Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Md. Moshiur Rahman

Title: Utilization of Okra (*Abelmoschus esculentus*) stalk as a raw material for particleboard manufacturing

Supervisor(s): Md. Obaidullah Hannan, Professor, Forestry and Wood Technology Discipline, Khulna University

Programme: Bachelor of Science in Forestry

UTILIZATION OF OKRA (*Abelmoschus esculentus*) STALK AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

Md. Moshiur Rahaman
STUDENT ID: 110540

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
BANGLADESH

2016

UTILIZATION OF OKRA (*Abelmoschus esculentus*) STALK AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

Md. Moshiur Rahaman
STUDENT ID: 110540

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
BANGLADESH

2016

UTILIZATION OF OKRA (*Abelmoschus esculentus*) STALK AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

COUSRE TITLE: PROJECT THESIS

COURSE NO: FWT-4114

[This dissertation has been prepared for the partial fulfillment of the requirements of Four years professional B. Sc. (Hons.) degree in Forestry from Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh.]

Supervisor

20.04.16

Md. Obaidullah Hannan
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladesh

Submitted By

Moshiur
20.04.16

Md. Moshiur Rahaman
Student ID: 110540
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladesh

DECLARATION

I, Md. Moshiur Rahaman, hereby declare that this project thesis is based on my own research work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at other institutions.

Moshiur

Md. Moshiur Rahaman

Date: 20.04.16

Dedicated
To
My Beloved Parents

ACKNOWLEDGEMENT

My first articulate gratitude to almighty Allah for his blessings upon me for the successful completion of this thesis paper.

It is a great pleasure to express my gratitude and indebtedness to my supervisor Prof. Md. Obaidullah Hannan for his guidance, encouragement, moral support and affection through the course of my work.

I am also grateful to Associate Prof. Md. Ashaduzzman who took keen interest in the work, and my intense appreciation to him for his friendly guidance, support, regular advice and constant supervision. This work could have been a distant dream if I did not get the moral encouragement and help from him.

Besides my advisors, I would like to thank my thesis mate Shafiq and Suresh for constant source of inspiration and ever-cooperating attitude which empowered me in working all the initial surveys, experiments and also to expel this thesis in the present form. I am also thankful to Md. Hanif Mia our laboratory assistant for helping me to complete the experimental work.

This work is also the outcome of the blessing, and support of my family. This thesis is the outcome of the sincere prayers and dedicated support of my family.

And at last I am extremely thankful to all my friends, well-wishers and classmates for their motivation and inspiration during this work.

ABSTRACT

Particle boards were produced from okra stalks using urea-formaldehyde as a binder. Water absorption and thickness swelling tests were carried out to determine dimensional stability of the boards while modulus of rupture and modulus of elasticity tests were carried out to assess the mechanical strength of the boards. Particle boards produced using an okra stalk ratio of coarse and fine particle 75:25 showed highest performance in terms of the lowest values of water absorption (79.09 %) and thickness swelling (15.19 %), as well as the highest values of modulus of rupture (26.7 N/mm^2) and modulus of elasticity (3448.833 N/mm^2). The particle boards produced met the ANSI/A208.1-1999 standard for general-purpose boards. The results of analyses of variance carried out revealed that the okra particle ratio had a marked influence ($p<0.05$) on the physical properties (water absorption and thickness swelling) and also on the mechanical properties (modulus of rupture and modulus of elasticity).

Table of Contents

List of figures

List of Tables

1.1 Background of the study

The global consumption of particleboard was 93.9 mil m^3 in 2009 (FAO 2010). The demand for particleboard has increased greatly with the growth of the world economy and trade especially in housing construction and furniture manufacturing. The low cost of raw materials such as wood particles and urea–formaldehyde (UF) resins makes it relatively cheap to produce wood products from particleboard.

Worldwide, sustainable agricultural residues are potential sources of raw materials for the manufacture of bio-based panel products. In wood-deficient countries, the use of agro-based fibers as alternative renewable sources for panel products has increased, and this trend is expected to continue through the 21st century (Bowyer and Stockmann, 2001). The abundance of agricultural residues has stimulated new interests in using agricultural fibers for global panel industries because of their environmental and profitable advantages (Rowell *et al*, 1997).

Panels made from cereal straw such as wheat, barley and oat fibers are manufactured commercially in a number of countries, including the United State (Bowyer and Stockmann, 2001). Many studies have examined a wide range of renewable agricultural residues for agro-based fibers such as sugar cane bagasse, banana stem, kiwi branch, coffee husk, cotton, kenaf, sunflower stalks and rice husk (Rowell *et al*, 1997; Guler *et al*, 2006).

Okra (Dheros) a shrub, *Abelmoschus esculentus*, of the family Malvaceae, bearing beaked, mucilaginous pods; used in soups, stews, etc. Okra is an annual plant in tropical regions, easy to harvest and a commercial crop. Okra grows in almost all parts of the country during summer-rainy season covering an area of about 5,399 ha with a production of about 17,325 m tons. Fruits are green, 14-18 cm long with five ridges and elongated tips. Yield is about 16 m tons/ha. (Banglapedia, 2006).

After harvesting Okra fruits, the stalk is of no economic value. However, instead of just being a huge waste, the stalk can be utilized as an alternative source of raw material of particle board. It is imperative to study on alternate utilization of Okra to increase its economic value. Therefore, particle board manufacturing from Okra, as an alternative source of raw material for particle board, will add new economical dimension of the shrubs Okra. In order to find out the suitability of Okra as an alternative source raw material for particle board industries and to increase its economic value, chipping, flaking, drying, screening, blending and manufacturing of particle board from rain tree will be studied. The chemical composition of okra is approximately similar to the chemical content of jute/kenaf stick. The Chemical compositions of Okra stick are Holocellulose (72.70%), Alpha Cellulose (40.80%), Pentosans (22.10%), Lignin (23.50%), Extractives (1.90%) and Ash (1.00%). The main reason behind the use of okra in composite material industries are highly available, low bulk density, toughness, abrasive in nature , resistance to withering, and unique composition (Chanda and Roy, 2008).

1.2 Objectives of the study

- To introduce Okra plant as an alternative source of raw material for manufacturing of particleboard.
- To assess the physical and mechanical properties of particle board made from Okra stalks.

2.1 General Information about particle board

2.1.1 Particleboard

Wood particleboards are relatively dense material (density range of 26 to 50 lbs. per cu. ft.), usually in panel form, made from dry wood particles that have been coated with a binder, formed, and bonded to shape by pressure and heat.

Denser boards, those in the 51 to 75 pounds per cubic foot density range, are classified as hardboards, and those boards (density of 15 to 25 lbs. per cu. ft.) that are not as dense as particleboard are called insulation board (Salehuddin, 1992).

Particleboards are not more than a few decades old production. First unsuccessful efforts were made in the early 1920's for manufacturing as for the lack of suitable adhesives. New techniques introduced in the 1930's in resin applications paved the way for the industrial production of particleboard in the early 1940's (Moslemi, 1985). Today's particleboard provides industrial users the high, consistent quality and range of "design" flexibility needed for fast, efficient lines and high-quality products that consumers require.

A particleboard is a board (or sheet) constituted from fragments of wood and or other lingo-cellulosic materials (chips, shavings, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Anon, 1970).

Particleboard is used widely in the manufacture of furniture, cabinets and floor underlayment. Panels are made in a variety of sizes and density, thus providing great opportunity to design the ultimate product with the specific particleboard needed. Particleboard is a wood panel product consisting of wood particles of various sizes that are bonded together with a synthetic resin or binder under heat and pressure. The recovery and use of residual wood in the manufacture of particleboard helps make optimal use of our forest resource (Salehuddin, 1992).

2.1.2 Types of particle board

The major types of particles used for particleboard are the following:

Shaving: A small wood particle of indefinite dimensions produced when planing or jointing wood. It is variable in thickness and often curled (Anon, 1970).

Flake: A small particle of predetermined dimension produced by specialized equipment. It is uniform in thickness, with fiber orientation parallel to the faces (Anon, 1970).

Chip: A piece of wood chopped from a block by a knife or hammer, as in hammer mill (Anon, 1970).

Sawdust: Produced by sawing, in a wide range of sizes. It is usually further refined (Anon, 1970)

Sliver: Nearly square cross section, with length at least four times the thickness (Anon, 1970)

Excelsior: Long, curly, slender slivers (Anon, 1970).

The ANSI (American National Standards Institute standard for particleboard (1999) includes three board-density classifications:

High density: 800 kg/m3 (50 lb/ft3) or greater

Intermediate density: 640 to 800 kg/m3 (40 to 50 lb/ft3)

Low density: less than 640 kg/m3 (40 lb/ft3)

2.1.3Parameters affecting board properties

- A number of parameters or factors affect the final board properties, whether the product is fiberboard or particleboard.
- The most important characteristic of a species for particle-board manufacture is specific gravity (SG).
- According to general rule (1) The lower-density species are preferred (2) The medium-density woods are used if readily available at a good price (3) The highest-density woods are avoided.
- It might seem that high-density woods should produce the strongest particleboard.
- In fact, the lower the wood density, the higher the board strength at any given density. This is because lighter-weight species have more particles per kg furnish, require higher pressures for proper densification, and thereby achieve better glue line contact.
- It might seem that high-density woods should produce the strongest particleboard. In fact, the lower the wood density, the higher the board strength at any given density. This also indicates that the strength of particleboard is largely determined by glue bond quality, not by wood strength.

2.1.4 Variables affecting the quality of particleboard

- **Particle geometry and slenderness ratio (s):** The main aspect of particle geometry is the slenderness ratio range of 120 to 200 seems best (Salehuddin, 1992).

- **Raw materials and compression ratio:** Particleboard must be compressed during hot pressing from 5 percent to 50 percent. Lower-density raw materials have greater compression ratio. So higher modulus of rupture, modulus of elasticity, internal bond and tensile strength properties are achieved (Salehuddin, 1992).
- **Binder mixing proportion and mixing:** Generally adhesives mixing proportion for particleboard is different for different types of adhesives. Based on ratio of wood flour and binder WPC board property will vary (Anon, 2006).
- Pressing time, temperature, pressure etc. are also affecting the quality of particleboard.

2.1.5 Uses of particleboard

Particleboards are used as:

- Shelves
- table tops
- cabinets
- wall cases
- benches
- book cases
- kitchen cabinets
- piano and organ parts
- flush-door cores
- mobile homes
- Floor underlayment, etc.

2.1.6 Advantages of particleboard

- Particleboards overcome some inherent weakness of solid wood and make useful products out of wastes, small pieces of wood and inferior species thus ensuring complete utilization of raw materials, make products with unique properties and can tailor products for particular end-use.
- The characteristic defects of wood such as knots, spiral grain, etc., may either be eliminated or scattered throughout the particleboard during manufacturing. Thus ensure not occurring defects during service condition.

- The variation in strength and stiffness due to anisotropy in wood is largely overcome as also the differential change in dimension due to absorption and desorption of moisture along or across the grain of wood.
- During the manufacture of particleboard, various treatments, such as heating, incorporation of chemical additives, etc. may be carried out to improve many physical and mechanical properties including the dimensional stability.
- By using different species and adhesives, or particles of different size and geometry, particleboard may be manufactured suitable for exposure to weather, for interior use, for interior paneling, for exterior sideboards, for load bearing flooring purposes and so on.
- Perhaps the most important advantage of particleboard is that it can be made in large dimensions (Salehuddin, 1992).

2.2 General information about Okra (*Abelmoschus esculentus*)

Okra (*Abelmoschus esculentus*), whose local name is Dherosh, is a monocotyledon plant. Okra *Abelmoschus esculentus L.* (Moench), is an economically important vegetable crop grown in tropical and sub-tropical parts of the world. This crop is suitable for cultivation as a garden crop as well as on large commercial farms.

Okra is known by many local names in different parts of the world. It is called okra in England, gumbo in the United States of America, guino-gombo in Spanish, guibeiro in Portuguese and bhindi in India. It is quite popular in Bangladesh because of easy cultivation, dependable yield and adaptability to varying moisture conditions.

2.2.1 Taxonomy, geographic origin and distribution

2.2.1.1 Taxonomy

Okra was earlier included in genus Hibiscus, section Abelmoschus in the family Malvaceae (Linnaeus, 1753). The section Abelmoschus was subsequently proposed to be raised to the rank of distinct genus by (Medikus, 1787).

About 50 species have been described by taxonomists. The taxonomical revision undertaken by van Borssum Waalkes (1966) and its continuation by Bates (1968) constitutes the most fully documented studies of the genus Abelmoschus. Taking classification of van Borssum Waalkes as the starting point, an up-to-date classification was adopted at the International Okra Workshop held at National Bureau of Plant Genetic Resources (NBPGR) in 1990 (IBPGR 1991) as given in table.

Name	Okra
Kingdom	Plantae
Division	Magnoliophyta
Class	Magnoliopsida
Order	Malvales
Family	Malvaceae
Genus	Abelmoschus
Species	esculentus

2.2.1.2 Geographical origin and distribution

Abelmoschus esculentus is grown commercially in India, Turkey, Iran, Western Africa, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Burma, Japan, Malayasia, Brazil, Ghana, Ethiopian, Cyrpus and the Southern United States.

Abelmoschus esculentus is found all around the world from Mediterranean to equatorial areas as may be seen from the geographical distribution of cultivated and wild species shown in figure

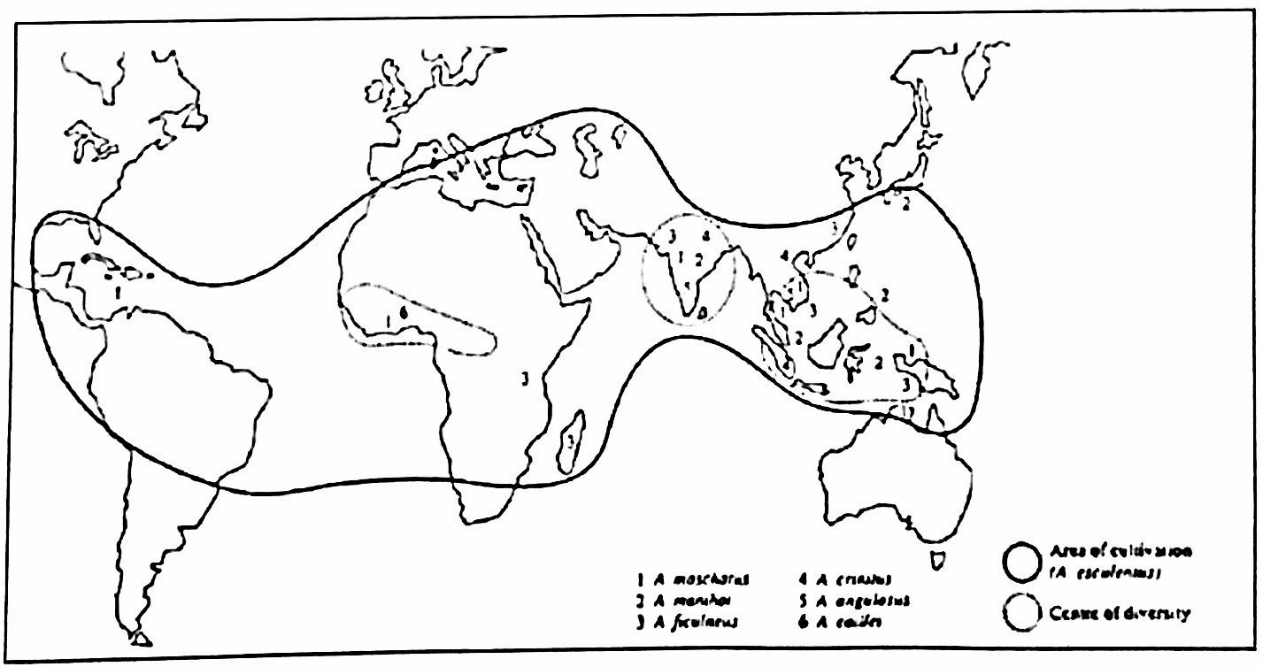

Fig. 1. Geographical distribution of Abelmoschus species (Purewal and Randhawa, 1947)

Cultivated and wild species clearly show overlapping in Southeast Asia, which is considered as the center of diversity. The spread of the other species is the result of their introduction to America and Africa. There are two hypotheses concerning the geographical origin of *A. esculentus* some authors argue that one putative ancestor (*A. tuberculatus*) is native to Uttar Pradesh in northern India, suggesting that the species originated from this geographic area. Others, on the basis of ancient cultivation in East Africa and the presence of the other putative ancestor (*A. ficulneus*), suggest that the area of domestication is north Egypt or Ethiopia, but no definitive proof is available today. For *A. caillei*, only found in West Africa, it is difficult to suggest an origin outside. Its origin by hybridization with *A. manihot* is difficult to accept even if its presence, mentioned in the Flora of West Africa (Hutchinson and Dalziel. 1958) was not recently confirmed in this area and herbarium samples are lacking.

2.2.2 Botanical features of okra

Okra is an upright annual, herbaceous 3 to 6 feet tall plant with a hibiscus-like flower It is a tropical direct sown vegetable with a duration of 90-100 days. The botanical features are as indicated below:

2.2.2.1 Root

Okra plant has a deep taproot.

2.2.2.2 Stem

Its stem is semi woody and sometimes pigmented with a green or reddish tinges color. It is erect, variable in branching, with many short branches that are attached to thick semi woody stem. The stem attains heights from 3 feet in dwarf varieties to 7 or 8 feet in others.

2.2.2.3 Leaves

The woody stems bear leaves that are lobed and are generally hairy, some reaching up to 12 inches in length. Leaves are cordate (heart-shaped), simple, usually palmately 3-7 lobed and veined. Leaves are subtended by a pair of narrow stipules. The okra leaf is dark green in color and resembles a maple leaf.

2.2.2.5 Flowers

The flowers are borne vertically only on the orthotropic axis every two or three days.. The flower is axillary and solitary, borne on a peduncle 2.0 – 2.5 cm long. The flowers are large around 2 inches in diameter, with five white to yellow petals with a red or purple spot at the base of each petal and flower will last only for a day. Each blossom develops a small green pod. Flowers are almost always bisexual and actinomorphic. The perianth consists of 5 valvate, distinct or basally connate sepals and 5 distinct petals that are usually basally adnate to the androecium.

2.2.2.6 Fruit

The fruit is an elongated, conical capsule, comprising for the most part, and five cavities contain ovules. The fruit is actually long pod is generally ribbed, developing in the leaf axil and spineless in cultivated kinds. The fruit is normally yellowish green to green.

3.1 Collection of raw materials

Okra (local name Dherosh) plants were collected from Chuadanga district, Bangladesh. This raw materials are available in everywhere of Bangladesh. The height of the raw of that plants was 3-6 feet. The stems of okra were only used for manufacturing particle board.

3.2 Processing of raw materials

After collecting the fresh plants, the materials were kept under water to allow microbial degradation. Within 15–20 days the leaves degraded appreciably to allow fiber extraction. After extracting the fiber, the stalks of okra or the main stem was washed several time for complete removal of leaves and fibers. Fibers were removed as only main stem was used to manufacture particle board. The materials were kept under the sun at least 7 days for removal of water or moisture content. After that, the material was chipped individually by using hand tools. Subsequently, the chips were converted separately into particle with a grinder by using a mesh opening at 2 mm. The grinded particles of Dherosh stalks was screened through a mesh for classifying the coarse and fine particles. Particles between 2-0.5 mm were classified as coarse and the particles size less than 0.5 mm was classified as fine particles. Mixture of coarse and fine particles was also used.

3.3 Drying of Raw Materials

After that, the raw materials were dried in an electrically heated lab scale oven at 103±3°C for 24 hours. For use with binder, the particles must be dried and moisture content reduced about 2% to 7% moisture content (Anon, 2006).

3.4 Selecting variables

In this study temperature is fixed at 160°c and pressure is 5 MPa. According to Nadir *et al*, (2011), temperature has little effect on mechanical properties of WPC board. Different study shows that 5 MPa pressures and 160°c temperature are better for producing good quality particle board. So that fixing temperature at 160°C is very reasonable for this study.

Beside this, coarse and fine particle ratio is the independent variables. A lot of study proved that coarse and fine particle ratio has a great effect on particle board (Nadir *et al*, 2011). In such case with considering fixed variable temperature 160°C, Pressure 5 MPa and pressing time 6 min for each type of board was provided. Within this fixed variables three different ratio 100% coarse, coarse: fine (75:25) and course: fine (60:40) was taken for manufacturing particle board.

3.5 Specifications of manufactured Particle Board

Table 1: Specifications of manufacturing particle board from Okra (*Abelmoschus esculentus*)

Dimensions (mm)	150 x 150
Thickness (mm)	6 (Average)
Layer	Single
Board Types	3
Replications	3 (for each type)
Total board manufactured	9
Binder	Urea formaldehyde
Hot press temperature	160°C

3.6 Mixing of raw materials

After screening and drying raw coarse and fine particle were mixed according to predefined ratio. This process was accomplished manually by hand shaking.

3.7 Mat Formation

After mixing the raw materials, the mat was formed on steel plate. The average mat thickness of each type of board was five times higher of the target board thickness.

3.8 Hot pressing

After mat formation, a steel sheet placed onto the mat. At the same time the temperature, pressure and the pressing time of electric hot press was fixed and then it was switched on to rise temperature. When the temperature reached 160°C and then mat was given between the plates of hot press and switched on the pressure. The temperature and pressure buttons was switched off after completing pressing time (6 min). Then the each type of board was retained under pressure about 15 minutes. Therefore the total press time was about 25 minutes. The hot boards are removed from the press (or sawn across on continuous presses) and further conditioned to equilibrate board moisture content and to stabilize and fully cure the adhesives (AWPA, 2001).

3.9 Trimming

After the boards of each type were produced separately, these were trimmed at edges with the fixed type circular saw. The board is trimmed to obtain the desired length and width and to square the edges. Trim losses usually amount to 0.5% to 8%, depending on the size of the board, the process employed, and the control exercised (Youngquist, 1999).

3.2 Laboratory Test

The laboratory tests for characterization of physical properties and mechanical properties for each type of particleboards were carried out respectively in the Wood Technology Laboratory of Forestry and Wood Technology Discipline of Khulna University and in the Laboratory of Civil Engineering Department of Khulna University of Engineering and Technology, Khulna. The properties were tested according to the procedures defined in the American standard for particleboards (ANSI A208.1–1993) (NPA, 1993) as well as the Indian standard for particleboards (IS: 3087-1985) (Anon, 1985).

3.2.1 Preparation of samples for testing

Three replications of each type of boards were manufactured as stated earlier. For testing physical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same nine (9) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other nine (9) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was nine (9) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the same samples.

The dimension of samples for testing the physical properties was approximately (50 mm x 35 mm) and for testing the mechanical properties was approximately (180 mm x 35 mm).

3.2.2 Evaluation of physical properties

All the samples are cut into (50 mm x 35 mm) dimension for testing physical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Forestry and Wood Technology Discipline, Khulna University, Bangladesh. At first all the specimens are weighted and green dimension are taken at room temperature. Then all the samples are kept into oven for 24 hours. After drying oven dry weight and dry dimension are also measured. Next, the samples are soaked into water for 24 hour. Finally, the wet dimension are taken and all the physical properties are calculated by using following formula-

3.2.2.1 Density

Density of each sample was measured in the laboratory of Forestry and wood Technology Discipline, Khulna University, Khulna, Bangladesh.

Density was calculated by following formula,

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

Where,

D = Density

m = Mass of the sample

v = Volume of the sample

3.2.2.2 Moisture content

The moisture content was measured from the difference in weight after the sample had been drying in the oven at 103±3°C until constant weight was reached. Initial and final weight of the sample was measured by electric balance.

It was calculated by following formula,

$mc\ (\%) = \frac{m_{in} - m_{od}}{m_{od}} \times 100$ .... Equation 2 (Desh and Dinwoodie, 1996)

Where,

M.C. = Moisture content (%)

Mint = Initial mass of the sample (g)

Mod = Oven- dry mass of the sample (g)

3.2.2.3 Water absorption

The water absorption was measured from difference in weight of sample before and after 2 hours, 24 hours immersion in water and weight measured by electric balance. The water absorption calculated by following formula,

$$A_w(\%) = \frac{m_2-m_1}{m_1} \times 100 \text{.................................. Equation 3 (Youngquist et al, 1997)}$$

Where,

A_w = Water absorption (%)

m_2 = the weight of the sample after immersion in water

m_1 = the weight of the sample before immersion in water

3.2.2.4 Linear expansion

Linear expansion was measured by digital calipers from difference in length of sample before and after 2 hours, 24 hours immersion in water.

It was calculated by following formula,

$$\text{Linear expansion (\%)} = \frac{l_2 - l_1}{l_1} \times 100 \text{........................... Equation 4 (Youngquist et al, 1997)}$$

Where,

L2 = length of the sample after immersion in water

L1 = length of the sample before immersion in water

3.2.2.5 Thickness *swelling*

Thickness swelling was measured by digital calipers from difference in thicknes of sample before and after 2 hours, 24 hours immersion in water.

It was calculated by following formula,

$$G_t = \frac{t_2 - t_1}{t_1}$$ .... Equation 5 (Youngquist *et al*, 1997)

Where

Gt = Swelling (%)

T2 = Thickness of the sample after immersion in water

T1 = thickness of the sample before immersion in water

3.2.3 Mechanical properties

3.2.3.1 Modulus of rupture

Modulus of rupture (MOR) was measured by universal testing machine (UTM), (Model no:UTM-100, serial no:11/98-2443). It was calculated by following formula-

$$MOR = \frac{3PL}{2bd^2}$$ .... Equation 6 (Desch and Dinwoodie, 1996)

Where.

MOR = Modulus of rupture in N/mm^2

P = load in N

L = Span length in mm

b = width in mm

d = thickness in mm

3.2.3.2 Modulus of elasticity

Modulus of rupture (MOR) was measured by universal testing machine (UTM), (Model no: UTM-100, serial no: 11/98-2443). It was calculated by following formula-

$$MOE = \frac{P'\,L^3}{4\Delta bd^3}$$ .... Equation 7 (Desch and Dinwoodie, 1996)

Where,

MOR = Modulus of elasticity in N/mm^2

P' = Load in N at the limit of proportionality

L = Span length in mm

b = width in mm

d = thickness in mm

Δ = deformation of the board in mm at the limit of proportionality

3.4 Statistical analysis

All the data, produced during the laboratory tests for characterization of physical and mechanical properties of each type of particleboards, were analyzed by Microsoft office excel, 2013 and Minitab software for ANOVA (analysis of variance) and LSD (Least significant difference).

4.1 Physical properties

4.1.1 Density of particle board

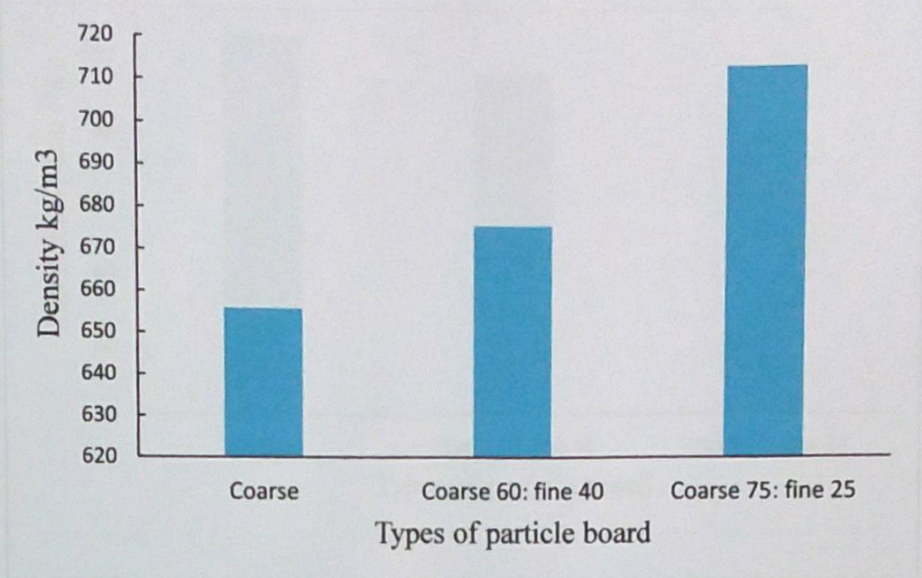

Fig. 2. Density of okra stalks particleboard

It was found that the average density of okra stalks particleboards from coarse particle was 656 kg/m^3, mixture of coarse and fine were 676 kg/m^3 and 713.67 kg/m^3. From statistical analysis it showed that there was a significant difference ($P< 0.05$) among the treatments. The particleboard made from coarse and fine ratio (75:25) showed the highest density and particle board only from coarse material showed the lowest density.

According to IS specification 3087 (Anon, 1985) the density of standard particleboard is 500-900 kg/m^3 and according to German standard Din 68761 (Verkor, 1975), particleboard standard is 590-750 kg/m^3.

4.1.2 Water absorption

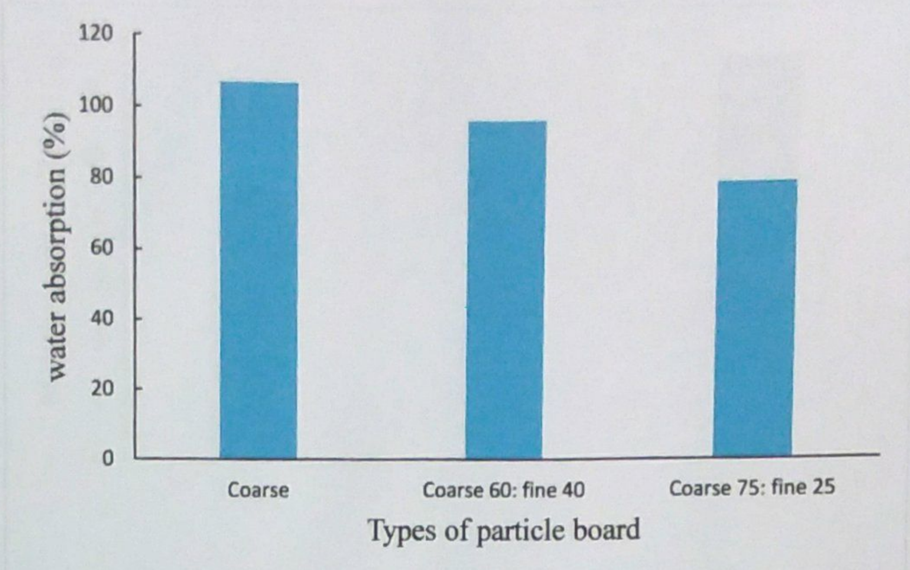

Fig. 3. Water absorption by okra stalks particleboard after 24 hours soaking

It was found that after 24 hours the percentages of water absorption of okra stalks particleboards from coarse particle, mixture of coarse and fine were 107.34%, 96.86% and 79.09% respectively. From statistical it was also found there was a significant difference ($P< 0.05$) among the three treatments. The particleboard made from coarse and fine ratio (75:25) showed the lowest and particle board only from coarse material showed the highest water absorption value.

According to IS specification 3087 (Anon, 1985) the absorption of water by standard particleboard is 50% after 24 hours soaking. The water absorption percentage by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) as well as Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int) (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975).

4.1.3 Moisture content after curing

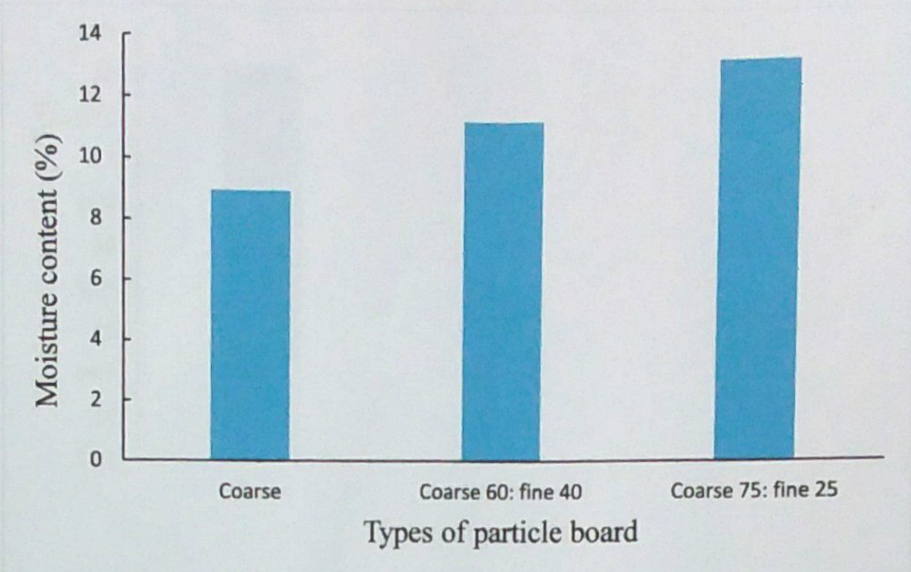

Fig. 4. M.C. % after curing in okra stalks particleboard

After curing, it was found that the moisture content of three type's okra stalks particleboard was 9 %, 11.34 % and 13.35% respectively. From statistical analysis it was also found there was no significant difference (P>0.05) among the three treatments.

The maximum moisture content in the standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the moisture content of standard particleboard is 5-8% (for 18 mm thick board) (The Laminex Group, 2003).

4.1.4 Thickness swelling

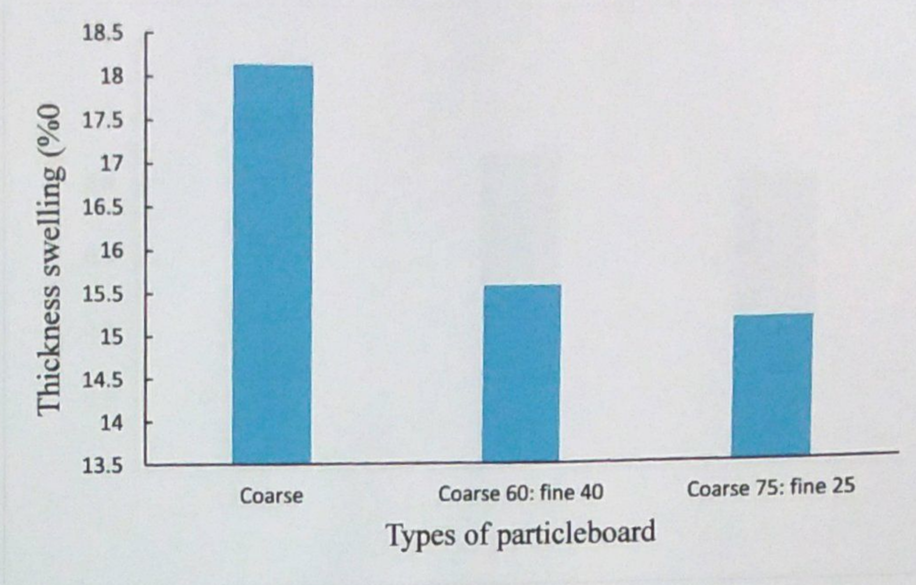

Fig. 5. Thickness swelling of okra stalks particleboard

It was also found that after 24 hours the percentage of thickness swelling was 18.17 %, 15.61 % and 15.19% in three types of okra stalks particleboard. From statistical analysis it was also found there was a significant difference ($P< 0.05$) among the three treatments. The particleboard made from coarse and fine ratio (75:25) showed the lowest and particle board only from coarse material showed the highest thickness swelling.

The thickness swelling percentage after 24 hours immersion in water by standard particleboard was not found as per ANSI A208.1–1993 (NPA, 1993) and IS: 3087-1985 (Anon, 1985) as well as British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975). But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the thickness swelling of standard particleboard is 15 % after 24 hours immersion in water for 18 mm thick board (The Laminex Group, 2003).

4.1.5 Linear expansion

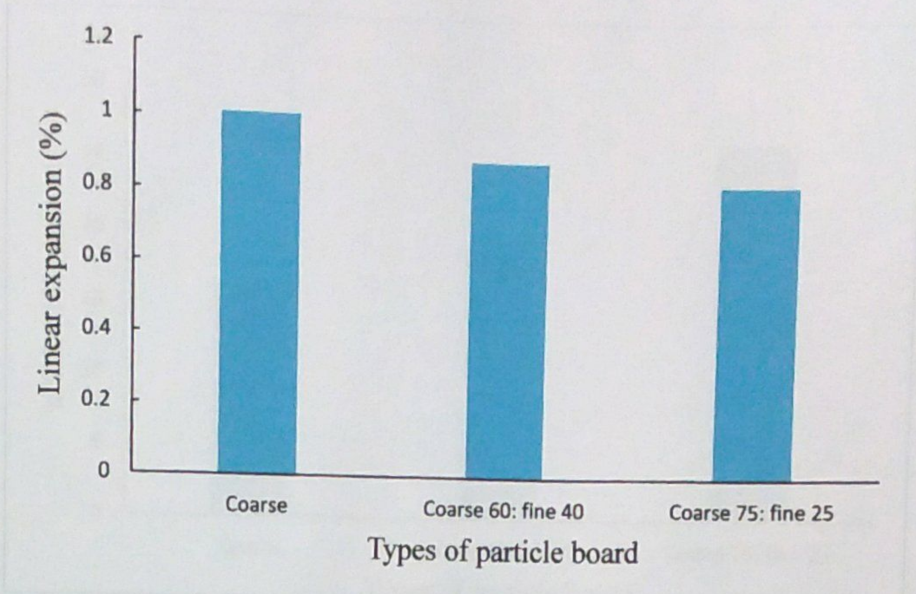

Fig. 6. Linear expansion of okra stalks particleboard after 24 hours soaking

It was found that after 24 hours the percentages of water absorption of okra stalks particleboards from coarse particle, mixture of coarse and fine were 1.01%, 0.89% and 0.83% respectively. From statistical analysis it was found that there was a significant difference ($P< 0.05$) among the three treatments. The particleboard made from coarse and fine ratio (75:25) showed the lowest and particle board only from coarse material showed the highest linear expansion.

The higher slenderness ratio and the density of particles may impart the lower linear expansion than other types of boards. High density board exhibits lower linear expansion. According to ANSI A208.1–1993 (NPA, 1993), the maximum average linear expansion of standard particleboard is 0.35 %, but the specified time was not found. The linear expansion percentage after 24 hours immersion in water by standard particleboard was not found as per IS: 3087-1985 (Anon, 1985), Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975).

4.2 Mechanical properties

4.2.1 Modulus of rupture

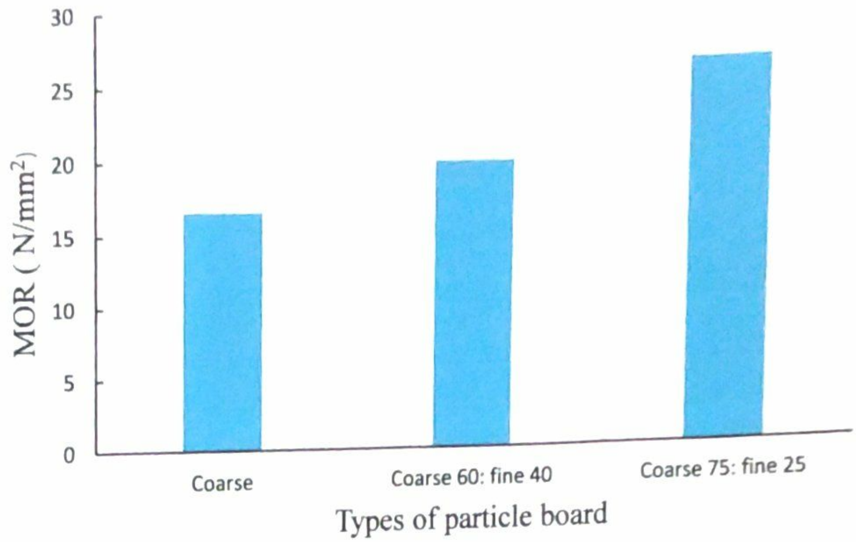

Fig. 7. Modulus of rupture of okra stalks particleboard

It was found that the MOR of okra stalks particleboards were 16.63 N/mm^2, 20.06 N/mm^2 and 26.7 N/mm^2. From statistical analysis it was also found that there was a significant difference ($P< 0.05$) among the three treatments. The particleboard made from coarse and fine ratio (75:25) showed the highest and particle board only from coarse material showed the lowest modulus of rupture (MOR).

According to ANSI A208.1–1993 (NPA, 1993), the MOR of standard particleboard is 16.5- 23.5 N/mm^2 for high density grade, 11.0- 16.5 N/mm^2 for medium density grade and 3.0- 5.0 N/mm^2 for low density grade. According to IS: 3087-1985 (Anon, 1985), the MOR of standard particleboard is 10.98 N/mm^2. But according to Australian and Newzeland Standard AS/NZS 1859.1: 2001.Int (The Laminex Group, 2003), British Standard BS: 5669 (Anon, 1979) and German Standard DIN 68 761 (Verkor and Leduge, 1975), the MOR of standard particleboard is 16 N/mm^2 (for 18 mm thick board), 13.80 N/mm^2 and 17.65 N/mm^2, respectively.

4.2.2 Modulus of elasticity

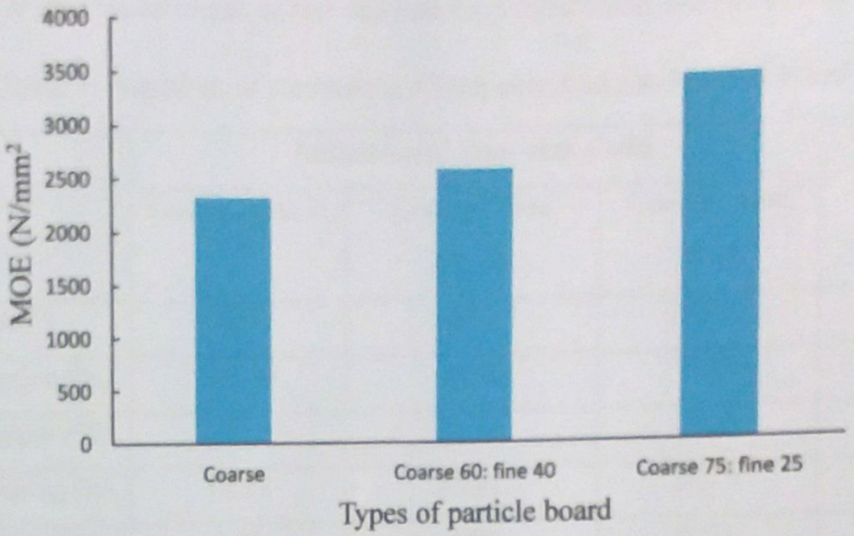

Fig. 8. Modulus of elasticity of okra stalks particleboard

It was also found that the MOE of okra stalks particleboards were 2336.67 N/mm^2, 2602.7 N/mm^2 and 3448.84 N/mm^2 and local market particleboard was 2870 N/mm^2. From statistical analysis it was found that there was a significant difference ($P< 0.05$) among the three treatments. The particleboard made from coarse and fine ratio (75:25) showed the highest and particle board only from coarse material showed the lowest modulus of rupture (MOE).

According to ANSI A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400- 2,750 N/mm^2 for high density grade, 1,725- 2,750 N/mm^2 for medium density grade and 550- 1,025 N/mm^2 for low density grade. But according to Australian and Newzeland Standard (AS/NZS 1859.1: 2001.Int), the MOE of standard particleboard is 2500 N/mm^2 (for 18 mm thick board) (The Laminex Group, 2003).

The result of physical and mechanical properties of okra stalk particleboards are compared with the properties of market available wood chip particle boards (Reza, 2015) to find out the feasibility of okra stalks as alternative source of raw material for particleboard manufacture in Bangladesh.

Table 2: Properties of particleboard from okra stalks and market board

Properties	Particleboard from okra stalks			Market Board
	Coarse particle	Coarse : Fine 60: 40	Coarse : Fine 75:25	
Density (Kg/m^3)	656	676	713.67	637
Water absorption (%)	107.34	96.86	79.09	57.22
Moisture content (%)	9	11.34	13.35	8.5
Thickness swelling (%)	18.17	15.61	15.19	14.11
Linear expansion (%)	1.01	0.89	0.83	0.79
MOR (N/mm^2)	16.62	20.06	26.7	23.11
MOE (N/mm^2)	2336.67	2602.7	3448.84	2870.27

Above table shows that physical properties (density, water absorption, moisture content, thickness swelling, and linear expansion) of particleboard made from okra are comparatively higher than market available mixed wood chip particleboards. But in case of mechanical properties, particle board made from mixture of coarse and fine particle (75:25) shows higher MOE and MOR than market board as density of that board is higher than market board.

5.1 Conclusion

It was investigated that the potential use of okra stalks for the production of particle boards using urea-formaldehyde as a binder. The following conclusions can be drawn:

- Particle boards can be produced from okra stalks using urea formaldehyde as a binder.
- Particle boards produced using coarse and fine particle ratio of 75: 25 are more dimensionally stable as evident in their smaller values of water absorption and thickness swelling compared with the other samples.
- Particle boards produced using coarse and fine particle ratio of 75: 25 have higher mechanical strengths as evident in the higher values of modulus of rupture and modulus of elasticity compared with the other samples.
- Particle boards that satisfy the ANSI/A208.1-1999 standard can be produced from okra stalks using urea-formaldehyde as a binder.
- ANOVA results show that the coarse and fine particle ratio significantly influenced the water absorption, thickness swelling modulus of rupture and modulus of elasticity.

5.2 Recommendations

Composite board of okra has satisfied the physical and mechanical properties of the international standards. But further study may be carried out also with different adhesives like Phenol Formaldehyde (PF), Melamine Formaldehyde (MF), Poly vinyl chloride (PVC), Poly-vinyl acetate (PVCA) etc., with different additives like talc, wax etc. to observe variations of the board manufactured from okra (*Abelmoschus esculentus*).

References:

Oh, Y. S., & Yoo, J. Y. (2011). Properties of particleboard made from chili pepper stalks. *Journal of Tropical Forest Science*, 473-477.

Bowyer, J. L., & Stockmann, V. E. (2001). Agricultural residues: An exciting bio-based raw material for the global panels industry. *Forest Products Journal*, 51(1), 10.

Banglapedia (2006). General information of okra retrieved from the website of Banglapedia [online], Available at: http://en.banglapedia.org/index.php?title=Okra (Accessed on 23 February 2015)

Chanda, M., & Roy, S. K. (2008). Industrial polymers, specialty polymers, and their applications (Vol. 74). CRC press.

Salehuddin, A. B. M. (1992). Wood and Fibre Composite Materials. Gen. Tech. Rep. UNDP/FAO BGD/85/011. Institute of forestry, Chittagong University, Chittagong, Bangladesh and Food and Agriculture Organization of the United Nations, Rome, Italy, pp. 24-35.

Moslemi, A.A. (1985). Particleboard; (volume – 1: Materials & Volume – 2 Technology.)

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

Anon, (1979). Specification for wood chipboard and methods of test for particleboard, BS 5669. British Standards Institution 28 pp.

Anon, (1979). Bangladesh Standard Specification for plywood tea chests (1st revision) BDS 18:1978. 3-DIT Avenue, Motijheel Commercial Area, Dhaka-2, Bangladesh.
28 pp.

Anon, (1981). Unpublished report of Particleboard and Veneering Plant, BFIDC, Kalurghat, Chittagong, Bangladesh.

Anon, (1983). Bangladesh Standard Specification for plywood. For general purposes (1st revision) BDS 799: 1983. 3-DIT Avenue, Motijheel Commercial Area, Dhaka-2, Bangladesh. 21 pp.

Anon, (1984). Draft research proposal, end-use classification of lesser used of un-used wood species. Bangladesh Forest Research Institute, Chittagong, Bangladesh. 43 pp.

Anon, (1985). Bangladesh standard specification for marine plywood. BDS 1115: 1985. Bangladesh Standard and Testing Institution, 116/A, Tejgaon Industrial Area, Dhaka-1208, Bangladesh. 11 pp.

Anon, (198). Specification for wood particleboards (medium density) for general purposes (First revision). IS: 3087-1985. Indian Standard Institution, New Delhi 19 pp.

Anon, (1986). Bangladesh standard specification for veneered decorative plywood. BDS 1158: 1986. Bangladesh Standard and Testing Institution, 116/A, Tejgaon Industrial Area, Dhaka-1208, Bangladesh. 9 pp.

Anon, (1987). Forest sector planning in Bangladesh, Project Profile No. 3. FAO Forestry Department, Rome. 4 pp.

Anon, (2000). International Workshop Asia- Pacific Cooperation, Research for Conservation of Mangroves, 26 -30 March, 2000; Okinawa, Japan.

Borssum Waalkes, J. V. (1966). Malesian Malvaceae revised. Blumea, 14(1), 1-213.

Choudhury, B., & Anothai Choomsai, M. L. (1970). Natural cross-pollination in some vegetable crops. Indian Journal of Agricultural Science, 40(9), 805-812.

Coghlan, A. (2000). So far so good-For the moment, the gene genie is staying in its bottle.

Datta, P. C., & Naug, A. (1968). A few strains of Abelmoschus esculentus (L.) Moench their karyological in relation to phylogeny and organ development. Beitr. Biol. Pflanzen, 45, 113-126.

Ford, C. E. (1938). A contribution to a cytogenetical survey of the Malvaceae. Genetica, 20(5), 431-452.

Gopalan, C., Rama Sastri, B. V., & Balasubramanian, S. (2007). Nutritive Value of Indian Foods, published by National Institute of Nutrition (NIN).

Hamon, S., & Yapo, A. (1985). Perturbation induced within the genus Abelmoschus by the discovery of a second edible okra species in West Africa. In I International Symposium on Taxonomy of Cultivated Plants 182 (pp. 133-144).

Hamon, S. (1988). Organisation évolutive du genre Abelmoschus (gombo): co-adaptation et évolution de deux espèces de gombo cultivées en Afrique de l'Ouest (A. esculentus et A. caillei).

Siemonsma, J. S. (1982). La culture du gombo (Abelmoschus spp.), légume-fruit tropical (avec référence spéciale à la Côte d'Ivoire). Publisher not identified.

Purewal, S. S., & Randhawa, G. E. (1947). Studies in Hibiscus esculentus (Ladyfinger) (Okra) I. Chromosome and pollen studies. Indian J. Agric. Sci.

ASTM. (1997) . Standard methods for testing small clear specimens of timber. ASTM D143. West Conshohocken, PA: American Society for Testing and Materials.

AWPA (Australian Wood Panels Association). (2001). Manufacture. Australian Wood panels Association Incorporated, Coolangatta Qld, pp. 1-6.

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

ANSI A208.1–1993. Gaithersburg, MD: National Particleboard Association.

Satyavati GV, Gupta AK, Tandon N. Medicinal Plants of India, vol. II. Indian Council of Medical Research, New Delhi, 1987: 490p.

Shrivastava, M.B. (1969). Introduction to Forestry. The Papua New Guinea University of Technology Leo.

The Laminex Group. (2003). Particleboard: The tradesman's essential guide. Laminex Group

Verkor, S. A. and Leduge, G. (1975). German Standard DIN 68 761: Cited in FAO Port Folio of Small Scale Wood Based Panel Plants. Koningin, Astridlaan, B- 8520/LAUWE/BEL, 54 pp.

Youngquist J., Myers G. and Harten T., (1992). Lignocellulosic–Plastic Composites from Recycled Materials. American Chemical Society, 1992.

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.

Joseph K., Thomas S. and Pavithran C., Effect of chemical treatment on the tensile properties of short sisal fibre-reinforced polyethylene composites. Polymer, 1996. 37, 5139

Reza, M.M. (2015). Utilization of Dhol Kolmi (*Ipomea carnea*) as a raw material for particleboard manufacturing, Unpublished Undergraduate Thesis, Forestry and Wood Technology Discipline, Khulna University, Khulna.

Appendix

Table 1: ANOVA for density

Dependent variable: Density

Source	df	Sum of Square	Mean square	F	P
Treatment	3	6957.7	2319.24	23.24	0.001
Error	6	598.7	99.78		
Total	9	7556.4			

*P < 0.05

LSD for density

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
3	3	713.67	A
2	3	676.00	B
1	3	656.00	B

Table 2: ANOVA for water absorption

Dependent variable: water absorption

Source	df	Sum of Square	Mean square	F	P
Treatment	3	2469.5	823.16	21.17	0.001
Error	6	233.3	38.88		
Total	9	2702.7			

*P < 0.05

LSD for water absorption

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
1	3	107.33	A
2	3	96.86	A
3	3	79.08	B

Table 3: ANOVA for Moisture content

Dependent variable: Moisture content

Source	df	Sum of Square	Mean square	F	P
Treatment	3	34.89	11.631	4.03	0.069
Error	6	17.33	2.889		
Total	9	52.23			

*P > 0.05

Table 4: ANOVA for Thickness swelling

Dependent variable: Thickness swelling

Source	df	Sum of Square	Mean square	F	P
Treatment	3	19.94	6.646	1.08	0.425
Error	6	36.86	6.144		
Total	9	56.80			

*P > 0.05

Table 5: ANOVA for linear expansion

Dependent variable: Linear expansion

Source	df	Sum of Square	Mean square	F	P
Treatment	3	0.065467	0.021822	61.37	0.001
Error	6	0.002133	0.000356		
Total	9	0.067600			

*P < 0.05

LSD for linear expansion

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
1	3	1.01333	A
2	3	0.8933	B
3	3	0.8300	C

Table 6: ANOVA for MOR
Dependent variable: MOR

Source	df	Sum of Square	Mean square	F	P
Treatment	3	160.91	53.636	20.24	0.002
Error	6	15.90	2.650		
Total	9	176.81			

*P < 0.05

LSD for MOR:

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
3	3	26.700	A
2	3	20.06	B
1	3	16.627	B

Table 7: ANOVA for MOE

Dependent variable: MOE

Source	df	Sum of Square	Mean square	F	P
Treatment	3	2028579	676193	7.31	0.020
Error	6	555337	92556		
Total	9	2583915			

*P < 0.05

LSD for MOR:

Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
3	3	3448.8	A
2	3	2603	A B
1	3	2337	B