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DECLARATION

I, Md. Mamunur Rashid, declare that this thesis is the result of my own research and it does not incorporate without acknowledgement any material submitted for the degree in any university.

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(Md. Mamunur Rashid)

Dedicated

To

My beloved parents

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ABSTRACT

This thesis paper presents the physical and mechanical properties of fiberboards manufactured from wastage part (husk) of supari (betelnut). The tested physical properties were density, moisture content, water absorption and thickness swelling, and the tested mechanical properties were modulus of elasticity (MOE) and modulus of rupture (MOR). The dimension of all types of fiberboards was 140mm×140mm×3mm. Four categories of temperature (180°c, 200°c, 220°c, and 240°c) were applied as a treatment for the supari husk fiberboards and responses or properties of the fiberboards for these temperatures were assessed. The physical and the mechanical properties of supari husk fiberboards were compared with commercially available fiberboards (CMF). All these types of fiberboards were medium density fiberboard (MDF). The MOE and MOR of supari husk fiberboards were satisfactory over commercially manufactured fiberboards. But in case of water absorption and thickness swelling, supari husk fiberboards did not provide satisfactory properties showing some sort of affinity to water. Similarly moisture content of supari husk fiberboards was higher than that of commercially produced fiberboards.

CHAPTER ONE
INTRODUCTION

1.1 BACKGROUND OF THE STUDY

With the increase of population of the world, the demand for wood and wood products are increasing day by day that creates a tremendous pressure on forest and forest products. This extra pressure damages our forest, degrade forest floor. It's one of the most important solution of that shortage is to be provision of alternative high growing fibrous agricultural plant production. Thus, people have placed a high emphasis on forest preservation and rational use of forestry and agricultural residues (Li *et al.*, 2010). However some agricultural plants produce higher cellulosic fibrous materials that to be the suitable substitute for certain fiber based industries. Among them betel nut husk fibers may serve as an alternative source in fiber based industries. Manmade fibers using glass, carbon, boron etc. are being used as reinforcing materials in the fiber reinforced plastics which have been widely accepted as materials for structural and nonstructural applications. The main reason for the interest in FRP (Fiber Reinforced Plastics) is due to their specific modulus, high stiffness, and strength to weight ratio compared to other conventional materials. However, these materials are prohibitively expensive in their use for other general purposes and applications. A great interest towards the development of composite materials reinforced with natural fibers has emerged in the last decade (Mwaikambo and Ansell, 2006). Today, the benefit of composites can be made by replacing synthetic fibers with various types of cellulose fibers. The significant factor in finding good fiber reinforcement in the composite is the strength of adhesion between polymer matrix and fiber (Sampathkumar *et al.*, 2012). In the plant, waste fibers can be described as lignocellulosic. Lignocellulosic materials include agricultural residue, wood, water plants, grasses, and other plant substances. Plant waste fibers have the composition, properties, and structure that make them suitable for usage of fibers in composites. Currently, hard cellulose fibers like flax, jute, banana, sisal, pineapple leaf fibers are used in textile, packaging, low-cost housing, paper manufacturing industries, and other general applications. These fibers are considered as hard cellulose fibers because of their high tensile modulus and low elongation at break (Sampathkumar *et al.*, 2012; Kumar, 2008). The use of other renewable resources such as agricultural residues in the production of composite panels (i.e., fiberboards and particleboards) has recently been considered attractive both from the economic and environmental point of view (Ayrilmis and Buyuksari, 2010). Kumar

(2008) has elucidated the economic and environmental benefits of agri-residues and stated that the increasing interest in introducing degradable, renewable, and inexpensive reinforcement materials which have been environment-friendly has stimulated the use of hard cellulose fibers. The low cost, low weight, low density and CO-neutral renewable nature make the natural fibers an attractive alternative. These fibers are abundantly available, nontoxic and provide specific strength even though low density. Similar result was found by Esmeraldo *et al.*, (2010), Pereira *et al.*, (2010), Radosavljevic *et al.*, (2008), Bledzki *et al.*, (2002) and Wambua *et al.*, (2009). Its other advantages are the availability of alternative fibers could reduce the pressure to harvest trees for papermaking, composites (fiber board, particle board) production. Second, alternative fibers may be grown or collected after harvesting food crops. Furthermore, lignocellulose fibers offer good thermal and insulating properties, and they are easily recyclable (Venkateshappa *et al.*, 2010). Fiberboard, a structural and decorative, is a fibrous-felted, homogeneous panel made from lignocellulosic fibers, combined with a synthetic resin or other suitable bonding system, and then bonded together under heat and pressure (ANSI Standards, 1994). Additives may be introduced during manufacturing to improve certain properties. Fiberboards are manufactured primarily for use as panels, insulation, and cover materials in buildings and construction where flat sheets of moderate strength are required. The furniture industry is by far the dominant fiberboard market. They are also used to a considerable extent as components in doors, cabinets, cupboards, and millwork (FAO, 1958). Synthetic resins commonly used on fiberboards production present negative side effects like the health risks caused by the emission of volatile organic compounds such as formaldehyde, or problems concerning issues such as waste disposal or recycling. Binderless boards overcome these difficulties using lignin instead of resin as adherent obtaining in this way a board which does not present formaldehyde emissions and that is completely biodegradable. Areca belongs to the species *Areca catechu L.* under the family palmecea and originated in the Malaya peninsula, East India. The husk of the areca constitutes about 60–80% of the total weight and volume of the fresh fruit. The husk fiber is composed of cellulose with varying proportions of hemicellulose (35–64.8%) and lignin (13.0– 26.0%), pectin and protopectin (Ramachandra *et al.*, 2004, Rajan and Kurup, 2005; Dhanalakshmi *et al.*, 2012). The present use of this highly cellulose material is as a fuel in area where areca nut processes. Thus the use of this husk fiber as structural material requires a detailed study on physical, chemical and thermal characteristics (Sampathkumar *et al., 2012*). Although there have been numerous studies on the mechanical behavior of natural fiber-reinforced composites, only a few references are available on areca fiber reinforced composites. Among all the natural fiber reinforcing materials, areca appears to be a promising material because it is inexpensive, abundantly available, and a very high potential perennial crop (Rajan *et al.* 2005). The average filament length (4 cm) of the areca husk fiber is too short compared to other bio fibers. Mainly two types of filaments are present - one very coarse and the other very fine. The coarse ones are about ten times as coarse as the jute fibers, and the fine are similar to jute fiber. The fiber could be used for making value-added items such as thick boards, fluffy cushions, non-woven fabrics, thermal insulators, and non-woven fabrics (Arifulla *et al.*, 2007). Naturally bonded fiberboards have been fabricated with the use of betelnut husk fibers. The physical properties (density, moisture content, water absorption and thickness swelling) and mechanical properties (modulus of elasticity and modulus of rupture) of the naturally bonded fiberboards have been assessed to show the potentiality of these boards in usage for household and commercial level.

1.2 OBJECTIVES OF THE STUDY

Betelnut husk is a source of fibers and considering husks as wastage, it is totally casted aside outside. So it becomes biodegraded. If this potential source of fibers can be utilized as composite materials, it can reduce pressure on the solid wood materials. This study mainly attempts to the feasibility of the utility of betel nut husk fibers for the structural materials. The specific objectives are as follows-

1. To assess the potentiality of *Areca catechu* husk as an alternative source of fibers for manufacturing fiberboards.
2. To assess the physical and mechanical properties of fiberboards made from *Areca catechu* husk and to compare these boards with the commercial fiberboard.

CHAPTER TWO
REVIEW OF LITERATURE

2.1 DETAIL INFORMATION ABOUT FIBERBOARD

2.1.1 Fiber board and its importance

Salehuddin (1992) stated that the fiberboard is a sheet material generally manufactured from ligno-cellulosic fiber with the primary bond from the felting of the fiber and their inherent adhesive properties. Fibers are bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. Bonding agents and supplementary materials may be added at the felting stage to improve certain properties like mechanical properties, resistance to moisture, etc. (Anon, 1970 and ANSI Standards, 1994).

Fiberboard is a generic name for construction panels made of wood or vegetable fibers. Some are homogenous materials, while others are laminated sheets with fiber cores and surfaces of ground wood. The earliest fiberboard panels were made with fibers from an array of materials including jute, straw, sugar cane stalks, flax, hemp, grass, newspaper, and peanut shells (Sampathkumar *et al.*, 2012, Kumar G. C. M. 2008). They were manufactured under names such as Fir-tex, Homasote, Masonite, Beaver Board, Feltex, Nu-Wood, and Upson Board. Wood has always been the most common fiber used in fiberboard.

Stark *et al.* stated in chapter-11on his book named 'Wood-based composite materials' that the term fiberboard includes hardboard, medium-density fiberboard (MDF), and cellulosic fiberboard. Fiberboards are classified by density. A fiberboard with specific gravity between 0.50 and 0.80 is classified as medium density fiberboard (MDF) and a fiberboard with specific gravity greater than 0.80 is classified as hardboard (ASTM Standards D1554-1986). Several things differentiate fiberboard from other types of boards, most notably the physical configuration of the wood element. Because wood is fibrous by nature, fiberboard exploits the inherent strength of wood to a greater extent than does other boards. To make fibers for composites, bonds between the wood fibers must be broken.

The production of fiberboard has been increasing consistently due to its numerous advantages over solid wood and other composite materials. Fiberboards with uniform fiber distribution in their structure meet most end-use requirements. With fiberboards, smooth and solid edges can easily be machined and finished for various purposes, especially furniture production. Smooth and uniform surfaces also provide an excellent substrate for paint and decorative overlays. The surface smoothness of MDF makes it the best material for cabinet manufacturing (Copur *et al.*, 2008). Fiberboard does not contain knots or rings, making it more uniform than natural woods during cutting and in service. However, Fiber board is not entirely isotropic, since the fibers are pressed together primarily through the sheet. Like natural wood, Fiber board may split when woodscrews are installed without pilot holes, and Fiber board may be glued, dwelled or laminated, but smooth-shank nails do not hold well.

2.1.2 Binderless fiberboards and its general features

Fiberboards are produced in vast quantities all over the world and are an excellent building material with high specific strength and good insulating properties (Laemsak N. and Okuma M., 2000, Wolcott et al., 1990). These fiberboards are produced mainly with the integration by the adhesives to the fibers. But recently new studies and research have been done to manufacture fiberboards without use of any binding materials; rather the ingredients of the fibers can be suited for the usage of adhesives. Mainly lignin is responsible for the bonding within the fibers. Bouajila *et al.* (2005) has shown two of the phenomenon liable to the bonding strength of the foberboards.

- lignin-lignin and lignin-polysaccharides cross-linking reactions that occur at high temperature.
- deformation of the system under pressure. As wood is a heterogeneous material, the irregularity inherent to the resulting surface will yield little contact area between adjacent wood elements. To produce a good adhesive bond, the wood must deform sufficiently to produce an intimate wood-wood contact. The largest contact area will result when the polymers of the wood are in a physical state to allow maximum deformation under minimum pressure, i.e., the rubbery state.

In principle, the wet process of fiberboard manufacturing is well adapted: at the beginning of board heating, fibers are water saturated and the softening temperature of wood fibers is low, between 60 and 90°C in the literature (Kelley *et al.*, 1987, Sakata I. and Senju R., 1975, Becker H. and Novack D., 1968). As the heating temperature is generally nearly 200°C (Salmen L. and Olsson A. M., 1998), the sample temperature could quickly increase above the softening point. But during the wet process, the softening temperature also increases due to the decrease of the water content. There is a competition between sample drying and sample heating. At the end of the process, the sample reaches 180–200°C; and the softening temperature of dry fibers is also around 180°C (Hoglund *et al.*, 1976, Ostberg *et al.*, 1990).

2.1.3 Types of fiber board

There are different types of fiber boards. They are classified according to their density. They are-

2.1.3.1. Wilson (2007) categorized fiberboards according to density as low-density (insulation) board, medium-density board and hardboard.

Low-Density Fiberboard: Low-density fiberboard was known as insulation board because of its sound-deadening and thermal qualities. This lightweight, rigid product made of fibrous pulp was available in sheets, planks, and tiles. Insulation board was best suited for interior applications because of its susceptibility to water damage. The thickness of insulation board ranges from **3/8** to 1 inch. Sheets were 4 to 8 feet wide and could be up to 16 feet long. Insulation board was secured to the building frame with adhesives, nails, screws, or patented methods such as dropped metal grids for ceilings, the forerunner of the suspended ceilings found in many offices today.

Medium-Density Fiberboard: Homasote, Beaver Board, and Upson Board were medium-density fiberboards promoted for use in a variety of applications. Homasote (**3/16**-inch-thick) introduced in 1916, was a homogenous material made of recycled newspapers (the source of its gray color) and petroleum wax.

Hardboard: Most historic hardboard was **1/8** to **5/16** inch thick, although two boards could be glued together to make a panel that was more rigid. Masonite Corp. introduced its first hardboard in the early 1930s. The Presdwood hardboard, from **1/10** to **5/16** inch thick, was used for interior finishes and as battens over other Masonite products. Panels could be nailed or glued vertically or horizontally, then painted or wallpapered.

2.1.3.2. Various types of hard boards are generally classified into three types according to their method of manufacture, density, mechanical and physical properties (Anon, 2011).

Medium hard board: It is a homogeneous fiber building board having a density between 480 kgm^{-3} and 800 kgm^{-3}

Normal hard board: A homogeneous fiber building board having a density between 800 kgm^{-3} and 1200 kgm^{-3}

Tempered hard board: A hard board is further treated in the course of manufacture to increase its density, strength and water resistance.

2.1.3.3. There are another three types of fiberboards depending on the specific gravity, this are-

1. Low Density Fiberboard (LDF): Low-density fiberboards have a specific gravity of between 0.15 and 0.45, and are used for insulation and for light-weight cores for furniture. They are usually produced by a dry process that uses a ground wood fiber (Berglund and Rowell, 2005; Youngquist, 1999).

2. Medium-Density Fiberboard (MDF): Medium-density fiberboard has a specific gravity of between 0.6 and 0.8 and is frequently used in place of solid wood, plywood, and particleboard in many furniture applications. It is also used for interior door skins, moldings, and interior trim components (Berglund and Rowell, 2005; Youngquist, 1999).

3. High-Density Fiberboard (HDF): High-density fiberboard has a specific gravity of between 0.85 and 1.2 and is used as an overlay on workbenches and floors, and for siding. It is produced both with and without wax and sizing agents. The wax is added to give the board water resistance (Berglund and Rowell, 2005; Youngquist, 1999).

2.1.3.4. According to Anon (1986), fiberboards are classified as the following

I. **Insulation board:** Insulation board having the density 445 kgm^{-3}.

II. **Wall board:** The density of wall board is about 481 kgm^{-3}.

III. **Medium hardboard:** The density of medium hardboard is 481 to 890 kgm^{-3}.

IV. **Standard hardboard:** Standard hardboard is a one kind of fiberboard having the density more than 890 kgm^{-3}.

V. **Super hardboard:** Super hardboard is also a fiberboard having the density more than 1200 kgm^{-3}.

2.1.3.5. According to Desch (1996), Fiber boards are classified depends on density as-

Table (1) - Fiber board classification

Type	**Density**
Hardboards	>800kg/m³
Mediumboards	350-800kg/ m³
Softboards	<350 kg/ m³
MDF	Nearly 790kg/ m³

2.1.4 Raw Materials for Fiberboard Manufacturing

Dependency on the wood fibers to manufacture different composite materials creates tremendous pressure on forest and this reckless utilization leads to degradation of forest. It should be considered more on non-woody lingo-cellulosic materials. In production point of view, the production of agricultural fiber is higher than the production of lignocellulosic fiber from forest. In 2006, the annual global production of lignocellulosic fibers from crops was about 4 billion tons, of which 60% came from agriculture and 40% from the forest (Justiz-Smith *et al.,* 2008). The materials that are used in fiber board manufacturing are shown in below-

2.1.4.1. Woody materials

a. Woods (soft wood, hard wood, sap wood, heart wood)
b. Planer savings of timbers,
c. Sawmill residues, such as saw dusts, slabs, edging, trimmings, etc.
d. Residues from timber cutting in furniture and cabinet manufacturing plants,
e. Residues from match factories,
f. Veneer and plywood plant residues,

g. Logging residues, such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning and
h. Bark

2.1.4.2 Non-woody materials

Almost any agricultural residue (such as husks, coconut coir etc.) after suitable treatment can be used to manufacture fiber board's (Salehuddin, 1992). There is a growing interest in the use of non-wood such as annual plants and agricultural residues as a raw material for pulp, paper and composites. The chemical compositions of non-wood materials have tremendous variations in chemical and physical properties compared to wood fibers (Gumuuşkaya and Usta, 2002; Rezayati-Charani *et al.*, 2006). They vary, depending on the non-wood species and the local conditions, such as soil and climate (Bicho *et al.*, 1999; Jacobs *et al.*, 1999). The non-wood materials generally have higher silicon, nutrient and hemicellulose contents than wood (Hurter, 1988). Some parts of the non-fibrous materials may be removed by the pre-treatment of the raw material, which has a positive influence on the ash content and the pulp, paper and fiberboard properties (Hurter, 1988; Chen *et al.*, 1987; Rodriguez *et al.*, 2008). Some of the non-wood materials are-

a) Jute sticks and jute fiber
b) Bagasse
c) Bamboo
d) Banana plant
e) Dhaincha stalks
f) Elephant Grass
g) Flax shaves
h) Cotton stalks
i) Cereal straw

2.1.5 General Manufacturing Steps of fiberboard

Fiberboard manufacture involves some of the specific activities that are bound for giving the shape of the fiberboard, if not; the standard properties of the board may not be attainable. The followings are the steps for manufacturing of fiberboard-

2.1.5.1 Methods of Fiber Production

Smook, G. A. (2002) defined pulping as the process by which wood or other fibrous materials is reduced to a fibrous mass. Basically it is the means by which the bonds are systematically ruptured in the wood structure. The tusk can be accomplished mechanically, thermally, chemically or by combinations of these treatments. Fibers are made by various pulping methods or by explosion process.

2.1.5.1.1 Mechanical pulping

There are broadly two methods for the production of mechanical pulp. One is the grinding of debarked logs and the other is the refining of wood chips and agricultural residues. Wood can be broken down into fiber bundles and single fibers by grinding or refining. In the grinding process, the wood is mechanically broken down into fibers. In the refining process, wood chips are placed between one or two rotating plates in a wet environment and broken down into fibers (Sridach W., 2010). If the refining is done at high temperatures, the fibers tend to slip apart as a result of the softening of the lignin matrix between the fibers, and, consequently, the fibers will have a lignin rich surface. If the refining is done at lower temperatures, the fibers tend to break apart and the surface is rich in carbohydrate polymers. Fiberboards can be formed using a wet-forming or a dry forming process (Berglund and Rowell 2005; Youngquist 1999).

The other method involves either treatment of the wood chips or agricultural residues with chemical; or thermal pretreatment prior to pulping in disk refiners or attrition mills. Solid wood is debarked and then chipped in a chipper and screened. The coarse chips are rechipped and fines sent to the boiler. In the chemi-mechanical pulping, neutral sulphite cook, sodium hydroxide cook or a lime cook is used. Thermo-mechanical pulping is based on the softening of the middle lamella or inter-cellular layers between the fibers due to heating at 150^{o} c to 180^{o} c. This facilitates separation of fiber (Smook, G. A., 2002). The chemical composition of the pulp remains almost identical to that of the original wood or other ligno-cellulogic materials. The original fiber structure is also preserved and very high yield, 90 to 93 percent is obtained (Salehuddin, 1992).

Refining is an important step for developing strength in wet-process fiberboards. The refining operation must also yield a fiber of high "freeness" (that is, it must be easy to remove water from the fibrous mat).

2.1.5.1.2 Explosion process

Here 100 kg of wood chips or agricultural residues are charged into a high pressure cylinder called a 'gan' and steam is admitted. The pressure is raised to 40kp/cm for 30 seconds. After a steaming period for another 30 seconds under this pressure, the stream pressure is quickly raised to 70 to 80kp/cm, raising the temperature to 285 to 295°c held for only about 5 seconds, before suddenly releasing the pressure by a hydraulically operated quick opening value. The 'gan' blown first under the influenced of high steam pressure, moisture, and high temperature, the wood under goes a hydrolytic reaction which breaks down the lingo-cellulosic bond. Secondly, the sudden release of the hydrolyzed chips to atmospheric pressure tears them sprat to produce a characteristically blows, fluffy fiber the fibers are washed with clean hot water to remove hydrolytic products and buffered before mat formation (Salehuddin, 1992).

2.1.5.2 Methods for fiber board manufacturing

Stark N. M., Cai Z. and Carll C. described the processes of fiberboard manufacturing. It is formed by wet, dry processes. Dry processes are applicable to boards with high density (hardboard) and medium density fiber (MDF). Wet processes are applicable to both high-density fiber board and low-density insulation board. The two processes are discussed in below-

2.1.5.2.1 Wet process

Wet-process fiberboards differ from dry-process fiberboards in several significant ways. First, water is used as the fiber distribution medium for mat formation. Secondly, some wet-process boards are made without additional binders. If the lingo-cellulosic contains sufficient lignin and if lignin is retained during the refining operation, lignin can serve as the binder. Under heat and pressure, lignin will flow and act as a thermosetting adhesive, enhancing the naturally occurring hydrogen bonds. The mat is typically formed on a Fourdrinier wire. The wet process employs a continuously traveling mesh screen, onto which the soupy pulp flows rapidly and smoothly. Water is drawn off through the screen and then through a series of press rolls.

Wet process hardboards are pressed in multi-opening presses heated by steam. The press cycle consists of three phases and lasts 6 to 15 min. The first phase is conducted at high pressure, and it removes most of the water while bringing the board to the desired thickness. The primary purpose of the second phase is to remove water vapor. The third phase is relatively short and results in the final cure. A maximum pressure of about 5 MPa (725 lb in–2) is used in the first and third phases. Heat is essential during pressing to induce fiber-to-fiber bond. A high temperature of up to 210 °C (410 °F) is used to increase production by causing faster vaporization of the water. Insufficient moisture removal during pressing adversely affects strength and may result in "springback" or blistering (Suchsland and Woodson, 1986).

2.1.5.2.2 Dry process fiberboard

Midwest Research Institute (2003) described the dry process of fiber preparation. The general steps used to manufacture dry process fiberboards include mechanical pulping of wood chips to fibers (digesting and refining), blending of fibers with resin and wax, drying, forming the resinated material into a mat, hot pressing, heat treatment of the pressed boards, and humidification.

Clean chips are either processed in pressurized refiners or are softened by steam in a digester and sent to atmospheric refiners. Pressurized refiners consist of a steaming vessel (digester) and of single or double revolving disks to mechanically pulp (refine) the chips into fibers suitable for making the board. The wood chips are discharged under pressure from the digester section of the pressurized refiner into the refiner section. The steam pressure is maintained throughout the entire refining process. Atmospheric refiners also use revolving disks to pulp the chips into fibers, but steam pressure is not maintained in atmospheric refiners.

Wax may be added to the wood chips in the digester. Phenol-formaldehyde (PF) resin and other additives (if used) are added to the wood fiber during or immediately following refining. Most dry process hardboard plants inject PF resin into a blowline that discharges the resinated fibers to a tube dryer. The turbulent conditions in the tube dryer facilitate mixing between the wood fibers and resin droplets. After drying, the resinated fibers are conveyed to a dry fiber storage bin where they await forming.

Single-stage or multiple-stage tube drying systems are most commonly used in dry process hardboard manufacture. Resinated fibers exiting the drying system enter a forming machine where they are deposited on a continuously moving conveyor. After the fiber mat is formed, it is pre-pressed in a band press. The densified mat is then trimmed by disk cutters and transferred to caul plates for the board pressing operation; the trimmed mat is transferred directly to the press. Many dry-formed boards are pressed in multi-opening presses. The typical press cycle is about 4 minutes. The hardboard presses are heated by steam to a temperature of around 210°C. Continuous pressing using large, high-pressure band presses is also gaining in popularity. Following pressing, boards are routed through a board cooler at some plants. However, most plants do not operate board coolers (Suchsland and Woodson, 1986; Maloney, 1993).

2.1.6 Post treatments of wet and dry process fiber board

Several treatments are used to increase dimensional stability and mechanical performance of fiberboards. **Heat treatment, tempering**, and **humidification** may be done singularly or in conjunction with one another (Maloney, 1993). Heat treatment—exposure of pressed fiberboard to dry heat—improves dimensional stability and mechanical properties, reduces water adsorption, and improves inter fiber bonding. Tempering is the heat treatment of pressed boards, preceded by the addition of oil. Tempering improves board surface hardness, resistance to abrasion, scratching, scarring, and water. The most common oils used include linseed oil, tung oil, and tall oil. Humidification is the addition of moisture to bring the board moisture content to levels roughly equivalent to those anticipated in its end-use environment. Air of high humidity is forced through the stacks where it provides water vapor to the boards. Another method involves spraying water on the back side of the board (Stark N. M., Cai Z. and Carll C.). **Surface treatment** is another form of post-treatment in which surface may be sealed, primed, enameled and lacquered, pulp-faced, moulded and embossed, laminated, provided with wood-grained effects, perforated, or flame-retardant treated (Salehuddin, 1992).

2.1.7 Uses of fiberboard

Fiberboard is the grainless wood of many uses, and can be used wherever a dense, hard panel material in the thicknesses as manufactured will satisfy a need better or more economically than any other material. The diverse usages of fiberboards are discussed in below-

a) It is used for construction, furniture and furnishings, cabinet and store fixture work, appliances, and automotive and rolling stock. In construction, hardboard is used as floor underlayment, facings of flush-doors, interior wall things, concrete forms, etc. (Bledzki *et al.*, 2002).

b) To be used in furniture and furnishing include drawer bottoms, dividers, mirror backs, insert panels, television, radio, stereo cabinet, etc. In auto-mobiles, trucks, buses and railroad cars, hardboard is used in interior linings, doors and interior sidewall panels, etc., and with face-laminated with plastic sheets in the ceilings, plat forms, etc.

c) Medium density fiberboard (MDF) of recent origin is manufactured with urea formaldehyde resin as a binder in the same quantities as are used in manufacturing particle board and substitute's particle board in many applications, e.g., house sidings (ANSI, 1994).

d) Special densified hardboard is used for making templates and jigs for manufacturing, as electrical panel materials, laboratory work surfaces, gears, cams, etc. (Rowell R.M., 1998).

e) Fiberboard of low density is used mainly for insulation purposes. Sheathing quality boards requiring high water resistance is asphalt additionally.

f) Semi-rigid insulation boards are used for heat-insulation in truck and bus bodies, automobiles, refrigerators, railroad cars, etc., wherever severe vibrations preclude the use of other insulating materials such as loose fill or batt insulation.

g) Acoustical type of insulation board is manufactured for sound-deadening that is to reduce transmission of sound through walls, with the boards predrilled with small holes for reducing echo (Salehuddin, 1992).

h) Fiber boards are manufactured primarily for use as panels, insulation and cover materials in buildings and for components of cabinets, cupboards and other constructions requiring flat sheets of moderate strength (Anon, 1985).

2.2 SOME INFORMATION OF ARECA PALM

2.2.1 General Description

Scientific name: *Areca catechu*

Common names: Areca palm or areca nut palm, betel palm

Local name: Supari

Figure (1): Betel nut plant

2.2.2 Scientific Classification

Kingdom	Plantae
Subkingdom	Tracheobionta
Superdivision	Spermatophyta
Division	Magnoliophyta
Class	Liliopsida
Subclass	Arecidae
Order	Arecales
Family	Arecaceae/Palmae
Genus	*Areca*
Species	*Areca catechu*

2.2.3 Botanical Description

Betel nut is a slender, single trunked, erect and monoecious palm with a prominent crown shaft (Shu B. L., 2010, Staples G. W. and Bevacqua R. F., 2006).

Size

The palm reaches a mature height of 10-20 m (exceptionally up to 30 m), with a trunk 25-40cm in diameter. Typhoons and tropical storms usually prevent the trees from reaching their maximum height. The canopy is typically 2.5-3 m in diameter and consists of 8-12 fronds (Staples G. W. and Bevacqua R. F., 2006). Orwa *et al.,* (2009) and Shu B. L. (2010) stated that the stem, marked with scars of fallen leaves in a regular annulated form, becomes visible only when the palm is about 3 years old.

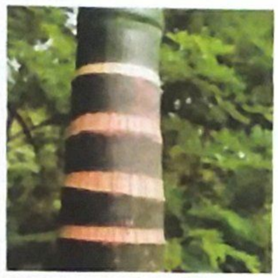

Figure (2): Stem of areca nut palm

Flowers

Flowers are unisexual, with both male and female Bowers borne in the same inflorescence. Inflorescences are crowded, much-branched particlesborne below the leaves. Each terminal branch has a few female Bowers borne at the base and numerous male Bowers extending from there out to the branch tip. Male flowers are solitary, alternate and distichous on rachillae; stamens 6; female flowers at bases of rachillae only, larger than male flowers. Fruits are yellow, orange, or red (Shu B. L., 2010).

Figure (3): Flowers of areca nut palm

Leaves

The adult palm has 7-12 open leaves, each with a sheath, a rachis and leaflets. The leaf stalk extends as the midrib until the end of the leaf and ends as leaflets (Orwa *et al.*, 2009, Bhat S.K., 1988).

Fruit

Fruit is a monolocular, one-seeded berry, 3.8-5 cm long, smooth orange or scarlet when ripe, with a fibrous outer layer *(*Orwa *et al., 2009).* Fibrous pericarp is 6 mm thick. Seeds are usually ovoid, globosa, or ellipsoidal, base sometimes hattened; endosperm ruminate, embryo conic allocated at seed base (Staples G. W. and Bevacqua R. F., 2006).

Figure (4): Seeds of betel nut

Root

Root system is adventitious, typical of monocots (Orwa et al. 2009), fibrous, with most roots concentrated in a 1m radius from the trunk and in the top 60 cm of soil. Primary roots are 1.4 cm in diameter, turning dark brown with age, and branch to give secondary and tertiary roots. Root hairs are absent; absorption takes place through thin-walled cells behind the root cap. Aerial roots are occasionally produced from the base of the trunk (Raghvan V. and Baruah, 1958). In plantation culture adventitious (prop) roots are encouraged by deep-planting seedlings, then gradually adding earth around the base of the palm, inducing root formation at the buried nodes (Staples G. W. and Bevacqua R. F., 2006).

2.2.4 Ecology

It is difficult to assess the habitat of betel nut as it almost always present in cultivation. Betel nut palm is ideally suited for tropical ever wet climates (humid tropical lowland, maritime tropical, subtropical wet, tropical wet forest) with high rainfall that is evenly distributed throughout the year (Staples G. W. and Bevacqua R. F., 2006). Although tolerant to moderate elevations on mountains, it generally does best in low altitudes. These palms are unable to withstand extreme temperatures or a wide variance of daily temperatures. Being a shade-loving species, areca nut always does well when grown as a mixed crop with fruit trees (Orwa *et al., 2009).* Staples G. W. and Bevacqua R. F., (2006) discussed the following environmental factors that are suited for growth of betel nut.

Elevation range: Elevation range is (o m- 900 m). But it may grow in elevation of 1000m (Orwa *et al., 2009*).

Mean annual rainfall: 6o-2oo in

Relative humidity: A range of relative humidity from 70 to 90% is found ideal for its growth.

Rainfall patern: It prefers uniform distribution of rainfall throughout the year.

Dry season duration (consecutive months with <40 mm rainfall): None, it requires uniform moisture year-round (Bhat S. K., 1988).

Mean annual temperature: 21- 28°C

Minimum temperature tolerated: Unknown, very cold sensitive

Tolerance

Drought: Betel nut has poor drought tolerance.

Full sun: The palm requires fill sun once out of the juvenile phase.

Shade: Seedlings require 50% or more shade to protect from sunburn. Juvenile palms are often planted out under bananas, which provide sun protection until the palms grow taller than the bananas (Bhat S. K., 1988).

Soil type: Betel nut palm grows in many types of soils varying in texture from laterite to loamy, provided the soil has thorough drainage, yet has the ability to retain optimum moisture. It thrives on deep (3 m) clay loams, often in valley bottoms where topsoil accumulates along water courses. Light and sandy soils are unsuitable unless copiously irrigated and manured (Staples G. W. and Bevacqua R. F., 2006). Soil should be deep to ensure a well-developed root system with high organic carbon content and a pH range from acidic to neutral (Orwa *et al.*, 2009). Betel nut palm thrives in a pH range of 5.o-8.o (mildly acidic to weakly alkaline) (Staples G. W. and Bevacqua R. F., 2006).

Waterlogging: Despite a strong ecological preference for moist to wet environments, betel nut palm does not tolerate waterlogged soils.

Salt spray: Betel nut is not tolerant to salt.

Wind: It has low tolerance for wind.

Abilities

Raghvan V. and Baruah. (1958) studied on the utilization of betel nut and some of the abilities of betel nut plant were discussed on that study.

Self-prune: Mature fronds are shed after 2 years; betel nut palm is considered a "self-pruning" palm species.

Coppice: Palms are incapable of regeneration, if the terminal bud is cut off; the palm dies.

2.2.5 Distribution

Pema Yuden and Sangay Dorji stated that the nuts or the hard dried endosperm of ripe and unripe seeds are chewed as a masticatory by about 400 million people around the world from Zanzibar to India and the Central Pacific. Today, the major arecanut growing countries are India, Sri Lanka, Bangladesh, Malaysia, Indonesia and the Philippines, with India leading the world production. In Bhutan arecanut could have been introduced a long time ago from India. Philipines has been postulated as the origin of betel nut, but many other regions are considered as the original homeland, including South and South East Asia (Staples G. W. and Bevacqua R. F., 2006). Orwa *et al., (2009)* has shown the following as the habitat of betel nuts.

Native: China, Indonesia, Malaysia

Exotic: Fiji, India, Japan, Kenya, Madagascar, Pakistan, Papua New Guinea, Philippines, Samoa, Solomon Islands, Sri Lanka, Tanzania, US.

2.2.6 Propagation

Betel nut palm is only propagated by seed, and while the same basic requirements are involved, the methods depend on the number of palms desired. Large plantations of betel nut palm are grown in India, Taiwan and Bangladesh, where mother tree and seed selection are apt to be practiced, and mass propagation is organized. Carefully selected seeds are planted in shaded beds or pits until they germinate, then seedlings are transplanted to nursery areas for growing on. Seedlings with five or more leaves are planted out at an age of 12-24 months. Seedlings require shade initially, so intercropping with banana or other crops is often practiced (Bhat S. K., 1988, Orwa *et al., 2009*).

2.2.6.1 Seed collection

Jalgoan has stated that betel nut is an exclusively seed propagated crop. Mother plant should be early bearers with high percentage of fruit set and more than ten years old. From these palm fully ripe and heavier nuts (>35kg) are selected. Only the largest, finally ripened fruits should be planted. Fruits are harvested either by climbing the tree and cutting the fruit cluster by using a long bamboo pole with a sharp knife attached.

2.2.6.2 Seed Processing and Storage

Staples G. W. and Bevacqua R. F., (2006) have stated that mature seeds of betel nut palm are sown as whole fruits. In some places the whole fruit is planted immediately after harvesting, in others the fruit is dried in sun for 1-2 days; in others the fruits are dried in shade for 3-7days. Like many tropical species, betel nut palm seed cannot be stored for more than a few days without losing viability. Planting within 7days after harvest is the standard.

Seed storage behavior is uncertain. Despite reports of sensitivity to desiccation, pre drying is widely practiced in nursery cultivation to promote germination. For example, a report of 52% germination after 21 days drying suggests that *A. catechu* may not show recalcitrant seed storage behavior. There are about 63 seeds/kg of seeds produced in a seasons (Orwa *et al.*, 2009).

2.2.6.3 Pre-planting treatments

No pre-planting treatment is practiced. Fruits are planted whole, with the husk. Drying fruits before planting does not increase seed germination rates. There is no mention in the literature of scarification, hormone treatments, or fungicide use.

2.2.6.4 Growing area

Zoysa, N. D., (2000) suggested that betel nut palm should not direct-seeded in the ground. The normal practice is to sow seeds in shaded germination areas, and then transplant the germinated seedlings into nurseries for 1-2 years before final planting out in the field. Seeds may be sown in groups of 20-50 in shallow pits, 2.5 cm apart and covered with sand; in rows 6-9 in apart; or tied up in plantain leaves in rich moist soil and germinated. Areca nut is sensitive to drought, and therefore irrigation is essential in areas with prolonged dry spells. Green manuring using leaves and cattle manure has been applied with success in areas with poor soils (Orwa *et al.*, 2009).

2.2.6.5 Germination

Germination is completed about 90 days after sowing, at which time the seedlings have one bifid (forked) leaf (Bhat S. K., 1988).

2.2.6.6 Time to out planting

Growth rates of seedlings are variable transplanting from nursery bed to field typically takes place at I-2 years (although this ranges from 3 months to 4 years). Seedlings should be selected for quick germination and vigor; it is best to cull out slow-growing seedlings.

2.2.6.7 Approximate size at time of out planting

Young seedlings with two or three leaves are transplanted to secondary nursery beds; data provided by Jalgoan. Seedlings should bear five leaves at the time they are planted out in the field; no trunk is present at this early stage. A ball of earth around the roots is transplanted from nursery bed to field (Staples G. W. and Bevacqua R. F., 2006).

2.2.7 Pests and Diseases

Pests causing major crop losses include leaf-feeding mites such as cholam mite (Oligonychus indicus) and palm mite (Raoiella indica). Others are spindle bug (Carvalhoia arecae), inflorescence caterpillar (Tirathaba mundella) and root grub (Leucophlis lepidophora) (Macdu E. R. 2000). Diseases resulting in heavy economic losses include anaberoga (foot rot), bacterial leaf stripe disease, bud rot, inflorescence die-back, koleroga (rotting disease), stem bleeding, sun scorch and yellow leaf disease (Orwa *et al.*, 2009).

2.2.8 Supari Husk Fiber and Its Characteristics

2.2.8.1 Supari husk fiber

The areca nut husk fibers are mainly found in the coat of the areca nut. It is predominantly composed of cellulose and varying proportions of hemicellulose, lignin, pectin and protopectin (Rajan *et al.*, 2005). In areca nut fibers these components are present in different proportions. These polymers are the basic constituents of the cell wall and are responsible for most of the physical and chemical properties, such as dimensional instability to moisture, biodegradability, flammability, thermo- plasticity, and degradability by ultraviolet light, acids, and bases (Venkateshappa *et al.*, 2010).

2.2.8.2 The characteristics of areca husk fiber

On the core of the areca nut there are three layers of sheets of fibers. The fibers adjoining the inner layers are irregularly lignified group of cells called hard fibers, and the portions of the middle layer below the outermost layer are soft fibers (Rasheed S. and Dasti A. A., 2003). The total hemicellulose content varies with the development and maturity, the mature husk containing less hemicellulose than the immature ones. The lignin content proportionately increases with the development until maturity (Mathew A.G. and Govindarajan V.S., 1964). The husk constitutes about 60–80% of the total weight and volume of the fresh fruit (Ramachandra *et al.*, 2004). The average filament length (4 cm) of the areca husk fiber is too short compared to other biofibers. Mainly two types of filaments are present – one very coarse and the other very fine. The coarse ones are about ten times as coarse as the jute fibers and the fine are similar to jute fiber. The fiber could be used for making such items such as thick boards, fluffy cushions and non-woven fabrics (Ghosh *et al.*, 1975). Lignin is the main constituent of areca nut fiber, responsible for its stiffness. It is also partly responsible for the natural color of the fiber. Complete delignification will result in the breakdown of the fiber into ultimate cells. Lignin is closely associated with cellulose and hemicellulose in hardening and strengthening of plant cell wall.

Properties	Dry	Ripe (golden yellow)	Raw (green)
Length (cm)	5.5	5.8	5.9
Moisture content (%)	8.05	79.84	68.39
pH of extract	7.0	3.0	5.5
Reducing sugar content (mg g−1 of fresh fiber)	1.8	19.2	14.3
Non-reducing sugar content (mg g−1 of fresh fiber)	0.68	0.98	1.04

Following table (2) shows the physicochemical properties of areca nut husk fiber (Rajan *et al.*, 2005):

Venkateshappa *et al.*, (2010) assessed the physical properties of areca nut on his study named 'Flexural behavior of areca fibers composites' and found the following properties which are shown in the following table (3)-

Diameter(mm)	Length of fiber(mm)				Density(gm/cm^3)
	Short	Medium	Long	Average	
0.285-0.89	18-29	30-38	39-46	29-38	1.05-1.25

2.2.9 Chemistry of Areca Nut Husk Fibers

Sampathkumar *et al.*, (2012) stated that the lignocellulosics are three-dimensional, polymeric composites made up primarily of cellulose, hemicellulose and lignin. In natural fibers, semi crystalline cellulose is the main reinforcement material. The cellulose is held together by amorphous hemicelluloses and fibers are cemented together in the plant by lignin which is commonly known as plant cell adhesive.

The husk of the Areca is a hard fibrous portion covering the endosperm. G. C. M. Kumar, (2008) has stated that betel nut fiber constitutes 30–45% of the total volume of the fruit. Areca husk fibers are predominantly composed of hemicelluloses and not of cellulose. In the following table, the chemical composition of Areca fibers is shown along with few known fibers. Areca fibers contain 13 to 24.6% of lignin, 35 to 64.8% of hemicelluloses, 4.4% of ash content and remaining 8 to 25% of water content. Similar results have found by Anil et al., (2008); Rajah et al., (2005), and Sampathkumar et al., (2012). Following table compares the chemical composition of areca fiber with some other important natural fibers. Areca fiber is highly hemicellulosic and is much greater than that of any other fibers. The properties of natural fibers depend mainly on the nature of the plant, locality in which it has grown, age of the plant, and fiber extraction method used. Areca fibers are hard and show similarity to coir fibers in cellular structure (Kumar G. C. M. 2008).

Fiber	**Lignin %**	**Cellulose%**	**Hemicellulose %**	
Areca	13 – 24.6	--	35-64.8	
Maize stalk	10-13	38- 42	21-23	
Coir	40-45	32-43	0.15-0.25	
Sisal	10-14	66-72	12	
Banana	5	63–64	19	

Table (4): Chemical composition of natural fibers [Arifulla, A. et al. (2007), Anil, S.G et al. (2008); Rajah, A. et al. (2005), Kumar G. C. M. (2008), Sampathkumar D. et al. (2012)].

2.2.10 Supari Husk Fiber Production in the World

Among all the natural fiber-reinforcing materials, areca appears to be a promising material because it is inexpensive, availability is abundant and a very high potential perennial crop. The major areca nut growing countries are India, Sri Lanka, Bangladesh, Malaysia, Indonesia, China and the Philippines, with India leading the world production (Staples G. W. and Bevacqua R. F., 2006). In India, areca nut cultivation is coming up on a large scale basis with a view to attaining self sufficiency in medicine, paint, chocolate, gutka, etc. It is estimated that about 6 Lakh tonnes of areca husk is available in south West-India. India dominates the world in area (57%), production (53%) of areca nut (0.379 million tonnes in 2002) (Rajan et al., 2005). In Bangladesh, Southern part is mainly oriented for betel nut cultivation. A lot of batel nut palms are cultivated in Bagherhat, Barisal, Pirozpue, Khulna, Bhola, Potuakhali, Borguna and Satkhira. But scattered plantations of this plant are found all over the country.

Ramappa B.T., (2013) tried to show the total areca nut production in the world in his study named 'Economics of Areca nut Cultivation in Karnataka, a Case Study of Shivamogga District'.

The following table (5) shows the area, production and yield of areca nut in different countries.

	2001					2009(P)				
Country	Area		Production		Productivity Kg/Ha	Area		Production		Productivity Kg/Ha
	„000ha,	% to total	„000 tonnes	% to total		„000ha,	% to total	„000 tonnes	% to total	
India	315.20	52.84	373.10	52.71	1184	400.04	54.81	489	56.38	1222
Indonesia	102.02	17.10	45.59	6.44	447	125.00	17.13	52	6.11	416
China	51.03	8.55	165.08	23.32	3235	59.00	8.08	162	18.68	2745
Bangladesh	77.80	13.04	47.00	6.64	604	79.00	10.82	56	6.46	709
Mynamar	34.98	5.86	51.46	7.27	1471	36.00	4.93	57	6.57	1583
Thailand	14.00	2.35	23.00	3.25	1643	16.00	2.19	26	3.51	1625
Malaysia	1.50	0.25	2.50	0.35	740	0.80	0.11	1.3	0.15	1625
Maldives	0.05	0.01	0.04	0.01	-	0.04	0.01	0.33	0.04	8250
Nepal	-	-	-	-			2.00	0.27	3.6	0.42
Srilanka	-	-	-	-			12.00	1.64	20	2.31
Keny	0.00		0.09	0.01	-	-		0.09	0.01	
World	596.50		707.80	100.0	1187	729.88		867.32	100.0	1188

Source: Directorate of Arecanut and Spice Development,Calicut & Food & Agricultural Organisation,Rome

2.2.11 Uses and Importance of Arecanut

Betel nut palm yields diverse products that are used throughout its range. In addition to the well-known stimulant properties, the seed is used medicinally in numerous internal and external preparations. The husks, shoots, buds, leaves, and roots also have local medicinal uses. The fibrous fruit husks stripped from the seed have many uses, including as a home fuel source. The trunks of culled trees are used for crude construction; the fallen fronds are used in making alcohol; the spathes and leaf sheaths are used in wrapping, packing, and as hats and sandals. The inflorescences and bowers are used ceremonially in diverse cultures. In the following section, the overall usages are discussed-

Nut or seed

This provides, fresh or dried, ripe or unripe, the betel nut that is chewed as a stimulant narcotic. Betel nut is commercially important in South Asia and locally important in the Pacific and many other tropical old world areas (Staples G. W. and Bevacqua R. F., 2006).

Leaf vegetable

The terminal bud (palm cabbage or palm heart) is edible, although bitter. In Java it is eaten as made into pickles. In the Philippines the cabbage is eaten raw as salad, or cooked. The tender shoots are eaten after cooking in syrup. In the Philippines the bowers are sometimes added to salads.

Masticant or stimulant

The practice of chewing the areca nut either alone or in combination with betel leaves of pan, lime, tobacco, camphor of spices, the combination then being called "tambula" has been in existence from time immemorial. Chewing is to increase the production of saliva and gastric juices and thus aid in the digestion. It is believed to strengthen the gums & the teeth & cleanses & deodorizes the mouth. It is also an appetizer and a stimulant (Ramappa B.T., 2013). Current estimates that 10% of the world's population is regular consumers, comprising perhaps 600 million people, suggest the desirability of widening perspectives (Croucher R. and Islam S., 2002). Areca nut is the fourth most commonly used social drug, ranking after nicotine, ethanol and caffeine. Arecoline, the principal alkaloid in area nut, acts as an agonist primarily at muscarinic acetylcholine receptor sand stimulates the central and autonomic nervous system. This leads to subjective effects of increased well-being, alertness and stamina. It is known to improve concentration and relaxation (Chandak et al., 2013).

Beautiful or fragrant Bowers

The fragrant bowers are used in weddings and funerals in some SE Asian countries.

Timber

The trunks of the trees provide a source of construction material. Either split or whole they are used for rafters and for wattle in house construction throughout Southeast Asia; they are used in constructing elaborate crematory and temporary structures (Staples G. W. and Bevacqua R. F., 2006). They can also be used in making a variety of utility articles such as rulers, shelves and waste paper baskets. Nails made from areca stem are widely used in the furniture industry (Orwa *et al.*, 2009).

Fuelwood

Fallen fronds, bracts, inflorescences could be used for fuel; culled trees could be used as firewood. In practice, the husks removed from the fruits during processing are used as domestic fuel after drying (Rethinam P., 2001).

Fibers, weaving or clothing

Staples G. W. and Bevacqua R. F., (2006) have stated that the tough leaf bases are used in hats, inner soles for slippers, and are an excellent paper pulp source. Husks are used for insulating wool, boards, and for manufacturing airfares (a solvent). In the Philippines the husk is used to make tooth brushes. Based on various studies, it has been proposed that the husk fibers could be used in making such items as thick boards, fluffy cushions and non-woven fabrics.

Wrapping or parcelization

The leaf sheaths and spathes are used as wrapping and as a substitute for cardboard packing material. In the Philippines the leaf sheaths are used to make book covers. In

Sri Lanka the leaf sheaths are used as plates, bags, and for wrapping (Staples G. W. and Bevacqua R. F., 2006). Trial experiments have shown that satisfactory yield and quality of brown wrapping paper could be prepared from blends of arecanut and bamboo or banana pseudostem pulp (Orwa *et al.*, 2009).

Tannin/dye

Black and red dyes are produced from tannins and these tannins are a by-product of boiling the nuts during processing the commercial product (Raghvan V. and Baruah, 1958).

Oil/lubricant

Fat from the betel nut is used as an extender for cocoa butter (Raghvan V. and Baruah, 1958).

Medicine

Areca nut is used against anaemia, fits, leucoderma, leprosy, obesity and worms. In combination with other ingredients, it is also a purgative and an ointment for nasal ulcers. Kernels of green and mature fruits are chewed as an astringent and stimulant, often with the leaves or fruit of betel pepper (Piper betel) and lime (Orwa *et al.*, 2009).

Ceremonial/religious importance

Betel nut chewing is culturally important in many Asian and Pacific societies, and the literature on the subject is extensive. In the early twentieth century it was postulated that Pacific island societies could be labeled as either kava cultures or betel cultures, based on which substance they consumed (Norton, 1997). Furthermore, the whole inflorescences are used in religious rituals in Sri Lanka and are displayed on the front of vehicles during pilgrimages, to bring good luck. The trunks are used to construct crematory and temporary ceremonial structures in several Asian countries.

The offering of betel nuts & flowers, placed on a few leaves of pan, in pujas or worship is a very common, traditional time honored practice. Persons held in esteem are offered a few pieces of arecanut with betel leaves as a sign of respect and welcome, while entering the house. Again, exchange of betel nut with betel leaves between marriage contracting parties is an important part of betrothal ceremonies throughout India. It was also a common practice for long, among the cultivating tenants in Kerala & Karnataka & perhaps in other states as well, to offer the landlord a few areca nuts while paying the rent (Ramappa B.T., 2013). In Vietnam, the areca nut and the betel leaf are such important symbols of love and marriage that in Vietnamese the phrase "matters of betel and areca" is synonymous with marriage. There was also a custom for lovers to chew areca nut and betel leaf together, because of its breath-freshening and relaxant properties. A sexual symbolism thus became attached to the chewing of the nut and the leaf. The areca nut represented the male principle, and the betel leaf the female principle. Considered an auspicious ingredient in Hinduism and some schools of Buddhism, the areca nut is still used along with betel leaf in religious ceremonies, and also while honoring individuals in much of southern Asia (Anon, 2014).

Services

Soil improver: The arecanut leaves are a good source of organic manure, containing nitrogen, phosphorous and potassium (Orwa *et al.*, 2009).

Ornamental: In Florida and Hawaii, arecanut is used as an ornamental tree (Orwa *et al.*, 2009). The areca palm is also used as an interior landscaping species. It is often used in large indoor areas such as malls and hotels. It will not fruit or reach full size (Anon, 2014).

Intercropping: Experimental evidence indicates that intercropping with areca nut is not harmful to the main crop. When intercropped with black pepper, it acts as a live standard for training the pepper plants. Banana, cardamom, cowpea, paddy, pineapple, sorghum, vegetables and yams are also grown by farmers as intercrops with areca nut (Orwa *et al.*, 2009, Staples G. W. and Bevacqua R. F., 2006).

Commercial products

The dried nuts, whole or sliced, are the primary commercial product in international trade. Fresh nuts, either ripe or unripe, are an item in local commerce only, as they do not ship well. The commercial product is prepared from ripe or unripe fruits that are first husked; then the seeds, whole, split, or sliced, are dried in various ways (sunlight, with artificial heat, by smoking). Boiling the nuts before drying reduces the tannin content of the final product. The nuts are boiled in water to which some of the liquid from previous boiling has been added (Zoysa, N. D., 2000).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Manufacturing of Fiberboards

Fiberboard manufacturing involves some of the specific activities to shape the husk into a dimensional figure. The following activities had to do for manufacturing fiberboards.

3.1.1 Raw materials collection

At the beginning of manufacturing of fiber board, raw materials should be collected. Mature betel nut is better than the immature betel nut. After husking from the betel nut, the nut is used for masticating value and husk is thrown out. Betel nut husk is considered as the wastage and is used as fuel. Mature husks were collected from the betel nut shopkeeper free of cost who worked at Daulatpur Bazar, Khulna.

3.1.2 Preparation of raw materials

After collecting betel nut husk, it had been stacked and these husks were made ready to screen out the impurities. Betel nut stalk, plastic sheet and small pieces of paper were the impurities. The impurities were removed from betel nut husks with the help of fingers.

3.1.2.1 Fiber preparation

Chemical treatment corrodes or damages fiber and lignin, so chemical treatment should be avoided. Supari husk were dipped into water for 3 weeks to make it rotten to allow looseness the fibers. Finally with the help of hammer, husks were beaten. Hammering collapsed the bonding within the fibers and separated fibers were washed to remove finest particles present in the husks.

3.1.2.2 Drying of fibers

As the fibers were washed, it contained very much moisture. So, the fibers were dried on open air. With the use of fingers, the hammered fibers were separated thoroughly. The fibers were sorted to remove the united fibers and only the uniformly separated fibers were stored.

3.1.4 Mat forming

The fibers were then kept on a steel sheet to make a mat of fibers. Oil was placed on the sheet in a thin film and the top sheet similarly oiled in the inner part to avoid the attachment of the board with the sheet after board was manufactured. The mat should be the five to eight times of the fiber board. So, the mat would have been 15cm if it would be liked to manufacture

3mm fiberboard. Seven inch by seven inch frame was used to make a mat. Fibers are evenly spreaded in the frame to allow equality in shape.

3.1.5 Hot pressing

In hot press machine, time and temperature had to set and allowed it to raise temperature up to the desired limit. 180°c was the lower limit of temperature for a board and then the temperature was raised up to 250°c. Temperature was increased in the second board for 20°c and increase in temperatures was preceded for the last board. The mat was covered with steel sheet and then inserted into the hot press for pressing. Then the pressure was raised by switch on. The pressure (4.5KPa) was remained for 15 minutes. It was switched off the machine. So the temperature was dwindled gradually, but retained the pressure for 15 minutes. Then the pressure removed and mat was allowed to cool.

3.1.6 Trimming

After the board was manufactured, the edges of the board were trimmed with the fixed type circular saw. The well-pressed boards were then cut into reasonable sizes to test the boards in the laboratory.

Fig-T4 **Fig-T3** **Fig-T2** **Fig-T1**

3.2 Laboratory Tests

The physical properties for each type of fiberboards were assessed in the Wood Technology Laboratory of Forestry, Pulp and Paper Laboratory and MS Laboratory of Wood Technology Discipline in Khulna University (KU), Khulna, Bangladesh and the mechanical properties were tested in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh.

3.2.1 Density

Density of each sample was measured in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University, Khulna. Density was calculated with the following formula-

$$\rho = \frac{m}{v}$$ .... Equation 1. (Desch and Dinwoodie, 1996).

Where, ρ = Density in gm/cm^3; m = Mass of the sample in gm and v = Volume in cm^3.

3.2.2 Moisture content

The moisture content was determined, from the differences in weights before and after the sample has been drying in the oven. Initial and final weight of the samples was measured by electric balance. It was calculated by the following formula-

$$MC\ (\%) = \frac{m_{\text{int}} - m_{od}}{m_{od}} \times 100$$ ....Equation 2. (Desch and Dinwoodie, 1996).

Where,

MC = Moisture content (%)

m_{int} = Initial mass of the sample (gm)

m_{0d} = Oven-dry mass of the sample (gm)

3.2.3 Water absorption

Water absorption is expressed in percentage and defined as the difference in weight before and after immersion in water. The water absorption was calculated by the following formula-

$$A_w = \frac{m_2 - m_1}{m_1} \times 100$$ ....Equation 3. (Anon, 2010)

Where,

A_w = Water absorption (%)

m_2 = The weight of the sample after (24 hr.) immersion in water (gm)

m_1 = The weight of the sample before immersion in water (gm)

3.2.4 Thickness swelling

Thickness swelling was expressed in percentage and calculated by the following formula-

$$G_t = \frac{t_2 - t_1}{t_1} \times 100$$ ....Equation 4. (Anon, 2010)

Where,

G_t = Thickness swelling (%)

t_2 = Thickness of sample after immersion (24 hr.) in water (mm)

t_1 = Thickness of sample before immersion in water (mm)

3.2.5 Static Bending Strength test

3.2.5.1 Modulus of rupture (MOR)

Modulus of rupture (MOR) was expressed in N/mm² and measured with the Universal Testing Machine (UTM), model: WE-100, made by Time Group Inc. in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna.

The MOR was calculated from the following equation-

$$MOR = \frac{3PL}{2bd^2}$$ ....Equation 5. (Desch and Dinwoodie, 1996).

Where,

MOR is the modulus of rupture in N/mm^2

P= Load in N

L= Span length in mm

b= width of test sample in mm

d= Thickness of test sample in mm

3.2.5.2 Modulus of elasticity (MOE)

The Modulus of elasticity (MOE) was also measured with the Universal Testing Machine (UTM) in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna. The modulus of elasticity (MOE) was calculated from the following equation-

$$MOE = \frac{P'L^3}{4\Delta bd^3}$$ ....Equation 6. (Desch and Dinwoodie, 1996).

Where,

MOE is the modulus of elasticity in N/mm^2

P' is the load in N at the limit of proportionality

L is the span length in mm

Δ is the deflection in mm at the limit of proportionality

b is the width of sample in mm

d is the thickness/depth of sample in mm.

3.3 Analysis of Data

It is important to characterize the significance of all the samples of fiber boards. In the laboratory, the data was analyzed by using Microsoft Office Excel 2007 and SPSS (Statistical Package of Social Survey) software to assess the physical and mechanical properties of fiberboards manufactured from supari husk fibers.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Dimension of Manufactured Plywood

The dimension of the naturally bonded supari husk fiberboards was 140mm×140mm×3mm. and the dimension of board collected from market was 140mm×140mm×3mm respectively. The naturally bonded fiberboards under temperature and pressure were marked out T1 for 180°c, T2 for 200°c, T3 for 220°c, T4 for 240°c and commercially produced market fiberboard was marked out M.

4.1.2 Physical Properties

4.1.2.1 Density

The density of supari husk fiberboards of different treatments of temperatures remaining pressure and time constant was assessed in gram per cubic centimeter (g/cm^3) and it was found that the density of supari husk fiberboards was 0.738 g/cm^3, 0.744 g/cm^3, 0.723 g/cm^3, 0.745 g/cm^3 and the density of commercially profitable fiberboard (M) was 0.723g/cm^3 respectively. It was also found that there was significant difference (t=11.4, df=3 and $P<0.05$) of density within fiberboards.

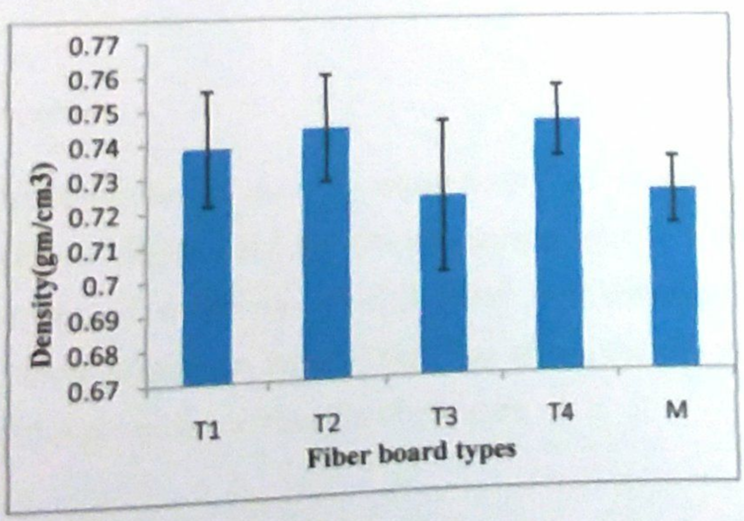

Figure (5): Density supari husk fiberboards and market fiber board

4.1.2.2 Moisture Content

The moisture contents of supari husk fiberboards of different treatments of temperature were found to 15.98%, 16.05%, 15.88% and 15.23% respectively (Fig. 6). The moisture content of commercially produced market fiberboard was 13.16% and it was also found that the moisture content of supari husk fiberboards was significantly different (t=-10.38, df=3 and P<0.p05) from that of market fiber board.

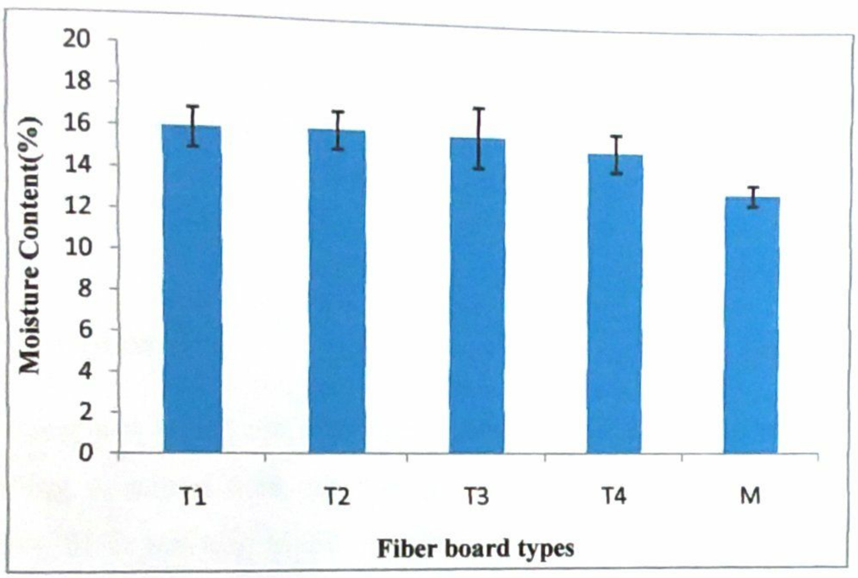

Figure (6): Moisture content of supari husk fiberboards and market fiber board

4.1.2.3 Water Absorption

It was found that the absorption of water by supari husk fiberboards of different treatments was 108.18 %, 108.05%, 100.60% and 94.90% respectively after 24 hours soaking in water (Fig. 7). The absorption of water was 87.07% found in commercially produced market fiberboard after 24 hours soaking in water. There was also a significant difference (t=3.18, df=3 and P<0.05) of this properties within the fiberboards.

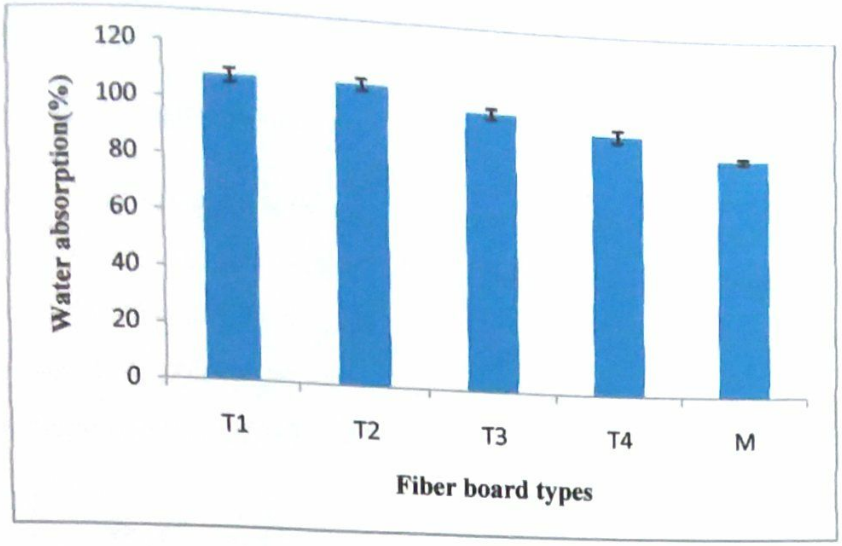

Figure (7): Water absorption of supari husk fiberboards and market fiber board after 24 hrs immersion

4.1.2.4 Thickness Swelling

Thickness swelling was tested after 24 hours immersion in water and it was found that the thickness swelling of supari husk fiberboards was 34.19%, 31.19%, 28.91% and 23.49% respectively (Fig. 8). It was also found that the thickness swelling of commercially produced market fiberboard was 19.63%. There was also a significant difference ($t=8.18$, $df=3$ and $P<0.05$) between the thickness swelling of the fiberboards.

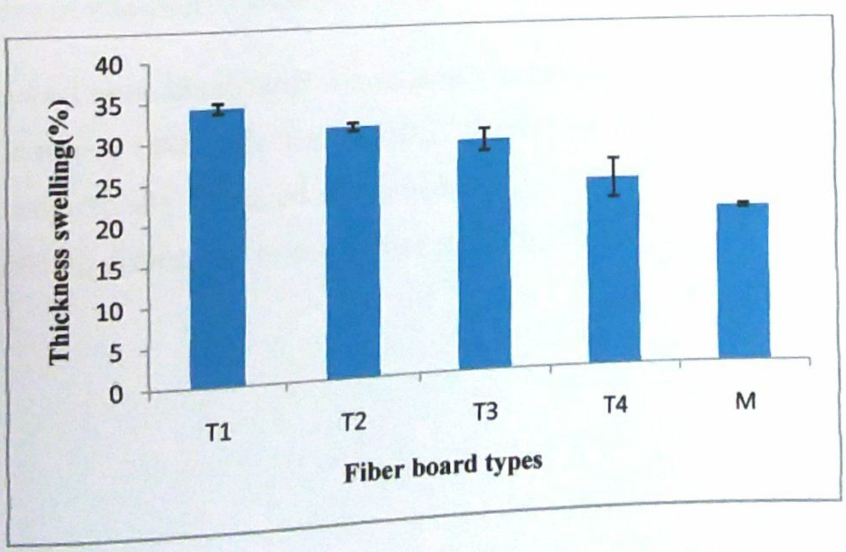

Figure (8): Thickness swelling of supari husk fiberboards and market fiber board after 24 hrs immersion

4.1.3 Static Bending Strength

4.1.3.1 Modulus of Rupture (MOR)

The MOR of supari husk fiberboards was tested in the unit of newton per square millimeter (N/mm^2,) and found to 34.12 N/mm^2, 36.85 N/mm^2, 38.89 N/mm^2 and 40.91N/mm^2 respectively (Fig. 9). The MOR of commercially produced market fiberboard was tested similarly and found to 38.79 N/mm^2. The MOR of supari husk fiberboards was not significantly different ($t=-1.01$, $df=3$ and $P>0.05$).

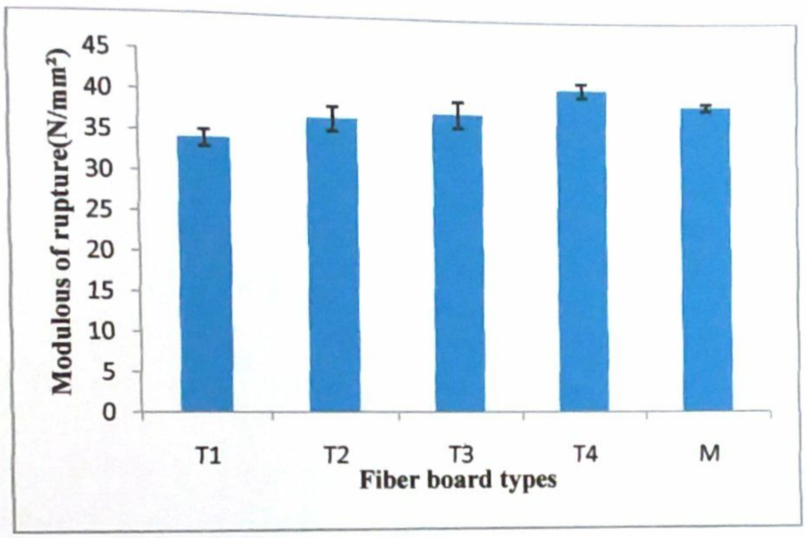

Figure (9): Modulus of rupture (MOR) of supari husk fiberboards and market fiber board

4.1.3.2 Modulus of Elasticity (MOE)

The MOE of supari husk fiberboards was assessed as the same unit used for MOR and found to 1102.34 N/mm^2 and 1488.13 N/mm^2, 1530.27 N/mm^2 and 1538.49 N/mm^2 respectively and the MOE of commercially produced fiberboard was 1293.29 N/mm^2. It was also found that there was significant difference ($t=-6.42$, $df=3$ and $P<0.05$).

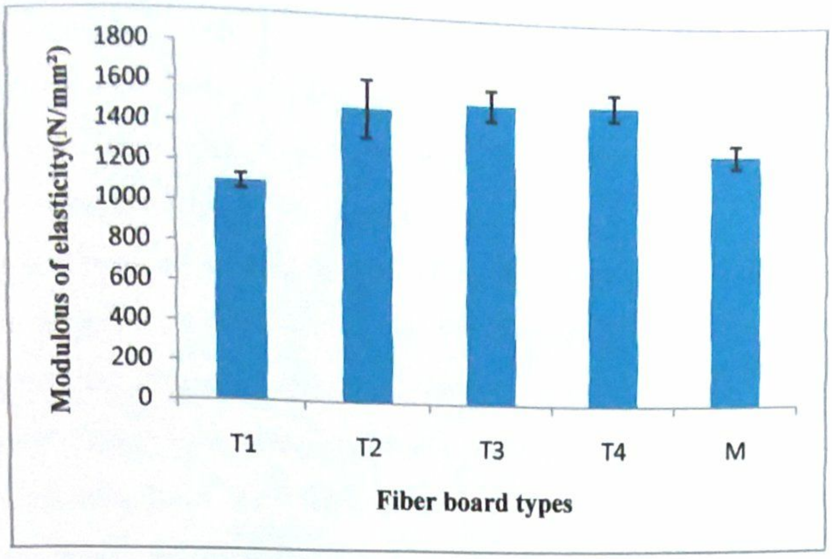

Figure (10): Modulus of elasticity (MOE) of supari husk fiberboards and market fiber board

4.2 DISCUSSION

4.2.1 Density

Density is an important parameter involved in showing fiber board performance and it virtually affects all the properties of fiberboard. It depends on the density of raw materials used, the type of adhesive applied, hot pressing conditions and other factors (Hsu *et al.,* 1988; Sekino, 1999; Velasquez *et al.,* 2003). Arias C. M., (2008) emphasized four factors that are significantly important for the density and these factors are pretreatment temperature, pretreatment time, pressing temperature and initial pressing pressure. The manufactured supari husk fiberboards are naturally bonded fiberboards. Density of these fiberboards was not similar with commercially manufactured fiberboard. The density of binderlesssupari husk fiberboards increased with the increase of the temperature from 180°c to 240°c. It was found that the density of supari husk fiberboards (0.738 g/cm^3, 0.744 g/cm^3, 0.723 g/cm^3, 0.745 g/c) was higher than the market fiberboards (0.723g/cm^3). The variation in density between two types of fiberboards may be due to the variation in density of the raw materials itself. Low pressing temperatures or high initial press pressures and long pressing times may favor an increase in density. To allow a good distribution of lignin between the fibers during the pressing process, it is necessary to apply enough heat and pressure to melt the lignin through the whole board (Arias C. M., 2008).

4.2.2. Moisture Content

The moisture content ensures good physical and mechanical properties and stable dimensions. The moisture content of supari husk fiberboards (15.98%, 16.05%, 15.88% and 15.23%) was higher than .that of market fiber board (13.16%). The adhesives mixed in the commercially produced fiberboard may lead to the lower affinity to moisture. With the increase of the temperature the moisture content of supari husk fiberboards had reduced. So temperature has direct impact on moisture content as temperature is related to the melting of lignin. At the elevated temperatures, the moisture is removed from the fiberboard and melted lignin distributed equally in the board and sealed the lumen of the fibers (Mancera *et al.*, 2011). This aspect is more pronounced in T4 fiberboard. So, these boards produced by higher temperature absorb less moisture than the boards produced at lower temperature. This type of variation in moisture content in two boards may be due to the variation in moisture content of raw materials itself. This variation within the boards may due to the types of materials used, its fiber characteristics, and chemical behavior of fibers.

4.2.3 Water Absorption

Most natural fibers absorb more moisture compared to synthetic fibers. Water is predominantly absorbed at the fiber interface and matrix. Physical and mechanical properties are also influenced by the water absorbed by samples (Kumar G. C. M., 2008). The water absorption of supari husk fiberboards (108.18 %, 108.05%, 100.60% and 94.90%) was higher than that of market fiber fiberboard (87.07%). The betel nut husk fiberboard manufactured at 180°c temperature showed higher water absorption level and with the increase of the temperatures, these fiberboards reflected lower affinity to water. The bonding within the fibers due to the melting of lignin with the accelerated temperature can lead to waning of water absorption. Lignin may plug the lumen of the cell wall (Mancera *et al.*, 2011) that reduces water absorption. The variation of water absorption between betel nut husk fiberboard and commercially produced fiberboard may have occurred due to variation in the affinity level to water and it increases the water absorption capacity of supari husk fiber. This variation may be due to use of difference in raw material, chemical constituent of fibers.

Kumar G. C. M., (2008) accomplished a research on areca fiber reinforced PF composites and used specimens of 10-mm thickness plate with size 50 mm wide and 75 mm long. The specimens were immersed in water for a period of 7–15 days. The amount of moisture in the composite increased with time and later it became constant. It absorbed about 6–7.2% of its weight. But the moisture content of naturally bonded fiberboards was higher than the moisture content of areca fiber reinforced PF composites. Though fiber reinforced PF composites were immersed more days than that of naturally bonded fiberboards, it showed less affinity to water and this less propensity might be due to the use of plastic in the areca fiber reinforced PF composites.

Arias C. M., (2008) stated that the dimensional stability of the fiberboards is related to partial hemicelluloses hydrolysis because hemicelluloses are very hydrophilic. WA decreased as the hemicelluloses content decreased. The same was true for thickness swelling. Some authors (Hsu, W. *et al.*, 1988; Jianying *et al.*, 2006; Suchsland *et al.*, 1987; Velasquez et *al.*, 2003) have obtained similar results with other materials. Kumar G. C. M., (2008) stated on his study named 'A study of short Areca fiber reinforced PF composites' that the amount of hemicellulose in betel nut husk fiber is 35%-64.8% and it is higher than that of fiber of Banana, Sisal, Maize stalk and Coir. This higher content of hemicellulose may lead to the higher affinity to moisture.

4.2.4 Thickness Swelling (TS)

Water absorption (WA) and Thickness swelling (TS) are physical properties related to the dimensional stability of the boards. These properties give us an idea of how the boards will behave when used under conditions of severe humidity and are especially important regarding boards that are to be used externally and it ensures the physical and mechanical properties of the board (Mancera *et al.*, 2011). The factors affecting water absorption are responsible for the thickness swelling of the fiberboards. The thickness swelling of betel nut husk fiberboards (34.19%, 31.19%, 28.91% and 23.49%) was higher than that of the commercially manufactured fiberboard (19.63%).

The water absorption values of the fiberboards differed according to density. Significantly less water was held by the fiberboards when fiberboard's density decreased. Denser fiberboards having a great amount of fibers and when the fiberboard is exposed to water, the hydrophilic fiber swells. . As a result of fiber swelling, micro cracking of the lignin bond occurs. The high cellulose content in fiber, further contributes to more water penetrating into the interface through the micro cracks induced by swelling of fibers (Dhakal et al., 2006). The fibers within the boards loosen, that is why more space created. So, this supari husk fiber board absorbs more water. The fiber volume fractions, the fiber chemical characteristics, temperature of water and water absorption time have influence on water absorption capacity.

4.2.5 Modulus of Rupture (MOR)

With the increase of the temperatures the MOR of supari husk fiber boards was increased accordingly. 240°c temperature produced board of higher MOR. In betel nut fiberboard, lower temperature intends to make low quality of bonding within the fibers. Actually at 180°c temperature lignin gets ready to bond, but with the increase of temperature it melts more and makes bond. The MOR of supari husk fiberboards at 230°c and 240°c (38.89 N/mm^2 and 40.91N/mm^2) was higher than that of market fiberboard (38.79 N/mm^2). The MOE depends on the raw materials used, the inherent properties of fiber and spatial arrangement of fibers (Xie *et al.*, 2011). It also depends on chemical constituents of fiber, fiber volume fraction and moisture content of the boards. The nature and the extent of natural bonding are the parameters affecting to the mechanical properties of the fiberboards. Internal Bond (IB) is the mechanical property that accounts for the strength of the bonds between the fibers; because the fibers are mainly oriented in the board plane (Arias C. M., 2008). As explained earlier that four factors (pretreatment temperature, pressing temperature, initial pressing time and initial press pressure) were statistically significant in affecting mechanical properties of the fiberboards. A suitable combination of process factors is the key to obtaining the desired properties. Low pressing pressures and intermediate pressing times are preferred. The pressing pressure should be low to avoid spoiling the fibers and enable the proper distribution of lignin between them. It has also been said that the mechanical properties of the boards are related to cellulose and lignin content of the material (Arias C. M., 2008; Suchsland, 1987).

The effect of absorption of moisture by the supari husk fiberboard leads to the degradation of fiber–matrix interface region creating poor stress transfer efficiencies resulting in a reduction of mechanical and dimensional properties (Yang G. C., 1996). MOR of the binderless boards is also affected by the moisture content present in the fibers (Widyorini *et al.*, 2011). Higher moisture content in the fibers leads to higher MOR. The betel nut husk fibers were higher moisture content than the commercially produced fibers as these fibers were not oven dried.

So the MOR of betel nut husk fiberboards at elevated temperature was higher than that of commercially produced fiberboards. The same trend was also found by Xu *et al.*, (2006) that fiberboard made from 30% moisture content fibers showed higher MOR and MOE values than those of air-dried fibers. High moisture content aids in plasticizing the fibers, enables faster heat transfer to the mat core, decreases the melting point of lignin, and therefore creates better contacts among fibers (Xu *et al.*, 2006). The moisture content of a mat entering the hot press is supposed to be a great importance in pressing composition board. Because no binder was added during board manufacturing, relatively high mat moisture content is required to promote the formation of hydrogen bonding and lignin bonding among the fibers (Xu *et al.*, 2006). Sekino *et al.*, (1999) indicated that the reduction in hygroscopicity, which is due to the changes in hemicelluloses during steam pretreatment, is one factor for improving the dimensional stability.

4.2.5 Modulus of Elasticity (MOE)

Similarly with the increase of temperature the MOE also increases in betel nut husk fiberboards. The MOE of commercially manufactured fiberboard (1293.29 N/mm^2) was lower than the most of the supari husk fiberboards (1488.13 N/mm^2, 1530.27 N/mm^2 and 1538.49 N/mm^2). But the fiberboard manufactured by heating at 180˚c temperature provides less value (1102.34 $N/mm^{2)}$ than that of commercial fiberboards. It was also observed that with the increase of the density, the MOE was increased. MOE is affected by the factors that are same for MOR.

CHAPTER FIVE

CONCLUSION

Several conclusions can be derived from the study:

The densities of supari husk fiberboards produced at different temperatures were 0.738 g/cm^3, 0.744 g/cm^3, 0.723 g/cm^3, 0.745 g/cm^3 respectively and the density of commercially profitable fiberboard was 0.723g/cm^3. All these fiberboards were medium density fiberboard.

The moisture contents found in supari husk fiberboards were found to 15.98%, 16.05%, 15.88%, 15.23% respectively and the moisture content of commercially produced market fiberboard was 13.16%.

The water absorptions by supari husk fiberboards were 108.18 %, 108.05%, 100.60%, 94.90% respectively and the absorption of water was 87.07% in commercially produced market fiberboard. The thickness swellings of supari husk fiberboards were 34.19%, 31.19%, 28.91%, 23.49% respectively and the thickness swelling of commercially produced market fiberboard was 19.63%.

The MOR of supari husk fiberboards of different temperatures was 34.12 N/mm^2, 36.85 N/mm^2, 38.89 N/mm^2 and 40.91N/mm^2 respectively. The MOR of commercially produced market fiberboard was 38.79 N/mm^2.

The MOE of supari husk fiberboards was 1102.34 N/mm^2, 1488.13 N/mm^2, 1530.27 N/mm^2 and 1538.49 N/mm^2 respectively and the MOE of commercially produced fiberboard was 1293.29 N/mm^2.

The MOR of supari husk fiberboards satisfied world standard value (24 N/mm^2) of ANSI (NPA, 1994). But in case of MOE, it didn't satisfy world standard value (2400 N/mm^2) of ANSI (NPA, 1994).

This study concluded that the strength properties of supari husk fiberboards manufactured at above 200°c were much better than that of commercially produced fiberboards. So supari husk fibers can be utilized as the raw material for fiberboard manufacture and it would be better if highly affinity of these fiberboards to water can be overcome. To improve the water repellent quality, special treatments can be applied.

REFERENCE

Anil, S. G., Ashish, J., Jaeethendra, H. J., and Santhosh, T. (2008). " Effect of matrix and composite curing time on mechanical behaviour of area composites - An experimental study," *B.E dissertation,* Dept. of Mechanical Engineering, GM institute of Technology, Davangere, Kamataka, India.

Anon (2014), en.wikipedia.org/wiki/Areca_nut

Anon, (1970). Indian Forest Utilization. Vol. 1. Forest Research Institute and Colleges, Dehra Dun, India.

Anon. (2011). http://www.banglapedia.org/httpdocs/HT/B_0094.HTM.

Anon. (2011). http://www.thefiberofmybeing.net/?p=1175.

ANSI Standards, (1994). A208.2-1994. Medium Density Fiberboard (MDF). National Particleboard Association, Gaithersburg, MD

Areca, Publication of Central Plantation Crops Research Institute, Kasargod, India, 2007.

Arias C. M. (2008). Binderless fiberboard production from *Cynara cardunculus* and V*itis vinifera.* ISBN: 978-84-692-1537-1/DL:T-300-2009

Arifulla, A., Goutham, N., Ravikumar, R B., and Santhosh Kumar, D. G. (2007). 'Mechanical characterization of area composites - An experimental study,' B.E dissertation, Dept. of Mechanical Engineering, GM Instiute of Technology, Davangere, Kamataka, India.

ASTM Standards, (1986). D1554-86. Standard Definitions of Terms Relating to Wood-based Fiber and Particle Panel Materials. ASTM, Philadelphia, PA.

Atack D. (1981). *Philos. Mag. A*, 43(3), 619.

Ayrilmis, N., Buyuksari, U. (2010). Utilization of Olive Mill Sludge in the Manufacture of Fiverboard. BioResource 5(3) 1859-1857.

Becker H. and Novack D.(1968). *Wood Sci. Technol.*, 2, 213.

Bhat S.K. (1988). Growth and performance of cacao (Theobroma cacao L.) and arecanut (Areca catechu L.) under mixed cropping system: Proc. of the 10th Int. Cocoa Research Conference, Central Plantations Crops Research Institute, Karnataka, India.

Bicho, P., Gee, W., Yuen, B., Mahajan, S., McRae, M., and Watson, P. (1988). Characterization of Canadian agricultural residues and their pulps. Proceedings of the TAPPI Pulping Conference; October 31–Novemberc 4, 1999; Orlando, FL, TAPPI Press, Atlanta, GA, 2:829–837.

Bledzki, A. K., Sperber, V. E., and Faruk, O. (2002). "Natural and wood fibre reinforcement in polymers," *Rapra Review Reports* 13(152).

Bouajila J., Limare A., Joly C. and Dole P. (2005). Lignin plasticization to improve binderless fiberboard mechanical properties. Polymer engineering and science.

Chandak R. M., Chandak M. G., RawlaniS. M. (2013). Currentconceptsaboutarecanut chewing. Reviewarticle. Journal ofContemporary Dentistry; 3(2).-78-81

Copur, Y., Guler C., Taşçıoglu, C., Tozluoglu, A. (2008). Incorporation of hazelnut shell and husk in MDF production. Bioresource Technology 99: 7402-7406.

Croucher R. and Islam S. (2002). Socio-economic aspects of areca nut use. Addiction Biology - 7, 139± 146

Desch, H. E. and Dinwoodie, J. M. (1996). Timber Structure, Properties, Conversion and Use. 7th edition, Macmillan press limited, London, pp. 102-127.

Detlefsen, W.D. (2002). Phenolic resins: Some chemistry, technology and history. A.V. (Eds.), Adhesive Science and Engineering – 2: Surfaces, Chemistry and Applications. Elsevier,Amsterdam, chap. 20.

Dhanalakshmi, S., P.Ramadevi, C.V.Srinivasa and B. Basavaraju, (2012). Effect of Esterification on Moisture Absorption of Single Areca Fiber. International Journal of Agricultural Sciences, 4(4): 227-229.

Esmeraldo *et.al.* (2010). Dawrf Green Coconut Fibers: A Versatile Natural Renewable Raw Bioresource; Treatment, Morphology and Physiochemical Properties. BioResource 5(4) 2478-2501.

Food and Agriculture Organization of the United Nations (FAO). (1958). Fiberboard and Particle Board. Rome.

Frazier, C.E. (2003). Isocyanate wood binders. In: Pizzi, A. and Mittal, K.L. (Eds.), Handbook of Adhesive Technology. (2nd ed.). Marcel Dekker, New York, chap. 33.

Ghosh S.K., Sinha M.K., Bandopadhyay S.B. (1975). An attempt for the use of arecanut husk fiber for textile purposes, J. Plant Crops 3, 29–33.

Gumuuşkaya, E. and Usta, M. (2002). Crystalline structure properties of bleached and unbleached wheat straw (Triticum aestevum L.) soda–oxygen pulp. Turk. J. Agric. For., 26(5):247–252.

Hidayat H., Keijsersb E. R. P., Prijantoa U., Damb J. E. G. V., Heeresc H. J. (2013). Preparation and properties of binderless boards from Jatropha curcasL. seed cake. Industrial Crops and Products 52 (2014) 245– 254.

Hoglund H., Sohlin U. and Tistad G. (1976). *Tappi*, 59(6), 144.

Hsu, W. E., S. W., *et al.* (1988) Chemical and physical changes required for producing dimensionally stable wood-based composites. Part1: Steam pretreatment. *Wood Science and Technology* 22.

Hurter, A.M. (1988). Utilization of annual plants and agricultural residues for the production of pulp and paper. Proceeding of TAPPI Pulping Conference 1988; New Orleans, LA, Book 1, TAPPI Press, Atlanta, GA, p.139–160.

Jacobs, R.S., Pan, W.L., Fuller, W.S., and MsKean, W.T. (1999). Genetic and environmental influences on the chemical composition of Washington State wheat straw. Proceedings of the TAPPI Pulping Conference; October 31–November 4, 1999; Orlando, FL, TAPPI Press, Atlanta, GA, 2:839-846.

Jalgoan. Areca nut cultivation under micro irrigation.

Jianying, X., W. Ragil, *et al.* (2006). Development of binderless fiberboard from kenaf core. *Journal of Wood Science* 52(3): 236-243.

Justiz-Smith, N. G., Junior Virgo, G., and Buchanan, V. E. (2008). Potential of Jamaican banana, coconut coir and bagasse fibers as composite materials. Material Characterization 59 (9), 1273-1278.

Kelley S. S., Rials T. G. and Glasser W. G. (1987). *J. Mater. Sci.*, 22, 617.

Krishnamurthy K.H, Supari or betel nut (Areca catechu, Linn.). www.namahjournal.com/.../Supari%20or%20betel%20nut%20%20vol%2010%20iss%201.html

Kumar G. C. M. (2008). A Study of Short Areca Fiber Reinforced PF Composites, Proceedings of the World Congress on Engineering. Vol II WCE 2008, July 2 - 4, 2008, London, U.K.

Laemsak N. and Okuma M. (2000). *Wood Sci.*, 46(4), 322

Lehman R. L (2004). Adhesives. Chapter 12: Materials.

Li K., Fu F., Zhan H., Zhan Y., and Lucia A. (2010). Analysis of the chemical composition and morphological structure of banana pseudostem. BioResource 5(2), 576-585.

Macdu E. R. (2000). What is wrong with the Betelnut in the CNMI? Northern Marianas College CREES Newsletter I(I): 4 pp.

Mancera C., Mansouri N. E. E., Vilaseca F., Ferrando F. and Salvado J. (2011). The effect of lignin as a natural adhesive on the physico-mechanical properties of *Vitis vinifera* fiberboards. *BioResources* 6(3), 2851-2860. 2851

Mathew A.G., Govindarajan V.S. (1964). Polyphenolic substances of arecanut II. Changes during maturation and ripening. Phytochemistry 3, 657–665.

Midwest Research Institute, Cary, NC, (July 2003). *Emission Factor Documentation For AP-42 Chapter 10, Wood Products Industry*, prepared for the U. S. Environmental Protection Agency, OAQPS/EFIG.

Mwaikambo, L.Y. and Ansell M.P. (2006). Mechanical property of alkali treated plant fibers and their potential as reinforcement materials.1.Hemp Fibers." Journal of Material Science 41(8), 2483-2496.

Norton, S.A. (1997). Betel: consumption and consequences. Journal of the American Academy of Dermatology 37: 81-88.

Orwa *et. al.* (2009). *Areca catechu*, Agroforestry Database *4.0*

Ostberg G., Salmen K., and Terlecki J. (1990). *Holzforshung*, 44(3), 223.

Pati A. K., Supari is a palm tree, mainly for the production of betel nut. www.prlog.org/10720128-supari-is-palm-tree-mainly-for-the-production-of-betel-nut-drabhay-kumar-pati-best-nutrition.html

Pereira, P.H.F., Voorwald, H.C.J., Cioffi, M.O.H. and Silva, M.L.C.P.D. (2010). Preparation and Characterization of Cellulose/Hydrous Niobium Phosphate Hybrid. BioResource 5(2), 1010-1021.

Radosavljevic L., Pecenka R. and Furll C. (2008). Natural binders for fibreboard made of Hemp, ID number: 15

Raghvan V., Baruah. (1958). Arecanut: India's popular masticatory- history, chemistry and utilization. Economic Botany. 12(4):315-345.

Rajan A, Kurup J. G., Abraham T. E. (2005). Biosoftening of arecanut fiber for value added products. Bioactive Polymer Engineering Section, Regional Research Laboratory (CSIR), Trivandrum 695019, India.

Rajan, A., J.G. Kurup, and T.E. Abraham, (2005). Biosoftening of Arecanut Fiber for Value Added Products. Biochemical Engineering Journal, 25(3): 237-242.

Ramachandra T.V., Kamakshi G., Shruthi B.V. (2004). Bioresource status in Karnataka, Renew. Sust. Energ. Rev. 8, 1–47.

Ramappa B.T. (2013). Economics of Areca nut Cultivation in Karnataka, a Case Study Of Shivamogga District. IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 3, Issue 1 (May. - Jun. 2013), PP 50-59 www.iosrjournals.org.

Rasheed S., Dasti A.A. (2003). Quality and mechanical properties of plant commercial fibers. Pak. J. Biol. Sci. 6 (9), 840–843.

Rezayati-Charani, P., Mohammadi-Rovshandeh, J., Hashemi, S.J., and Kazemi-Najafi, S., (2006). Influence of dimethyl formamide pulping of bagasse on pulp properties. Bioresour. Technol., 97(18):2435–2442.

Rodríguez, A., Moral, A., Serrano, L., Labidi, J., and Jiménez, L. (2008). Rice straw pulp obtained by using various methods. Bioresour. Technol., 99(8):2881-2886.

Rowell, M. R. (2005). Handbook of Wood Chemistry and Wood Composites. CRC press, 2000 N W. Corporate Blvd; Boca Roton, Florida 33431.

Rowell, R.M., (1998). Property Enhanced Natural Fiber Composite Materials Based on Chemical Modification. Eds., Prasad, P.N. Science and Technology of Polymers and Advanced Materials: Plenum Press, pp: 717-732.

Sakata I. and Senju R. (1975). *J. Appl. Polym. Sci.*, 19, 2799

Salehuddin, A. B. M. (1992). Wood and Fibre Composite Materials. Gen. Tech. Rep. UNDP/FAO BGD/85/011. Institute of forestry, Chittagong University, Chittagong.

Salmen L. and Olsson A. M. (1998). *Pulp Paper Sci.*, 24(3), 99

Sampathkumar D., Punyamurth R., Venkateshappa S. C. and Bennehalli B.(2012). Effect of Chemical Treatment on Water Absorption of Areca Fiber. Journal of Applied Sciences Research, 8(11): 5298-5305, ISSN 1819-544X.

Sekino, N., Inoue M., Irle M. and Adcock T. (1999). The Mechanisms Behind the Improved Dimensional Stability of Particleboards Made from Steam-Pretreated Particles. *Holzforschung* 53: 435-440.

Sekino, N.; M. Inoue; M. Irle; T. Adcock. (1999). The mechanism behind the improved dimensional stability of particleboards made from steam-pretreatment particles. Holzforschung 53:435–440

Selbo M. L. (1975). Adhesive bonding of wood. U.S. Dep. Agr., Technical Bulletin No. 1512. 124 pp.

Sellers J. T., Miller, G. D. and Smith, W. 2005. Tool wears properties of five extender/ fillers in adhesive mixes for plywood. Forest products Journal. 55(3):27-31.

Shu B. L. (2010). Areca Linnaeus, Sp. Pl. 2: 1189. 1753. Fl. China 23: 154–155.

Smook G. A. (2002). Handbook for Pulp & Paper Technologists.

Sridach W. (2010). The environmentally benign pulping process of non-wood fibers. Suranaree J. Sci. Technol. 17(2):105-123 Yang GC, Zeng HM, Li JJ, Jian NB, Zhang WB. Relation of modification and tensile properties of sisal fiber. Acta Sci Nat Uni Sunyatseni 1996;35:53–7.

Staples G. W. and Bevacqua R. F. (2006). Specific profiles for Pacific Islands agroforestry-*Areca catechu (Betel nut palm).*

Stark N. M., Cai Z., Carll C. Wood-based composite materials- panel products, glued-laminated timber, structural composite lumber, and wood–nonwood composite materials. Chapter-11.

Suchsland O., Woodson G.E. (1986). Fiberboard manufacturing practices in the United States, Agric. Handb. 640. Washington, DC: U. S. Department of Agriculture.

Suchsland, O., G. E. Woodson, *et al.* (1987). Effect on cooking conditions on fiber bonding in dry-formed binderless hardboard. *Forest Products Journal* 37: 65-69.

Velasquez, J. A., F. Ferrando, *et al.* (2003). Binderless fiberboard from steam exploded Miscanthus sinensis. *wood science and technology* 37: 269-278.

Venkateshappa S. C., Bennehalli B., Kenchappa M. G., and Ranganagowda R. P. G. (2010). Flexural behaviour of areca fibers composites. BioResources 5(3), 1846-1858.

Vick, C. B. (1999). Adhesive Bonding of Wood Materials. pp. 1-24. Chapter 9. In: Forest Products Laboratory (ed.), Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Wambua, P., Ivens, J., and Verpoest, I. (2003). " Natural fibres Can they replace glass in fibre reinforced plastics *Composites Science and Techno/oV 63(9),* 1259-1264.

Widyorini R, Yudha A. P., and Prayitno T. A.(2011). Some of the properties of binderless particleboard manufactured from bamboo. Wood Research Journal Vol.2 • No.2

Wilson, R. (2007). Early 20th-Century Building Materials Fiberboard and Plywood.

Wolcott P. M., Kamke F. A. and Dillard D. A. (1990). *Wood Fiber Sci.: J Soc. Wood Sci. Technol.*, 22(4), 345

Xu, J.; R. Widyorini; Y. Hidefumi; S. Kawai. (2006). Development of Binderless Fiberboard from Kenaf Core. J Wood Sci 52: 236-243.

Youngquist, J. A. (1999). Wood-based Composites and Panel Products. pp. 1-31. Chapter 10. In: Forest Products Laboratory (ed.), Wood handbook—Wood as an engineering material. Gen. Tech. Rep. FPL–GTR–113. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Yuden P, Dorji S. Existing resources, practices and potentials of the arecanut within the East-Central Region (Sarpang Dzongkhag).

Zoysa, N. D. (2000). Arecaceae. In: Dassanayake, M.D. (ed.). A Revised Handbook to the Flora of Ceylon. A.A. Balkema, Rotterdam, the Netherlands