The leaves are bipinnate, pinnae 3-10 pairs, 1.3- 3.8 cm long, leaflets 10-20 pairs, and 2-5mm long. Thin, straight, light grey spines present in axillary pairs, usually 3-12 pairs, 5-7.5 cm long in young trees, and mature trees commonly without thorns.

Flowers in globulous heads, 1.2-1.5 cm in diameter of a bright golden yellow colour, born either axillary or whorly on peduncles 2-3 cm long located at the end of branches.

Pods 7-15 cm long, green and tomentose when immature and greenish black when mature, indehiscent, deeply constricted between the seed giving a necklace appearance.

Seeds 8-12 per pod, compressed, ovoid, dark brown shining with hard testa, (Nature and Science, 2009).

2.3.5 Fuel characteristics:

The wood of *Acacia nilotica* is a very popular fuel both in the urban as well as rural area for heating and cooking (Ghose, 2004). It has a high calorific value of 4950 kcal/kg, making excellent fuel wood and quality charcoal. It burns slow with little smoke when dry. It has a 25% more shock resisting ability than teak, (Pandey and Sharma 2005). The wood is heavy with specific gravity of 0.67 to 0.68.

2.4.1 General information about *Tamarindus indica*:

Scientific classification: *Tamarindus indica* L.

Family: Fabaceae-Pea family

2.4.2 Common name:

Tamarinde (Africaans, French, Dutch), sbar, tamar hindi (Arabic), teteli (Assamese), asam koh (Chinese), tamarind (Danish, Swedish), humer, roka (Amharic), amli, nuli, tetul, tintiri (Bengali), magyee, majee-pen (Burmese), tamarenn (Creole), Madeira mahagony, Indian date, Indian date (English), ambali, amli (Gujarati), tentul, chinta, imli (Hindi), asam, tambaring (indonesian), asam, jawa (Malaysia), imli (Nepali), rakhai (Somali), puli, puliamavam, amliam (Tamil), traime (Vietnamese), tamarindo (Spnish, Italian, Japanese, Portuguese), bakham, makham (Thailand), tamarind (Trade name), tamarindipuu (Estonia), tamari hendi (Farsi), tintri, tintiddii (Sanskrit), imbli (Panjabi), (Coronel, 1991and Salim et al., 1998).

2.4.3 Distribution:

Native: Burkina Faso, Central African Republic, Chad, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Kenya, Madagascar, Mali, Mozambique, Niger, Nigeria, Senegal, Sudan, Tanzania, Uganda, Zimbabwe, (Orwa et al., 2009).

Exotic: Afghanistan, Australia, Bangladesh, Brazil, Brunei, Cambodia, China, Colombia, Cote d'Ivoire, Cuba, Dominican Republic, Egypt, Ghana, Guatemala, Haiti, Honduras, India, Indonesia, Iran, Jamaica, Laos, Liberia, Malaysia, Mauritania, Mexico, Myanmar, Nepal, Nicaragua, Pakistan, Panama, Papua New Guinea, Philippines, Puerto Rico, Sri Lanka, Thailand, Togo, United States of America, Vietnam, Zambia, (Orwa et al., 2009).

2.4.4 Description:

Tamarindus indica is a large evergreen tree up to 30 m tall, bole usually 1-2 m, up to 2 m diameter; crown dense, widely spreading, rounded; bark rough, fissured, greyish-brown. Leaves alternate, compound, with 10-18 pairs of opposite leaflets; leaflets narrowly oblong, 12-32 x 3-11 mm, petiole and rachis finely haired, midrib and net veining more or less conspicuous on both surfaces; apex rounded to almost square, slightly notched; base rounded, asymmetric, with a tuft of yellow hairs; margin entire, fringed with fine hairs. Stipules present, falling very early.

Flowers attractive pale yellow or pinkish, in small, lax spikes about 2.5 cm in width. Flower buds completely enclosed by 2 bracteoles, which fall very early; sepals 4, petals 5, the upper 3 well developed, the lower 2 minute.

Fruit a pod, indehiscent, subcylindrical, 10-18 x 4 cm, straight or curved, velvety, rusty-brown; the shell of the pod is brittle and the seeds are embedded in a sticky edible pulp. Seeds 3-10, approximately 1.6 cm long, irregularly shaped, testa hard, shiny and smooth. As the dark brown pulp made from the fruit resembles dried dates, the Arabs called it 'tamar-ul-Hind', meaning 'date of India', and this inspired Linnaeus when he named the tree in the 18th century. Tamarindus is a mono specific genus, (Orwa et al., 2009).

2.4.5 Fuel characteristics:

The wood of *Tamarindus indica* is a good fuel with a calorific value of 4850 kcal/kg, producing a great heat which is required mainly in brick making. The wood makes excellent charcoal (Chaturvedi, 1985). The ash of *Tamarindus indica* wood is used to remove hair from animal hides (Salim et al, 1998). Sapwood is light yellow; heartwood is dark purplish brown; very hard, durable and strong specific gravity 0.8-0.9g/cubic m, (Orwa et al., 2009).

2.5.1 General information about *Samanea saman*:

Scientific classification: *Samamea saman* (Jacq.) Merr.

Family: Fabaceae-Pea family

2.5.2 Common name:

Filinganga (Northern Merianas), gouannelgoul, saman (French), gumorni spanis(Yap), marmar (New Guinea), ohai (Hawaii), rain tree, monkey pod (English), tamalini (Samoa), sirsa (Fiji), acacia, pale de China(Phillipines), delmonty,(Spanish), (Staples and Elevitch, 2006).

2.5.3 Distribution:

Native: Northern South America, central America, Mexico, Colombia, Honduras, Panama, Costa Rica. In this areas, its occurs in low-elevation dry forests and grassland habitats

Exotic: American Samoa, Spain, Rota, Fiji, Papua New Guinea, Philippines, Bangladesh (Serajuddoula et.al, 1995), Bhutan (ILDIS,2002), Brunei, Cambodia (ILDIS,2002), India (1980), Indonasia (1870s), Myanmar, Pakistan (Athar and Mahmood, 1985), Singapore, Srilanka, Taiwan, Thailand, Veitnam, Benin (ILDIS, 2002), Burundi, Cameroon, Cenral African Republic, Congo, Gabon, Gambia (ILDIS,2002), Ghana (ILDIS,2002), Kenya (ILDIS,2002), Liberia, Malawi, Nigeria (ILDIS,2002), Rwanda, Aierra Leone, Sudan, Tanzania, Uganda, Zambia, Cuba, Haiti, Domonica, Argentina, Bolivia, Brazil, Peru, Australia, (Staples and Elevitch, 2006).

2.5.4 Description:

S. saman is a medium-sized or large tree of potentially great size, often reaching 25-30 m tall, occasionally 45 m, with a short stout bole to 2-3 m dbh and a wide, low, spreading crown, often twice as wide as the tree is high. It is a stately tree with heavy, nearly branches and an umbrella-shaped crown.

The bark is gray brown, rough and furrowed into ridges. A full botanical description is provided by (Barneby and Grimes, 1996).

Leaves are large, 6-25 mm long and 3-8 cm wide, bipinnate with 3-6 pairs of pinnae per leaf, 6-9 pairs of leaflets per pinna and large leaflets, 24-62 mm long and 10-25 mm wide. The new growth and leaf rachis are covered in short, velvety, tawny pubescence. The leaflets are rhombic-oblong or elliptic in shape, unequal at base, dark olive green, glabrous and slightly glossy above, dull grey-green and hairy below.

The flowers are arranged in loose umbelliform heads which develop in groups of 2-5 in the axill of leaves on actively growing shoots. The terminal or central flower on each head is sessile and enlarged compared to the peripheral flowers.
The fruits are broadly linear, compressed pods 10-22 cm long and 1.5-2.2 cm wide and 0.5-1 cm thick. They are green and fleshy when unripe and turn dark blackish-brown pulp. The pods are indehiscent and contain 5-10 mature seeds that is 8-11.5 mm long and 5-7.5mm wide, (Staples and Elevitch, 2006).

2.5.5 Fuel characteristics:

The wood of *Samanea saman* produces 5200-5600 kcal/kg calorific values when it burns and it is a source of high quality firewood and charcoal, (Mondol, 2011). Therefore, this study was undertaken to evaluate the fuelwood characteristics of four selected species and indicated that which tree species are better suited as fuelwood species among the four species.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Sample collection:

Four tree species were selected according to its local use as fuelwoods from wood vendors in Jhenaidah districts. 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 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, extractive, cellulose, hemicelluloses and lignin content of the wood etc.

3.2 Sample preparation:

Then, in the sawmill, the logs were converted into 8×2×2 cm^3 wood block for the determination of moisture content, density and also into some wood powder for the determination of ash content, calorific value, extractive, cellulose, hemicelluloses and lignin content 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. 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-

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

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). 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. 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, approximately 1g of oven dry wood powder of per sample was tested from the laboratory of Khulna University of Engineering Technology, KUET.

3.6 Determination of Extractives, Cellulose, Hemicellulose and Lignin content:

The content of cellulose, hemicellulose and lignin in lignocellulosic biomass samples will be calculated according to the experimental method reported elsewhere (Yang et al., 2006).

Extractives: The determinations of the amount of extractives were carried out by solvent extraction (100ml acetone for 1g of dried biomass sample) at 60°C. Then the biomass sample was dried (110°C) until a constant weight. The solid residue was then cooled to room temperature in a drier and weighted. The weight difference of before and after of the extraction was the amount of extractives.

Hemicellulose: The hemicellulose content was determined by adding .5g of extractive-free dried biomass sample to a 150 ml of NAOH solution (20 g/l) and boiled for 3.5 h with recycled distilled water. The residue was filtered and washed to remove Na+. After the washing the residue was dried and weighted. The amount of hemicellulose was calculated by the weight difference of before and after of this treatment.

Lignin: The determination of lignin was performed by Klason method. In this method, 15 ml of H_2SO_4 (71%) was added to .5 g extractive-free dried biomass sample. The mixture was then heated and stirred for 2h. After that, the mixture was diluted to 4% H_2SO_4 concentration. The resulting mixture was boiled for 4h with recycled water. The residue was filtered, washed and dried. The weight difference after and before the treatment was the amount of lignin.

Cellulose: The amount of cellulose was calculated from the weight difference of extractives, hemicellulose and lignin.

3.7 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 muffle furnace at 450°C for four hours according to ASTM standard Method Number 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-

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

3.8 Determination of Fuel Value Index, FVI:

The fuelwood value index (FVI) was calculated by following method (Purohit and Nautival, 1987) –

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

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Extractives, Cellulose, Hemicellulose and Lignin content of the species:

In the present study, Table-1 presents the extractive, cellulose, hemicelluloses and lignin content of the four species. In (Nasser et al., 2014), it was demonstrated that, statistically, all of the extractive, cellulose, hemicelluloses and lignin content showed significant differences from each other among the species. In present study, it can be clearly seen that, the selected four different species presented different value 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) >*Leucaena leucocephala* (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). Normally the extractive, cellulose, hemicelluloses and lignin content for wood ranges from according to 2- 6%, 45-50%, 15-35% and 23-30 in tree species (Fengel et al., 1993). But in present studied, the extractive, cellulose, hemicelluloses and lignin content of the samples ranged from according to 1.34-5.05%, 41.6-48.45%, 19.35-29% and 24.5-37.25%. It can be seen that, the *Tamarindus indica* had higher lignin content than normal range of wood species (Table 1).

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

Species	Wood Component %			
	Extractives(%)	Cellulose(%)	Hemicelluloses(%)	Lignin(%)
Leucaena leucocephala	5.05	48.45	19.35	27.15
Acacia nilotica	3.34	47.27	24.9	28.1
Samania saman	5	41.6	29	24.5
Tamarindus indica	1.34	41.42	20	37.25

Table 2: Fuelwood characteristics of four tree species of Jhenidah District in Bangladesh

Species	Moisture Content %	Density (g/cm^3)	Ash content %	Calorific Value (kJ/g)	FVI
Leucaena leucocephala	57.45	0.653	1.09	19.165	1998.51
Acacia nilotica	48.88	0.749	1.12	19.179	2623.97
Samania saman	47.74	0.627	1.99	17.036	1124.35
Tamarindus indica	40.05	0.820	2.21	16.338	1513.62

4.2 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 0.1% 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 other wood species (Chow and Lucas, 1988). A study was carried out which reported that the wood of *Leucaena leucocephala* burns steadily with little smoke, few sparks and produces less than 1% ash (Devi et al., 2013). A study was carried out from (Puri et al., 1994) where the ash content of *Acacia nilotica* was 2.1%. A study was carried out from (Kumar, 2003) where the ash content of *Tamarindus indica* was 2.13 and *Samanea saman* was 1.56 in heartwood.

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).

Therefore, these trees absorb more mineral elements from soil and store them cell wall and cell cavities. That's why, they exhibits more ash content percentages than normal range of ash content percentages. 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 unfavourable 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, 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).

4.3 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 the available heat of combustion. A study was carried out from (Kumar, 2003) where the moisture content of *Tamarindus indica* was 41.2% and *Samanea saman* was 57.25 in heartwood.

Table- 2 showed that, among the four tree species studied highest percentage of moisture content was recorded 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 the present study, *Tamarindus indica* exhibited high density wood with low MC%.

4.4 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 lignifications 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, 2001).

In the present study, highest wood density was observed in *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) (Table 2).

4.5 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. The species which had a high amount of volatile matter, resin, wax and lignin had greater energy content (Howard, 1973; Koch, 1972; Harder and Einspahr, 1976).

High calorific values may be due to high concentration of extractives and lignin content in wood (Kataki and Konwer, 2001; 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 studied, of all the four selected tree species, exhibited highest calorific values in order of *Acacia nilotica* (19.179)> *Leucaena leucocephala* (19.165)>*Samanea saman*(17.036)> *Tamarindus indica* (16.338) (Table-2).

4.6 Ranking based on FVI:

The FVI is an important characteristic for screening desirable fueclwood species (Purohit and Nautiyal, 1987; Jain, 1993). FVI of four tree species of present studied was in order of *Acacia nilotica* (2623.97) > *Leucaena leucocephala* (1998.51) >*Tamarindus indica* (1513.62) > *Samanea saman*(1124.35). Of all the four observed tree species, highest FVI was recorded in *Acacia nilotica* (2623.97) due to higher calorific value as compared to other species.

Therefore, out of four tree species of present studied, this tree may be regarded as the best quality of fuelwood species followed by *Acacia nilotica* > *Leucaena leucocephala* >*Tamarindus indica* > *Samanea saman*.

4.7 Relationship between FVI and other properties:

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

Table-3 showed that, cellulose, hemicelluloses, lignin, extractives, 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 is increases, then the value of FVI will be decreases. Here, two tailed test of significance is used. Ash is considered as an undesirable material in most industrial situation. 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 (Nessar et al., 2014). Because, the result of (Nessar et al., 2014) also showed a highly negative significant effect with heating value (r= -0.87). In present studied, species with high ash percentage such as, *Tamarindus indica, Samanea saman* yielded lower heat values than others. Although, (Bhatt and Todaria, 1992) and (Kataki and Konwer, 2001) too recorded decreasing heat of combustion with increasing ash percentage in their study.

CHAPTER FIVE

CONCLUSION

The results of this study emphasize that, the calorific value should not be the only factor to be taken into account when evaluating fuelwood, but extractive, cellulose, hemicellulose, lignin, ash content, density and negative environmental impact should also be considered. 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* shown the lowest density, cellulose and lignin content but they have relatively high extractive content than *Acacia nilotica and Tamarindus indica*.

Considering the FVI value, In the present study, the preferred wood species are *A. nilotica* followed by *L. leucocephala, T. indica and S. saman* which would constitute a viable wood species to be specifically planted as fuelwood.

This study also revealed the highly negatively significant correlation between FVI and ash content.

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