FUELWOOD CHARACTERISTICS OF SOME INDIGENOUS TREE SPECIES OF ASSAM

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In
the memory
of
my Late Father
who left us on June 3, 2000

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CERTIFICATE

This is to certify that the matter embodied in the thesis entitled ***'Fuelwood characteristics of some indigenous tree species of Assam'*** by Sri Dhanapati Deka for the award of degree of Doctor of Philosophy of Tezpur University is a record of bonafied research work carried out by him under my supervision and guidance. The results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Date: 29.3.2004

Prof. D. Konwer

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Dhanapati Deka

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INTRODUCTION

Energy is an essential input for industrial and economic development and for improving the quality of life. The world population is growing fast and the people of the world are demanding more and more energy since they aspire to raise their standard of living. The nations consuming more energy per capita have better living standards than the others. Until the 18th century almost all energy used by man was supplied locally from traditional energy sources such as human and animal power, wood, dung, crop residues, charcoal, peat, coal and the utilization of wind and water power. Before man has started using petroleum, coal was the major source of energy. It became the foundation upon which early industrial society was built. But in the last few decades petroleum has captured a larger market share and it rivaled coal as a source of energy. At present petroleum and natural gas provide more than 55% of the total world energy demand. But by now we all are fully aware of the fact that world's production of petroleum and natural gas will start to decrease in one or two decades and the world's petroleum resources are expected to last only for next 30 - 40 years. As the substitute of the fossil fuels, the use of various new and renewable sources of energy such as biomass energy, solar energy, geothermal energy, ocean energy, wind energy, biogas, chemical energy, hydrogen energy etc. are getting more and more importance all over the world.

The most obvious renewable source of energy is the sun itself and the best solar energy-converting machine available is the green plant. The solar energy incident upon the earth can be used for the direct biological processes of photosynthesis. In the process of photosynthesis solar energy absorbed by green plants provides energy to reduce carbon dioxide and forms carbohydrates, which are then utilized as energy sources and raw materials for all other synthetic reactions in the plant. Thus solar energy is captured and stored in the plants in the form of chemical energy. Stored plant energy may be released by burning it directly or various processes such as thermochemical gasification, pyrolysis, hydrolysis, fermentation to ethanol, esterification to biodiesel, biomethanation etc. may be utilized to obtain potential fuels.

Wood as fuel

To-day, fuelwood has become a recognized source of energy, and demand will increase enormously in the coming decades. Indeed, wood products arc likely to continue as the most important universal fuel for rural areas of developing countries. Wood is renewable and its production can be sustained. And this could be donc fairly inexpensively without masses of foreign exchanges. Since energy for rural development has become one of the most crucial issues, fuelwood is beginning to enter the mainstream of national and international priorities and policies. Many government ministries other than forestry have become interested in funding tree growing. Development-assistance agencies have also shown a new awareness of the importance of trees. All over the world foresters and even national political leaders are beginning to recognize the need to integrate forestry into rural development in new ways. The US

Congress has directed the Agency for International Development (AID) to give emphasis on forestry and firewood plantations in its rural development programmes. The World Bank, the world's largest lending institution, has announced its intention to multiply its support for such activities as village woodlots, farm forestry and environment rehabilitation.

Fuelwood is not limited to household use. Large energy plantations are planned in many countries to fuel machines such as electric generators, railroad locomotives, driers for fish, tobacco, grain, and other agricultural products, factories milling sugar, timber or other materials, pottery, brick, charcoal and limestone kilns and metal smelters.

Fuelwood production can be good for economic development in rural areas. Growing trees for fuelwood can be successfully combined with the production of posts, poles and timber. The production and sale of fuelwood to nearly urban centers can provide many jobs and much rural cash income.

A logical response to the fuelwood situation is to plant more trees. All countries of the world have some unused or misused areas, which are not used for conventional agriculture. The best use of such areas is tree cultivation.

Fuel production has long been considered the lowest use of wood, and foresters have traditionally cultivated trees primarily for other purposes such as timber, pulpwood, post and pole. For these products, the species needed to grow are not those that would be grown purely for fuel. Fuelwood planting can use species with short boles, crooked trunks or wood that splits as it dries. Shrubs may also prove satisfactory for village fuelwood silviculture if it grows fast and produces a dense wood that burns with intense heat. In practice, fuelwood may come both as a primary crop from fuelwood forests and as a secondary crop from timber forests.

In addition to fuel, woodlots in an around villages and cities can provide stable and pleasant surroundings. They provide shade, shelter, beautification and habitats for a variety of wildlife. The plantation also reduces soil erosion, influence local temperature and humidity. Woody plants, besides providing fuel calories, can also be source of vegetable oils and fruits and nuts for food, forage for livestock and silkworms; edible leaves and shoots for sauces, curries, salads, honey, green manure for fertilizing soil, medicines and pharmaceuticals, extractives such as resins, rubber, gum and dyes, timber, lumber, posts, poles and pulp for paper, tanbark for tannin used in leather industries, shade for plantation crops such as coffee and cocoa etc..

Trees for fuelwood can be planted in 'nonforest' areas such as along roadsides, in shelterbelts, on farms, on unused land and in schoolyards, churchyards, market squares, parks and home gardens. For plantation of trees the correct spacing is important for production, but it is necessary to assure geometric precision, as is required where mechanized equipment must pass between them. Fuelwood plantations, if carefully managed and protected from fire, animals etc. can be self-renewing. They are usually managed as rotations of about 10 years. The timing varies with the quality of the soil, species used, temperature, moisture available and intensity of cultivation. Rotations of less than 5 years seem feasible in many areas, especially for those species that regenerate by sprouts.

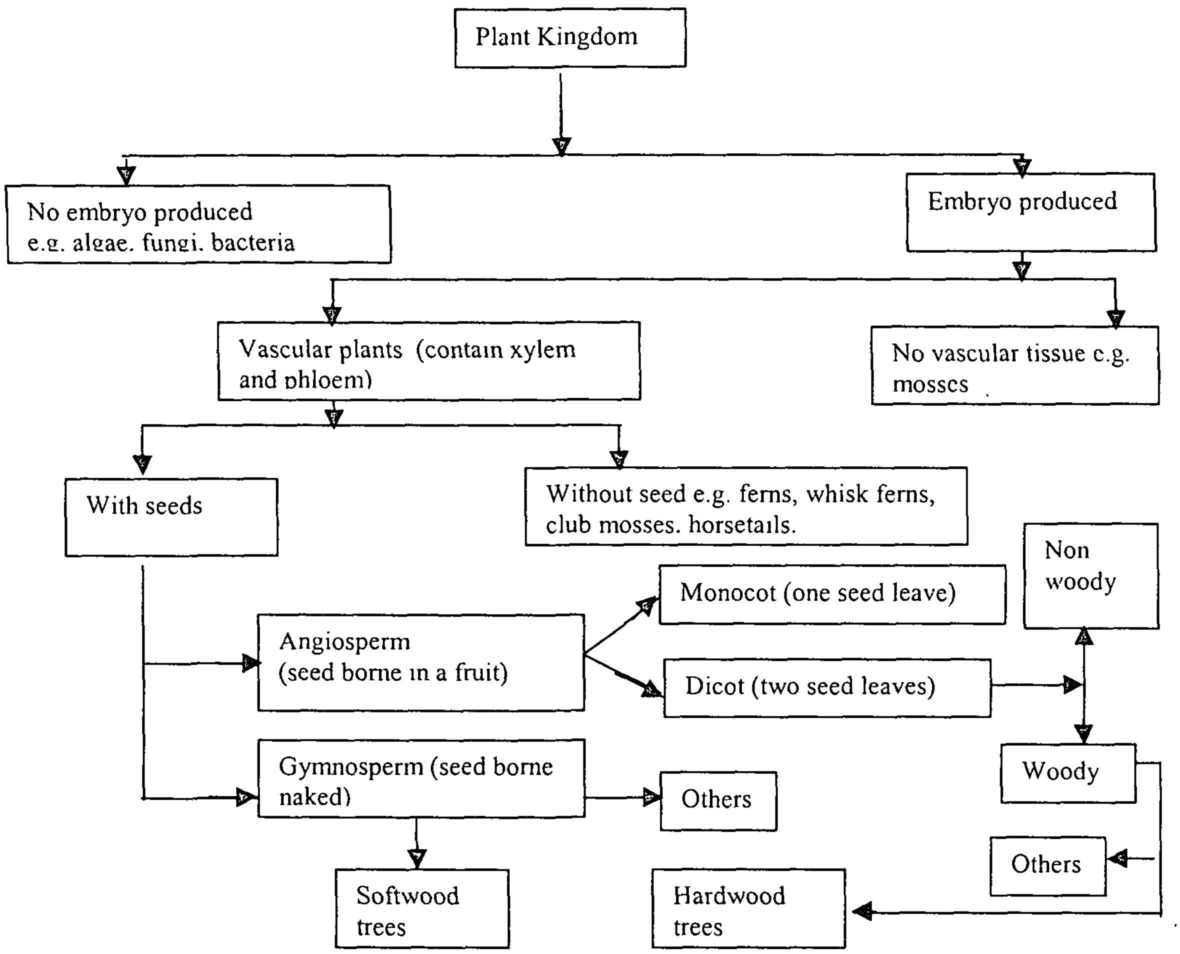
Properties of wood as fuel

Wood, a natural, cellular, composite material of botanical origin possesses unique structure and chemical characteristics that render it desirable for a broad variety of end uses (Parham *et al.*, 1984). In order to understand the utility and behaviour of wood as energy source, it is essential to define these anatomical, physical and chemical properties of wood. Anatomical characteristics of importance include the structure of wood fibers and the pathways for moisture movement. Physical properties of interest include moisture content, specific gravity, void volume and thermal properties. Chemical characteristics of importance include the summative analysis (holocellulose and lignin content), proximate and ultimate analysis and higher heating value.

The anatomical, physical and chemical properties of wood need to be understood before any thorough treatment of material handling and combustion theory can occur. Anatomical properties identify the macroscopic structures of softwood and hardwood. Physical properties deal with the relationship between specific gravity and moisture content. Chemical properties refer to carbohydrate and lignin structures and their contents as related to fuel reactivity and heating value (Tillman *et al.*, 1981).

Softwood and Hardwood structures

Wood is obtained from two board categories of plants known commercially as softwood and hardwood. These general names cannot be used universally to refer to the actual physical hardness or density of all woods because some softwoods are quite hard (e.g. Dougla-fir and Southern yellow pines) and some hardwood are soft (e.g. Cotton wood.). From a more scientific perspective, softwoods are tree species of a class of plants called gymnosperm (seeds are borne naked and hardwood are woody, dicotyledonous (two seed leaves) angiosperm (seeds are borne in a fruit structure). Hardwoods have leaves that are generally broad or bladelike and most commercial species at least in temperate climate are deciduous, which means they commonly shed their leaves each fall at the end of the tree's growing seasons (Scheme 1). In soft wood, the cells making up 90-95% of the wood volume are fibrous in form (morphology) and are thus termed fibrous. Hardwoods, on the other hand, are composed largely of fibers and much wider cells called vessel elements. The vessel elements are joined end-wise to tubes or vessels along the stem, branch or root and are seen as pores on the wood cross section (Fig.1).



Scheme1: Botanical origin of commercial wood (Parham *et al.*, 1984)

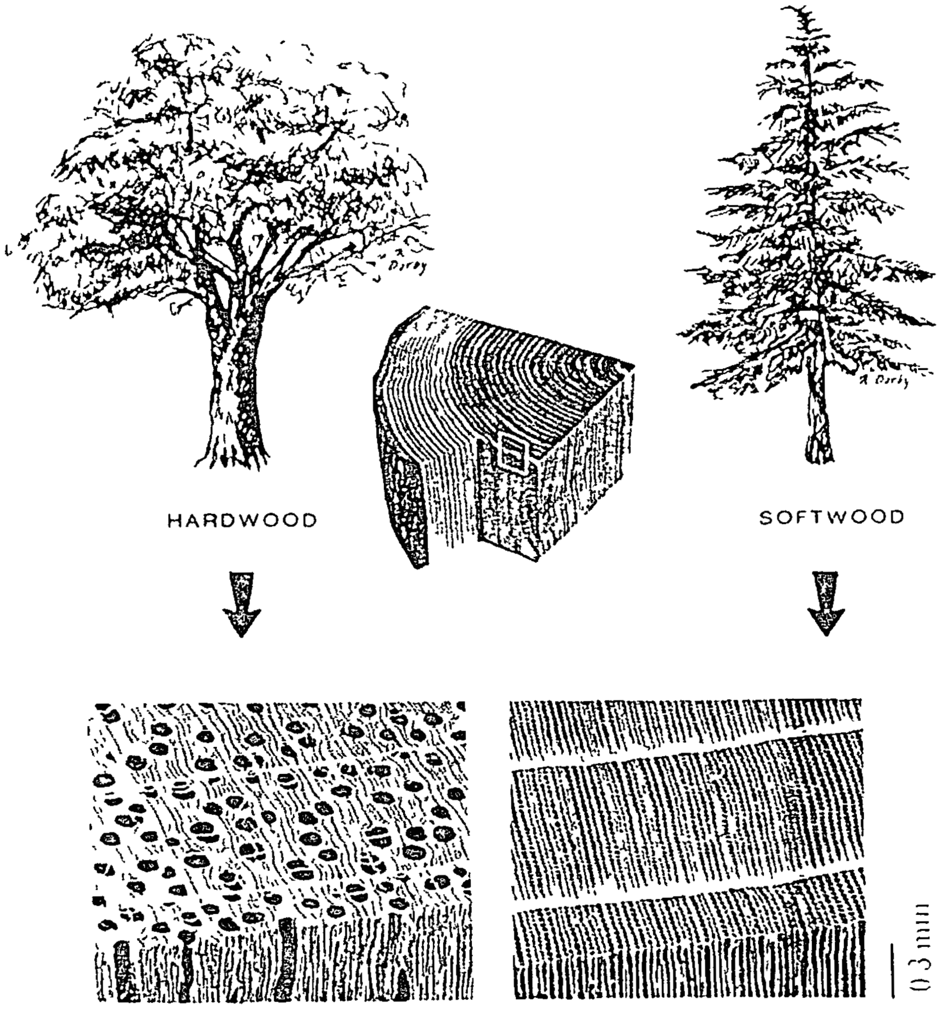


Figure 1 Cross section of softwood and hardwood structure showing pores of vessel element of hardwood and trachide of softwood

As chemical and physical compositions of softwoods and hardwoods are different, their chemical nature or reactivity of wood tissue at cellular level potentially influences the use of tree species for various end uses.

Physical properties of wood

Hygroscopicity

Wood is hygroscopic in nature and absorbs water. Water is absorbed by capillary uptake in the lumen of the wood structure; this absorbed water is known as free water. The sorption of water into the wood microstructures is adsorption and adsorbed water is called 'bound water' (Tillman *et al.*, 1981). As a consequence of its hydrophilicity, wood tissues seek to maintain, through either gain or loss of moisture, an equilibrium moisture content with the surrounding atmosphere. If the wood takes on water, the cell walls proceed to swell until the cell walls reach the wood's fiber saturation points. If water is lost below the fiber saturation points due to diffusion and evaporation, the result is wood shrinkage (Parham *et al.*, 1984).

Moisture content

Moisture content is the most commonly used property of fuelwood. Its quantity is inversely proportional to the amount of heat that is recovered from conventional combustion where the latent heat of evaporation is lost with flue gases. Moisture content of wood varies over a wide range. Originally a living tree acquires its moisture through water uptake from the soil. It is found as bound water in cell walls and free water in cell lumen of both wood and bark. The moisture content varies from one tree part to another. It is often the lowest in the stem and increases towards the roots and the crown. Seasons are also known to effect moisture content (Hakkila, 1962). When a tree is felled the water supply is cut off and the tree slowly comes to equilibrium moisture content with the ambient air. The equilibrium moisture content depends on the temperature and relative humidity of the ambient air (Nurmi, 1992).

Moisture content of wood is typically reported as percent moisture content oven dry and percentage moisture content green. Sometimes moisture content in air dry wood is also determined (Skaar, 1972).

MC_{OD}= Weight (H_2O) / Weight (dry wood matter)	OD—oven dry
MC_G = weight (H_2O) / [Weight (dry wood + weight (H_2O)]	G — green
MC_{AD} = Weight (H_2O) / Weight (air dry wood.)	AD—air dry

Density and Specific gravity

One chief drawback of woody fuels is their bulkiness. This bulkiness makes storing, handling and shipping difficult and also reduces the efficiency of burning due to the low heat value to mass/volume relationship. To minimize this drawback, heavy woods are desirable for fuel, which are expressed in terms of wood density or specific gravity. Wood's buck density – the mass or weight of wood per unit volume, are usually expressed as grams per cubic centimeter or kilograms per cubic meter (Panshin *et al.*, 1980). It is difficult to determine the bulk density of the woody material as the weight and volume of wood tissue change with its moisture content.

To circumvent these problems, a special or artificial parameter known as basic density is used. It is an artificial parameter because the weight and volume requirements needed for its calculation are made an extremely difficult wood condition—the completely dry (or oven dry) state for volume measurement. In this way, even though wood changes in weight and volume with changes in moisture content, measurement of weight and volume of a given sample are possible at conditions that are as nearly constant and reproducible as can be obtained with wood tissue. With this measurement, basic density of different wood sizes is possible.

Basic density of wood can also be expressed as basic specific gravity of wood. The specific gravity is the weight of any given volume of a substance divided by the weight of an equal volume of water (Panshin *et al.*, 1980). As both the weight and volume of wood vary with the amount of moisture contained in it, specific gravity as applied to wood is an indefinite quantity unless the condition under which it is determined is clearly specified. The specific gravity of wood is generally based on the weight when oven dry, but the volume may be that in the oven dry, partially dry (air dry) or green condition.

$$\text{Basic specific gravity} = \frac{\dfrac{\text{OD weight}}{\text{Basic density}}}{\text{Density of water}} = \frac{\text{Green volume}}{1} = \frac{\text{OD weight}}{\text{Wt. of displaced water}}$$

Though the term basic density and basic specific gravity give the same information but they are different only in the fundamental sense that basic specific gravity is a pure number and basic density is not.

In soft wood, basic density is strongly related to the volume proportion of late wood and its average fiber wall thinness. However, hardwood basic density depends not only on fiber wall thickness but also involves the volume ratio of fibers to vessel. Native commercial wood falls mostly in the basic density ranges of 0.35 - 0.65 g/cm^3, although basic density of native hard wood species can be as low as 0.21g/cm^3 and as high as 1.04 g /cm^3 (Panshin *et al.*, 1980).

Woods with basic density values that fall in the range of < 0.36, 0.36 - 0.50 and > 0.50 g /cm^3 are considered light, moderately light to moderately heavy and heavy respectively and include both temperate and tropical woods (Panshin *et al.*, 1980).

Chemical Properties of wood

The chemical composition of wood cannot be defined precisely for a given tree species or even for a given tree. Chemical composition varies with tree parts (root, stems or branches of wood), geographic location, climatic and soil conditions (Pettersen, 1984).

Chemically, wood is made up of cellulose, hemicellulose, lignin, extractives and ash-forming minerals. Cellulose microfibrilla embedded in a matrix of hemicellulose and lignin, form the plant cell wall and main components of biomass. A short introduction to the chemical wood components follows the general scheme in Fig.2.

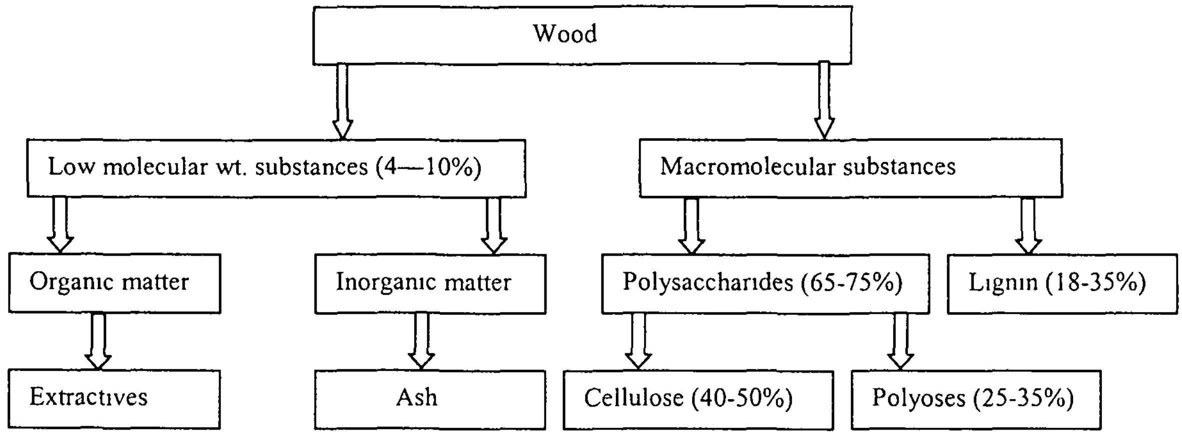


Fig. 2: General scheme of the chemical wood components (Fengel *et al.*, 1984)

The ultimate and proximate analysis of wood samples is also the reflection of the status of wood as fuel. A typical analysis of dry wood yields carbon (52%), hydrogen (6.3%), oxygen (40.5%) and nitrogen (0.4%) (Demirbas, 2001a). The combustion characteristics of the wood fuel can be better judged for its heating value and air born emission with the ultimate analysis values. Higher percentages of carbon and hydrogen give higher heating value. Higher percentage of nitrogen gives higher amount of NO_x as air born emission.

Wood fuel characteristics also differ according to its proximate analysis components. Demirbus (2000) reported the components of proximate analysis of wood and wood bark as follows:

Wood: Volatile matter (80%), fixed carbon (19.45%) and ash (0.6%).

Bark: Volatile matter (74.7%), fixed carbon (24%) and ash (1.3%)

Coal has substantially less volatile matter while having more fixed carbon and ash than wood and bark. The large amount of volatile matter associated with wood is a result of the high number of functional groups and the low number of aromatic structures in it. Thus combustion makes wood more reactive as compared to coal. Wood has substantially less ash content than coal. Ash-forming minerals in wood usually are calcium, potassium and silica (Wenger, 1984).

Macromolecular substances of wood

Carbohydrate

The carbohydrate portion of wood comprises of cellulose and hemicellulose. Cellulose content ranges from 40 - 50% of the dry wood weight and hemicellulose ranges from 25 to 35%.

Cellulose

Cellulose is one of the major wood components making up approximately one half of both soft wood and hard wood. It can be briefly characterized as a linear high-molecular weight polymer built up exclusively by β-D-glucose. Because of its chemical and physical properties as well as its super molecular structure, it can fulfill its function as the main structural component of the plant cell walls (Fig. 3).

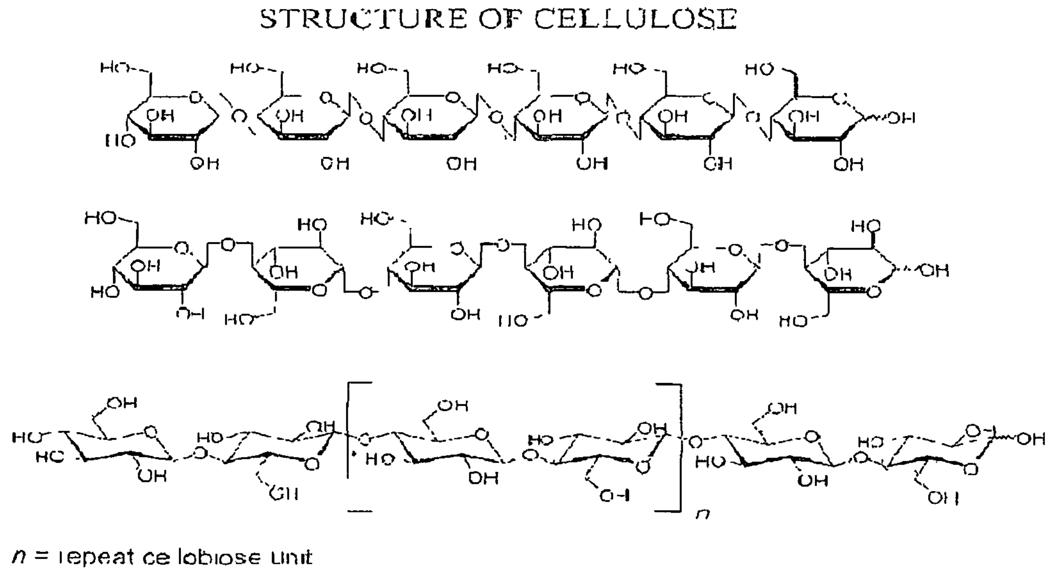


Fig. 3: Structure of cellulose

Cellulose is insoluble in the most solvents including strong alkali. It is difficult to isolate cellulose from wood in a pure form because it is intimately associated with lignin and hemicellulose.

Hemicellulose

Hemicellulose is in closed association with cellulose in the cell wall. Five neutral sugars, the hexoses - glucose, mannose, galactose and the pentoses - xylose and arabinose are the main constituents of the polyoses. Some polyoses contain additional uronic acid such as 4-0-methylglucouronic acid and galacturonic acid residues. Generally, hemicelluloses are of much lower molecular weight than cellulose, having side groups and being branched in some cases (Fig.4).

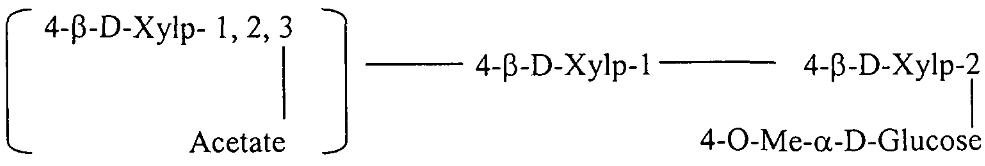
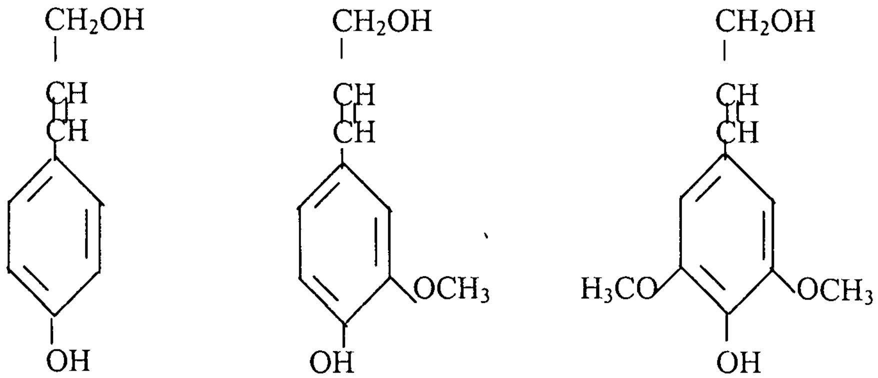


Fig.4: Branching pattern in hemicellulose structure.

Hemicellulose is soluble in alkali and easily hydrolysed by acids. Hardwood contains more percentage of hemicellulose than softwood.

Lignin

Lignin is the third macromolecular wood component. The molecules of lignin are built up quite differently from those of the polysaccharides, as they consist of an aromatic system composed of phenylpropane units. The precursors of lignin biosynthesis are p-coumaryl alcohol (I), coniferyl alcohol (II) and sinapyl alcohol (III).



I II III

Fig. 5: The precursors of lignin biosynthesis

Coumaryl alcohol is a minor precursor of softwood and hardwood lignin. Coniferyl alcohol is the predominant precursor of softwood lignin and sinapyl alcohol is the precursor of hardwood lignin. The most common system of molecular organization of lignin is by β-O-4, β-5 and β-β linkages where 5-5, β-1 and 4-0-5 linkages are also present.

There is more lignin in soft wood than hardwood and there are some structural differences between hardwood and softwood lignin. In most cases, wood properties are related to the shape, orientation, size and frequency of the structural elements of lignin in wood. Softwood lignins are insoluble in 72% H_2SO_4 and Klason lignin provides an accurate measure of the total lignin content. Hardwood lignins are somewhat soluble in 72% H_2SO_4 and acid soluble lignin portion may be 5-10% of the total percentage of lignin.

Extraneous Components

The extraneous components (extractives and ash) in wood are the substances other than cellulose, hemicellulose and lignin. They do not contribute to the cell wall structure and most are soluble in neutral solvents.

Extractives-the extraneous materials soluble in neutral solvents constitute 4-10% of the dry weight of normal wood species that grow in temperate climates. They may be as much as 20% of the wood of tropical species. Extractives are a variety of organic compounds including fats, waxes, alkaloid, protein, simple and complex phenols, simple sugars, pectin, mucilage, gums, resins, terpens, saponins and essential oils. Many of these components function as intermediates in tree metabolism, as energy reserves or as part of the tree's defense mechanism against microbial attack. They contribute to wood properties such as color, odor and decay resistance.

Ash is the inorganic residue remaining after ignition of biomass materials at a high temperature. It is usually less than 1% of wood from temperate zone. It is slightly higher in wood from tropical climate.

Energy value of wood fuel

The energy content of different plant materials determines their calorific value (heat content). This value depends in the percentage of carbon and hydrogen, which are the main contributors to the heat energy value of a biomass material.

Calorific value of fuel

The calorific value of a combustible material as determined is the heat liberated during complete combustion of its unit mass with oxygen and the condensation of the products to the temperature of determination. The value may be expressed in any standard heat units, but the basic unit is the Joule (10^7 erg). Three different conventions are commonly used in deriving the heating value of biomass fuels: (1) gross calorific value (2) net calorific value and (3) usable heat content.

Gross Calorific Value and Net Calorific Value

When a fuel containing hydrogen is burnt, water is invariably produced; if this water is condensed it gives up its latent heat, as steam together with the heat liberated on cooling from its condensation point to the temperature of the calorimeter. The total calorific value, gross or higher heating value of a fuel is the number of heat units liberated when unit weight of fuel (or unit volume, in the case of gases) is burnt and the products of combustion are all cooled to 60^0F, the water vapor in them being condensed. In many cases, however, this heat carried by the waste product from hydrogen during combustion or stirred in water evaporated from the fuel, is not available for conversion into work. Thus it plays no part in raising the flame temperature of burning gases, or in developing energy in a gas engine. For all such computation it must be eliminated, and the value after this deduction is termed as the Net Calorific Value. The definition is similar to that of the gross value expect that whilst the products are assumed to be cooled to 60^0F, the water vapor does not condense and give up its latent heat.

In the standard test procedure, wood samples are usually oven-dried before calorimetric analysis. Values thus derived are Gross anhydrous CVs. Published anhydrous CVs for wood range from 18.0 MJ/ Kg to 24.0 MJ /Kg. But CV varies by species and tree components and is higher for resinous conifers (typically 20.0 - 23.0 MJ/Kg) than for hardwood species (typically 18.5-20.0 MJ/Kg). An average anhydrous calorific value for wood of 18.6 MJ/Kg is cited in Fuel Handbook and is used as a basic reference value (Lyons *et al.*, 1985).

Usable heat content

Gross and net calorific values are useful measures of a fuel's energy content. But, in practice, they do not represent the heat energy, which can ultimately be recovered when fuel is burned in a combustion chamber. In calculating the net calorific value, it is assumed that the gaseous products of combustion are discharged at ambient temperature (25^0C), so that no heat is lost except the latent heat of moisture vapor (typically 200^0C in an efficient furnace), and energy is lost in (1) superheated moisture vapor; (2) dry flue gases and (3) any excess air. These losses must be accounted for determining the usable heat content (or renewable heat energy) of wood fuel.

Combustion quality of fuelwood

Heat of combustion is the most fundamental property in connection with the fuel quality and therefore, it is frequently thought of being the best means to compare one fuel with another. Because combustion is an oxidation reaction, the amount of heat liberated for a combustion process is related to the reduction state of the fuel. Thus, the heat of combustion is dependent upon the chemical make up of the fuel both at the molecular and atomic levels. This would account for the extremely high heat of combustion value for aliphatic hydrocarbons—high H : C ratio and absence of oxygen atoms. For the various components in the wood, the reduction state is in the following order: resins > lignin > cellulose and hemicelluloses. Normally, substances rich in reduced components give a high heat of combustion value. Thus, the heat value of woody material is generally modified to some extent by the amount of resinous extractives.

Combustion quality of fuelwood is also dependent on its moisture content. Presence of moisture in the fuel does not change its higher heating value, but the usable heat per unit mass does change – reduce for the following reasons: Firstly, there is simply less combustible substance per unit weight of fuel. Secondly, fuel moisture also causes heat loss during the combustion, because some energy must be consumed to vaporize the water. Thus, the available heat produced during the combustion of fuel is diminished.

Inorganic minerals (ash, after combustion) are non-combustible and their presence in wood has an adverse effect on the heat of combustion because they reduce the heating value of per unit weight of the fuel. Wood ash generally has been considered inert. Carbon residues should not be a problem if combustion is efficient and has no effect on the fuel quality. However, in boiler furnaces, where high burning temperature are achieved, slag and clinkers are formed from the melting and fusion of ash. Thus, tree species having high ash content are less desirable for industrial fuelwood.

In terms of potential air pollution, the quality of fuel is altered to some extent by its emission. In wood combustion, SO_2, CO and hydrocarbon emissions are negligible or limited and they generally present no problem at current practices. Nevertheless, small amount of NO_x occurs if fuel contains a significant amount of nitrogen. Hence, material having high nitrogen content like some hardwood foliage is less acceptable for fuel (Wang *et al.*, 1982.).

Fuelwood demand and supply in India

Fuelwood occupies a predominant place as an energy source for heating and cooking in rural India. The National Commission of Agriculture (1976) estimated that fuelwood, agricultural waste and animal dung constituted the major biomass energy sources in India accounting approximately 90% of the energy consumed in households. The major portion of this i.e. about 85% (62% wood fuel, balance 23% agricultural waste and cowdung) was consumed in villages. At national aggregate level, fuelwood and charcoal (from wood) accounted for 46% of the total energy consumed in India (NCAER, 1985). Forest Survey of India (FSI, 1988) in its report of 1987 estimated an annual demand of fuelwood at the level of 222 Mt. The Planning Commission study group (1991) on fuel for VIII plan estimated the demand of fuel wood during 1991, 1996 and 2001 as 306.4, 342.8 and 383.58 Mt respectively. Rural Energy Data Base prepared by Tata Energy Research Institute (TERI) in 1991 indicated the consumption demand of firewood in India was 252.1 Mt/year. As such there has been considerable variation in the assessment of fuelwood requirement of the country. A policy paper prepared by the Ministry of Environment and Forest in 1992 indicated that the unrecovered removal of fuelwood from forests was amount to be around 220 Mt/year.

Presently, in India, the fuelwood requirement is fulfilled from managed and unmanaged forests and through imports. About 70% of the requirement is fulfilled from collected fuelwood from the forests and nearby sites. When fuelwood at nearby sites is exhausted, villagers go tapping the distance forests. Woman and children mainly do collection of wood. It is brought from a distance on head, shoulder or back and about 50Mt of woods are removed from the forests every year in this way (Anon, 1986-87). The availability of fuelwood from the forests is continuously declining at an ever-increasing rate due to indiscriminate deforestation and slow regeneration as well as afforestation. According to official forestry figures, the area under forests is approximately 75mha of which no more than 30-32mha is considered to have optimum tree cover. The rate of depletion of forest is nearly 1.5mha per annum. At this rate of deforestation, the remaining forest resources are expected to rapidly beckon exhausted if the plantation programmes are not intensified. According to the fuelwood committee report of the Planning Commission (Anon, 1984) and Central Forestry Commission (Anon, 1992), the availability of fuelwood from forests was estimated to be 45 Mt in 1990, against the projected demand by different estimations was around 220 Mt. As reported by Ravindranath *et al.* (1995), the source of fuelwood can be forests, degraded forests, tree plantations, strips or rows of trees along road sides, streams, railway lines, canals, crop land boundary and bunds (separating small plots), common land and homestead garden. The annual use of fuelwood is estimated to be 227 Mt/yr, out of which 181 Mt is used in the domestic sector for cooking in rural areas. The total contribution of forests to meet the fuelwood demand is estimated to be 70.5Mt, out of which only 27 percent is expected to come from the felling trees, possibly leading to deforestation.

So, there has been a big gap between demand and availability of fulewood in India, which can be alleviated by increasing the fuelwood quality and quantity.

Selection of promising tree species for energy plantation

Indeed almost all kinds of trees and shrubs are used as fuelwood. But, efforts to increase energy self-sufficiency, promoted at local, national and international level have included the development of high density, short rotation fuelwood plantation on public and private lands. Both exotic and indigenous tree species are planted under afforestation and social forestry programmes without having exact information about their energy status. A systematic approach to produce much needed fuelwood is to evaluate the performance of various tree species under varying agro-ecological conditions of the developing countries (NAS, 1980). The plant species selected for the fuelwood purpose should have (a) multiple uses, (b) wide adaptability to difficult sites, (c) capacity to establish with little after care, (d) ability to fix atmospheric nitrogen, (e) fast growth, (f) tolerance to wide range of environments, soil types, rainfall regimes, terrain and (g) ability to produce wood of high calorific value (Burely 1980, Mann 1984).

Realising the importance of producing biomass for energy, the Ministry of Non-conventional Energy Sources (MNES), Govt. of India established Biomass Research Centres in different agro-climatic regions in India. One of the major goals of these centres was to identify productive tree species and to develop packages of practices for high yields from short-rotation tree crops.

Although many multipurpose tree species are being studied worldwide, it is important to identify locally available indigenous tree species, which can thrive best in the local climate. Local people's choice should be considered for selecting the tree species as they have an intimate knowledge of the local environment (Jungerius, 1985). They have detailed knowledge of local tree species, and know what species will grow where and why (Leach *et al.*, 1989). To ensure sustainability, long-term productivity, reduction of soil-erosion, restoration of soil nutrients status, and reduction of risk of pests and diseases, FAO (1993) suggested multi-tier forests systems where all tree species do not come to the harvest stage at the same time along with multi species plantation where shallow and deep-rooted tree species are planted for optimum use of soil nutrients.

The North-Eastern region of India has been characterized with different topography, soil characteristics and climatic conditions as compared to other parts of the country. In the forests of North East India there are a large number of tree species. Most of the tree species available in this region may not be available in other parts of the country. But very little is known about the fuelwood characteristics of these tree species. Recently Kataki *et al.* (1996, 2001) reported fuelwood characteristics of some indigenously grown tree species of North-East India. They reported that *Albizia lucida, Syzygium fruticosum, Pterospermum lanceaefolium and Premna bengalensis* are some of the indigenous tree species, which can be recommended for energy tree plantation. Konwer *et al.* (2001) also studied some indigenously grown tree species of North-East India for fuelwood quality and the tree species reported by them having desirable fuelwood quality were *Machilus bombycina, Castanopsis indica, Litsea monopetala, Litsea glutinosa, Lagerstroemia specicosa, Derris indica* and *Cassia fistula.*

Assam is one of the states of North-East India. Since out of a large number of fuelwood species grown in Assam, the fuelwood characteristics of only a very few species are known, it is of interest to make a detailed study on the fuelwood characteristics of some indigenous fuelwood species which are traditionally preferred for fuel by the rural people of Assam.

Considering the above, the present investigation was carried out with the following objectives:

1. to survey and screen the indigenous fuelwood species which are traditionally preferred for fuel by the rural people of Assam.
2. to determine the physicochemical characteristics such as moisture content, density, ash content, calorific value etc., of different plant parts namely wood, bark etc. of the selected fuelwood species.
3. to determine the percentage of cellulose, hemicellulose, lignin and extractives contents in different part of the fuelwood species.
4. to determine the percentage of carbon, hydrogen, nitrogen and oxygen contents in different plant parts.
5. to determine the percentage of calcium, potassium, sodium, magnesium, iron, zinc, copper and silicon contents in the ash samples produced by different plant parts.
6. to study the effect of physicochemical characteristics, biochemical constituents and elemental compositions of the different plant species with their fuelwood quality.

Such a study may be helpful to screen the desirable indigenous tree species for inclusion in energy plantation and also for evaluation of their biomass production potential.

CHAPTER II

REVIEW OF LITERATURE

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REVIEW OF LITERATURE

As the underground fuels become more scarce and expensive, the importance of fuelwood is increasing dramatically. To-day, fuelwood is a recognized source of energy. This has catapulated tree-growing into the arena of world energy production. However, there is little understanding and reliable information on the extent of wood energy supply and demand, fuelwood characteristics of different tree and shrubs species, growth and biomass productivity of different tree species in different agroclimatic conditions etc.

A report of an Ad Hoc panel of the Advisory Committee on Technology Innovation Board on Science and Technology for International Development Commission on International Relations, National Academy of Sciences, Washington, DC. (1980) has listed a large number of promising firewood species of Humid Tropics, Arid and Semiarid Region and Tropical Highlands. The list is given below.

Humid tropics

Acacia auriculiformis	*Albizia lebbek*	*Alnus jorullensis*
Anogeissus latifolia	*Anogeissus leiocarpus*	*Avicennia spp.*
Azadirachta india	*Brugniera spp.*	*Cajanus cajan*
Calliandra calothyrsus	*Cassia siamea*	*Cassia spectabılis*
Casuarina cunninghamiana	*Casuarina equisetifolia*	*Casuarina lepidophloia*
Eucalyptus camaldulensis	*Eucalyptus citriodora*	*Eucalyptus grandis*
Eucalyptus microtheca	*Eucalyptus saligna*	*Eucalyptus tereticornis*
Gliricidia maculata	*Gliricidia sepium*	*Gmelina arborea*
Grevillea robusta	*Guazuma ulimifolia*	*Inga edulis*
Inga vera	*Leucaena leucocephala*	Mangroves
Mutingia calabura	*Parkinsonia aculeata*	*Pithecellobium dulce*
Pongamia glabra	*Rhizophora mangle*	*Rhizophora mucronata*
Sesbania grandiflora	*Syzygium cummii*	*Terminalia spp.*
Thema guineensis	*Thema nicrantha*	*Thema orientalis*

Tropical Highlands

Acacia dealbata	*Acacia decurrens*	*Acacia mearnsii*
Alnus glutinosa	*Alnus jorullensis*	*Alnus nepalensis*
Alnus rubra	*Casuarina cunninghamiana*	*Casuarina equisetifolia*
Casuarina junghuhniana	*Casuarina luchmannii*	*Eucalyptus bicostata*
Eucalyptus camaldulensis	*Eucalyptus citriodora*	*Eucalyptus globulus*

Eucalyptus gomphocephala	*Eucalyptus grandis*	*Eucalyptus macarthuri*
Eucalyptus maidenii	*Eucalyptus saligna*	*Eucalyptus viminalis*
Grevillea robusta	*Trema orientalis*	

Arid and Semiarid Regions

Acacia arabica	*Acacia auriculiformis*	*Acacia brachystachya*
Acacia cambagei	*Acacia cyanophylla*	*Acacia cyclops*
Acacia decurrens	*Acacia holosericea*	*Acacia mollissima*
Acacia nilotica	*Acacia raddiana*	*Acacia seyal*
Acacia tortilis	*Albizia lebbek*	*Anogeissus leiocarpus*
Anogeissus pendula	*Azadirachta India*	*Cajanus cajan*
Cassia siamea	*Casuarina cristata*	*Casuarina decaisneana*
Casuarina equisetifolia	*Casuarina glauca*	*Casuarina stricta*
Colophospermum mopane	*Eucalyptus camaldulensis*	*Eucalyptus citriodora*
Eucalyptus gomphocephala	*Eucalyptus microtheca*	*Eucalyptus occidentalis*
Eucalyptus tereticornis	*Eucalyptus viminalis*	*Gmelina arborea*
Haloxylon aphyllum	*Haloxylon persicum*	*Pinus brutia*
Pinus eldarica	*Pinus halepensis*	*Pithecellobium dulce*
Prosopis alba	*Prosopis caldenia*	*Prosopis chilensis*
Prosopis cineraria	*Prosopis farcta*	*Prosopis juliflora*
Prosopis pallida	*Prosopis tamarugo*	*Tamarix spp.*
Tamarix aphylla	*Tamarix articulata*	*Terminalia glaucescens*
Zizyphus jujuba	*Zizyphus mauritiana*	*Zizyphus nummularia*

Fuelwood is a major necessity for many people in India, particularly in the rural areas where other sources of energy such as electricity or gas are just not available. Some 65% of the nearly 950 million people live in 500000 villages and depend mainly upon fuelwood energy for meeting their energy need for cooking and warming (Tewari, 1998). Population growth and increased exploitation of forests have resulted in severe shortage of fuelwood, charcoal and other wood-based fuels needed for cooking, heating and commercial uses. As most of the requirement of fuelwood is met by cutting trees or extracting dead wood from the nearby forests, the unsustainable rate of extraction may lead to deforestation and thereby destroy the environmental benefits that acquire to society from forests. During the last 50 years, deforestation in India has taken place to a great extent (Forest survey of India, 1989; Hadden, 1986). As a result of this, deterioration of environment has taken place leading to various hazards such as flood, soil erosion, loss of wildlife etc. (Mukherjee, 1994). To meet the widening gap between the demand and supply of fuelwood in India Deol (1983) has suggested some feasible approaches for energy plantation on wasteland, farmland and degraded forest areas. He has emphasized to select fast growing and high yielding tree species for successful raising of fuelwood plantation. Groves and Chivuya (1989) reported that different species fit different uses and normally no one species had all the desirable firewood characteristics.

In India the Ministry of Non-conventional Energy Sources (MNES) launched a biomass programme, the main aim of which was to optimize the productivity of biomass and develop suitable packages of practices for promising fuelwood species. Under this programme several biomass research centres were established in different agro-climatic regions of the country. Work was conducted on a total of 70 fast growing fuelwood tree species for preparing detailed packages of practices, including standardization of nursery requirements, application of biofertilizers, pest and disease management and biomass productivity assessment under field conditions. Already packages of practices have been developed for 35 fast growing and short rotation fuelwood species for producing an average of about 20 - 25 tonnes of biomass per hectare per year.

Biomass productivity assessment studies conducted at Bhubaneshwar have indicated a maximum yield of over 80 tonnes per hectare of *Acacia nilotica* followed by 76 tonnes per hectares in *Cassia siamea*, 70 tonnes for *Leucaena leucocephala* and 51 tonnes per hectare in *Casuarina equisetifolia* after 5 years of growth. Similarly, biomass yield of 20 tonnes per hectare per year has been obtained for *A. stipulata* in a rotation of 6 years at Garhwal, U. P. Study conducted at Madurai, T. N. indicated that *Albizia lebbek, Hardwickia binata, Samarina saman, Cassia siamea and Erythrina indica* yielded 21 to 27 tonnes of biomass per hectare per year. *Prosopis juliflora* was found to yield about 12 tonnes of biomass per hectare per year under highly alkaline conditions.

Ghate *et al.* (1990) studied some of the indigenous fuelwood species from Western Ghat of Maharastra with respect to their availability, fuel characteristics and suitability in energy plantation. From their studies they recommended *Acacia chundra*, *Carallia brachiata, Holigara grahamii. Pongamia pinnata* and *Zizyphus mauritiana* etc. for inclusion in energy plantation. . Tree species such as *Acer oblongum*, *Betula alonoides, Grevillea robusta, Limonia acidissima, Lyonia ovalifolia,* *Madhuca indica, Melia azedarch, Morinda tinctoria, Pyrus pashia, Quercus langinosa, Rhamnus triqueter, Stereospermum xylocarpum* etc. have been recommended as fuelwood for Central India (Gera *et al*., 1996; Jain, 1999). Recently Jain (1998) studied fuelwood characteristics of 33 trees from Central Himalayan Region of North India and reported that *Acacia mallissima, Cedrela serrata, Elaegnus unbellata, Embelica officinalis, Fraximus micrantha, Mangolia grandiflora, Salix wallıchiana, Machilus duthiei, Myrica lapida, Pistacia integerrima, Prinsepia utilis, Prunus armenica, Pyracantha crenulata, Quercus dilata, Quercus glauca, Quercus semecarpifolia, Sapindus mukorossi* and *Viburnum contifolium* have relatively better fuelwood qualities among the species studied. Jain (1992) studied the fuelwood characteristics of 26 hardwood and 16 softwood species of India and found that the hardwood species required little post-planting care and thrived best in the environment of low nutrient content. He emphasized to identify the indigenous fuelwood species, which are generally preferred by local people for plantation on non-agricultural lands.

From an investigation on fuelwood quality of tree species grown in alkaline soil, Goel and Behl (1996) reported that *Prosopis juliflora* and *Acacia nilotica* were found to be the most suitable species for short rotation fuelwood forestry programme because of their wood density, biomass yield, low ash and moisture content and good heat of combustion at the juvenile stage.

Puri *et al.* (1994) determined the calorific value of six indigenous species and four exotic species and found that indigenous tree species are better suited as fuelwood species as they contain high density wood, low ash content and low nitrogen percentage. Fuelwood characteristics of some Indian trees and shrubs have been documented by Krishna and Ramaswamy (1979), Purohit and Nautiyal (1987) and Bhatt and Todaria (1990).

In the North Eastern region of India, a large number of trees and shrubs grow well in their natural habitats. But very little is known about their fuelwood characteristics. Recently, Kataki and Konwer (2001, 2002) and Konwer *et al.* (2001) have reported the fuelwood characteristics of some of the indigenous tree species of north-east India.

The selection of a particular tree species for various end uses is based mainly on its physical and chemical properties.

Wood always holds varying amounts of moisture. The effect of wood moisture content on the availability of heat energy has been quantified by a number of investigators (Murphey and Cutter, 1974; Ince, 1977; 1979). Wood for use as a primary fuel is usually cut 3 to 4 months before use in the tropics and 6 to 12 months in temperate zones in order that the moisture content should be reduced to 25-30 % resulting an increase in the calorific value 3.5 to 4.0 % (Earl, 1975). On the other hand, wood containing about 25 % moisture is susceptible to biological degradation, mainly through microbial attack. The green moisture content of wood varies greatly among tree species and also varies from one tree part to another (Karchey and Koch, 1979). It is often the lowest in the stem and increases towards the roots and crowns. Seasons are also known to effect moisture content (Hakkila, 1962). When a tree is felled, the water supply to it is cut-off and then its moisture content slowly comes to an equilibrium state with the ambient air. The equilibrium moisture content depends on the temperature and relative humidity of the ambient air (Nurmi, 1992). The moisture content not only acts as a heat sink and lowers the combustion efficiency but also has a limiting effect on the economics and transportation range of the fuel (Shafizadeh, 1984).

Specific gravity is one of the most important physical characteristics of wood because of its positive association with fuel value and cellulose content and negative association with moisture content (Farmer 1991; Kenny, 1990; Ranny *et al.*, 1990). Wood with higher specific gravity is generally less susceptible to decay. The specific gravity of the cell walls of all wood species is approximately 1.5. However, because of the porous nature of wood, specific gravity value (based on oven dry weight and green volume) ranges from 0.29 to 0.54 for most softwoods and from 0.31 to 0.80 for most hardwoods (Resch, 1982). Shukla and Rajput (1981) determined the standard specific gravity for different species of Eucalyptus from different localities and observed that there was a large variation in specific gravity of Eucalyptus hybrid of different ages as well as different trees of the same age. They also observed that age of tree had significant effect on specific gravity. Bhat *et al.* (1990) determined the wood specific gravity in stems and branches of some timbers from Kerala and observed that specific gravity decreased from base to top without any marked change in the middle position of both stem and branches (benteak, cashew, erythrina, dhaman and gurjan).

Density value of wood sample ($P\mu$) can be used to determine its porosity (V_a), given the moisture content (MC) from the following relationship (Siau, 1984).

$$V_a = 1 - P\mu\,(0.667 + 0.01MC)$$

The quality of fuel for general utility application is indicated by the amount of heat energy derived from a unit mass of the fuel. Any property, which influences the heating value either positively or negatively therefore, defines the fuelwood quality. Relationships between the properties can be built into a fuelwood value index incorporating species growth, tree size and yield potential which may then be used in the comparison and selection of different feedstock for different application (Senelwa, 1997).

The calorific value of different forest communities reported by a large number of authors are given below (Table 1).

Table 1: Calorific value of different forest communities

Forest community	Calorific values (cal/g dry wt.)	Author
Tundra Forest (Deciduous shrubs)	4.7	Bliss(1962)
Deciduous shrubs (South Georgia)	4.4	Smith and Walton (1973)
Tropical rain forest	3.9 (3.6-4.3)	Golley (1961)
Tropical moist forest	4.1(4.0-4.3)	Golley (1969)
Bemontane forest	4.1-4.2	Golley (1969)
Deciduous forest	3.3-4.3	Sharma (1972)
Sal & Teak plantation	3.7-5.1	Foruqi (1972)
Teak Plantation	4.2	Singh (1978)

Deol (1983) studied coppicing power, specific gravity and calorific value of 34 tree species and found that *Prosopis chilensis* had excellent coppicing power, highest specific gravity (0.8-0.92) and highest calorific value (5000/5500 Kcal/Kg) followed by *Leuceana leucocephala* which had specific gravity 0.55-0.7 and calorific value of 4200-4600 Kcal/Kg. Davis and Eberhard (1991) reported that moisture content and density are the most important properties in ranking the firewood species. High density, high heat of combustion, low ash and moisture contents are desirable characteristics of good quality fuelwoods. Wood density varies with the species, age, geographical location, climate, and planting density and growth rate (Gongalez, 1990). Heinsdijk (1987) reported that in *E. globulus*, 1-year-old plants showed a density of 0.541 while in 26 years old plants it was 0.773. Similarly, he found that in *E.camaldulensis*, the wood density was 0.538 at the age of 5 years, which increased to 0.765 at the age of 26 years. However, the differences in *E. verminilis* wood density between 5 and 15 year old trees was marginal (0.613 for 5 years old trees and o.659 for 15 years old trees). Goel *et al.* (1996) suggested that *P. juliflora* should be harvested after five years of plantation while *A. nilotica* after six years. Data on the wood density of juvenile wood support the above 5-years old tree of *A. auriculiformis* and *T. arjuna.* The study suggested that harvest operation in *A. auriculiformis* and *T. arjuna* should begin aftèr 10 years. So, wood density can be used as a useful parameter to fix harvest rotation cycle, particularly for short rotation forestry plantation.

Fuelwood characteristics of wood varies among species, among silvicultural treatments and also among components of the tree i.e. wood, bark and leaves, but not along the height of the tree. Senelwa *et al.* (1999) reported that wood properties were significantly different from those of barks and leaves. A study by Fuwape *et al.* (1997) on biomass yield and energy value of some fast-growing multipurpose trees in Nigeria revealed that the stem biomass constituted an average of 75% of the above-ground biomass while the branch biomass was 22% and the foliage biomass constituted an average of 3%. The implication is that 97% of the above ground biomass would be available as solid fuel. One of the most important characteristics of fuelwood is its dry matter content at the time of harvest. The results of a study conducted by Neenan *et al*., (1979) on calorific value for young sprouts of nine hardwood species revealed that wood was significantly higher in dry matter and leaves significantly lower in dry matter content than the other components. In general, bark was lower in dry matter content than wood. Singh *et al.* (1982) observed considerable variation in calorific value among species and components. They reported that leaves component contained highest calorific values in most of the species. They found higher calorific value in above ground parts compared to below ground parts.

Since bark is some times removed from industrial round wood and used separately as a fuel source, its characteristics are to be examined independently of the wood components. A tree grows rapidly first in height and then its rate of diameter increments picks up. In *Eucalyptus tereticornis*, the bark forms up to 70 percent of the volume of the tree up to two years of age and reduces to 46 percent at third year. Even at a rotation of 8 years when the majority of unirrigated Eucalyptus plantation are harvested the bark forms 32 percent of the total wood extracted (Chaturvedi, 1982). The declining proportion of bark on the stem with age showed that tree components do not grow in direct proportions. Wood fiber forming tissues (xylem cells) in a stem accumulates faster than the bark forming tissue (Phloem cells). Senelwa *et al.* (1999) also reported the accumulation of more woody materials than bark between 3 and 5 years of age of trees.

Musselman and Hocker (1981) and Singh and Kostecky (1986) found that species in genera Pinus, Picea, Betula and Populus from New Hampshire and Manitoba had higher heating values in bark than wood. These results indicate that bark is a desirable component of wood as fuel, unlike in industrial process, because it enhances the energy content of the fuel. The significance of bark components is more pronounced in branches and crown than in stems as it makes up roughly one third of the branch mass. Branches and crown have higher heating value than stems because of their higher amount of bark content. From the fuelwood point of view this is a positive aspect because branches are of low quality, low value and most often a totally unacceptable raw materials for most sectors of the wood working industry. When trees are harvested with branches, in fact the energy recovery will increase in mass and per unit weight of wood. Inspite of the differences within different components, the differences between species for the total stem, crown or whole-tree biomass are small and may not be very significant (Nurmi, 1992). In North European tree species, the heating value of outer bark is found to be higher than those of wood or inner bark. Kandya (1982) determined the calorific value of nine plant parts (trunk wood, trunk bark, branches, twigs, leaves, root wood, root bark, secondary and tertiary roots) of six forest trees. (*Tectona grandis*, *Terminalia tomentosa*, *Diospyros melanoxyle*, *Butea monosperma*, *Anogeissus latifolia* and *Lannea coromandelica* and has reported that generally calorific value was highest in leaves and lowest in trunk bark. Singh *et al.* (1982) has also determined the calorific value in different components of some important trees and shrubs species from tropical deciduous forests and observed that leaves contain the highest calorific value in most of the species. Further, they also observed that the calorific values were higher in above ground components as compared to underground parts. Foruqi (1972) observed the highest calorific value in leaves followed by branches, bole and root in *Shorea robusta* and *Tectona grandis* plants. The calorific values reported by Desh Bandhu (1971) in different tree components in decreasing order were in: leaf, root, branches and bole, while the calorific values observed by Singh (1978) in the decreasing order were in: leaf, root and bole.

The higher heating value of wood is directly related to its elemental composition. For fuels such as coal, the Dulong's formula (Perry and Chilton, 1973) defines the higher heating value as a fraction of the carbon, hydrogen and sulphur contents. The heat content is related to the oxidation state of the natural fuels in which carbon atoms generally dominate and overshadow small variation of hydrogen content (Susott *et al.*, 1975). Susott *et al.* (1975) found a linear relationship between the higher heating value and the carbon content of the natural fuels, chars and volatile matter. Thc bark components do have a higher percentage of carbon and hydrogen than wood (Nurmi, 1992). The nitrogen content of leaves varies from 1.5 to 3.0 percent whereas twigs contain approximately 1.0 percent; bark 0.75 percent and wood 0.28 percent of nitrogen. One percent of nitrogen corresponds to 10 calories per gram (Spector, 1956; Tamm, 1964; Leaf, 1968; Henry, 1973; Pfander and Others, 1969).

The heating values of biomass fuel can be determined experimentally and can be calculated from the ultimate and /or proximate analysis data (Kucukbayrak *et al.*, 1991). Demirbus (1997) reported that calculation of HHVs from their ultimate and proximate analysis data show mean differences from measured values ranging from 0.1% to 4.0%. Glove *et al.* (1994) reported the relationship between heating value and chemical composition of selected agricultural and forest biomass. He found that regression model with the ultimate elemental composition as independent variable gave better correlation to measure gross heating value than those based on the proximate chemical composition.

The higher volatile matter in wood as compared to bark from the same species indicates that wood is more reactive than bark. Volatile matter variation results from differences in volumetric percentage of the vessels in the different species and components. Vessel in the wood structure act as macropores and provide paths of least resistance for volatiles on emission. The pores determine wood porosity, and together with occlusions in vessels, may determine the ease with which volatiles escape from the wood interior, some are deposited and recombine into the solid char matrix as pyrolytic carbon. This is detected as fixed carbon and results in low volatile matter content measured in hardwood species than in softwood species. The low fixed carbon content obtained in several species reflected their high volatile matter content and showed that the bulk of the fuelwood material is consumed in the gaseous state during combustion (Senelwa *et al.*, 1999).

From a combustion standpoint, the moisture content will predict the heat required for evaporating and superheating the water. The ash content predicts the residue handling requirements and the volatile matter and fixed carbon content predict the requirements for the division of combustion air flow between over fire or secondary and under fire or primary air. This division of airflow has been useful in smoke abatement and air pollution control (Mingle *et al.*, 1968).

The heat of combustion of wood depends upon its chemical composition. Softwood of Pinus species contains a high amount of resin, waxes and lignin, which give a high heat of combustion (Martin, 1963; Hough, 1969; Howard, 1971,1973; Koch, 1972; Horder and Einspahr, 1976). Chandler *et al.* (1983) reported the greater higher heating value of softwood than hardwood, as softwood contains more resins or extractive content. The tendency for organic solvent soluble extractive (OEC) and total extractive content (TEC) to increase with increasing stocking density and to decrease with rotation age, in single stem and coppice crops of all ages showed there were varying quantities of extractives at different stages of the tree growth (Senelwa *et al.*, 1999).

Fuwape (1989) determined the chemical components in various plant parts such as wood, bark, branch and leaves of *Gmelina arborea* and found the highest holocellulose, and ∝-cellulose contents in wood whereas bark contained highest lignin and extractive contents. He also determined the calorific value and ash content of the plant parts and observed that the highest calorific value was produced by heartwood followed by sapwood, bark, branch and leaves. He also reported that removal of extractives from wood caused a reduction in calorific value. Bark and leaves were found to produce higher percentage of ash as compared to other parts.

Lignin is rich in carbon and hydrogen, which are the heat producing elements and hence has a higher heating value than carbohydrates. White (1986) reported that there was a highly significant linear correlation between the higher heating value of the extractive-free wood and lignin content. As reported by Fangrat *et al.* (1998), there was an evidence of correlation of heat of combustion to the burning weight loss of the samples, where they found no statistically significant correlation of heat of combustion to lignin content. Demirbus (2001b) showed a highly significant linear relationship between the lignin content and the determined HHV of the lignocellulosic materials. He concluded that the HHV of the renewable natural fuels could be calculated by using the lignin content data obtained from simple chemical analysis. The calculated HHVs using new correlations showed mean difference from the measured values ranging from 0.07 to 0.26%.

The quality of lignin present in wood is important for some conversion processes. Feedstock with a lignin type exhibiting a low guaiacyl/syringyl ratio will be mainly ether bonded, which is desirable for the production of ethanol and pyrolytic oils. The higher heat content associated with the carbon bonding of lignins exhibiting a high guaiacyl/syringyl ratio will be desirable for combustion and gasification (Agblevor *et al.*, 1990; Chum, 1991).

The chemical nature of wood substances, particularly that of the polysaccharides, renders wood cell walls hygroscopic (or hydrophilic). The -OH groups on the cellulose and hemicellulose are responsible for great affinity to water and have a very strong propensity to form hydrogen bonds (Panshin *et al.,* 1980). Lignin, on the other hand possesses comparatively few free hydroxyls, and as a result is much less hygroscopic. In fact, for all practical purposes, lignin is generally considered to be essentially hydrophobic.

The degree of polymerization and crystallinity of cellulose (Stevens *et al*, 1985) as well as the extent of hydrogen bonding (Chum, 1991) and linkages of side-chains (Ranney *et al.*, 1990) associated with hemicellulose and α-cellulose fractions may effect the suitability of feedstock for certain conversion processes. As the biomass is heated the different components react differently at different temperatures. The volatile extractives like the monoterpens could evaporate without major change, and the rest of the components partially break down to volatile components leaving a carboneous char that contains the mineral components. The lignin component has a higher tendency for charring, whereas cellulose and hemicellulose readily decompose to volatile products at temperature above 300^0C (Shafizadeh *et al.*, 1980).

Knowledge of the composition and specialization of inorganic elements in fuel is of vital importance for studies of combustion related topics, such as ash and deposit formation as well as sulphur and chlorine retention in ash.

Evaluation of physical and chemical properties of wood ash is important in the development of processes for its disposal and utilization.

The disposal of wood ash is a growing problem as environmental regulations become more stringent and landfill sites become less available and more expensive (Campbell, 1990).

Wood ash has been used in a variety of agricultural applications as it is an excellent source of potassium, lime and other plant nutrients (Lerner and Utzinger, 1986; Naylor and Schmidf, 1986; Campbell, 1990; Etiegni, 1990). Wood ash has also been used as a binding agent, a glazing base for ceramics (McWhinnie, 1979), a road base, an additive in cement manufacturing and an alkaline material for the neutralization of different types of acidic wastes.

Etiegni and Campbell (1991) made a study to evaluate the temperature dependence of wood ash yield and chemical components. They reported that wood ash decreased by approximately 45% as the combustion temperature increased from 538 to $1093^{0}C$. They also observed that potassium, sodium, zinc and carbonate content decreased with increase of temperature whereas other metal ions remained constant or increased. Wood ash leachate was found to certain 92% hydroxide and 8% carbonate. It was also reported that total dissolved solids of the ash increased by 500% as the p^{H} decreased from 13 to 5.

The ash from biomass fuels contains only trace amount of heavy metals, which makes it fairly easy to dispose of. Some of the heavy metals are found to be good fertilizers (Ferm *et al.*, 1993; Hakkila, 1986; Wattez *et al.*, 1987; Naylor *et al.*, 1986; Lerner and Utzinger, 1986) and can be used as mineral nutrient for forest and agricultural soils. From a study on the characteristics of ashes from wood and straw, Olanders *et al.* (1995) concluded that Potassium content was 3 times higher in straw ash than in wood ash or bark ash. They also observed that ash from wood or bark had higher percentage of carbonate content. $CaCO_3$ and SiO_2 were identified as the major crystalline compound in the wood or bark ash, while the straw ash was dominated by $CaCO_3$, KCl, K_2SO_4 and SiO_2. The higher percentage of ash content in bark and leaves were reported as 2.6-5.7% and 3.6-11.2%, respectively as compared to 0.4-1.2% in wood. According to Senelwa *et al.* (1999), higher ash content in bark and leaves was due to the concentration of potassium in the actively metabolizing portions of the tree crown and leaf area where nutrients from the soil are fixed prior to relocation to other parts of the plant. Shafizadeh (1981) also observed that bark produced more ash than wood. He indicated that silica and other insoluble inorganic compounds in plant act as a heat sink, while the other soluble ionic compounds could have a catalytic effect on the gasification and combustion of biomass fuels. Wood ash is dominated by calcium, silicon, aluminium, potassium and magnesium (Lerner and Utzinger, 1986; Etiegni and Campbell, 1991).

Many ash-forming inorganic species are associated with organic compounds in biomass fuels. During combustion the organic structures are decomposed and the ash formers are released. Alkaline earth metals leave the combustion zone as solid particles while the alkali metals are transported in vapour form as chlorides, hydroxides or oxides (Hupa, 1980; Ots, 1989). These compounds can react with SO_2 in the combustion gas and form sticky sulphate particles, which adhere to heat exchange surface and form hard deposits (Ots, 1989). There is also some possibility of vapour-phase CaO condensing on surface and reacting further with SO_2 to form $CaSO_4$ (Hupa, 1980).

CHAPTER III

MATERIALS AND METHODS

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The Study site

The sites selected for the study were the forests and different localities of the state of Assam, located in the North-East India. The state is located between $24^0 8'$ to $28^0 9'$ N latitude and $89^0 42'$ to $95^0 16'$ E longitudes. The state comprises of the plains of the Brahmaputra valley and the Barak valley with some hilly zones and experiences a humid sub-tropical climate with an average rainfall ranging from slightly below 1400mm to slightly above 3000 mm. The mean maximum temperature goes up to 37^0 C in summer and mean minimum temperature comes down to 10^0 C in winter. Soils are acidic in nature. The region is covered by hot humid to humid eco-region with alluvium-derived soils. The soil has been classified in the soil taxonomy sub group of Aeric Haplaquept, Aeric Fluvaquest and typic Dystrocrupt (NBSS and LUP, 1999). Details of geographical location, physiography, characteristics of soils under different agro-ecological sub regions of Assam are presented in Annexure I.

Species selection

A total of sixteen indigenous hardwood tree species grown in their natural habitats were collected from the forests and different localities of six different agro-climatic zones of Assam during the months November and December, 1998. Each zones comprises with two or more districts having almost same climate, topography and soil characteristics (Annexure II).

On the basis of the consideration of local people's preference for the best fuelwood species among the tree species grown in a particular locality, the tree species were identified and selected for the present study. The species were viz. *Lannea grandis* (Dennst.) Engl., *Eugenia jambolana* Lam., *Palaquium obovatum* Clarke., *Amoora rohituka* Wight. and Arn., *Ficus infectoria* Roxb., *Diospyros peregrina* (Gaertn.) Gurk., *Albizzia lucida* Benth., *Lagerstroemia flos-reginae* Retz., *Stereospermum chelonoides* DC., *Schima wallichii* Chois., *Albizzia procera* Benth., *Cassia fistula* Linn., *Machilus bombycina* King., *Terminalia belerica* Roxb., *Eurya acuminata* DC. and *Cassia siamea* Lim..

Characteristics of the tree species

Characteristics of the selected tree species on the basis of their botanical description, wood quality, availability etc. are described elsewhere (Gupta 1981, Dutta 1985, Dutta 1989 and Kanjila *et al*., 1997):

1.Botanical Name: *Lannea grandis* (Dennst.) Engl. Syn: *Odina wodier* Roxb.

Vernacular (Assamese) Name: Ket-keshi, Thot mola

Family: Anacardiaceae

Fig. 6: *Lannea grandis* (Dennst.) Engl

A small to middle sized tree. Leaves - pinnately compound, alternate, exstipulate. Inflorescences - panicle of many small flowers. Flowers - small, regular, bisexual, sometimes polygamous, usually 5, sometimes varying from 3 to 7. Calyx - sepals usually 5, sometimes varying from 3 to 7, free or united. Corolla - petals as many as sepals, sometimes absent, free or connate. Androecium - stamens 10 - 5, free, inserted on an annular disc. Gynoecium - carpels commonly (3 -1), ovary superior or sometimes inferior, often 1- celled, rarely 2 to 5 celled. Fruit - commonly a 1-celled and 1-seeded drupe. Seed - exalbuminous, with a large curved embryo.

The heartwood is white, moderately hard and durable, used for making houses, furniture, as paper pulp and firewood. The gum obtained from the bark is used in confectionery, beaten up with coconut oil is applied to sprain and bruises. Powdered bark is used in leprosy. Found in Lakhimpur, Dibrugarh, Nagoan and Kamrup districts of Assam, lower Arunachal Pradesh and Nagaland.

2. Botanical Name: *Eugenia jambolana* Lam. Mod. Name: *Sizygium jambolanum* DC. Syn: *E. cumini* (L.) Skeel.

Vernacular (Assamese) Name: Kolajamu, Borjamu.

Family: Myrtaceae.

Fig.7: *Eugenia jambolana* Lam

A small to middle sized evergreen tree. Cultivated in the gardens for the fruits and as ornamental. Root - taproot, branched. Stem - erect, woody, branched. Leaves - opposites, petiolate, exstipulate, ovate or ovate-lanceolate, usually long petiolate, entire; venation reticulate, unicostate. Inflorescence - flowers crowded in small rounded clusters, terminal on branches of lateral panicles. Flowers - regular, bisexual, actinomorphic, epigynous. Calyx - 4, gamosepalous. Corolla - 5, polypetalous, petals rounded, concave, fall off as the flowers opens. Androecium - Indefinite, in several series, longer than the petals and inserted around the mouth of calyx tube; anthers dithecous, dorsifixed. Gynoeceium - Bicarpellary, synocarpous, ovary inferior. Fruit - drupe like a berry, dark purple in colour.

Wood is hard and durable, reddish in colour, used for house building as batons, rafters and as firewood. Fresh juice of bark with goat milk is very good for diarrhea and dysentery. Ripe fruit are edible, very good for liver, dysentery, diarrhea etc. Found in all the districts of Assam.

3. Botanical Name: *Palaquium obovatum* Clarke.

Vernacular (Assamese) Name: Kathulua.

Family: Sapotaceae

Fig.8: *Palaquium obovatum* Clarke

A middle sized tree. Bark - dark-brown, somewhat rough, green below epidermis, white inside but with close reticulated brown veins. Leaves - rather crowded near the ends of branchlets, 5 - 10 by 2 - 4 in., obovate, ovate-oblong or elliptic-obovate, acute, glabrescent above, glabrous beneath; midrib strong, channeled above; lateral nerves more conspicuous beneath, 10 - 12 on either half, more or less parallel, tertiaries obscure; petiole 0.5 - 0.7 in. long. Flowers - in dense fascicles, axillary or above the scar of fallen leaves. Calyx - segments ovate. Corolla - glabrous outside, more than twice the length of the calyx; lobes longer than the tube, lanceolate, blunt. Stamens - exerted; anthers minutely villous; filaments glabrous; style twice the length of corolla. Fruit - berry, 0.7 in. across, globose.

Wood is hard, dark yellow coloured, fine-grained, good for house building, furniture and firewood. Keeps well under water. Found in Sibsagar, Nagaon and Darrang districts of Assam.

4. Botanical Name: *Amoora rohituka* Wight. & Arn. Syn: *Aphanamixis polystachya* Wall. Syn: Aglaia poslystachya (Wall.) Parker.

Vernacular (Assamese) Name: Omari, Amari.

Family: Meliacea

Fig.9: *Amoora rohituka* W. and A.

A middle sized evergreen tree with a dense spreading crown. Bark - greyish-brown outside exfoliating in circular pieces, warty, bright red underneath the corky layer, red inside, gradually lighter inwards. Leaves - crowded at the ends of the branchlets, 12 - 24 in. long, vivid green, leaflets 9 - 19, opposite, 3 - 9 by 1.5 - 4 in., ovate, oblong or obovate, acuminate. Male spikes panicled about as long as leaves, female simple, much shorter. Flowers – sessile, rarely very shortly pedicelled. Calyx - 5-partite, lobes rounded and with very thin ciliolate margins. Petals - 3, broad elliptic to orbicular. Anthers - 6, about 0.1 in. long, lanceolate. Ovary - 3-celled with two superposed ovules in each cells. Fruit – capsule, 1 - 1.5 in. long, obovate in out line, yellow when ripe, smooth, 3-valved. Seeds - usually not more than 2 in each fruit.

Wood is hard, durable, polished well, pink in colour, used for furniture, house building purpose, cart wheels, agricultural implements etc. Oil called 'Rohituka' having camphor line is extracted from the seeds, used for illuminating and in paint industry. Found in Lakhimpur, Dibrugarh, Sibsagar, Darrang, Kamrup, North Cacher and Nagaon districts of Assam and lower Nagaland.

5.Botanical Name: *Ficus infectoria* Roxb. Syn: *F. lacor.* Buch-Hans.

Vernacular (Assamese) Name: Pakori.

Family: Moraceae

Fig.10: *Ficus infectoria* Roxb

A middle sized or large deciduous tree with spreading crown; epiphytic in early life, sometimes bending down a few aerial roots. Bark - greyish, 0.3 in. thick; blaze red, with yellow vertical lines, fibrous, turning brown. Leaves – 3 - 8 in. by 1.5 - 3.5 in., oblong-elliptic, oblong-ovate or ovate, abruptly and shortly acuminate, entire, often undulate, rather membranous, glabrous, shining above; lateral nerves 6 - 9 on either half, looping within the margin; base 3-nerved, cuneate, rounded or sub-cordate; petiole up to 3.5 in. long, stipules about 0.5 in. long, pubescent outside, broadly ovate. Male flowers -

stamen 1; anther broad receptacle in axillary pairs, usually sessile, sub-globose, 0.25 - 0.35 in. across, occasionally larger, white when ripe or flushed with red and dotted; basal bracts 3, ovate or orbicular, free.

Wood is very soft. Leaves and twigs are used as fodder sometimes. Wood is light yellowish or cream coloured. Found in Sibsagar, Dibrugarh, Nawgaon, Kamrup districts of Assam and Nagaland.

6. Botanical Name: *Diospyros peregrina* (Gaertn.) Gurk. Syn: *D. embryopteris* Pers.

Vernacular (Assamese) Name: Kendu Goch

Family: Ebenaceae

Fig.11: *Diospyros peregrina* (G.) Gurk

A middle sized handsome evergreen tree with a spreading crown. Bark - blackish with numerous white blotches. Leaves - distichous, 4 - 8 in. by 1.3 - 2.5 in., oblong or narrowly oblong, subacute or obtuse, glossy green, smooth, glabrous, base rounded; petiole often twisted, 0.3 - 0.5 in. long. Flowers - tetramerous, white or cream coloured, scented. Male flowers in short pedunculate rusty pubescent cymes of 2 - 7 flowers; peduncles 0.3 - 0.5 in. long. Calyx - 0.25 in. long, silky pubescent; segments 4, broadly ovate, pubescent within, margins ciliate. Corolla - 0.3 - 0.4 in., broadly tabular; lobes fleshy, rounded. Stamens - many in pairs at the base of the corolla; anthers linear, hairy up to the middle. Female flowers usually solitary, subsessile, larger than the male flowers; peduncles pubescent, ovary 8-celled; style 4-lobed at the tips. Fruit - globose, 1.5 - 2.5 in. across, covered with deciduous ferruginous scurf. Seeds - up to 8, compressed, imbedded in a glutinous pulp; albumin smooth.

Wood is moderately hard, used for building construction and as firewood. Found in Goalpara, Kamrup and Sibsagar districts of Assam and lower Nagaland.

7. Botanical Name. *Albizzia lucida* Benth.

Vernacular (Assamese) Name: Moj

Family: Leguminosae

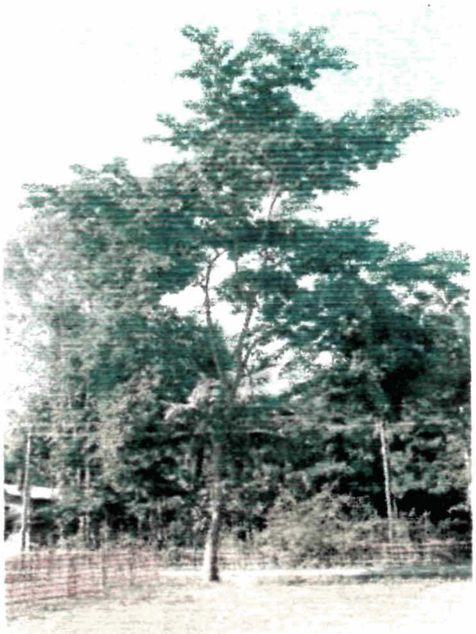

Fig.12: *Albizzia lucida* Benth

A middle sized nearly evergreen tree. Bark - nearly smooth, with horizontal wrinkles, and warty with lenticels. Inflorescences - brown, silky, rachis 0.6 - 2 in. long, with a large cup-shaped gland, 0.2 - 1 in. from the base and sometimes another near the top. Leaves - leaflets 2, sometimes 3, rarely 1 pair (second pair of pinnae when present eglandular with 1 pair of leaflets), generally 2 - 6 by 1 - 1.7 in., terminal pair usually largest, lowest sometimes only 1.2 by 0.6 in., oblong-lanceolate or oblanceolate, somewhat abruptly acuminate; petiole up to nearly 0.1 in. long. Heads - small, peduncled; peduncles 5 - 1 in. long, slender, glabrate or puberulous with age. Calyx - about 0.07 in.

long, campanulate. Corolla - about 0.50 cm long, silky outside, filaments 0.5 - 0.6 in. long, pale yellow, staminal tube slightly shorter than corolla tube. Seeds - 6 - 9, orbicular.

Heart wood is hard and durable, good for house building and furniture works, cart wheel and firewood. Found in Lakhimpur, Sibsagar, Nagaon, Darrang and Kamrup districts of Assam, Nagaland and Meghalaya.

8. Botanical Name: *Lagerstroemia flos-reginae* Retz. Syn: *L. speciosa* (L.) Pers.

Vernacular (Assamese) Name: Ajar, Ajhar

Family: Lythraceae

Fig.13: *Lagerstroemia flos-reginae* Retz

A large and rather branchy tree. Bark - light grey or pale brown, smooth, peeling off in irregular flakes. Leaves - usually 4 - 8.5 in. by 1.5 - 3.2 in., elliptic, oblong-elliptic or oblong-lanceolate, acuminate, glabrous on both surfaces, nerves prominent beneath, 10 - 12 on either half, joining to form an intra-marginal nerve which becomes discontinuous towards the base; petiole 0.2 - 0.4 in. long. Flowers - very handsome, mauve purple, 2 - 3 in. across in downy terminal panicles up to 1 ft. long, ultimate branches cymosely 1 - 3 flowered; pedicles stout, pubescent, jointed below the middle. Calyx - 0.5 - 0.6 in. long, turbinate, covered with grey or brown tomentum, tube ribbed, ribs 12 - 14, alternately broad and narrow; teeth 6 - 7, spreading, acute. Petals - 6 - 7, 1 - 1.5 in. long, much crumpled and wary with deeper coloured veins. Seeds - including the wing about 0.5 in.

Heart wood is dark brown in colour, very durable, hard, insect and moisture resistant, used for making boats, railway sleepers, bridges, posts, beams, flooring and as firewood. Barks and leaves are valid purgative. Root is astringent, stimulant. Found in all over Assam.

9. Botanical Name: *Stereospermum chelonoides* DC. Syn: *S. tetragonum* DC.

Vernacular (Assamese) Name: Paroli

Family: Bignoniaceae

Fig.14: *Stereospermum chelonoides* DC.

A large deciduous tree. Leaves - usually pinnately compound, opposite, exstipulate. Inflorescence - often a dichasial cyme. Flowers - bisexual, zygomorphic, hypogynous. Calyx - sepals 5, gamosepalous. Corolla - petals 5, gamopetalous. Androecium - stamens 4, epipetalous, anthers 2-lobed divaricate. Gynoecium - carpels 2, syncarpous, ovary superior, usually 2 locular. Fruit - a 2-valved capsule, sometimes a berry. Seeds - exalbuminous.

Wood is moderately hard and durable. Used for railway sleepers, house building, tea boxes, furniture, firewood etc. Fairly common in Assam and Nagaland.

10. Botanical Name. *Schima wallichii* Chois.

Vernacular (Assamese) Name: Nagabhe, Makorisal

Family: Ternstroemiaceae (Theaceae).

Fig.15: *Schima wallichii* Chois.

A large tree up to 90 ft. in height and 11 ft. in girth with a narrow crown in youth but develop to a very large spread one after height is completed. Bark - plain and of a salty colour when young, but brownish grey to almost black and rather deeply longitudinally cracked into rectangular plates on mature trees, finely fibrous, blaze cheesy red, 0.7 – 1.5 in. thick; the juice is said to be caustic. Branchlets – lenticellate, buds and young parts depressed pubescent or villous. Leaves - 3.5 - 9.5 in. by 1.4 - 3.2 in. oblong or elliptic-lanceolate, acute or acuminate, usually entire, thinly coriaceous; glabrous and shining above, more or less pubescent, especially along the midrib and other nerves beneath, or glabrescent; midrib depressed above, lateral nerves reddish; 12 - 16 cm either side of the midrib, oblique, slightly arched, petiole 0.6 - 0.8 in. long, sharply margined, more or less pubescent. Flowers - white, scented, axillary, solitary, 1.2 - 2 in. diam. Sepals - 5, imbricate. Petal - 5, connate. Stamens - many; ovary hairy towards the bottom, upper portion glabrous. Fruit - 5-celled loculicidal capsule, 0.5 - 0.7 in. dia..

The wood is moderately hard, used for veneers, ply, making lead pencils, planks and scantling. It is very good for firewood and making charcoal. Found in Sibsagar, Mikir Hills, Lakhimpur, Dibrugarh, Darrang and Nagaon districts of Assam and Nagaland.

11.Botanical Name. *Albizzia procera* Benth.

Vernacular (Assamese) Name: Boga Koroi

Family: Leguminosae

Fig.16: *Albizzia procera* Benth.

A tall handsome sub-deciduous tree, attaining over 80 ft. in height and 7 ft. in girth. Bark - nearly smooth, yellowish grey or brown outside. Leaves - rachis, 10-18 in. long, basal gland large, oblong or oval, pinnae 2 - 6 pairs, 5 - 9 in. long, often with glands between the upper 1 - 2 pairs of leaflets, heads 0.5 in. across, usually in fascicles of 2 - 5. Flowers - sessile, yellowish white. Calyx - about 0.1 in. long, tubular, glabrous outside. Corolla - upto 0.2 in. long. Stamens - 0.4 - 0.5 in. long; filaments yellowish; Pods – 4 - 8 in. by 0.6 - 0.9 in. glabrous, reddish brown, flexible. Seeds – 6 - 12.

Heart wood is hard and durable, gives fine polish, used for house building, furniture works, paneling, cart wheels, rice pounders, bridges, firewood and charcoal preparation. Bark is used to poison fish in rivers. Found in all over Assam and lower Nagaland.

12.Botanical Name: *Cassia fistula* Linn.

Vernacular (Assamese) Name: Sonaru

Family: Leguminosae

Fig.17: *Cassia fistula* Linn

A middle to large deciduous tree with bright golden yellow flowers blooms just before new leaves come. Root - tap root branched. Stem – erect, branched, woody. Leaf - compound, pinnate or bipinnate. Inflorescence - racemose. Flower – zygomorphic, bisexual, perigynes. Calyx – 5, poly or gamosepalous. Corolla – 5, polypetalous. Aestivation - imbricate.

Heart wood is very hard and durable, used for house posts, furniture, agricultural implements, tool handles etc. Commonly found in all over Assam, lower Nagaland and often planted.

13.Botanical Name: *Machilus bombycina* King.

Vernacular (Assamese) Name: Chom Goch

Family: Lauraceae

Fig.18: *Machilus bombycina* King

A middle to big sized tree with spreading crown. Bark - light dark-grey, rather rough. Blaze - mucilaginous, reddish or pinkish-brown. Inflorescences - silky. Leaves - 2.5 – 5 in. by 0.8 - 2 in., elliptic-lanceolate to obovate-lanceolate, oblong-lanceolate, acuminate or sub-acuminate; coriaceous, glabrous above, addressed silky beneath when young, minutely silky or puberulous with age; base cuneate or acute; lateral nerves 6 - 8 on either half, slender. Petiole - 0.3 - 0.7 in. long. Panicles - sub-terminal, upto 4.5 in. long, branches spreading; pedicles up to 0.35 in. long, silky. Flowers - about 0.25 in. long. Perianth tube obsolete; segments oblong or oblong-lanceolate, silky on both surface, often more densely outside except towards the base, inside villous with spreading hairs. Filaments - villous at the base. Fruit - globose, 0.25 - 0.3 in. across.

Wood is hard used as ordinary timber. It is good for firewood and charcoal preparation. Muga silk worms are mainly reared on the leaves of this tree. Found through out Assam (particularly in upper Assam), lower Meghalaya, and lower Naglanad.

14.Botanical Name: *Terminalia belerica* Roxb. Syn: *Myrobalanus belerica* Geartn.

Vernacular (Assamese) Name: Bhomora Guti, Bhoira

Family: Combretaceae

Fig.19: *Terminalia belerica* Roxb

A large deciduous tree commonly grown as an avenue tree. Bark - ashy dark-grey or brown, rough, exfoliating in irregular brownish small scales. Blaze - pale yellow, turning brownish on exposure. Inflorescences - rusty tomentose. Leaves - alternate, clustered at the ends of branches, 3 - 10 in. by 2 - 5 in., obovate to broadly elliptic, obtuse, subacute or apiculate at the apex, margin with a pellucid rim, coriaceous, puberulous when young, dark green and glabrous when mature, often punctate above when mature; lateral nerves 5 - 8 sometimes up to 10 on either half; base narrowed, often unequal. Petiole – 1 - 3.5 in long, gland absent or inconspicuous. Flowers - 0.25 in. across, greenish yellow with an unpleasant smell, in slender axillary and extra-axillary interrupted drooping spikes from new shoots, 3 - 6 in. long, and hermaphrodite upper flowers often male; bracts minute, villous, canducous. Calyx - hairy outside, woolly within, about 0.25 in. across; limb cup-shaped, expanded, teeth 5, triangular, Drupe about 1in. long, globose, often abruptly narrowed to a short stalk, grey velvets, obscurety ribbed when dry. The fruits are used for tanning. The ripe dry fruit known as beleric myrobalan (bahera) is astringent, bitter tonic and laxative. It is given in piles, dropsy, diarrhoea, leprosy, biliousness, dyspepsia and headache. Half ripe found is given as purgative and fully ripe as an astringent. Fruit is one of the 'Triphalas'.

Wood is hard and heavy used for house building and as firewood. Found in all over Assam and Nagaland.

15.Botanical Name *Eurya acuminata* DC.

Vernacular (Assamese) Name: Murmura

Family: Theaceae

Fig.20: *Eurya acuminata* DC.

A small to middle sized evergreen tree, sometimes up to 40 ft. in height: branchlets terete, the decurrent ridges if at all present not prominent; young parts generally grey-hairy. Bark - dark-brown and fairly smooth outside, reddish inside and thin. Leaves – 2 - 4 in. by 0.5 - 1.4 in. oblong to linear, lanceolate, generally caudate-acuminate, closely crenate serrate, subcoriaceous, glabrous and often shining above, midrib impressed above, prominent and hairy beneath: main lateral nerves about 12 on either half alternating with shorter intermediate ones: base sub acute; petiole very short, puberulous. Flowers - 0.15 - 0.25 in. long, white with a very heavy unpleasant smell, 2 bracteolate, nodding up to 8 from the lower leaf axils and 2 or even 1 from the upper. Sepals - concave, pubescent outside, outer 2 smallest. Petals - white, alternating with the sepals, 0.1 - 0.2 in. long, much exceeding the sepals. Stamens – 15 - 24, shorter than the petals, Ovary - pubescent; styles 3 -5, united beyond the middle in the type. Fruit - capsule globose, 2 in. across, crowned with the remains of the style. Seeds - bluntly trigonous.

Wood is reddish in colour, very hard and durable used for making implements, handles and plough. An excellent firewood tree. Found in Dibrugarh, Sibsagar and Lakhimpur districts of Assam, Meghalaya and Nagaland.

16. Botanical Name: *Cassia siamea* Lam.

Vernacular (Assamese) Name: Bonsiris, Kala Koroi

Family: Leguminosae

Fig.21: *Cassia siamea* Lam.

A small to middle sized tree. Leaves - compound with pinnate or stipules absent. Flowers - zygomorphic. Calyx - free or the 2 upper sepals may be united; the aestivation is imbricate, Corolla - ascending imbricate. Stamens - 10 or few, free or united in one or two bundles.

Wood is not too hard, yellow in colour after fresh cut. Found in all over Assam (mostly in upper Assam) and planted as roadside tree.

Field sampling

16 different tree species of the age groups of 5 to 10 years old were selected for the study. Three randomly selected trees of each of the species were sampled from a particular locality. For each species, 20 cm long sample was cut for three butt diameter classes: 1 - 5 cm, 5.1 - 10 cm, and 10.1 - 15 cm outside the bark. Each sample was labeled and bagged immediately in a polyethylene bag and sealed to avoid loss of moisture from the freshly cut trees. Samples of each of the tree species collected from different localities were thoroughly mixed to make a representative sample. Some were sampled to keep diameter classes identities.

Ranking of firewood characteristics

Key informants were used to identify firewood qualities according to Kumar (1989). 20 key informants with equal number of men and women were selected from each locality considering their experience with firewood utilization as source of energy. Pair-wise ranking was followed to identify the firewood property and ranked species accordingly (Abbot *et al.*, 1997). Finally a ranking matrix for sixteen species using indigenously preferred ten quality criteria was drawn and scores were given to the species according to their comparative ranking value. A negative criterion such as sparking was made positive to non –sparking.

Drying profile

Drying profiles to observe the drying rates of the tree species were prepared. All the freshly cut stem samples were weighed accurately within 5 hours of cutting. They were then left to dry in the sun for 8 weeks. A drying profile of each of the samples was maintained by recording the weight loss of the samples at one-week interval.

Analytical test on firewood properties

Sample preparation

A disc of 2 cm thickness and 4 cm diameter was taken from each of the freshly cut tree species without removing the bark portion and kept in an oven for moisture removal. The oven-dried disc taken from each of the diameter classes of individual tree species were mixed thoroughly and then ground (using a Wiley mill) to pass a 0.4 mm (40 mesh) screen (as per TAPPI T257 Om- 85 methods). The ground sample of individual tree species was kept in air- tight containers.

To prepare samples from bark alone, bark portion of each of the tree species was separated from the stem and followed the same procedure as described above for the preparation of representative bark samples.

Preparation of extractive free samples

Wood extractives are materials soluble in neutral solvents and are not generally considered as part of the wood substances. These materials should be removed before any chemical analysis of wood substances.

Ethanol-benzene mixture was used to extract waxes, fats, some resins, and possibly some portions of wood gums. Hot water was used to extract tannins, gums, sugars, starches and colouring matter. The procedures for ethanol-benzene and hot water soluble extractives are described below.

Determination of Total extractives content

Total extractive content was determined according to the method reported by Senelwa *et al.* (1999). He has describes a modified method for determination of extractives content distinguished into two categories — organic (non-polar) solvents soluble extractives (i.e. ethanol: benzene mixture and ethanol, OEC), and water (polar solvent) soluble extractives. The sum of polar and non-polar solvent soluble extractives content was taken together as total extractives content (TEC).

Approximately 2 g of oven dry ground sample of particle size 180-250 μ was weighed and taken into a filtering thimble having coarse porosity. The tip of the thimble was closed with loose cotton to prevent the specimen go out. The thimble was then placed into a soxhlet extraction apparatus with ground glass joints and with 250 ml extraction flask fitted with a condenser. To determine OEC, the samples were extracted with 125 ml of a 33:67 volume mixture of 95% ethanol: benzene for 4 hrs. followed by another 4 hrs. extraction with 125 ml of 95% ethanol. The ethanol was drained off and evaporated to constant weight.

The samples were further boiled in distilled water at 100^0C (boiling water bath) for 3 hrs. and then oven dried at 80^0C to constant weight. OEC and TEC were determined as % weight loses after extraction with organic solvent (ethanol and benzene mixture) followed by hot water extraction.

Proximate analysis of wood and bark samples

Proximate analysis gives the relative amount of ash, fixed carbon and volatile matter in a fuel as a percentage of its oven-dry weight.

Procedure

Preparation of samples

Wood and bark samples of each of the tree species were ground separately to pass through a 40-mesh sieve. For determination of ash and volatile matter content the samples were made extractives free as per procedure stated above. Moisture content of the samples was determined for freshly cut green samples.

Determination of Moisture content

The moisture content was determined according to the method described in the Forestry Hand Book (Wenger, 1984). 10 g of sample was weighed immediately upon sampling and then air-dried. This air-dried sample was taken immediately in an aluminum moisture box and kept in an oven heated at 105 ± 3^{0}C until constant weight was obtained. The difference of the oven dry weight of the sample and the fresh weight of the sample was used to determine the percentage of moisture content as follows:

$$\% \text{ Moisture content} = \frac{\text{Fresh weight} - \text{Oven dry weight}}{\text{Fresh weight}} \times 100$$

For each sample, the estimation was done in triplicate and the mean value was reported.

Determination of Ash content

For determination of ash content, TAPPI standard method, T211 om-85, was followed. At first, an empty 25 ml. silica crucible was heated in a muffle furnace at 575 ± 25^{0}C for 15 min. and allowed to cool in a desiccator for 45 min. and then weighed accurately. Representative sample of each of the plant parts was made oven-dry, weighed and transferred into the crucible and kept in a muffle furnace at 575 ± 25^{0}C to ignite for a period of 3 hrs or longer to burn away the carbon, completion of which was indicated by the absence of black particles. Crucible was then removed from the furnace and kept in a desiccator and weighed accurately. The percentage of ash content was calculated as follows:

$$\% \text{ Ash content} = \frac{\text{Weight of the ash}}{\text{Weight of the sample}} \times 100$$

For each sample, the estimation was done in triplicate and the mean value was reported.

Determination of Volatile matter

Volatile matter of wood and bark samples was determined by the method described in ASTM Test No. D-271-48.

A platinum crucible of 10 ml capacity was taken and cleaned its surface by rubbing with fine steel wool and heated in a furnace at 950^0C for 2 min. and cooled in a desiccator for 15 min., then the weight of the platinum crucible was taken. $^1/_2$ to $^3/_8$ in. of top of the crucible was filled up with the ground samples and gross weight was taken, and then heated in the furnace at 950^0C for 2 minutes. After the volatile matter escaped, the crucible was removed from the furnace and cooled in air for 2 to 5 mins. and then cooled in a desiccator for 15 min.. The percentage of weight loss of the samples was reported as volatile matter as follows:

$$\text{a) \%Volatile matter} = \frac{\text{Wt. loss of dry sample}}{\text{Net wt. of dry sample}} \times 100$$

$$\text{b) \%Volatile matter} = \frac{\left[\dfrac{\text{Wt. loss of wet sample} \times 100}{\text{Gross wt. of wet sample}}\right] - \text{percent moisture}}{100 - \text{percent moisture}} \times 100$$

For each sample, the estimation was done in triplicate and the mean value was reported.

Determination of Fixed carbon content

Fixed carbon content of wood and wood base materials (bark) was determined by simple calculation as given in ASTM Test No. D-271-48. The calculation was done as follows:

% F.C. (on dry basis) = 100 - [volatile matter (%) + ash (%)]

% F.C. (on wet basis) = 100 - [volatile matter (%) + ash (%) + moisture (%)]

Ultimate analysis of the samples

Carbon, hydrogen and nitrogen contents of the wood and bark samples were determined by using an elemental analyzer (PE 2400 C, H, N, -analyzer, Perkin Elmer). Chlorine and sulphur were not considered since they are known to be negligible for wood and wood base materials. Oxygen was determined by difference between the total weight of the sample and the combined weight of C, H, N and ash content in it.

Determination of Specific gravity

Specific gravity of the samples was determined as per ASTM – D 2395-93 (volume by water/ mercury immersion method).

Procedure:

Weight: The weight of the specimen was measured to a precision of ± 0.2%. Before weighting the specimen it was dried in an oven maintained at 103 ± 20^0C.

Volume: The volume of oven-dried specimen was determined by measuring the volume of water displaced by it.

Mode of measurement:

A container was placed holding enough water to completely submerge the specimen on the pan of an automatic balance. The specimen was held by means of a sharp, pointed, slender rod so that the specimen was completely submerged without touching the sides of the container. The weight added to the automatic balance was equal to the weight of water displaced by the specimen. The weight in grams was numerically equal to the volume in cubic centimeters.

Calculation

Specific Gravity: Specific gravity was calculated as follows:

Sp. gr. = KW/V

Where

W = weight of specimen at derived moisture content

V = Volume of specimen at desired moisture content and

K = Constant whose value was determined by the units used to measure weight and volume as follows:

K = 1, when weight was in g and volume was in cm^3.

Determination of Biochemical constituents of the samples

The biochemical constituents viz. hollocellulose (cellulose + hemicellulose) and lignin of the wood and bark samples were determined indirectly by using the Tecator Fibertec I and M systems (Foss Tecator). Methods of this system are based on subsequent steps of chemical treatments to solubilize "nonfibre" components and final determination of the biochemical constituents arc obtained from the dry weight of residue of the treatments. The chemical treatments were done by treating the ground dry samples with Neutral Detergent Solution (Sodium Lauryl Sulphate and EDTA) to get residue of Neutral Detergent Fiber (NDF) containing Cellulose 100% + Hemicellulose 100% + Lignin 100% followed by treated the residue with acid detergent solution i.e. CTAB in sulfuric acid solution to get residue of Acid Detergent Fiber (ADF) containing Cellulose 100% + Lignin 100%. The residue was further treated with 72% sulphuric acid to get residue of Acid Detergent Lignin (ADL) containing lignin 100%. Subtraction of the value of ADF from NDF gave us the value of hemicellulose content while subtraction of ADL from ADF gave cellulose content. Sample for this purpose was ground to pass a mess-sieve size of –40+60 and was defatted with acctone three times with 25 ml portion/g sample in the FiberTec cold Extraction unit prior to extraction in the hot extraction unit.

Determination of Calorific value

The calorific values of the samples were determined with the help of a Bomb Calorimeter as per the method recommended by the Indian Standard Institution (IS: 1359-1955). The protocol for calorific value determination was as follows:

Protocol for calorific value measurement (Gupta *et al.*, 1996)

Calorific value as determined with a bomb calorimeter is defined as the number of heat units liberated by a unit mass of the substance when burnt in a sealed enclosure of constant volume in an atmosphere of pure oxygen gas.

At first, the bomb calorimeter was standardized by burning pure and dry benzoic acid to give the effective heat capacity of the system. About 1g of completely dried sample was weighed accurately. The sample was then compressed to make a pellet and its weight was taken. Nichrome firing wire was stretched across the electrodes within the bomb and a cotton thread was tied around the wire and arranged the loose ends of the thread so that they were in proper contact with the sample pellet in the crucible and then the bomb was reassembled The bomb was filled with pure oxygen at a pressure of 18 atmospheres. 2.0 kg of water was transferred to the calorimeter vessel. Oxygen filled bomb was kept inside calorimeter vessel. After adjusting the stirrer and covers in proper position, the main supply and stirrer mechanism was switched on. After an interval of not less than ten minutes, temperature to 0.01^0C was recorded continuously for each one-minute interval. Reading was taken continuously till rate of change of temperature was found less than 0.0072^0C/minute. After that, the ignition circuit was closed and temperature variation was recorded. Bomb and thermometer were removed from the calorimeter and bomb was opened after releasing the pressure. The length of the nichrome wire left unused was measured for correction.

Calculation

Weight of fuel pellet (g) = W

Thread correction (cal) = Weight of cotton thread (mg) X calorific value of cotton thread (cal/mg)

= x

Firing wire correction (cal) = Length of firing wire consumed (cm) X mass/length of wire (mg/cm) X Calorific value of Nichrome wire (cal/mg)

= y

Temperature rise (t^0C) = Final Temperature - initial temperature

Apparent heat capacity of system ($cal/^0C$)= z

Total heat liberated (cal) = z X t

= p

Subtract thread correction (cal) = p – x

Subtract wire correction (cal) = (p- x) – y

= q

Heat liberated from W g of fuel (cal) = q

Hence heat liberated from 1 g of fuel (cal)= q/W

Therefore, calorific value of the fuel (cal/g)= q/W

Fuel value index calculation

The fuel value index (FVI) was calculated following the method of Purohit and Nautiyal (1987) as follows:

$$FVI = \frac{\text{Calorific value (KJ/g) x Density (g/cm}^3\text{)}}{\text{Ash content (g/g) x Water content (g/g)}}$$

Ash analysis for elemental determination

The analysis of ash for determination of elements viz. Ca, Mg, K. Na, Fe, Zn, Cu, Al etc was done by using an Atomic Absorption Spectrophotometer. For this, 500 ± 5.0 mg ground extractive free samples were digested in a muffle furnace at 500^0C for 4 hrs. The ash thus formed was kept in a desiccators for cooling and then dissolved with 10 ml 1N HCl solution and transferred in to a 50 ml volumetric flash The plant tissue liquid digest containing the elements to be determined was atomized into either an acetylene/air or acetylene/ nitrous oxide gas mixture at a temperature between 2,000 to 2900^0C in an Atomic Absorption Spectrophotometer (Hanlon, 1998).

For determination of silica content in wood, the wood sample was first converted to ash as per method described earlier. The ash thus obtained was further digested in 50% HCL (evaporated to dryness thrice) and filtered through the Whatman no. 42 filter paper. The same filter paper was ignited in a muffle furnace at 550^0C and cooled. The weight of the residue is considered as the silica content. Silicon was calculated as one of the constituents of silica.

CHAPTER IV

RESULTS AND DISCUSSIONS

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With an ever-increasing population in developing countries, the demand for fuelwood will increase enormously in the coming decades. It has been reported that tree felling for firewood accounts for the largest share of wood use in developing countries causing rapid deforestation (Banerjee *et al.*, 1992). To avert this situation it is necessary to establish large-scale energy plantations on unused and degraded lands. However, while selecting the tree species for energy plantation, special attention should be given to the indigenous tree species, which are traditionally preferred for fuel by the local people. A report of National Academy of Sciences (1980) on fuelwood crops also recommended that for energy plantation special attention should be given to the tree species found locally and traditionally preferred for fuel.

In Assam, fuelwood are used by the rural people mainly for cooking and water heating. In winter season they are also used for space heating. Use of firewood for lighting, kindling, brick burning and industrial applications were reported to be very limited (Deka *et al.*, 1999; Deka, 2000).

Assam has a large number of forests covering around 27% of total geographical area of the state. Besides the reserved forests, wood lots, farm forests are seen every where in the state. Because of the soil fertility and heavy rainfall in the state, a large number of tree and shrubs species grow well in their natural habitats. But there is conspicuous lack of knowledge of their fuelwood characteristics.

The present study deals with the screening of the most promising fuelwood species of Assam, based on the knowledge gathered by the rural people from their long experiences for selecting the firewood and also from the laboratory analytical tests on fuelwood characteristics. Attempts have also been made to explain the fuelwood qualities of the species from their chemical and biochemical compositions. Ashes of the tree species were analysed to examine the possibility of using the ashes mainly as fertilizers for mineral nutrients for forests and agricultural soils. Analysis of ashes may also be helpful for their disposal.

Chapter IV: Part-1

Ranking of 16 traditionally preferred indigenous fuelwood species of Assam on the basis of pair-wise comparison

Species ranking by pair-wise comparison

Abbot *et al.* (1997) determined the important fuelwood characteristic used by rural people in Malawi by the pair-wise comparison of preferred indigenous tree species. This was further compared with a fuel value index based on the properties of basic density, moisture and ash content. The main criteria used by villagers to rank fuelwoods were drying rate, duration of ember production and moisture content. The procedure used in their study was a low technology, but accurate enough to establish the important indigenous tree species to be managed for fuelwood production and the study recommended that fuelwood management planning should recognise the role of indigenous quality criteria in rural people's choice of fuelwoods.

In the present study, an attempt has been made to rank 16 traditionally preferred indigenous fuelwood species of Assam on the basis of pair-wise comparison for selection of firewood species considering certain fuelwood quality criteria.

Table- 2 presents the results of the pair-wise ranking process. Sixteen species were ranked by 10 criteria. The rank of each species and criterion is presented in the right-hand column and bottom row respectively. The pair-wise ranking (Table-2) indicated that the respondents' most preferred species were *S. chelonoides*, *C. fistula*, *M. bombycina*, *A. lucida* and *E. jambolana*. It was observed that no one species had all the desirable fuelwood characteristics.

Table- 2: Ranking matrix for 16 firewood species using 10 quality criteria

Species Name	Species quality criteria*										Total species score	Rank**
	Fast drying	Hot Flame	Produces ember	Flame not smoky	Easily flammable	Non-sparking	Light weight when dry	Bright flame	Easily split	Low moisture when fresh cut		
L. grandis (D.) Engl.	6	1	-	-	-	-	6	-	2	-	15	10
E jambolana Lam	8	7	7	6	5	6	3	3	1	2	48	4
P obovatum Clarke	7	4	4	1	-	6	-	-	-	-	22	8
A rohituka W & A	7	7	6	4	3	3	1	2	2	1	36	6
F infectoria Roxb	3	4	3	3	5	2	6	-	4	-	30	7
D peregrina Gurk	-	5	2	3	-	5	-	-	-	-	15	10
A lucida Benth	9	6	7	6	8	5	3	5	5	-	54	3
L flos-reginae Retz	7	4	3	-	-	-	-	2	2	-	18	9
S chelonoides DC	9	9	8	7	7	5	2	4	2	4	57	1
S wallichii Chois	9	6	4	1	1	2	1	2	2	2	30	7
A procera Benth	6	6	6	5	6	2	-	4	-	4	39	5
C fistula Linn	4	9	9	8	7	4	2	4	3	5	55	2
M bombycina King	8	8	7	7	8	6	3	-	5	3	55	2
T belerica Roxb	2	6	3	2	2	-	3	-	-	-	18	9
E acuminata DC	8	7	6	5	4	3	2	2	-	2	39	5
C siamea Lam	4	4	2	-	-	2	-	3	-	3	18	9
Total criterion score	96	93	77	58	56	51	32	31	28	26		
Criteria Rank	1	2	3	4	5	6	7	8	9	10		

--no marking indicates that the particular tree species is not considered suitable to rank by the respondents for that specific quality criteria

* Species scoring of each criteria is given by considering 10 (best) value

** Ranking ranges from 1 (best) to 10 (worst)

Ranking of firewood characteristics

From Table- 2, it is seen that the most important criteria for ranking of fuelwoods were 'fast drying rate', 'hot flame' and the 'ability to produce embers', 'flame without smoke' and 'easy flammability'. Other criteria are found to be less important as not mentioned for most of the times by the respondents during selection of the firewood species on the basis of their quality.

Drying rate

'Fast drying rate' was the criterion most frequently used by the respondents in the ranking of fuelwood species. After fresh cut, villagers generally keep firewood on open space for sun drying. They use the firewoods for burning after keeping it for 6 – 8 weeks for sun drying. A similar study on firewood quality done by Abbot *et al.* (1997) indicated that the rate at which wood dries out became more important as wood scarcity increased. According to Table-2, the tree species having fast drying rates were *S. chelonoides*, *S. wallichii*, *E. jambolana* and *E. acuminata*.

Hot flame

'Hot flame' is another important criterion frequently mentioned by the respondents in ranking the preferred fuelwood species. Considering the requirement of firewood mainly for cooking, the respondents indicated that 'hot flame' could provide sufficient heat for quick cooking. Among the sixteen fuelwood species under the study, *S. chelonoides*, *C. fistula* and *M. bombycina* were found to produce hot flame during burning. The next groups of species found to produce slightly less hot flame were *E. jambolana*, *A. rohituka* and *E. acuminata* (Table- 2).

Ember production

For production of long-lasting embers, for slow cooking and space heating, C. *fistula*, *S. chelonoides*, *E. jambolana*, *A. lucida* and *M. bombycina* (Table-2) were found to be the most suitable species. The respondents informed that long-lasting embers can give uniform heat and would be more effective for space heating in winter season and brick burning.

Flame not smoky

In Assam, food is cooked mostly by women and in rural households kitchens normally do not have proper ventilation for release of smoke. Therefore, fuelwood species that produce less smoky flame are preferred by the users.

Table- 2 shows that C. *fistula*, *M. bombycina* and *S. chelonoides* were found to produce comparatively much less smoke on burning as compared to the other species under investigation.

Flammability

Though some respondents considered flammability as one of the important criteria for selection of firewood species, many others considered that with the help of some easily burning dry biomass materials such as rice straw or dry bamboo could be used to start fire. During this initial burning, excess moisture present in the firewood can be evaporated. But, easily flammable tree species take less time to start fire and thereby reduce the trouble of initial burning operation.

In the present study it was found that *A. lucida*, *M. bombycina*, *C. fistula* and *S. chelonoides* were easily flammable as compared to other firewood species (Table-2).

Non-sparking

Sparking from the firewood during burning is an undesired quality. It may create hazards to nearby or around the burning places. In the present study, respondents did not mention this criterion frequently for selection of firewood. They indicated that except one or two species, most of the species had very little sparking behaviour.

From Table- 2, it is seen that *E. jambolana*, *P. obovatum*, *M. bombycina*, *A. lucida*, *S. chelonoides* and *D. peregrina* were some of the tree species reported to be considered among the best quality non-sparking species.

Light weight when dry

This is a less important selection criterion of firewood from the end-user's point of view. In the present investigation, though some of the species such as *L. grandis*, *F. infectoria* and *T. belerica* showed considerable light weight when dry, but found to be incompatible for the most favoured fuelwood characteristics such as fast drying, hot flame, ember production etc. (Table- 2).

Bright flames

Most of the respondents mentioned that firewood was not generally used for illumination. Normally villagers used electricity or kerosene for illumination. Sometimes near the reserved forest areas, villagers used bundle of dry bamboo sticks for illumination during local movement at night. However, it was reported that *A. lucida*, C. *fistula*, *M. bombycina*, *S. chelonoides* and *A. procera*, produced bright flame on burning.

Easiness of splitting

Easiness of splitting is an important criterion of firewood for those who do business of firewoods. But for villagers it is not an important criterion, as reported by the respondents.

Tree species rich in this criterion were reported to be *A. lucida* and *M. bombycina* (Table- 2).

Low moisture when fresh cut

This criterion was not considered to be much important by the respondents for selection of firewood. Rural people generally do not use fresh cut firewood. After cutting the trees they keep them for several weeks for drying before use.

Among all the fuelwood species, C. *fistula, E. jambolana*, *A. rohituka*, *S. chelonoides* and *A. procera* were reported to have low moisture content when freshly cut.

Chapter IV: Part-2

Ranking of the fuelwood species on the basis of Fuel Value Index and its comparison with pair-wise ranking

Ranking of the tree species from Fuel Value Index (FVI)

Fuel Value Index (FVI) is an important character for screening desirable fuelwood species. This factor depends upon calorific value and density as positive character and moisture and ash contents as negative characters (Goel and Behl, 1996). The formula used for computation of the FVI is as below:

$$FVI = \frac{\text{Calorific value (KJ/g) x Density (g/cc)}}{\text{Ash content (g/g) x Moisture content (g/g)}} \quad (1)$$

In the present study FVI of the fuelwood species was calculated using formula No.1 and the results are presented in Table- 3 under column FVI-1. In general woods having high calorific value, high density, low ash and moisture contents are known as ideal fuelwood species. From Table- 3, it is seen that *S. chelonoides* has the highest FVI (4738.74) among all the species under investigation followed by C. *fistula* (4704.98), *M. bombycina* (4411.98), *A. lucida* (4006.56), *E. acuminata* (3743.96), *A. rohituka* (3741.03), *E. jambolana* (3714.11) etc. With low moisture and ash contents, *S. chelonoides* possesses the highest calorific value (21.65 ± 0.25 MJ/Kg) and density (0.975 ± 0.13 g/cm^3).

Fuel Value Index of the fuelwood species was calculated by using the modified method reported by Bhatt and Todaria (1992) in which calorific value and

Table- 3: Analytical tests on fuelwood properties of 16 indigenous tree species

Species Name	Green moisture (%, wt.) **mc.**	Ash (%, oven dry wt.) **a.**	Calorific value (MJ/Kg., oven dry wt.) **Cv.**	Density (g/cm³, oven dry wt.) **d.**	FVI – 1 **Cv.x d. / a. x mc.**	FVI – 2 **Cv. x d. / a.**	FVI – 3 **Cv. x d. / mc.**
L. grandis (D.) Engl.	54.06 ± 0.33	2.95 ± 0.23	18.55 ± 0. 23	0.502 ± 0.75	0583.92	0315.66	17.23
E. jambolana Lam.	43.92 ± 0.02	1.08 ± 0.30	20.18 ± 0. 12	0.873 ± 0.21	3714.11	1631.21	40.11
P. obovqtum Clarke.	49.01 ± 0.82	1.85 ± 0.32	19.63 ± 0. 18	0.653 ± 0.45	1413.76	0692.88	26.23
A. rohituka W. &A.	45.31 ± 0.53	0.95 ± 0.58	20.41 ± 0. 15	0.798 ± 0.34	3741.03	1714.44	35.95
F. infectoria Roxb.	50.84 ± 0.18	1.27 ± 0.22	19.92 ± 0. 21	0.569 ± 0.22	1755.46	0892.47	22.29
D. peregrina Gurk.	56.31 ± 0.23	2.75 ± 0.05	18.64 ± 0. 51	0.710 ± 0.32	0854.64	0481.25	23.50
A. lucida Benth.	41.31 ± 0.51	0.95 ± 0.18	20.03 ± 0. 88	0.785 ± 0.12	4006.56	1655.11	38.06
L. flos-reginae Retz.	53.06 ± 0.38	1.97 ± 0.02	19.19 ± 0. 28	0.584 ± 0.15	1072.14	0568.88	21.12
S. chelonoides DC.	46.89 ± 0.29	0.95 ± 0.41	21.65 ± 0. 25	0.975 ± 0.13	4738.74	2221.97	45.02
S. wallichii Chois	45.12 ± 0.89	3.12 ± 0.32	19.87 ± 0. 13	0.774 ± 0.35	1092.48	0492.92	34.03
A. procera Benth	48.13 ± 0.21	1.14 ± 0.23	20.35 ± 0. 5 8	0.713 ± 0.41	3134.99	1272.76	30.15
C. fistula Linn.	43.23 ± 0.24	0.83 ± 0.34	21.56 ± 0. 24	0.783 ± 0.11	4704.98	2033.91	39.05
M. bombycina King.	40.29 ± 0.12	0.91± 0.08	20.74 ± 0. 29	0.838 ± 0.27	4411.98	1909.90	43.13
T. belerica Roxb.	42.18 ± 0.82	1.79 ± 0.38	19.91 ± 0. 14	0.657 ± 0.10	1732.51	0730.71	31.01
E. acuminata DC.	39.02 ± 0.57	0.86 ± 0.99	20.63 ± 0. 39	0.609 ± 0.13	3743.96	1460.89	32.20
C. siamea Lam.	53.69 ± 0.38	2.25 ± 0.75	19.79 ± 0. 08	0.677 ± 0.04	0875.58	0545.45	24.95

density were considered as positive characters and ash content alone as negative character. The formula used for computation of FVI in this method is as below:

$$\text{FVI} = \frac{\text{Calorific value (KJ/g) x Density (g/cc)}}{\text{Ash content (g/g)}} \qquad (2)$$

and the results are presented in Table- 3 under the column FVI-2. In this calculation also species *S. chelonoides* showed the highest FVI (2221.97) followed by *C. fistula* (2033.91), *M. bombycina* (1909.90), *A. lucida* (4006.56), *E. jambolana* (1631), *E. acuminata* (1460.89) etc.

The removal of % ash content from the index of fuelwood quality provides a FVI which is more simple to determine but equally effective. Abbot *et al.* (1997) have also calculated FVI of firewoods considering calorific value and density as positive characters and moisture content alone as negative character. In this method the formula used for computation is as below:

$$\text{FVI} = \frac{\text{Calorific value (KJ/g) x Density (g/cc)}}{\text{Moisture content (g/g)}} \qquad (3)$$

The results of FVI of the tree species calculated using formula no. 3 are also presented in Table- 3 under column FVI-3. It is seen from Table-3 that when calorific value and density were considered as positive characters and moisture content alone as negative character, the FVI (FVI-3) of *S. chelonoides* was found to be the highest (45.02), Table- 4: Ranking of 16 indigenous tree species on the basis of their Fuel Value Indexes and pair-wise comparison values

Species Name	Ranking of species on the basis of FVI			Ranking of species on the basis of pair-wise comparison
	FVI-1	FVI-2	FVI-3	
L. grandis (D.) Engl.	16	16	16	10
E. jambolana Lam.	7	6	3	4
P. obovatum Clarke.	11	11	11	8
A. rohituka W. & A.	6	4	6	6
F. infectoria Roxb.	9	9	14	7
D. peregrina Gurk.	15	15	13	10
A. lucida Benth.	4	5	5	3
L. flos-reginae Retz.	13	12	15	9
S. chelonoides DC.	1	1	1	1
S. wallichii Chois.	12	14	7	7
A. procera Benth.	8	8	10	5
C. fistula Linn.	2	2	4	2
M. bombycina King.	3	3	2	2
T. belerica Roxb.	10	10	9	9
E. acuminata DC.	5	7	8	5
C. siamea Lam.	14	13	12	9

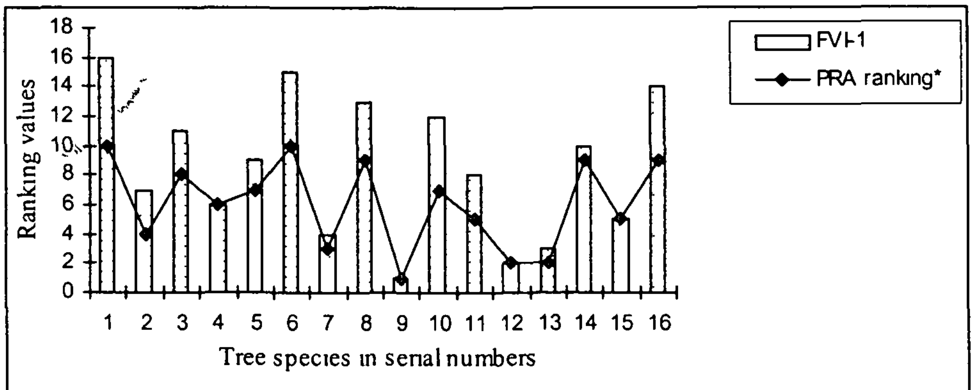

Fig 22a

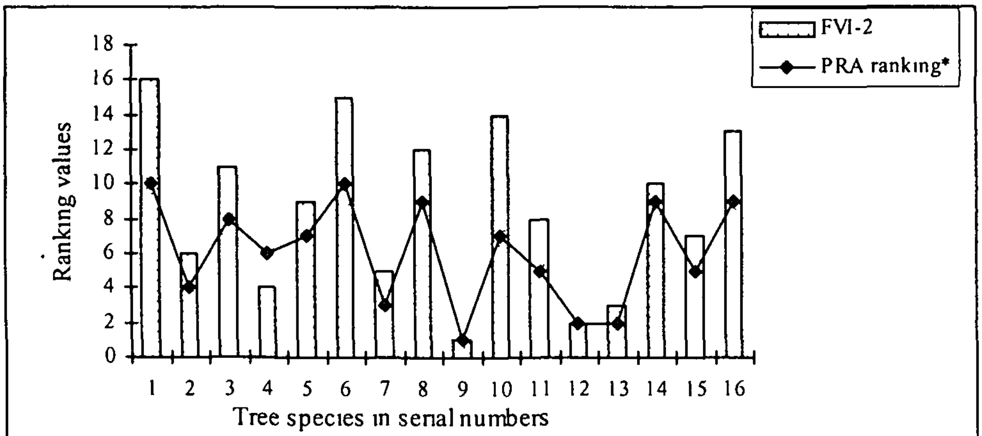

Fig 22b

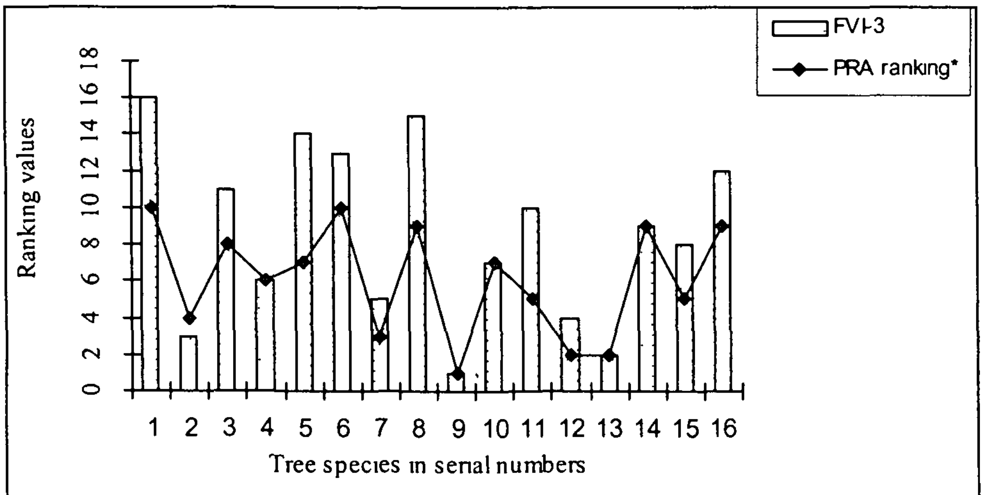

Fig 22c

Fig22a-22c Ranking resemblance of FVI (1-3) with pair-wise ranking values

1 L grandis (D) Engl 2- E jambolana Lam 3-P obovatum Clarke 4-A rohituka W & A
5-F infectona Roxb 6-D peregrina Gurk 7-A lucida Benth 8-L flos-reginae Retz
9-S chelonoides DC 10-S wallichii Chois 11-A procera Benth 12-C fistula Linn
13-M bombycina King 14-T belerica Roxb 15-E acuminata DC 16-C siamea Lam

followed by *M. bombycina* (43.13), *E. jambolana* (40.11), C. *fistula* (39.05), *A. lucida* (38.06), *S. wallichii* (34.03), *E. acuminata* (32.20) etc. whereas lowest FVI was shown by *L. grandis* (17.23).

Ranking of the tree species on the basis of Fuel Value Indexes (FVI-1, FVI-2, FVI-3) and the ranking of the same tree species found on the basis of pair-wise comparison are presented in Table- 4.

From Table- 4 and Fig-22c, it is seen that the ranking of the species on the basis of FVI-3, which was calculated considering calorific value and density as positive characters and moisture content as negative character, has more resemblance with the ranking of the fuelwood species obtained on the basis of pair-wise ranking with key informants. The common people's preference for selection of fuelwood species is based mainly on the characteristics such as ember production, high heating value and low moisture content. The ash content is not an important characteristic for them. The characteristics of higher density used in the index are those that provide better quality embers; an important criterion in the pair-wise matrix. Low moisture content improves the index value of a fuelwood and in terms of pair-wise matrix criterion: improves flammability and reduces the weight of air-dry wood. However, Table- 2 and 3 show that people's preferences are also determined by a series of minor properties, which are not considered by either of the simple FVI.

From Table-4, it is seen that the decreasing order of ranks of the preferred fuelwood species under study on the basis of pair-wise ranking is as follows:

S. chelonoides, C. *fistula* , *M. bombycina*, *A. lucida*, *E. jambolana*, *A. procera* , *E. acuminata* , *A. rohituka* and so on.

FVI study (FVI-3) of the fuelwood species also shows the decreasing order of preference as below:

S. Chelonoides, *M. bombycina*, *E. jambolana*, *C. fistula*, *A. lucida*, *A. rohituka* and so on.

The present study reveals that for the rapid evaluation of indigenous fuelwood species, the pair-wise ranking procedure, used by rural people may easily be applied. Though it is a simple technology, but accurate enough to evaluate the fuelwood species.

Chapter IV: Part-3

Drying behaviour of the fuelwood species and the effect of moisture content on heating value

Drying behabiour of the fuelwood species

The green moisture content of the freshly cut woods was not perceived important by the village people, as most of the firewoods were left for 6-8 weeks of sundry before their use. When a tree is felled the water supply is cut off and the tree will slowly come to an equilibrium moisture content with the ambient air. The equilibrium moisture content depends on the temperature and relative humidity of the ambient air (Nurmi, 1992). With a view to know the drying behaviour of the tree species under study, an experiment was carried out by keeping three diameter classes of the tree species viz. 0 – 5 cm, 5 – 10 cm and 10 – 15 cm and 20 cm in length on sundry for 8 weeks. The percent weight loss by each of the wood species was recorded after interval of each week. The results are presented in Table- 5. The percent weight loss is reported as an average of the three diameter classes. As the seasons affect the drying behaviour (Hakkila, 1962) of wood, the climatic data during the experiment were recorded and presented in Table- 6.

From Table- 5, it is seen that after 7 days of sun dry, the highest percentage of weight loss was with S. *wallichii* followed by *A. rohituka*, *E. jambolana*, S. *chelonoides* etc. while *D. peregrina* showed the lowest weight loss.

After 14 days of sun dry, the highest weight loss was shown by *E. acuminata* followed by *A. rohituka*, S. *wallichii*, *M. bombycina*, *L. flos-reginae* etc. and lowest weight loss was shown by *D. peregrina.*

Table- 5: % Weight loss of the tree species after different periods of sundry[a]

Species Name	Green moisture (% wt.)	Weight loss in percentage at days after sundry							
		7 DAS	14 DAS	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS
***L. grandis* (D.) Engl.**	54.06 ± 0.33	16.51	22.26	26.88	31.36	38.15	44.53	49.00	55.44
E. jambolana Lam	43.92 ± 0.02	20.65	27.3	31.71	35.84	43.75	48.72	51.94	52.64
P. obovatum Clarke	49.01 ± 0.82	16.80	24.64	29.40	33.32	35.00	41.58	45.08	48.16
A. rohituka W. & A.	45.31 ± 0.53	21.70	33.6	39.06	42.00	44.10	47.88	49.98	52.52
F infectoria Roxb.	50.84 ± 0.18	13.44	22.54	28.98	38.72	40.25	47.88	52.92	55.44
*D. peregrina*Gurk	56.31 ± 0.23	10.36	16.94	19.95	21.84	23.1	26.04	27.93	31.36
A. lucida Benth	41.31 ± 0.51	16.31	27.3	34.44	38.36	40.95	43.26	48.51	54.88
L. flos-reginae Retz.	53.06 ± 0.38	18.83	28.14	30.66	32.48	37.10	40.32	43.40	45.92
S. chelonoides DC.	46.89 ± 0.29	19.67	26.46	30.03	31.64	36.05	39.06	41.16	42.56
S. wallichii Chois	45.12 ± 0.89	24.64	30.94	36.33	37.24	41.30	44.10	46.55	47.60
A. procera Benth	48.13 ± 0.21	17.15	25.90	30.45	34.16	40.95	43.26	47.04	48.16
C. fistula Linn.	43.23 ± 0.24	18.69	23.30	30.24	35.00	37.8	43.68	47.53	50.40
M. bombycina King	40.29 ± 0.12	18.97	28.72	31.92	35.56	38.85	44.94	49.16	51.52
T belerica Roxb.	42.18 ± 0.82	11.97	20.72	24.99	28.56	33.25	36.15	41.16	42.00
E. acuminata DC.	39.02 ± 0.57	19.18	34.16	40.11	43.96	45.85	50.4	52.92	53.20
C siamea Lam	53.69 ± 0.38	11.97	20.72	24.99	24.56	33.25	36.15	41.16	42.00

a-all values are the average value of three diameter classes
DAS-days after sundry

After 21 days of sun dry, the highest weight loss was shown by *E. acuminata* followed by *A. rohituka* and *S. wallichii*. However, it was observed that the rate of weight loss gradually decreased after 14 days of sundry.

After 56 days of sun dry, the highest weight loss was found in *L. grandis* (55.44%) and *F. infectoria* (55.44%), though their initial weight loss upto 28 days was poor. Other tree species such as *A. lucida*, *E. acuminata*, *E. jambolana*, *A.*, *M. bombycina* etc. also showed higher weight loss after 56 days of sun dry. *D. peregrina* showed the lowest weight loss from the beginning of sundry upto 56 days.

After 35 days of sundry almost all the tree species showed low rate of moisture loss which indicated that 5 to 6 weeks of sun dry may be regarded as the best drying period for the fuelwood species under investigation.

With a view to co-relate the drying behaviour of the tree species with their diameter classes, we took samples of three diameter classes (1 – 5 cm, 5 – 10 cm and 10 – 15 cm) of some commonly preferred tree species such as *S. wallichii*, S. *chelonoides*, *M. bombycina*, *E. jambolana*, *A. rohituka* and *E. acuminata* and allowed them for sundry for 56 days. The results of the experiment are presented graphically in Fig. 23a to Fig. 23f. The rates of moisture loss in all the tree species under study were significant for all the diameter classes till 4-5 weeks of drying. After this period, the drying rates exhibited similar trend. From the graphs, it is seen that smaller sized wood samples had higher initial moisture loss than the larger sized samples. This observation is in agreement with

Table- 6: Climatic data recorded during the drying period (8 weeks), 2001

Study period		Temperature (^{0}C)		Atmospheric humidity (%)		Rainfall (mm)
Months	Weeks	Minimum	Maximum	8.30am	5.30pm	
November	First	18.0	28.0	87.63	84.57	nil
	Second	17.2	29.0	88.6	81.4	nil
	Third	17.0	28.5	86.0	80.57	nil
	Fourth	16.18	27.24	87.63	84.47	nil
Monthly average		16.87	27.96	87.57	82.58	nil
December	First	14.83	23.92	88.2	83.0	nil
	Second	13.27	22.2	93.28	79.42	nil
	Third	11.89	24.77	85.57	68.57	nil
	Fourth	12.12	23.8	96.0	66.0	nil
Monthly average		13.12	23.67	93.43	76.0	nil

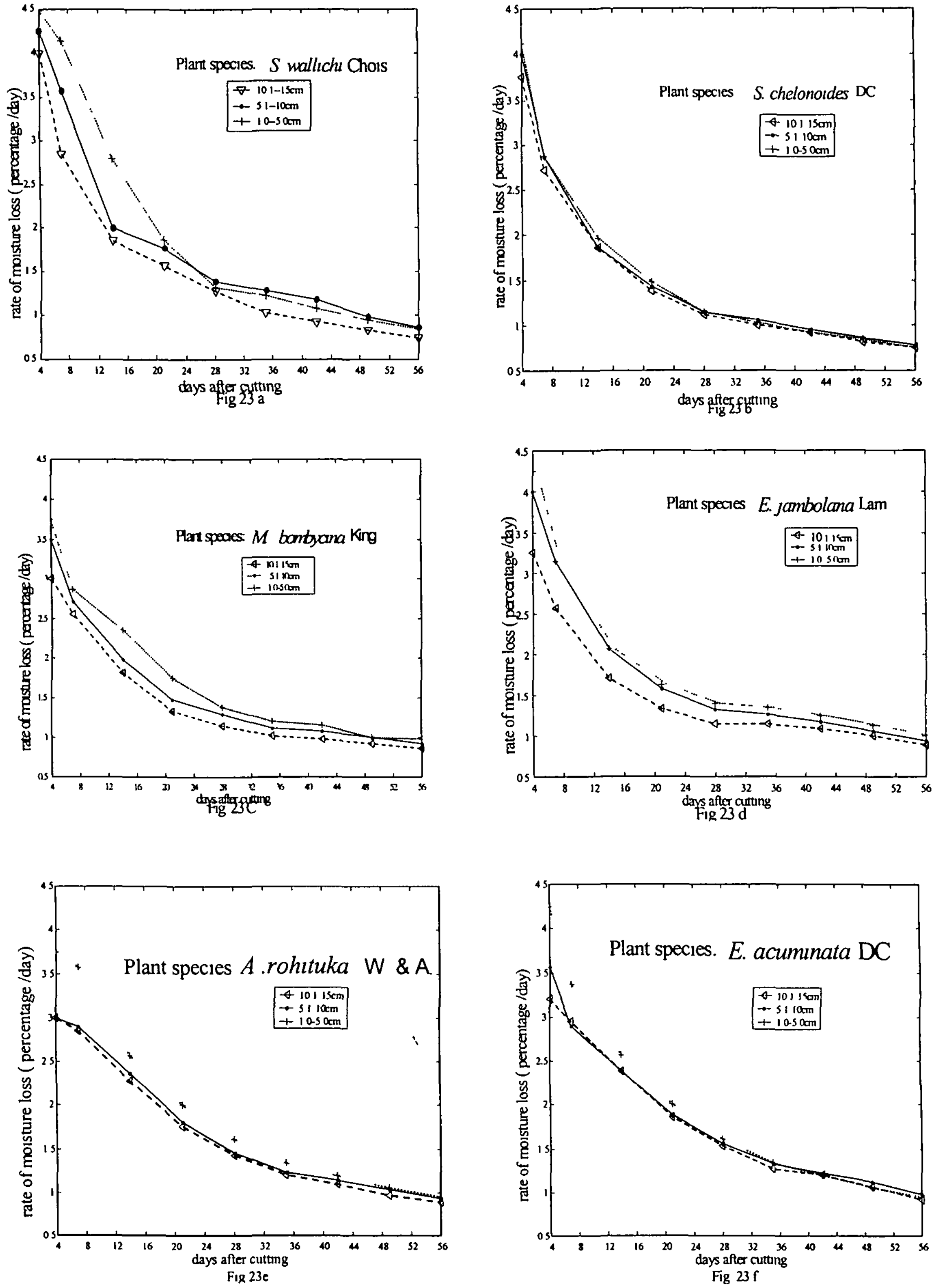

Fig. 23a-23f: Rate of moisture loss of different diameter classes after fresh cut the findings of Abbot *et al.* (1997) for some other tree species. Thus, it may be concluded that for immediate drying of firewood, smaller diameter classes, such as small branches are preferable whereas larger diameter classes may be suitable for use in later.

The differences in drying rates of the fuelwood species may be due to their wide range of bound and free water in the plant cells. On drying, the bound water is lost immediately and depending upon their bound water loss from lumen, the rate of drying in the initial period may vary (Shafizadeh, 1981). The water absorbed by capillary uptake is known as free water. The loss of free water is equilibrated with the ambient relative humidity. Hence, prevailing climatic condition of a particular region or location may play role on drying rates of tree species.

Effect of moisture content on heating values of the tree species

Moisture content may vary with fuelwood species due to differences in the hygroscopicity of different fiber complexion and that such differences may influence the suitability of biomass for various applications. The economic value of fuelwood is also dependent on its moisture content.

Moisture does not contribute to the heating value but reduces the heat available from fuel by (i) lowering the initial gross calorific value of the wood; (ii) reducing the combustion efficiency since heat is absorbed in evaporation of water in the initial stages of combustion which lowers both the flame temperature and the radiant heat

Table- 7: Relationship of moisture content and heating value of the tree species

Species Name	Green moisture (%, wt.)	Gross Heating Value (oven dry weight) MJ/Kg	Gross Heating Value* (at green moisture) MJ/Kg	Net Heating Value** (at green moisture) MJ/Kg	Usable Heat Content*** (at green moisture) MJ/Kg
L. grandis (D.) Engl.	54.06 ± 0.33	18 55 ± 0 23	08 52	6 619	5 217
E jambolana Lam	43.92 ± 0 02	20 18 ± 0 12	11 32	6 619	6 984
P obovatum Clarke	49.01 ± 0.82	19 63 ± 0 18	10 02	7 615	6 097
A rohituka W. &A.	45.31 ± 0.53	20 41 ± 0 15	11 17	8 344	6 742
F infectoria Roxb.	50.84 ± 0.18	19 92 ± 0 21	09 79	7 254	5 778
D peregrina Gurk	56.31 ± 0.23	18 64 ± 0 51	08 14	6 175	4 825
A lucida Benth	41.31 ± 0.51	20 03 ± 0 88	11 76	9 134	7 439
L flos-reginae Retz.	53.06 ± 0.38	19 19 ± 0 28	9 01	6 816	5 391
S chelonoides DC.	46.89 ± 0.29	21 65 ± 0 25	11 49	8 033	6 467
S. wallichii Chois	45.12 ± 0.89	19 87 ± 0 13	10 90	8 382	6 775
A procera Benth.	48.13 ± 0.21	20 35 ± 0 58	10 56	7 789	6 250
C fistula Linn.	43.23 ± 0.24	21 56 ± 0 24	12 02	8 557	6 930
M bombycina King	40.29 ± 0.12	20 74 ± 0 29	09 81	7 362	5 874
T belerica Roxb.	42.18 ± 0.82	19 91 ± 0 14	11 23	8 962	7 288
E acuminata DC	39.02 ± 0.57	20 63 ± 0 39	12 58	9 585	7 838
C siamea Lam.	53.69 ± 0.38	19 79 ± 0 08	09 16	6 692	5 281

* Gross CV at moisture content (m) is given by
$C_g = C_{ga} \times (1-m)$ (MJ/Kg)
Where, C_g = Gross CV
C_{ga} = Gross anhydrous CV,
m = moisture content, as a fraction of wet weight Reference Lyons *et al* (1985)

** Thus, C_n = 17 28 – 19 72 m (MJ/Kg)
C_n = Net Heating Value

*** Usable Heat Content = 14 64 – 17 43m (MJ/Kg) transfer; and (iii) by the hydrolysis effect of hot water (Senelwa, 1997). Water at or near boiling point promotes hydrolysis of the wood resulting in the production of water and carbondioxide.

In Table-7, a relationship between the moisture content of fuelwoood species and their heating values; gross heating values (GHV), net heating values (NHV) and usable heat content (UHC) is presented. The calculation for gross heating value, net heating value and usable heat content were made as per the formula reported by Lyons *et al.* (1985).

It is seen from the Table-7 that there is no direct relationship between the initial green moisture content with the gross heating values of the tree species. The gross heating values of the tree species range from 18.55 ± 0.23 MJ/Kg to 21.65 ± 0.25 MJ/Kg, while gross heating values at green moisture content ranges from 8.14 MJ/Kg to 12.58 MJ/Kg. Similarly, the net heating values (at green moisture) range from 6.175 MJ/Kg to 9.585 MJ/Kg. But the usable heat content (at green moisture) decreased to a lower range 7.838 MJ/Kg to 5.217 MJ/Kg. S. *chelonoides* showed the highest gross heating value (at oven dry wt.) whereas *L. grandis* showed the lowest gross heating value. Gross heating value (at green moisture) and net heating value (at green moisture) and usable heat content (at green moisture) were found to be the highest in *E. acuminata* which contained the lowest green moisture (39.02 ± 0.37 %). It signifies that the species with low green moisture content are more desirable as firewood to get effective and usable heat. On the other hand, S. *chelonoides* having the highest gross heating value (at oven dry wt.) showed less available gross heating value (at green moisture) 11.49 MJ/Kg, net heating value (at green moisture) 8. 033 MJ/Kg and usable heat content (at green moisture) 6.467

MJ/Kg than those showed by *E. acuminata*. It may be due to the fact that S. *chelonoides* contains higher percentage of moisture (46.89 ± 0.29 %) than *E. acuminata* (39.02 ± 0.37 %). Thus, moisture content in fuelwood may be considered as a negative characteristic on heating value.

Chapter IV: Part-4

Fuel quality of barks of the tree species

Fuel quality of barks of the tree species

Bark is an integral part of the fuelwood. Since bark is often removed from industrial round wood and is used separately as a source of fuel, it was of some interest to examine the fuel qualities of the bark samples of the tree species under the present investigation. The properties of barks differ sufficiently from those of wood and variability in properties among tree species is higher in barks than in woods. Bark in the feedstock makes the materials more heterogeneous and therefore accurate prediction of its reactions, emissions and products become more difficult to access (Kenny, 1990; 1991; Senewla *et al*, 1999).

Important fuel characteristics of bark samples such as green moisture content, ash content, density, gross heating values (on the basis of oven dry wt. and ash free dry wt.) are presented in Table-8 along with the percent weight of barks present in the stems of various diameter classes of the tree species.

From Table- 8, it is seen that the proportion of bark on stem (% wt.) decreases with the increase of diameter of the stems. Among all the species under study *S. wallichii* possesses the highest percentage of bark in all the diameter classes of the stems while *C. siamea* contains the lowest percentage of bark in all the diameter classes of the stem. The bark of *L. flos-reginae* contains the highest percentage of green moisture (62.59 ± 0.12 % wt.) followed by *C. siamea* (62.55 ± 0.81 % wt.), *D. peregrina* (61.90 ±

Table- 8 Quantitative analysis of the barks of 16 indigenous tree species

Species Name	Green moisture (%,wt)	Ash (%, dry wt)	Density (g/cm^3, oven dry wt)	Gross Heating Value (MJ/Kg oven dry wt)	Fuel Value Index (FVI)	Proportion of bark on stem (%, wt)		
						0-5cm*	5 1-10cm*	10 1-15cm*
L. grandis (D.) Engl.	62 59± 0 12	5 84±0 02	0 478 ± 0 23	17 95± 0 29	234 73	19 12	15 23	14 45
E jambolana Lam	55 18 ± 0 24	2 93± 0 42	0 651 ± 0 37	18 43± 0 56	742 09	15 80	13 92	10 65
P obovatum Clarke	57 32 ± 0 03	4 33± 0 38	0 482 ± 0 62	18 78± 0 22	364 71	12 75	11 00	10 75
A rohituka W & A	59 22 ± 0 37	3 08± 0 64	0 701 ± 0 48	19 27± 0 76	740 59	15 47	14 52	13 92
F infectoria Roxb	58 01 ± 0 29	4 05± 0 09	0 512 ± 0 60	18 76± 0 05	408 83	18 78	16 34	13 28
D peregrina Gurk	61 90 ± 0 58	5 41± 0 02	0 609 ± 0 52	18 01±0 28	327 52	13 76	13 01	12 48
A lucida Benth	53 82 ± 0 73	3 07± 0 82	0 571 ± 0 85	18 98± 0 39	585 84	14 29	13 78	11 17
L flos-reginae Retz	63 92 ± 0 23	4 86± 0 28	0 522 ± 0 78	18 91± 0 32	317 75	12 54	11 68	09 95
S chelonoides DC	47 52 ± 0 63	4 12± 0 29	0 881 ± 0 29	19 35± 0 72	870 72	13 81	11 45	10 52
S wallichii Chois	48 48 ± 0 18	6 87± 0 05	0 640 ± 0 69	17 92± 0 09	344 34	21 43	17 17	16 37
A procera Benth	50 10 ± 0 72	3 91± 0 08	0 598 ± 0 53	19 34± 0 82	572 62	15 25	14 22	12 76
C fistula Linn	52 32 ± 0 88	3 84± 0 72	0 631 ± 0 22	19 85± 0 64	623 43	13 45	11 09	10 49
M bombycina King	58 81 ± 0 29	3 20± 0 41	0 506 ± 0 25	18 55± 0 08	560 63	15 67	13 53	12 89
T belerica Roxb	50 37 ± 0 21	4 02± 0 18	0 519 ± 0 34	18 26± 0 06	468 02	12 75	10 06	09 99
E acuminata DC	53 21 ± 0 91	3 25± 0 75	0 601 ± 0 51	19 52±0 34	678 38	15 67	13 09	11 51
C siamea Lam	62 55 ± 0 81	3 81± 0 23	0 497 ± 0 67	17 87±0 38	372 67	11 62	10 48	09 78

* Stem diameter

0.58 % wt.) etc. and *S. chelonoides* contains the lowest percentage of moisture (47.52 ± 0.63 5 wt.).

Among all the species, the bark of *S. wallichii* produced the highest percentage of ash (6.87 ± 0.05 % wt.) whereas *E. jambolana* produced the lowest percentage of ash (2.93 ± 0.42 % wt.).

The density of the bark samples were within the range of 0.478 ± 0.23 g/cm^3 to 0.881± 0.29 g/cm^3. The bark of *S. chelonoides* showed the highest density value, while *L. grandis* showed the lowest density value.

From Table- 8, it is seen that the gross heating values of the bark samples of the tree species ranges from 17.84 ± 0.33 (MJ/Kg) to 19.85 ± 0.64 (MJ/Kg) which are comparatively lower than those of their respective wood samples. The bark of *C. fistula* showed the highest heating value while that of *C. siamea* was the lowest.

The FVI of bark of each species was calculated considering density and calorific value as positive characters and ash content and moisture content as negative characters and the results are shown in Table-8. The FVI of bark of *S. chelonoides* was found to be the highest (870.72) followed by *E. jambolana* (742.09), *A. rohituka* (740.59) etc. The lowest FVI of bark was shown by *L. flos-reginae* (317.75).

From the results (Table- 8), it can be seen that the bark portions of the tree species can also be used as fuel for cooking or space heating. However, barks of *S. chelonoides, E. jambolana* and *A. rohituka* may be preferable as fuel.

Chapter IV: Part-5

Proximate and Ultimate analysis and Biochemical composition of the tree species and their fuelwood qualities

Proximate and Ultimate Analysis of the tree species

Proximate analysis is the standard test method for evaluating solid fuel. Proximate analysis indicates the percentage of fuel burned in solid and gaseous states, and shows the quantity of non-combustible ash removing on the fire grates or ash pit, or entrained with flue gases. From a combustion stand point, the volatile matter (VM) and fixed carbon (FC) content predict the requirement for the division of air flow between over fire or secondary air and under fire or primary air. This division of air flow has been useful in smoke abatement and air pollution control (Mingle *et al.*, 1968; Lyons *et al.*, 1985). Ash content predicts the residue handling requirements in a combustion process.

The large amount of volatile matter associated with wood is a result of high number of functional groups and low number of aromatic structure in wood. It has been reported by various investigators that wood with high amount of volatile matter, resin, wax and lignin content produces more heat during combustion (Groves and Chivuya, 1989; Jain, 1994).

Ultimate analysis is used to calculate the quantity of oxygen (combustion air) required to sustain combustion reactions. Combustion is a series of chemical reactions by which carbon is oxidized to water. The pathways of combustion are determined largely by the structure of combustible molecules, particularly as it determines the location and accessibility of the carbon and hydrogen. Similarly, the higher heating value is determined by the relative proportion of carbon in a solid fuel (Tillman, 1978). Higher carbon content influences positively to the heating values of the fuel. It also permits the estimation of the amount of water formed by burning hydrogen present in the fuel. Because fuelwood is almost sulphur free and low in nitrogen content, it provides minimal SO_x and NO_x pollutants in the atmosphere.

It was of some interest to carry out the proximate and ultimate analysis of the wood and bark samples of the tree species and to examine the effect of fixed carbon, volatile matter, ash, carbon, hydrogen, nitrogen and oxygen contents on the fuel quality of the tree species.

The results of the ultimate and proximate analysis of the wood and bark samples of each of the tree species under investigation are presented in Table- 9.

From Table- 9, it is seen that the percentage of carbon, hydrogen and oxygen are higher in wood than the bark samples. Among all the tree species under study, wood of *S. chelonoides*, *C. fistula*, *E. jambolana* and *A. lucida* showed the higher percentage of carbon content, which may be attributed to their higher lignin content in wood (Table- 10). Nurmi (1992) also reported higher carbon and hydrogen content in wood than bark of some Northern European tree species. In the present study, the carbon content ranges from 44.08 % to 50.82 % and hydrogen content ranges from 6.29% to 6.59% which are close to the values of wood samples of other tree species reported by Singh (1979).

Table- 9: Ultimate and Proximate analysis of wood and bark samples of 16 indigenous tree species

Species Name	Plant Parts	Ultimate Analysis (Oven dry wt)				Proximate Analysis (Oven dry wt)		
		C (%)	H (%)	N (%)	O (%)	Ash (%)	VM (%)	FC (%)
L. grandis (D.) Engl.	Wood	44 081	6 295	0 288	46 386	2 95	73 07	23 98
	Bark	42 831	5 721	0 573	45 035	5 84	68 38	25 78
E jambolana Lam	Wood	48 253	6 421	0 791	43 455	1 08	68 73	30 19
	Bark	45 018	5 917	0 823	45 312	2 93	65 21	31 86
P obovatum Clarke	Wood	47 170	6 586	0 279	44 115	1 85	73 41	24 74
	Bark	45 023	6 002	0 611	44 034	4 33	64 43	31 24
A rohituka Wight	Wood	48 201	6 441	0 499	43 909	0 95	71 24	27 81
	Bark	46 269	6 133	1 027	43 491	3 08	67 33	29 59
F infectoria Roxb	Wood	47 818	6 599	0 185	44 128	1 27	71 61	27 12
	Bark	45 671	5 931	0 281	44 067	4 05	68 01	27 94
D peregrina Gurk	Wood	44 085	6 335	0 737	46 797	2 75	74 87	22 38
	Bark	43 811	5 827	0 810	44 142	5 41	65 72	28 87
A lucida Benth	Wood	49 135	6 447	0 737	42 731	0 95	70 80	28 25
	Bark	46 503	6 288	1 535	42 604	3 07	67 11	29 82
L flos-reginae Retz	Wood	46 988	6 306	0 330	44 406	1 97	72 95	25 08
	Bark	44 101	5 981	0 873	44 085	4 86	66 92	28 22
S chelonoides DC	Wood	50 418	6 532	0 670	41 390	0 99	68 96	30 10
	Bark	47 036	6 385	1 276	41 183	4 12	64 25	31 63
S wallichii Chois	Wood	47 342	6 584	0 484	42 470	3 12	67 07	29 81
	Bark	44 339	6 379	0 485	41 927	6 87	65 92	27 21
A procera Benth	Wood	48 102	6 578	0 443	43 737	1 14	71 14	27 72
	Bark	46 038	6 434	0 795	42 823	3 91	68 27	27 82
C fistula Linn	Wood	50 829	6 533	0 470	41 338	0 83	70 44	28 73
	Bark	47 831	6 238	0 893	41 198	3 84	66 22	29 94
M bombycina King	Wood	46 112	6 423	0 377	45 578	0 91	72 18	26 91
	Bark	44 623	6 303	0 542	45 332	3 20	67 38	29 42
T belerica Roxb	Wood	47 312	6 444	0 385	44 069	1 79	72 89	25 32
	Bark	43 108	6 002	0 692	44 036	4 02	68 19	27 79
E acuminata DC	Wood	49 128	6 521	0 455	46 036	0 86	72 90	26 24
	Bark	47 023	6 383	0 497	42 847	3 25	64 37	32 38
C siamea Lam	Wood	46 445	6 318	0 910	44 107	2 25	72 24	25 51
	Bark	42 784	6 218	1 732	44 056	3 81	67 81	26 98

VM- Volatile Matter, FC- Fixed Carbon

The quality of fuelwood may be further screened on the basis of its emission during burning which contributes to air pollution (Jain, 1998). High nitrogen content in wood on burning may emit nitrogen oxides, which are harmful to health.

In the present study, the nitrogen content was found to be higher in bark than wood of all the tree species under study. *C. siamea* showed highest nitrogen both in wood (0.910 %) and bark (1.732 %) followed by *A. lucida*; wood (0.737 %) and bark (1.535 %). Jain (1999) have also observed higher percentage of nitrogen content in *Pongamia globra* (0.917%), an indigenous tree of Central India. From the results (Table-9) it can be said that the tree species under investigation may not create significant problem of NO_x pollution during their burning.

From Table- 9, it is seen that the woods of all the tree species had lower ash content and fixed carbon content than the respective bark samples, while the volatile matter content was found to be higher in woods than the barks. This is in agreement with the results reported by Senewla *et al.* (1999) and Demirbus (2001a) for some other tree species. In the present study, volatile matter in the woods varied from 67.07% to 74.87%. These values agrees with those of some forest trees of Ireland reported by Lyons *et al.* (1985) and some biomass samples of Turkish sources (Demirbus, 1997). Senewla and Sims (1999) reported that volatile matter variations resulted from differences in volumetric percentage of the vessels in the different species and components. Vessels in the wood structure act as macropores and provide paths of least resistance for volatile on emission. If the passage ways are not clear and the reactive volatile cannot readily escape from the wood interior, some are deposited and recombine into the solid char matrix as pyrolytic carbon, which is detected as fixed carbon. Thus, combustion makes wood more reactive than coal (Tillman *et al.*, 1981). For the same reason, bark is less reactive than wood (Senewla *et al.*, 1999). Fixed carbon content in bark ranges from 25.511 % to 32.38 % which is in agreement with the result already reported by other workers (Fuwape *et al.*, 1997; Lyons *et al.*, 1985)

From the results of the present study (Table- 9), it is observed that the fixed carbon contents of woods of *E. jambolana* (30.19%), *S. chelenoides* (30.10%), *S. wallichii* (29.81%), *C. fistula* (28.73%) and *A. lucida* (28.25%) were higher than those of the other tree species under study. The higher fixed carbon content may be responsible for the higher heating value of these tree species.

Biochemical constituents of the fuelwood species

The caloric content of wood is dependent on its biochemical constituents such as cellulose, hemicellulose, lignin, extractives and ash forming minerals. Fuwape (1989) reported the influence of biochemical constituents on heating value of wood. Soft wood of Pinus species were reported to contain relatively higher percentage of resin, wax and lignin which are responsible for their high heat of combustion (Martin, 1963; Hough, 1969; Howard, 1971, 1973; Koch, 1972; Horder and Einspahr, 1976). The process of combustion involves the thermal degradation of the fuel and subsequent oxidation of the products. Cellulose and hemicellulose which are composed entirely of sugar units have a

Table- 10: Biochemical compositions of wood and bark samples of the tree species[a]

Species Name	Plant parts	Cellulose[b] (%, wt)	Hemicellulose[b] (% wt.)	Lignin[b] (% wt.)	OEC (%, wt.)	TEC (%, wt.)
L. grandis (D.) Engl.	Wood	55.75	14.28	29.97	0.96	3.02
	Bark	45.18	27.31	27.51	2.21	5.18
E. jambolana Lam	Wood	57.69	08.23	34.08	1.12	1.93
	Bark	39.91	28.75	31.35	3.22	4.82
P. obovatum Clarke	Wood	60.31	08.14	31.55	2.95	3.76
	Bark	40.90	29.02	30.08	5.98	8.64
A. rohituka W. & A.	Wood	58.31	09.18	32.51	1.84	1.96
	Bark	41.05	27.84	31.11	3.44	4.12
F. infectoria Roxb	Wood	62.27	10.68	27.05	1.74	2.94
	Bark	45.06	29.42	25.52	2.01	3.61
D. peregrina Gurk	Wood	63.10	10.29	26.61	1.63	2.16
	Bark	40.05	32.82	27.13	2.89	3.74
A. lucida Benth	Wood	56.55	08.73	34.72	1.81	1.97
	Bark	30.50	36.29	33.21	4.39	4.54
L. flos-reginae Retz	Wood	58.19	12.26	29.55	2.85	3.80
	Bark	49.53	21.46	29.01	3.16	4.04
S. chelonoides DC	Wood	53.79	10.78	35.43	3.68	3.95
	Bark	31.06	33.93	35.01	5.74	6.34
S. wallichii Chois	Wood	54.51	15.79	29.70	2.10	2.45
	Bark	29.55	43.35	27.10	3.61	4.17
A. procera Benth	Wood	57.08	12.44	30.48	2.52	3.01
	Bark	42.42	27.63	29.92	2.07	3.91
C. fistula Linn	Wood	59.91	03.43	36.66	1.38	1.86
	Bark	33.44	29.95	36.61	3.04	1.97
M. bombycina King	Wood	53.73	10.07	36.20	3.57	4.66
	Bark	40.27	23.70	36.03	5.98	7.48
T. belerica Roxb	Wood	61.18	14.02	24.80	2.49	4.15
	Bark	39.96	29.73	30.31	3.71	4.62
E. acuminata DC	Wood	51.18	15.73	33.09	2.05	4.27
	Bark	35.52	31.29	33.19	3.05	6.73
C. siamea Lam	Wood	56.24	15.05	28.01	2.11	3.28
	Bark	43.18	26.61	30.21	2.89	4.22

a-all estimation are the average of triplicate value b- estimation is on ash and extractive free basis

OEC--Organic Extractive Content (Alcohol Benzene soluble), percentage of the total

TEC—Total Extractive Content (OEC + Hot water Soluble), percentage of the total relatively low heat content because of their high level of oxidation while lignin and extractives have a lower degree of oxidation and a considerably higher heat of combustion (Shafizadeh, 1981). It has been reported that the quality of woody feedstock may have an impact on the efficiency of some energy conversion systems (Stevens *et al*, 1985; Butner *et al*, 1988). Wood with high holocellulose content and low proportion of bark content is preferred for bioconversion processes, while wood with high lignin content is desirable for thermochemical processes (Kenney, 1990).

In this part of the study, biochemical constituents such as cellulose, hemicellulose, lignin, organic extractives and total extractives content of the wood and bark samples of each of the tree species were determined and their effects on the heating values of the woods and barks are discussed. The results of the biochemical constituents of the samples are presented in Table- 10.

From Table- 10 it is seen that cellulose content of wood was found to be higher than that of bark of all the tree species under study whereas hemicellulose content of bark was higher than that of wood. Kataki and Konwer (2001) also reported a similar trend of cellulose and hemicellulose contents in woods and barks of some indigenous tree species of north-east India.

Among all the plant species under study, wood of *D. peregrina* contained the highest percentage of cellulose, the bark of *L. flos-reginae* showed the highest percentage of cellulose and the bark of *S. chelonoides* contained the lowest percentage of cellulose. On the other hand, wood of S. *wallichii* was found to contain the highest percentage of hemicelluloses followed by *E. acuminata* and *L. grandis* whereas bark of S. *wallichii* showed the highest percentage of hemicellulose.

From the results (Table- 10), it is seen that lignin content of wood and bark samples of the tree species varies to a little extent only. But most of the tree species showed higher lignin content in wood than bark. The woods and barks of *C. fistula*, *M. bombycina*, *S. chelonoides* and *E. jambolana* were found to contain higher percentages of lignin which is responsible for higher heating values of these tree species. Lignin is rich in carbon and hydrogen, which are the heat producing elements and hence lignin has higher heating value than that of carbohydrates.

Extractives contribute to higher heating value in fuelwood (Shafizadeh, 1981; Fuwape, 1989). Extractives in fuelwood are non-structural aromatic compounds, which possess one or more phenolic hydroxyl group. In wood extractives include terpene, tannins, resins, sugars, starches, fats, oils, proteins and organic acids, most of which are soluble in organic solvents. Boiling distilled water dissolves the inorganic salts, some organic acids and the carbohydrate components including starch and simple sugars.

Since combustion is an oxidation reaction and the heat of combustion of an organic compounds is related to its level of oxidation or state of reduction, organic compounds containing only carbon and hydrogen produce more energy when burned than those containing oxygen.

In the present study, higher caloric values of *S. chelonoides*, *M. bombycina* and *C. fistula* (Table- 2) may be attributed to their higher extractive contents (Table- 10).

The barks of *P. obovatum*, *S. chelonoides*, *M. bombycina* and *E. acuminata* contained higher percentage of total extractives among all the plant species under study. In general, barks were found to contain higher percentages of organic extractives content as well as total extractives content (Table- 10).

The woods and barks of *S. chelonoides* and *M. bombycina* were found to contain relatively higher percentage of organic extractives content (Table- 10) which may be responsible for their higher heating values.

Chapter IV: Part-6

Characteristics of ashes from wood and bark samples of the tree species

Characteristics of ashes from wood and bark samples of the tree species

Wood combustion produces ash, which is highly alkaline. Many ash-forming inorganic elements are associated with organic compounds in wood. During combustion the organic structures are decomposed and ash-formers are released. Mainly alkali and alkaline earth metals are released. Wood ash contains only trace amounts of heavy metals. Some of the alkaline earth metals leave the combustion zone as solid particles while the alkali metals are transported in vapour forms as oxides, hydroxides and chlorides. When wood is burned with coal, the alkalis can act as absorbents for the sulphur present in coal (Hupa, 1980; Someswar and Jain, 1993; Claussen and Rasmussen, 1993).

Wood ashes are found to be good fertilizers and can be used as mineral nutrients for forest and agricultural soils (Hakkila, 1986; Wattez and Courty, 1987; Naylor and Schmidt, 1986; Lerner and Utzinger, 1986). Wood ash is also used as a road base, an additive in cement production, a binding agent and an alkaline material for neutralization of acidic waste. Etiegni and Campbell (1991) have reported that wood ash leachate contained 92% hydroxide and 8% carbonate, which create problems for its disposal.

The elemental analysis of wood ash is essential in order to develop recycling processes, which could expand its uses. The composition of ashes varies

Table 11: Elemental analysis of wood and bark ash [a]

Species Name	Plant parts	Major Elements (% of Ash)							
		Ca	Si	K	Na	Mg	Fe	Zn	Cu
L. grandis *(D.) Engl.*	Wood	14 03(0 4138)*	1 20(0 0354)	09 08(0 2678)	0 82(0 0241)	1 56(0 0462)	1 44(0 0425)	0 41(0 0120)	0 010(0 0002)
	Bark	21 08(1 2310)	2 53(0 1477)	05 73(0 3346)	0 31(0 0181)	0 84(0 0490)	0 45(0 0262)	0 22(0 0128)	0 008(0 0004)
E jambolana Lam	Wood	16 08(0 1736)	1 51(0 0164)	10 92(0 1117)	2 08(0 0224)	2 08(0 0224)	3 11(0 0335)	0 58(0 0063)	0 021(0 0002)
	Bark	19 22(0 5631)	2 88(0 0843)	08 49(0 2487)	1 41(0 0413)	1 12(0 0323)	1 30(0 0382)	0 23(0 0067)	0 003(0 0001)
P obovatum Clarke	Wood	16 58(0 3068)	0 89(0 0164)	04 73(0 0875)	1 35(0 0251)	1 92(0 0355)	3 73(0 0691)	0 51(0 0094)	0 016(0 0003)
	Bark	36 78(1 5920)	1 62(0 0701)	04 18(0 1809)	0 69(0 0297)	0 88(0 0381)	0 36(0 0154)	0 32(0 0138)	0 006(0 0003)
A rohituka Weight	Wood	23 34(0 2217)	2 01(0 0191)	10 37(0 0985)	2 17(0 0207)	1 57(0 0150)	4 25(0 0404)	0 78(0 0074)	0 031(0 0003)
	Bark	29 68(0 9137)	3 25(0 1001)	07 15(0 2202)	0 71(0 0217)	1 39(0 0430)	1 02(0 0314)	0 42(0 0129)	0 009(0 0002)
F infectoria Roxb	Wood	10 47(0 1328)	1 18(0 0149)	10 11(0 1283)	1 06(0 0134)	1 59(0 0203)	2 32(0 0295)	0 66(0 0083)	0 064(0 0008)
	Bark	28 33(1 1470)	2 08(0 0843)	09 07(0 3673)	0 54(0 0216)	1 00(0 0408)	0 18(0 0072)	0 35(0 0141)	0 011(0 0004)
D peregrina Gurk	Wood	19 41(0 5337)	1 70(0 0473)	05 01(0 1397)	1 10(0 0304)	1 27(0 0350)	1 15(0 0318)	0 48(0 0132)	0 033(0 0009)
	Bark	30 13(1 6303)	2 23(0 1206)	03 91(0 2115)	0 41(0 0222)	0 72(0 0391)	0 51(0 0275)	0 29(0 0156)	0 007(0 0004)
A lucida Benth	Wood	29 68(0 2820)	0 92(0 0087)	11 25(0 1068)	3 71(0 0353)	1 82(0 0173)	1 77(0 0168)	0 50(0 0047)	0 018(0 0002)
	Bark	38 72(1.1880)	1 34(0 0411)	09 00(0 2763)	1 17(0 0359)	1 08(0 0330)	0 95(0 0292)	0 42(0 0109)	0 005(0 0001)
L flos-reginae Retz	Wood	12 82(0 2525)	1 05(0 0206)	07 81(0 1538)	0 98(0 0193)	2 21(0 0535)	1 84(0 0362)	0 43(0 0084)	0 036(0 0007)
	Bark	20 99(1 0204)	1 82(0 0884)	06 55(0 3183)	0 40(0 0195)	1 19(0 0581)	0 41(0 0200)	0 24(0 0116)	0 009(0 0004)
*S chelonoides*DC	Wood	12 99(0 1234)	1 38(0 0134)	09 93(0 0943)	4 39(0 0416)	1 57(0 0149)	1 61(0 0152)	0 61(0 0057)	0 082(0 0008)
	Bark	36 58(1 5071)	2 75(0 1133)	08 62(0 3551)	1 99(0 0819)	0 63(0 0259)	0 64(0 0263)	0 48(0 0197)	0 012(0 0005)
S wallichii Chois	Wood	03 39(0 1059)	0 86(0 0268)	04 42(0 1379)	1 13(0 0351)	1 17(0 0368)	1 67(0 0523)	0 75(0 0234)	0 009(0 0003)
	Bark	14 85(1 0201)	2 58(0 1752)	01 84(0 1264)	0 49(0 0336)	0 58(0 0398)	0 91(0 0283)	0 23(0 0158)	0 001(0 0001)
A procera Benth	Wood	35 47(0 4044)	1 75(0 0199)	10 12(0 1153)	1 04(0 0118)	2 62(0 0299)	3 77(0 0429)	0 54(0 0061)	0 069(0 0006)
	Bark	41 38(1 6160)	2 52(0 0485)	07 25(0 2834)	0 50(0 0199)	1 03(0 0452)	0 65(0 0254)	0 45(0 0172)	0 005(0 0002)
C fistula Linn	Wood	13 41(0 1112)	1 81(0 0150)	05 16(0 0482)	1 41(0 0116)	1 95(0 0162)	4 43(0 0368)	0 19(0 0015)	0 071(0 0011)
	Bark	38 07(1 4627)	2 91(0 1117)	03 84(0 1282)	0 72(0 0276)	0 92(0 0353)	0 84(0 0323)	0 12(0 0046)	0 004(0 0001)
M bombycina King	Wood	21 03(0 3176)	0 99(0 0149)	11 28(0 1703)	2 03(0 0306)	1 28(0 0289)	3 21(0 0484)	0 58(0 0087)	0 019(0 0003)
	Bark	28 73(0 9193)	1 31(0 0419)	09 14(0 2924)	0 98(0 0313)	0 62(0 0198)	0 94(0 0308)	0 31(0 0099)	0 007(0 0003)
T belerica Roxb	Wood	10 31(0 1846)	1 60(0 0286)	05 99(0 1072)	1 49(0 0266)	1 22(0 0218)	1 73(0 3090)	0 44(0 0078)	0 062(0 0005)
	Bark	22 04(0 8862)	2 12(0 0852)	02 07(0 0838)	0 87(0 0390)	0 73(0 0293)	0 47(0 0188)	0 15(0 0048)	0 011(0 0004)
E acuminata DC	Wood	29 01(0 2494)	0 92(0 0079)	12 01(0 1032)	3 02(0 0259)	1 83(0 0157)	2 38(0 0204)	0 84(0 0072)	0 087(0 0007)
	Bark	33 86(1 1004)	1 52(0 0494)	08 15(0 2648)	1 51(0 0490)	1 03(0 0334)	0 77(0 0250)	0 58(0 0183)	0 007(0 0002)
C siamea Lam	Wood	19 71(0 4435)	2 27(0 0511)	09 15(0 2058)	1 87(0 0120)	2 11(0 0474)	2 21(0 0497)	0 41(0 0092)	0 044(0 0010)
	Bark	27 74(1 0508)	3 05(0 1162)	05 08(0 1935)	0 64(0 0240)	1 36(0 0518)	0 39(0 0148)	0 28(0 0106)	0 013(0 0005)

[a]—analysis was done at 500°C according to standard laboratory procedure

* Value in parenthesis indicates elemental composition in percentage of dry fuel

between different plants, depends on the combustion method and on the growing conditions from where the biofuel was taken (Sutliffe *et al.*, 1981).

In the present study, ashing of wood and bark samples of 16 indigenous tree species of Assam was done at 500^0C according to the standard methods. Ashes were analysed separately for their calcium, silicon, potassium, sodium, magnesium, iron, zinc and copper contents and the results are presented in Table- 11.

From Table-11, it is seen that wood ashes and bark ashes were dominated by calcium, silicon and potassium. However, as compared to the wood ashes, the concentrations of these elements in bark ashes were found to be higher. Earlier workers (Hakkila, 1986; Mishra *et al.*, 1993; Hupa, 1980) have also reported higher ash content in bark and also higher concentrations of calcium and silicon in bark, while percentage of potassium and sodium were higher in wood. Sodium, magnesium, iron, zinc and copper contents were found to be higher in wood ashes than the bark ashes (Table- 11).

Among all the tree species under study, the wood ash of *A. procera* showed the highest value of calcium content followed by wood ashes of *A. lucida*, *E. acuminata* and of *S. chelenoides*, *C. fistula*, *E. jambolana* and *A. rohituka,* while calcium content in bark ashes is highest in *A. procera* followed by *A. lucida*, *C. fistula*, *P. obovatum, S. chelonoides*, *E. acuminata* and *D. peregrina*.

For firewood silicon content above 70% are preferred because woods release their heat slowly and retain it for a longer period of time after the fire has died off (Jain, 1999; Bhatt and Todaria, 1992). Silica content in wood species were found to vary widely from 0.86% to 2.27% and in barks its concentrations were much higher, ranging from 1.31% to 3.05%. Wood of *C. siamea* was found to contain the highest percentage of silica content among all the species under investigation whereas its concentration was found to be the highest in the bark of *A. rohituka*. Wood ashes of other tree species such as *E. jambolana, A. rohituka, D. peregrina, S. chelonoides, C. fistula and A. procera* were also found to be highly siliceous (Table –11*).* Wood ash of *S. chelonoides* was found to contain the highest percentage of sodium followed by *A. lucida* and *E. acuminata*. Iron content in the wood ashes of *C. fistula, A. rohituka*, *P. obovatum*, *A. procera*, *M. bombycina* and *E. acuminata* were found to be much higher than that of the other tree species under study.

Zinc content and copper content in the wood ash and bark ash of the tree species were found to be insignificant.

CHAPTER V

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

In Assam people have traditionally been relying on fuelwood as a primary source of energy which in turn is responsible for rapid deforestation in the state. To avert this situation it is highly necessary to establish large-scale energy plantation on unused and degraded lands. However, while selecting the tree species for energy plantation, special attention should be given to the indigenous tree species, which are traditionally preferred for fuel by the rural people.

A large number of tree and shrub species grow well in Assam in their natural habitats, but no proper studies have been made so far to identify the promising indigenous fuelwood species for energy plantation.

The present study was undertaken with a view to identify some promising indigenous fuelwood species of Assam growing in their natural habitats in different localities. The important fuelwood characteristics used by rural people of Assam were determined by pair-wise comparison of traditionally preferred indigenous species. A total of 16 indigenous tree species namely *Lannea grandis* (Dennst.) Engl., *Eugenia jambolana* Lam., *Palaquium obovatum* Clarke., *Amoora rohituka* Wight. and Arn., *Ficus infectoria* Roxb., *Diospyros peregrina* (Gaertn.) Gurk., *Albizzia lucida* Benth., *Lagerstroemia flos-reginae* Retz., *Stereospermum chelonoides* DC., *Schima wallichii* Chois., *Albizzia procera* Benth., *Cassia fistula* Linn., *Machilus bombycina* King., *Terminalia belerica* Roxb., *Eurya acuminata* DC. and *Cassia siamea* Lim. were selected on the basis of rural people's choice. A ranking matrix was drawn from the pair-wise comparison of these tree species. The ranking was further compared with that of the species obtained from Fuel Value Index calculated on the basis of the properties of basic density, moisture, calorific value and ash content. Proximate analysis , ultimate analysis and biochemical compositions of the tree species were determined and their effects on fuelwood qualities were discussed. The ashes produced by wood and bark of each of the tree species on burning were analysed for determination of major elements present in them. Such information may be useful in disposing the ashes or for their use as fertilizers.

From the ranking matrix of these 16 tree species using 10 quality criteria: 'fast drying', 'hot flame', 'ember production', 'flame not smoky', 'easily flammable', 'non-sparking', 'light weight when dry', 'bright flame', 'easiness of splitting' and 'low moisture when fresh cut', it was found that *S. chelonoides* is the best fuelwood species followed by *C. fistula, M. bombycina, A. lucida, E. jambolana, E. acuminata and A. rohituka.*

S. chelonoides, S. wallichii, E. jambolana and *E. acuminata* showed faster drying rates whereas *S. chelonoides, C. fistula, M. bombycina, E. jambolana, A. rohituka* and *E. acuminata* were found to produce hot flame on burning.

For ember production *C. fistula, S. chelonoides, E. jambolana, A. lucida* and *M. bombycina* were found to be the most suitable species.

C. fistula, M. bombycina and *S. chelonoides* produced comparatively much less smoke on burning as compared to the other species under study .

Among all the 16 tree species, *A. lucida, M. bombycina, C. fistula* and *S. chelonoides* were found to be easily flammable.

E. jambolana, P. obovatum M. bombycina, A. lucida, S. chelonoides and *D. peregrina* were found to be the best quality non-sparking species.

L. grandis, F. infectoria and *T. belerica* showed considerable light weight when dry, but found to be incompatible for the most favoured fuelwood characteristics shown by other tree species.

A. lucida, C. fistula, M. bombycina, S. chelonoides and *A. procera* were reported to produce bright flame on burning whereas *A. lucida* and *M. bombycina* were found to be easy for splitting.

Among all the species *C. fistula, E. jambolana, A. rohituka, S. chelonoides* and *A. procera* were reported to have low moisture content when freshly cut.

Fuel Value Index of each of the tree species was calculated using three different formulae. When Fuel Value Index (FVI-1) was calculated considering calorific value and density as positive characters and ash content and moisture content as negative characters, *S. chelonoides* showed the highest FVI value followed by *C. fistula, M. bombycina, A. lucida, E. acuminata, A. rohituka, E. jambolana* etc.

When FVI was calculated considering calorific value and density as positive characters and ash alone as negative character, the species *S. chelonoides* showed the highest FVI (FVI-2) followed by *C. fistula, M. bombycina, A. lucida, E. jambolana, E. acuminata* etc.

Again when FVI was calculated considering calorific value and density as positive characters and moisture alone as negative characters, *S. chelonoides* showed the highest FVI (FVI-3) followed by *M. bombycina, E. jambolana, C. fistula, A. lucida, S. wallichii, E. acuminata* etc.

Descending order of ranks (best to worst) of the preferred fuelwood species under study based on pair-wise ranking is as follows:

S. chelonoides, C. *fistula* , *M. bombycina*, *A. lucida*, *E. jambolana*, *A. procera* , *E. acuminata* , *A. rohituka* and so on.

Among all the three formulae used for calculation of FVI, FVI-3 had more resemblance with the ranking of the fuelwood species obtained on the basis of pair-wise ranking with key informants and the descending order of preference is as follows:

S. chelonoides, *M. bombycina*, *E. jambolana*, C. *fistula* , *A. lucida*, *A. rohituka* etc.

With a view to know the drying behaviour of the tree species under study an experiment was conducted by keeping three diameter classes of the species viz. 0 – 5 cm, 5 – 10 cm and 10 – 15 cm and 20 cm in length on sun dry for 8 weeks.

In the first 7 days of sun dry, the highest percentage of moisture loss was shown by *S. wallichii* followed by *E. jambolana and S. chelonoides.*

After 14 days of sun dry, the highest percentage of moisture loss was shown by *E. acuminata* followed by *A. rohituka, S. wallichii, M. bombycina and L. flos-reginae.*

After 35 days of sun dry almost all the tree species showed low rate of moisture loss which indicated that 5 to 6 weeks of sun dry may be regarded as the best drying period for the fuelwood species.

It was further observed that smaller sized wood samples had higher initial moisture loss than the larger sized samples.

In order to find out co-relations between moisture content of the fuelwood species and their heating values, gross heating values (GHV), net heating values (NHV) and usable heat contents (UHC) were calculated.

From the results, it was seen that there was no direct relationship between the initial green moisture content with the gross heating values of the tree species. However, it was found that *S. chelonoides* showed the highest gross heating value while *L. grandis* showed the lowest gross heating value. Gross heating value (at green moisture) and net heating value (at green moisture) and usable heat content (at green moisture) were found to be the highest in *E. acuminata* which contained the lowest green moisture. From this study, it may be concluded that tree species with low moisture content are more desirable as fuelwood to get effective and usable heat.

When the fuel characteristics of barks of each of the tree species were determined, it was observed that the bark of *S. chelonoides* showed the highest FVI, followed by the barks of *E. jambolana* and *A. rohituka*. The lowest FVI of bark was shown by *L. flos-reginae*. From the experimental results, it can be concluded that bark portions of the tree species can also be used as fuel for cooking and space heating. However, barks of *S. chelonoides, E. jambolana* and *A. rohituka* may be preferable as fuel.

From ultimate analysis of the wood and bark samples of the tree species, it was found that the percentages of carbon, hydrogen and oxygen content was higher in wood than the bark. On the other hand , nitrogen content was found to be higher in bark than wood of all the species under study. However, from the results it can be said that the tree species under investigation may not create significant problem of NO_x pollution during their burning.

Volatile matter content was found to be higher in woods than the barks while fixed carbon content was found to be higher in barks than the woods of all the tree species.

From the results of the present study it was found that fixed carbon contents of woods of *E. jambolana* (30.19%), *S. chelenoides* (30.10%), *S. wallichii* (29.81%), *C. fistula* (28.73%) and *A. lucida* (28.25%) were higher than those of other tree species. The higher fixed carbon content in these species may be responsible for their higher heating values.

From the study of biochemical constituents of the tree species it was found that cellulose content of wood was higher than that of bark of all the tree species whereas hemicellulose content of bark samples was higher than that of wood samples.

Among all the tree species wood of *D. peregrina* and bark of *L. flos-reginae* were found to contain the highest percentage of cellulose, whereas wood of *S. chelonoides* was found to contain the highest percentage of hemicellulose followed by *E. acuminata* and *L. grandis.* Most of the tree species showed higher lignin content in wood than bark. The woods of *C. fistula, M. bombycina, S. chelonoides* and *E. jambolana* were found to contain higher percentage of lignin which is responsible for higher heating values of these tree species. In general, barks of all the tree species were found to contain higher percentage of organic extractives as well as total extractives contents. The woods and barks of *S. chelonoides, C. fistula and M. bombycina* were found to contain relatively higher percentage of organic extractives which may be responsible for their higher heating values.

In order to develop processes for disposal of ashes or to utilize them as fertilizers, it was of some interest to analyse the wood and bark ashes of the tree species.

From the experimental results it was found that both wood ashes and bark ashes were dominated by calcium, silicon and potassium. However, as compared to the wood ashes, the concentration of these elements in bark ashes were found to be higher while sodium, magnesium, iron, zinc and copper content were found to be higher in wood ashes.

Among all the tree species, the wood and bark ashes of *A. procera* showed the highest percentage of calcium content and wood ash of *C. siamea* contained the highest percentage of silica. Wood ashes of other tree species such as *E. jambolana, A. rohituka, D. peregrina, S. chelonoides, C. fistula* and *A. procera* were also found to be highly siliceous. Wood ash of *S. chelonoides* contained the highest percentage of sodium. Zinc and copper contents in the wood and bark ashes of the tree species were found to be insignificant.

From the present study it can be concluded that among all the 16 traditionally preferred indigenous tree species of Assam , *Stereospermum chelonoides* DC., *Cassia fistula* Linn., *Machilus bombycina* King, *Albizzia lucida* Benth., *Eugenia jambolana* Lam. and *Amoora rohituka* W. and A. are the most promising fuelwood species. Besides their very good fuelwood qualities, some of them have other important traditional uses.

Cassia fistula Linn. has good medicinal value. Its root is useful in fever and heart diseases and leaves cure ring worms. Black pulp of its ripe fruits is good for relieving thoracic obstruction and liver trouble of children. Bananas ripe very soon if they are kept with leaves of this plant (Dutta, 1985).

Fresh juice of bark of *Eugenia jambolana* Lam. mixed with goat milk is good for diarrhea and dysentery. Its ripe fruits are edible and they are very good for liver, diabetes, jaundice, urinary trouble etc. Traditional black dyes are prepared from the juice of its bark (Konwer and Kataki, 2004).

Leaves, root and bark of *Stereospermum chelonoides* DC. are used as febrifuge. The mixture of its flowers with honey is good for hic-cough. Root is considered as a component of *"Dasamulas"*.

An oil called "Rohituka oil" is extracted from the seeds of *Amoora rohituka* W. and A. is used in paint industries. The oil is also good for rheumatic pains.

Machilus bombycina King. is an important plant of Assam. Muga silk worms are mainly reared on the leaves of *Machilus bombycina* King. Muga silk worm is an unique type of silk in the world, It is very rare and costly silk. Juvenile *Machilus bombycina* King. plants are good for rearing Muga silk worms.

However, before recommending these tree species for large scale energy plantation, their growth rates, biomass productivity, nutrient uptake behaviour and optimum period of harvesting should be investigated.

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Annexure I

Geographical Setting of Assam

1. Location and Extent:

Assam is situated in North-East India.

Longitude: $89^0 42'$ to $95^0 16'$ E

Latitude : $24^0 8'$ to $28^0 9'$ N

Bordering States/Countries:

East	Arunachal Pradesh, Nagaland, Manipur and Mynmar
West	West Bengal, Meghalaya, Bangladesh
North	Arunachal Pradesh, Bhutan
South	Nagaland, Manipur, Mizoram, Meghalaya, Tripura

Area:

Area (in sq. Km.)	78,523
% of forest cover (1995-96)	27.41

Source: NER data , http:// www.necouncil.nic.in

2. Physiography:

The state can be broadly divided into three physiographic units viz. The Brahamaputra Valley, the Central Assam Valley and the Barak Valley

2.1: The Brahmaputra valley:

The river Brahmaputra flows through the middle of the valley from east to west with more than 35 tributes with an antecedent drainage pattern.

Altitude: 32 to 132 m above MSL.

Special Character:

(I) Alluvium deposition in the valley brought down by the Brahamaputra and its tributaries.

(ii) Bills, Oxbow lakes and huge marshes tract are common.

2.2. The Central Assam Range:

It comprises Karbi Anlong and North Cachar Hills district.

Altitude: 1713m (at Haflong) and 300-900m (at North Cachar Hills) above MSL.

2.3. The Barak Valley:

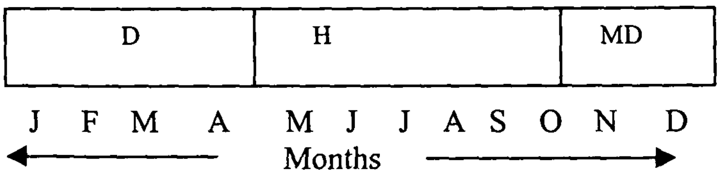
The Barak Valley which occupies a triangular area is surrounded on the north, east and south by high hills. The elevation of the valley in south-west is low; it gradually rises towards east attaining 46m near Karimganj and 57m near Silchar. The valley is peculiarly low lying with swamps and perfectly level alluvial flat excepting some low altitudes.

3. Climate:

3.1. Type:

Climate is humid sub-tropical type influenced by monsoon. This region is experienced with hot summer and mild to moderate cool winter.

3.2. Moisture availability period:



D-Dry, MD-Moderate dry, H-Humid

3.3. Rainfall: Av. 1400-3000mm

Rainfall quantity	Months
Large	June to August
Small	April to May (Pre monsoon) & September to October (Post monsoon)
Scanty	November to February

4. Land Utilization:

Description	Area ('000 ha)	Percentage
1. Net shown area	2706	34.5
2. Forests	2152	27.41*
3. Barren and non-cultivated land	1441	18.4
4. Land put to non-agricultural use	914	11.6
5. Land put to misc. tree crops & groves	227	2.9
6. Permanent pasture and other grazing land	164	2.1
7. Cultivable waste land	104	1.3
8. Current fallow	80	1.0
9. Fallow land other than current	64	0.8
Total	7852	100.0

* As per NIC data, 1995-96

Source: Statistical Hand Book of Assam, 1996, Dept. of Statistics and Economics, Govt. of Assam

Soils of Assam

Assam is endowed with a wide range of climates, physiographic settings, geology and vegetation sequences. The interaction amongst these factors in the ecosystems with time and space lead to result in the formation of different kinds of soils with time and space lead to result in the formation of different kinds of soils with different properties, limitations and potentials.

1. Distribution and Classification of soils:

The major soils of the state are classified in 4 orders viz. Alfisols, Entisols, Inceptisols and Kltisols: 9 sub orders, 15 great groups and 26 subgroups and 83 soil family associates. The soil contributes by different order to the total geographical area can be shown as follows:

Soil order	% distribution to the Total Geographical Area (TGA)
Inceptisols	41.4
Entisols	33.6
Alfisols	11.3
Ultisols	05.6
Miscellanous viz. marshy land & Rivers	08.1

2. Characteristics of soils under different Agro-Ecological sub regions:

Agro-ecological sub-region	Description	Area % of TGA
16a Warm per-humid Agro-ecological sub-region	Brahmaputra plains and North eastern Hills, cool to warm per humid agro-ecological sub-region with medium deep loamy alluvium derived soils, low to medium AWC (50-100 mm/m) and more than 330 days Length of Growing Period (LGP)	1 09
15a Per-humid agro-ecological sub-region	Brahmaputra, Assam plains and North Eastern Hills, hot per-humid agro-ecological sub-region with medium to deep loamy alluvium derived soils, high AWC (200-250 mm/m) and more than 330 days of LGP	16 74
15b. Hot-Humid Agro-ecological sub-region	Brahamaputra, Assam plains and North Eastern Hills, hot humid agro-ecological sub-region with medium to deep loamy red and lateritic and alluvium derived soils with medium to very high AWC (150-300 mm/m) and more than 330 days of LGP	35 90
15c. Hot Humid agro-ecological sub-region	Brahamaputra, Assam plains, Meghalaya plateau- North Eastern Hills, hot humid agro-ecological sub-region with medium to deep loamy alluvium derived and red and lateritic soils with medium to very high AWC (150-300 mm/m) and 300 to 330 days of LGP	29 20
15d. Hot humid Agro-ecological sub-region	North Eastern Hills-Purvanchal, Brahamaputra, Assam plains, hot humid Agro-ecological sub-region with deep loam to clayey red and lateritic and alluvium derived soils with medium to very high AWC (150-300 mm/m) and 270 to 300 days of LGP	1 38
15e. Hot moist sub-humid Agro-ecological sub-region	North Eastern Hills-Purvanchal, Meghalaya plateau and Assam plains, hot moist sub-humid Agro-ecological sub-region with deep loam to clayey, red and lateritic and alluvium derived soils with medium to very high AWC (150-300 mm/m) and 300 to 330 days of LGP	6 29
15f. Hot moist sub-humid Agro-ecological sub-region	North Eastern Hills-Purvanchal, Assam plains, hot moist sub-humid Agro-ecological sub-region, deep loamy red and lateritic and alluvium derived soils with medium to very high AWC (150-300 mm/m) and 270 to 300 days of LGP	3 96
17b. Warm humid agro-ecological sub-region	North Eastern Hills-Purvanchal, Assam plains, hot moist sub-humid Agro-ecological sub-region, deep loamy red and lateritic and alluvium derived soils with medium to very high AWC (150-300 mm/m) and more than 330 days of LGP	5 44

Annexure II

Six Agro-climatic Zones of Assam:

1. North Bank Plains Zones (NBP): The districts covered under this zone are Lakhimpur, Dhemaji, Sonitpur & Darrang
2. Upper Brahamaputra Valley Zones (UBV): The districts covered under this zone are Dibrugarh, Tinsukia, Sibsagar, Jorhat & Golaghat
3. Central Brahamaputra Valley Zones (CBV): The districts covered under this zone are Nowgaon & Morigaon
4. Lower Brahamaputra Valley Zones (LBV): The districts covered under this zone are Kamrup, Barpeta, Nalbari, Goalpara, Dhuburi , Bongaigoan & Kokrajar
5. Barrak Valley Zones (BV): The districts covered under this zone are Cachar, Karimgonj & Hailakandi
6. Hills Zones: The districts covered under this zone are Karbianlong, North Cachar

Source: NBSS & LUP (1999): National Bureau of Soil Survey & Land Use Planning (ICAR). NBSS Publ.24. Technical Bulletin.