Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Md Monirul Islam

Title: Feasibility study of Pahari Mandar (*Erythrina variegate* L.) as a raw materials for plastic board manufacturing

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

Programme: Bachelor of Science in Forestry

FEASIBILITY STUDY OF PAHARI MANDAR (*Erythrina variegata L.*) AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

Md. Monirul Islam
STUDENT ID: 090530

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE
LIFE SCIENCE SCHOOL
KHULNA UNIVERSITY
KHULNA – 9208
BANGLADESH
2017

FEASIBILITY STUDY OF PAHARI MANDAR (*Erythrina variegata L.*) AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

Md. Monirul Islam

STUDENT ID: 090530

FORESTRY AND WOOD TECHNOLOGY DISCIPLINE

LIFE SCIENCE SCHOOL

KHULNA UNIVERSITY

KHULNA – 9208

BANGLADESH

2017

FEASIBILITY STUDY OF PAHARI MANDAR (*Erythrina variegata L.*) AS A RAW MATERIAL FOR PARTICLEBOARD MANUFACTURING

COURSE TITLE: PROJECT THESIS

COURSE NO: FWT-4114

[***This thesis paper has been prepared and submitted for partial fulfillment of B.Sc. (Hons.) degree in Forestry under Forestry and Wood Technology Discipline, Khulna University, Khulna.***]

Supervisor

Prof. Md. Obaidullah Hannan
Forestry and Wood technology Discipline
Khulna University
Khulna, Bangladesh.

Submitted By

Md. Monirul Islam
Student ID. 090530
Forestry and Wood technology Discipline
Khulna University
Khulna, Bangladesh.

DECLARATION

I, Md. Monirul Islam, declare that this thesis is the result of my own works and it has not been submitted or accepted for a degree in any other university or institute.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for the title and summary to be made available to outside organizations only for research and educational purposes.

Signature

Md. Monirul Islam

Dedicated to

My Beloved parents and Late Grandfather

ACKNOWLEDGEMENT

My first articulate gratitude is 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 Professor Md. Obaidullah Hannan for his guidance, encouragement, moral support and affection through the course of my work.

I am also grateful to Professor Dr. Md. Iftekhar Shams 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 Asit, Zohurul and Toma 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. My special thanks to Md Shaidul Islam for his helping hand for supplied the row materials. I am also thankful to Md. Hanif Mian Lab. Technician, Forestry and Wood Technology Discipline, Khulna University, Khukna 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.

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

Md. Monirul Islam

TABLE OF CONTENTS

Contents **Page no.**

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

Anon	Anonymous
ASTM	American Society for Testing and Materials
cm	Centimeter
g/cm3 or gm/cm^3	Gram per cubic centimeter
Ha	Hectare
kg/m^3	Kilogram per cubic meter
KN	Kilo Newton
m	Meter
mm	Millimeter
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
N/mm^3	Newton per square millimeter
OD	Oven dry Dimension
SD	Standard deviation
UF	Urea Formaldehyde
UTM	Universal Testing Machine
ANOVA	Analysis of Variance
LSD	Least Significant Difference
APCC	Asian and Pacific Coconut Community
AWPA	Australian Wood Panels Association
BBS	Bangladesh Bureau of Statistics
FAO	Food and Agricultural Organization of United Nations
lb/ft^3	Pound per cubic feet
MPa	Mega Pascal
PVAC	Poly- vinyl acetate
rpm	Rotor per minute
PVC	Poly-vinyl chloride
WP	Wood particle

ABSTRACT

This study was conducted to investigate the feasibility (physical and mechanical properties) of Pahari Mandar (*Erythrina variegata L.*) for particleboard manufacturing. Particle boards were produced from *E. variegata L.* using urea-formaldehyde (8%) as a binder and the hot pressing temperature was 160°C and the pressure was 5 MPa fixed. The physical properties i.e. moisture content, water absorption, thickness swelling and linear expansion were examed. The mechanical properties i.e. modulus of rupture and modulus of elasticity were also examed. All the properties are statically tested. It was found that the density of coarse, fine and mixture of produce board was 700 Kg/m^3, 748 Kg/m^3 and 688 Kg/m^3 respectively. Moisture content was 5.11 (%), 5.42 (%) and 5.19 (%) for coarse, fine and mixture respectively. Particleboard produced from the coarse particles of *E. variegata L.* gave the best results in terms of the lowest mean values of water absorption (73.48 %) and thickness swelling (33.02 %). Modulus of rupture was 21.53 N/mm^2, 17.50 N/mm^2 and 21.97 N/ mm^2 whether modulus of elasticity was 1912.14 N/mm^2, 1631.67 N/mm^2 and 2085.35 N/mm^2 for coarse, fine and mixture respectively. Most of the physical and mechanical properties followed the standard specification. 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 and as it indicates the three types of board are good quality, it can be an alternative raw material for particleboard manufacturing. Further study *of E. variegata L.* may increase the potential use as alternative sources of raw materials for particleboard manufacturing based on its physical and mechanical properties.

1. Introduction

1.1 Background of the Study

The world population is increasing dramatically as well as Bangladesh. So the daily necessary things are increasing day by day for over population. Besides others things the demand of wood based products are also increased, because wood have been used as a building materials from thousands years ago. Wood is one of the earth's most valuable and abundant renewable natural resources, which can be used for indefinite period of time (Lahiry, 2001). It is a materials used by man for thousands of years without precise knowledge of its properties (Wangaard, 1981). But our forest resources are very limited. So we have to think the proper utilization of low quality wood and others lingo-cellulous materials to reduce the pressure of high quality wood. In this case, particleboard is the best alternatives for proper utilization of low quality wood. Because particleboard is made or consisted of low quality wood or fragments of wood and other lingo-cellulosic materials combined (Srivastava, 1969). Actually particleboard is a panel products manufactured under pressure and heat from particle of wood and other lingo-cellulosic materials bonded entirely with a binder, generally a synthetics resin, to which other chemicals may be added to improve certain properties (Salehuddin, 1992).

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. Panel products have increased, and this trend is expected to continue through the 21st century (Bowyer & Stockman 2001).

Wood is one of the most valuable resources on the earth and it conforms to the most varied requirements (Anon, 1986). About 70 % demand for timber and 90 % for fuel wood of the country is met from the trees grown in groves of Bangladesh (Anon, 1987). There are about 150 tree species grown in homestead and village groves of Bangladesh (Das, 1990). Only a few of them are being used by ply wood, tea chest and particleboard industries. 16 timber are recommended for decorative veneer and ply wood (Anon,1986) , 17 for ply wood (Anon,1985), 46 for manufacture of ply for general purpose (Anon,1983), 36 for plywood and batten for tea chest (Anon, 1979), and 5 selective species, viz; Civit

(*Swintonia floribunda*), Garjan (*Dipterocarpus spp*.) Chapalish (*Artocarpus chaplasha*), Narikeli (*Pterygota alata*) and Pitali (*Trewia nudiflora*) are recommensded for particleboard manufacturing plant of BFIDC (Anon,1982).This timber species make the total of 120 which particularly from only 55 timber species out of 500 hard wood timber species available in the forest of Bangladesh (Anon, 1984). In addition Kadam (*Anthocephalus cinensis*), Chatian (*Alstonia scholaris*), Jute stick, etc. are used in the private particleboard industry in Bangladesh. These species are now in short supply because of their extensive extraction. To reduce pressure on these species and fulfill the demand of the particleboard industries of Bangladesh, it is essential to introduce an alternative species for manufacturing particleboard (Islam et al., 2006).

Erythrina variegata is a well-known fast growing perennial tree species. It is widely distributed in Asia as well in the world. *Erythrina variegata* is lingo-cellulosic material, which reduce soil erosion and increase soil fertility. It is also a multipurpose tree species. It can be grown in most of the areas of Bangladesh. It grows naturally and required least maintenance and tending operation. It produces low density wood and uses to produce low quality timber, mainly as fuel wood and fence or barrier. So it is imperative to study on alternate utilization of *Erythrina variegata* to increase its economic value. Therefore, particleboard manufacturing from *Erythrina variegata* , as an alternative source of raw material for particleboard , will add new economical dimension *of Erythrina variegata* tree.

1.2 Objectives of the Study

i. To assess the feasibility of *Erythrina variegata L.* as a raw for particleboard manufacturing (physical and mechanical properties).

2. Literature Review

2.1 General Information about Particle Board

2.1.1 Definition of Particleboard

A Particleboard is a board (or sheet) constituted from fragments of wood and/or other lingo-cellulosic materials (chips, shaving, flakes, splinters, sawdust, etc.), bonded with organic binders with the help of one or more agents like heat, pressure, humidity, catalyst, etc. (Srivastava, 1969). It may be classified as a panel products manufactured under pressure and heat from particles of wood or other lingo-cellulosic materials bonded entirely with a binder, generally a synthetic resin, to which other chemicals (e.g., fire retardant, fungicide, water retardant etc.) may be added to improve certain properties (Salehuddin, 1992).

2.1.2Development history of Particle Board

In 1902, Ernst Hubbard published a paper, "The Utilization of wood-waste". This was the first publication about making particleboard (Eastman, 1997). The particleboard panels were made by hot-pressing a mixture of sawdust and blood albumen. In 1905, Watson, an American inventor, invented a modern flake board by using wood particles. In 1914, Carl G. Muench produced particleboard panels using a technology similar to papermaking. In 1940, Humble found a way to utilize large volumes of sawdust and planer shaving in Germany. In 1941, during the World War II, one of the factories in Bremen, Germany startedusing spruce chips and phenolic adhesives for manufacturing particleboard panels. Farley and Loestscher Mfg. Co., an American manufacturer, also started to produce the particleboard in the US during the same period of time. At that time, the particleboard market grew rapidly in Europe and the US.

By the end of the 1940s, logs for making plywood were on a short supply in Europe. Hence, some plywood was substituted by particleboard. In the meantime, in North America, there was a large amount of sawmill wastes, which stimulated the production of particleboard. The early typical process for manufacturing particleboard used hammer mill to break wood into small particles.

In the 1960s, the production of particleboard grew significantly with the innovation of hot press and resin technology. The Willammette Industries constructed in 1960 a new particleboard plant in Albany, Oregon to produce a new type of particleboard panels called

"Duraflake" or "three-layer particleboard" that laid out fine particles in the outer layers and coarse particles in the inner layer. The Duraflake presents smooth outer surfaces and was durable, aesthetic, cost-competitive, and of large size, which enabled it to dominate the furniture market at that time (Maloney, 1977). The most commonly used wood for particleboard manufacturing in the northern part of the US was Douglas fir. The low p^H level in Douglas fir facilitated the cure of UF resins used for making particleboard (Gent et al., 1989). Today's particleboard manufacturer provides high-quality products that consumers require due to up gradation of manufacturing techniques (Anon, 2007).

2.1.3 Types of Particle Board

In general, there are four types of particleboard panels: random (no distinct layer), graduated (gradual transition between layers), three-layer (fine particles for faces and coarse for cores), and five or more layer particleboards (finer for faces, slender and flat for intermediate, coarse for core layers). The three-layer particleboard is most commonly manufactured in the wood composite industry. These types of particleboard consist of a core layer and two face layers. The size of the core particle is coarser than that of the face particles. The coarse core materials provide the bulk of particleboard and the fine face materials provide smooth surfaces for laminating, painting, overlaying, or veneering. Most applications for particleboard require smooth surfaces (Vansteenkiste, 1981).

Particleboard was later classified according to its density: high density, medium density and low density (Salehuddin, 1992).

2.1.4 Density of the Particleboard

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

High density: 800 kg/m^3 (50 lb. /ft^3) or greater

Intermediate density: 640 to 800 kg/m^3 (40 to 50 lb./ft^3)

Low density: less than 640 kg/m^3 (40 lb. /ft^3)

2.1.5 Raw materials for Particleboard

2.1.5.1 Lingo-cellulosic materials

2.1.5.1.1 Woody materials

There are some woody materials are used for manufacturing particleboard. Some common woody materials are Saw dust, planer saving, sawmill residues, (such as slabs, edging, trimming etc.), residues from timber cutting in furniture and cabinet manufacturing plants, residues from match factories, veneer and plywood plant residues, logging residues, (such as short logs, broken logs, crooked logs, small tree tops and branches, forest thinning etc.), and bark (Salehuddin, 1992).

2.1.5.1.2 Non-woody materials

There are also some non-woody materials are used to produce particleboard such as Jute sticks,bagasse,bamboo,flax shaves, cotton stalks, cereal straw, almost any agricultural residue such as husks, coconut coir etc. after suitable treatment (Youngquist, 1999).

2.1.5.1.3 Chemicals

2.1.5.1.3.1 Binder or Adhesive

Adhesive or binders are the materials used in the fabrication of timber structures and components offers a neat and efficient method of bonding together the separate pieces of wood, or of board products such as plywood, chip wood, or fiberboard, which comprise the finished products. ASTM (1997) defined an adhesive as a substance capable of holding materials together by surface attachment. The bond attained must meet the strength requirements for the structure as a whole and this bond must remain unaffected by the condition to which it will be exposed throughout its life (Youngquist, 1999)

2.1.5.1.3.1.2 Types of adhesive or binder

There are mainly two types of adhesive. One originated from natural sources known as natural adhesive and another is synthetic adhesive.

Natural adhesive: Adhesive of natural origin such as animal, casein, soybean, starch and blood glues are still being used to bond wood in some plants and shops, but are being replaced more and more by synthetics. Animal glue is probably the natural adhesive most widely used, although casein is being used a great deal for structural laminating (Vick, 1999).

Synthetic adhesive: Adhesive of synthetic origin are called synthetic adhesive. These are man-made polymers which resemble natural resins in physical characteristics but which can be tailored to meet specific woodworking requirements. Synthetic adhesives can be categorized into two groups, namely thermosetting adhesives and thermoplastic adhesives (Natasa, 2011).

Thermosetting adhesives: These types of adhesives are usually based on formaldehyde. Thermosetting polymers make excellent structural adhesives because they undergo irreversible chemical change and on reheating they do not soften and flow again. They formed cross-linked polymers that have high strength, have resistance to moisture and other chemicals, and are rigid enough to support high, long-term static loads without deforming. So this type of adhesive is widely used now-a-days. Phenol formaldehyde, resorcinol formaldehyde, melamine formaldehyde, isocyanides, urea formaldehyde and epoxy are some examples of wood adhesives that are based on thermosetting polymers (Natasa, 2011).

Thermoplastic adhesives: These are based on poly-vinyl acetate (PVAC). Thermoplastics are long-chain polymers that soften and flow on heating and then harden again by cooling. They generally have less resistance to heat, moisture and long-term static loading than do thermosetting polymers. Common wood adhesives that are based on thermoplastic polymers include polyvinyl acetate emulsions, contacts, hot-melts etc. (Vick, 1999).

2.1.6 Parameters 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.

2.1.7 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.

2.1.8 Uses of particleboard

Another advantage of particleboard is its very broad application. About one third of the particleboard goes into making kitchen and stereo/TV cabinates (Haygreen et al., 1996).Other common applications for particleboard include stair treads, home structures, table and counter tops, shelving, domestic, institutional and office furniture, vanities, speakers, sliding door, lock block, interior signs, displays, table tennis tables, pool tables, and electronic game consoles (Nemli et al., 2005).

2.1.9 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 Indian coral tree (*Erythrina variegata*)

2.2.1 Taxonomy (Classification)

Domain: Eukaryota
Kingdom: Plantae
Phylum: Spermatophyta
Subphylum: Angiospermae
Class: Dicotyledonae
Order: Fabales
Family: Fabaceae
Subfamily: Faboideae
Genus: Erythrina
Species: *Erythrina variegata*

(**Source:** http://www.iucnredlist.org/details/19891448/0)

2.2.2 English name: Indian coral tree, Indian koral tree, Tiger's claw, Lenten tree

2.2.3 Botanical name: *Erythrina variegata*

2.2.4 Family*: Leguminosae* (Fabaceae)

2.2.5 Type: Tree

2.2.6 Synonyms

2.2.6.1 Preferrd scientific names*: Erythrina variegata*

2.2.6.2 International common name: English: variegata coral tree; French: arbre au corail*; *arbre immortel

2.2.6.3: Local common name:

India: badapu; baditha; cavucayam; chaldua; haliwara; maidal; mandar; mandaro; modugu mullu-mutala; murukku; paldua; paliwara; panarve; panarweo; pangara; pangra; paricadam; parijata; phandra; tella; varjam; warjipe

Indonesia: dadap; dadap ayam; dedap blendung; dede bineh; thong baan

Malaysia: cenkering; dedap

Myanmar: penglay-kathit

Papua New Guinea: balbal

Philippines: andorogat; bagbag; dapdap; karapdap

Thailand: thong laang laai; thong phueak

2.2.7 Botanical description of *Erythrina variegata L.*

Erythrina variegata is a first growing, medium to large deciduous tree with 15-18 m tall and leaves are 6 inches long having spiny branches (Kumar et al., 2010). The genus *Erythrina variegata* (Leguminosae) consists of 110 species of trees and shrubs. It has an erect, spreading form, typically with several vertically oriented branches emerging from the lower stem. On favorable sites, the stem can reach a diameter at breast height (dbh) of 50 to 60 cm in just 15 to 20 years.

The smooth bark is streaked with vertical lines of green, buff, grey and white. Small black prickles cover the stem and branches. These become longer if the tree suffers moisture stress. They typically drop off as the girth of the stem expands (Hegde, 1993).

Leaves: The leaves are trifoliate. The leaflets are commonly variegated, medium to light green, heart shaped, 7 to 12 cm wide and 12 to 18 cm long. The trees are deciduous, typically losing their leaves before flowering except under very humid conditions.

Flowers: Brilliant orange-red flowers emerge in dense, cofiioal inflorescences 5 to 7 cm long and 2 to 3 cm wide, usually after the leaves have dropped. Flowering is normally followed byalavishproduction of seed. . Flowers in groups of 3 scattered along rachis, large, bright red(occasionally white); calyx eventually deeplyspathaceous, 2-4 cm long, glabrescent, standard ovate-elliptical, 5-8cm x 2.5-3.5 cm, more than twice as long as wide, shortly clawed, longitudinally centuplicate, recurred, bright red without white veins; wings and keel sub equal, 1.5-2.5 cm long, red; stamens 10, monadelphous, 5-7cm long, vanilla stamen basally connate with the tube for 1 cm, red; pistil with pubescent ovary and glabrous style. The flowers remain open for 2-3 days, but stop secreting nectar after the morning of the first day.

Seeds: The pods are thick and black-1.5 to 2 cm wide and 15 to 20 cm long. Each contains 5 to 10 egg-shaped seeds. These are glossy brown, red or purple and are 6 to 10 mm in diameter and 12 to 17 mm long.

2.2.8 Distribution

Erythrina variegata is native to the coast of India and Malaysia. It has been widely introduced in coastal areas of the Old World tropics, extending from East Africa and Madagascar through India, Indochina, Malaysia, northern Australia and Polynesia. The seeds can float on salt water for months, facilitating the spread of the species. Introduced to the Americas, it was so well established by 1825 that Candolle described two new species based on trees considered to be native to the New World (McClintock, 1982). It is now a very popular hedge species in southern Florida.

2.2.9 Ecology

Erythrina variegata is well adapted to the humid and semi-arid and tropics and subtropics, occurring in zones with annual rainfall of 800 to 1500 mm distributed over a five- to six-month rainy season. The species is most commonly found in warm coastal areas up to an elevation of 1500 m. The trees prefer a deep, well-drained, sandy loam, but they tolerate a wide range of soil conditions from sands to clays of pH 4.5 to 8.0. They can withstand waterlogging for up to two weeks and are fairly tolerant of fire. *Erythrina variegata* is bird pollinated, outcrossed and sometimes genetically incompatible.

2.2.10 Biophysical limits

Altitude: Up to 1900 m.

Mean annual rainfall: 1200-2500 mm.

Mean annual temperature: 20-32°C.

Soil type: *E. variegata* grows on a variety of soils from sandy loam to gravel. It tolerates seasonally waterlogged soils, and is also often found on saline, tropical, clayey and coral limestone soils.

2.2.11 Silviculture and Management

2.2.11.1 Establishment

Erythrina variegata is successfully propagated from seed or large stem cuttings. Seed should be scarified by soaking in hot water (80°C) for 10 minutes and then in tepid water overnight. Treated seeds normally germinate within 8 to 10 days. Well-watered seedlings are normally ready for planting at 10 weeks.

Woody cuttings establish best under dry conditions. They should always be held for at least 24 hours before planting to prevent attack by soil fungi. Cuttings establish quickly, producing axillary shoots in three to four weeks and then rooting. To produce tall trees with straight stems, it is important to retain the terminal bud of branch cuttings. The column shaped form, 'Tropic Coral', may not reproduce true to form from seed and should thus be propagated from cuttings.

2.2.11.2 Management

Erythrina variegata generally requires little maintenance. Once established, seedlings grow rapidly, usually to 3 m in one year. Cuttings typically produce more and larger side branches than seedlings; they should be pruned when young if upward growth and a clear bole are desired.

2.2.11.3 Pests and Diseases

Diseases: In Hawaii the trees are attacked by powdery mildew (*Oidium sp.*).

Pests: In Hawaii the trees are attacked by Chinese rose beetle (*Adoretus sinicus*), mealy bugs (*Phenacoccus spp.*)mites (*Tetranychus cinnabarinus* and *Polyphagotarsonemus latus*). Like other *Erythrina spp.*, it is a potential host ofthe fruit-piercing moth (*Othreis fullonia*), the hibiscus snow scale (*Pinnaspis strachani*), and the carob moth(*Ectomyelois ceratoniae*) as well as of their predators. In India, larvae of the beetle *Raphipodus* damage the roots.

2.2.12 Uses of *Erythrina variegate L.*

2.2.12.1 Products

Fodder: The leaves to a limited extend are used as fodder.

Fiber: The wood has been tested as a source of pulp for the paper industry. The fiber is acceptable for pulping, having good length, high flexibility and slenderness ratio and low Rankles ratio.

Medicine: The leaves and bark are widely used as cures in many South-East Asian countries. The bark is used as an antipyretic in Burma (Myanmar), in decoction to treat liver problems in China and intermittent fever in Indonesia. A decoction of the bark and leaves is used to treat dysentery in Indonesia; sweetened, it is considered a good expectorant. A decoction of the leaves may also be used to treat mastitis. The bark has also been used to treat rheumatism and to relieve asthma and coughs. The roots and leaves are often employed to alleviate fever in the

Philippines. Crushed seeds are used to treat cancer and abscesses in Indo-China, and are boiled in a little water as a remedy for snake bites in Malaysia. In India, the root and bark are called 'paribhadra', one of the reputed drugs of Ayurvedic medicine.

Timber: The wood is white and soft, spongy, fibrous and darker towards the Centre. Growth rings are visible. The density of the wood is 300 kg/m cubic. In New Britain, the wood is used for spears and shields. The light, spongy woods used in Cambodia as floats for fishing-nets.

Essential oils: In New Britain, blackened dried leaves are worn for their scent.

2.2.12.2 Services

Boundary or barrier or support: In India, Malaysia and Indonesia *E. variegata* is used as live support for betel (*Piperbetle L.),* black pepper (*Piper nigrum* L.), vanilla (*Vanilla planifolia* H.C. Andrews) and yam (*Dioscorea spp.*) vines. A columnar cultivar is planted in hedges as a wind break.

Ornamental: As an ornamental tree, the leaves of the variegated forms and the flowers being very showy.

Shade or shelter: In southern India, it is occasionally grown as a shade tree for cocoa and coffee; in Java it is not recommended for this purpose as it is leafless for up to a few months per year.

3. Material and methods

3.1 Methods and Procedures

3.1.1 Collection of Raw Materials

Erythrina variegata (local name Pahari mandar) was used as the raw materials for manufacturing the particleboards. It was about 8-10 years old and height was about 8 m. It was collected from local village of Khulna district (Bangladesh). This raw material is available in everywhere of Bangladesh. The Urea-Formaldehyde was collected from Akij particleboard industry.

3.1.2 Processing of Raw Materials

After cutting the fresh tree, the logs of the *Erythrina variegata* were cut into small pieces to 1-1.5 inches by using hand tools. Then the small pieces were dried for 28-30 days in the sun for removal of water or moisture content. Finally the chips were dried in an electric oven at 103±1°C for four hours. Then the chips were run into grinder to produce particles were also used.

3.1.3 Screening

For the purpose particles were screened through screener to separate the fine and coarse particles. At first the particles were screened by sieve no. 16 and then again screened by sieve no. 8. The particles which passed through sieve no. 8 were taken as fine particles.

3.1.4 Drying of Raw Materials

After that, the raw materials were dried in an electrically heated lab scale oven at 103±1°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). At this stage the particle moisture content was 5-6%.

3.1.5 Adhesive Preparation and Mixing with Particle

Urea Formaldehyde (UF) is one of the most common adhesives for particleboard manufacturing in Bangladesh. Urea formaldehyde (UF) resin is the main ingredient of the adhesive. Flour as extender and Ammonium Chloride (NH_4Cl) as hardener were used in the adhesive. Eight percent (8%) Urea-Formaldehyde (UF) adhesive were mixed with the particles.

3.1.6 Selecting Variables

There are two types of variables, i.e. dependent and independent. In this study, temperature and pressure are the independent variable. Temperature is fixed at 160°c and pressure is 5 MPa. 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, fine and mixture particle ratio is the dependent variables. A lot of study proved that coarse and fine 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 10 min for each type of board was provided.

3.1.7 Specifications of Manufactured Particle Board

Table 3.1 Specifications of manufacturing particle board from Pahari mandar(*Erythrina variegata L.*)

Dimensions (mm)	200 x 150
Thickness (mm)	7 (Average)
Layer	Single
Board Types	3(Course, Fine and Mixture(50:50)
Replications	2 (for each type)
Total board manufactured	6
Binder	Urea formaldehyde(UF)- 8%

3.1.8 Flow Chart of the Particleboard Formation Process

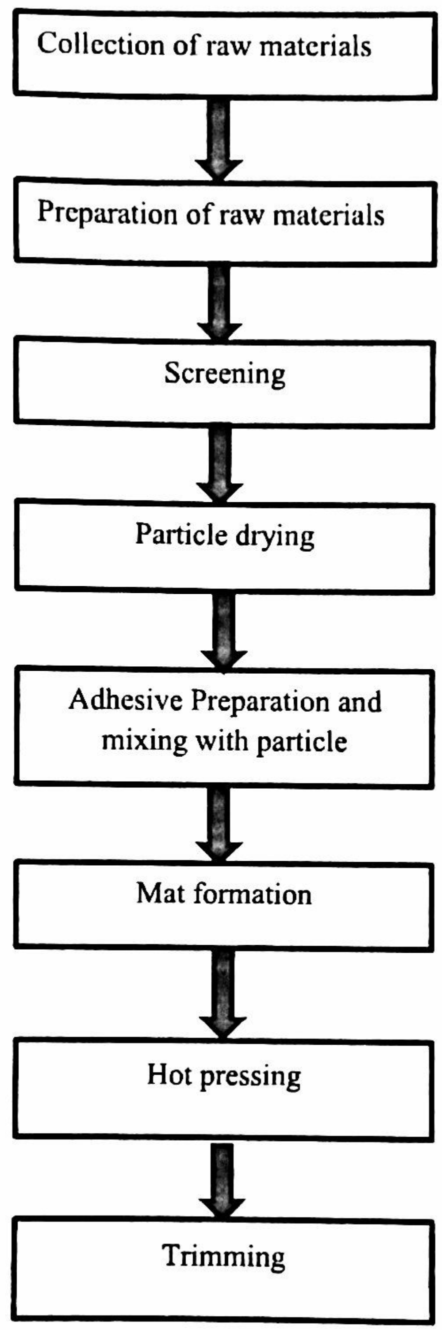

Figure: 3.1 Flow diagram of particle board manufacturing process

Figure: 3.2 *Erythrina variegata tree*

Figure: 3.3 Chips of *Erythrina variegata*

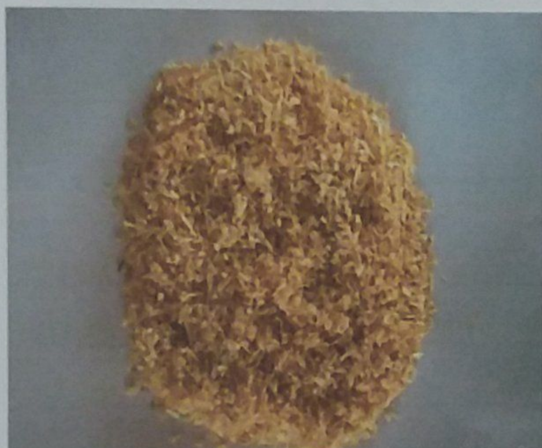

Figure: 3.4 Fine particles

Figure: 3.5 Coarse particles

Figure: 3.6 *Erythrina variegata* particleboard(Fine)

Figure: 3.7 *Erythrina variegata* particleboard(coarse)

Figure: 3.8 *Erythrina variegata* particleboard (Fine: Coarse)

3.1.9 Mixing of Raw Materials

After screening and drying the raw materials (Coarse and Fine) were mixed according to predefined ratio (8% UF). This process was accomplished manually by hand shaking.

3.1.10 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.

3.1.11 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 (10 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).

3.1.12 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, Khulna 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 six (6) for each type of particleboard for testing of physical properties. The Density and Moisture Content were determined on the same six (6) samples and the Water Absorption, Thickness Swelling and Linear Expansion were determined on the other six (6) samples. For testing mechanical properties, three samples were collected from each board of each type. So the total number of sample was sis (6) for each type of particleboard for testing of mechanical properties. The MOR and MOE were determined on the separate 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 (150 mm x 35 mm).

3.2.2 Determination 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,

Mc = 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,

$A_w(\%) = \frac{m_2 - m_1}{m_1} \times 100$................................ Equation 3 (Young quist 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,

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

Where,

l_2 = length of the sample after immersion in water

l_1 = 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 (Young quist et al, 1997)

Where

G_t = Swelling (%)

t_2 = Thickness of the sample after immersion in water

t_1 = thickness of the sample before immersion in water

3.2.3 Mechanical Properties

All the samples are cut into (150 mm x 35 mm) dimension for testing mechanical properties. The laboratory test for characterization of physical properties is carried out in the laboratory of Civil Engineering Department of Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh.

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-

$MOE = \frac{P' L^3}{4\Delta b d^3}$ .... Equation 6 (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

3.3 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,2010 and SPSS software for ANOVA (analysis of variance) and LSD (Least significant difference).

4. Result and Discussion

4.1 Result

After manufacturing particleboard mechanical properties of the particle board were tested in KUET, Khulna (Bangladesh) and the physical properties were tested in the laboratory controlled by Forestry and Wood Technology Discipline in Khulna University. The result of the tested sample and commercial board values are given below:

Table 4.1 Physical and Mechanical properties of different particle board

Properties	Particleboard from pahari mander (*Erythrina variegata*)			Commercial board
	Coarse particle	Fine particle	Coarse 50 : Fine 50	
Density (Kg/m^3)	700	748	688	637
Water absorption (%)	73.48	103.18	80.98	57.22
Moisture content (%)	5.11	5.42	5.19	8.5
Thickness swelling (%)	33.02	37.91	36.83	14.11
Linear expansion (%)	0.92	0.87	0.83	0.79
MOR (N/mm^2)	21.53	17.50	21.97	23.11
MOE (N/mm^2)	1912.14	1631.67	2085.35	2870.27

4.2 Discussion

4.2.1 Physical Properties

4.2.1.1 Density of Particle Board

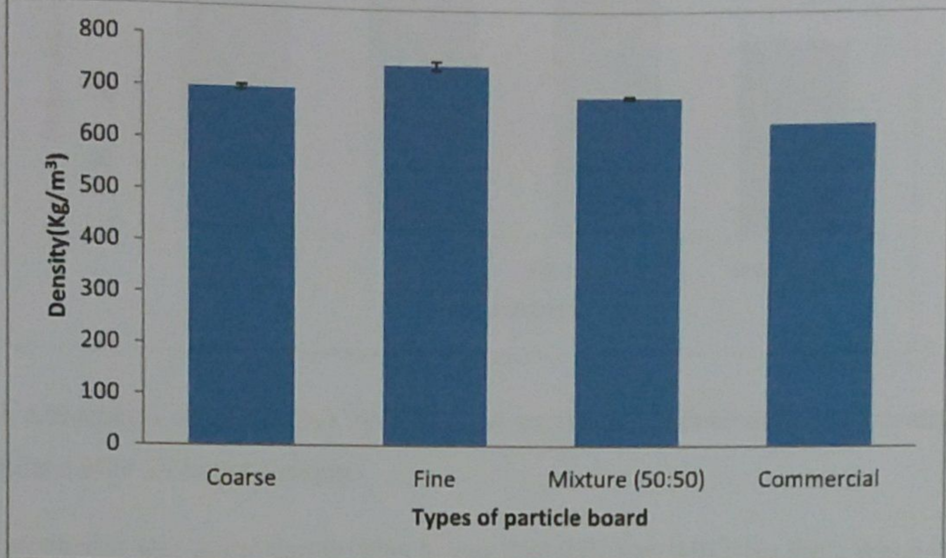

Fig.4.1 Density of *Erythrina variegata* particleboard and commercial particleboard.

From statistical analysis it was found that p value was less than 0.01 ($p < 0.01$) and it indicated that there was a highly significant difference among the treatments. The particleboard made from coarse and fine showed the highest density and particle board from mixture (50:50) material showed the lowest density.

It was also found that the average density of *Erythrina variegata* particleboards from coarse particle was 700 kg/m^3, fine and mixture were 748 kg/m^3, 688 kg/m^3 and commercial particleboard was 637 kg/m^3 (Reza, 2015 and Rahaman, 2016 unpublished thesis) respectively. 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.

4.2.1.2 Water Absorption

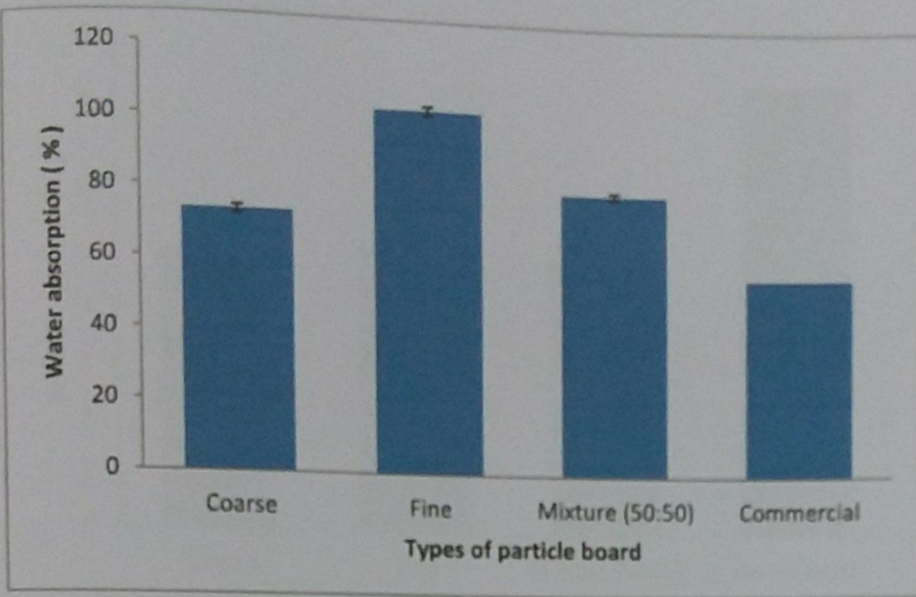

Fig. 4.2 Absorption of water (%) by *Erythrina variegata* particleboard and commercial particleboard after 24 hours soaking.

From statistical it was found that p value is less than 0.01 ($p < 0.01$). So there was a highly significant difference among the three treatments. The particleboard made from course and mixture (50:50) showed the lowest and particle board only from fine material showed the highest water absorption value.

It was also found that after 24 hours the percentages of water absorption were 73.48%, 103.8% and 80.98% in *Erythrina variegata* particleboard and 57.22% (Reza,2015 and Rahaman,2016 unpublished thesis) for commercial particleboard. 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).

4.2.1.3 Moisture Content

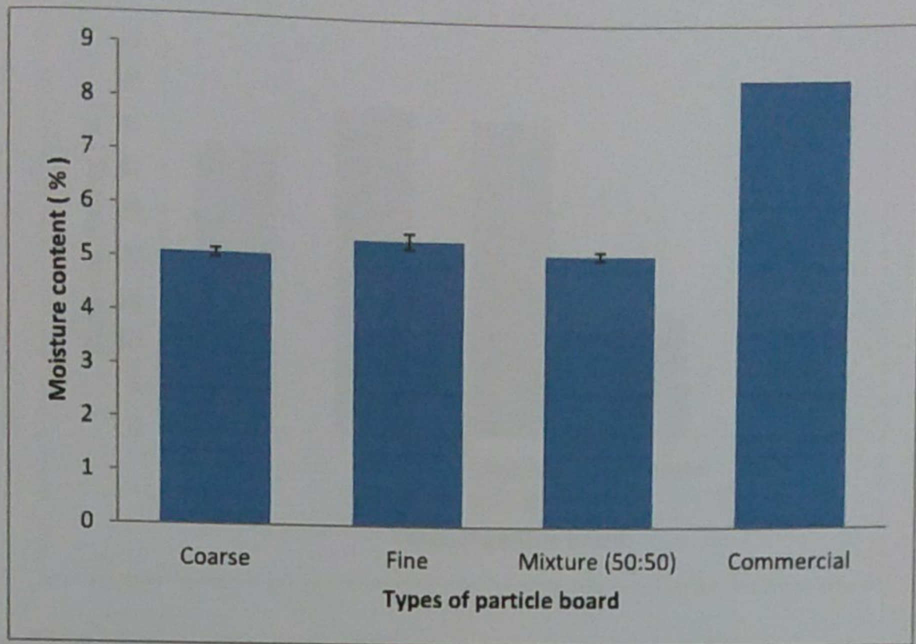

Fig. 4.3 M.C. (%) of *Erythrina variegata* particleboard and commercial particleboard.

From statistical it was found that p value is greater than 0.05 ($p > 0.05$). So there was no significant difference among the three treatments.

After curing, the moisture content was 5.11 %, 5.42 % and 5.19% for *Erythrina variegata* particleboard and 8.5% (Reza, 2015 and Rahaman, 2016 unpublished thesis) for commercial particleboard. 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).

4.2.1.4 Thickness Swelling

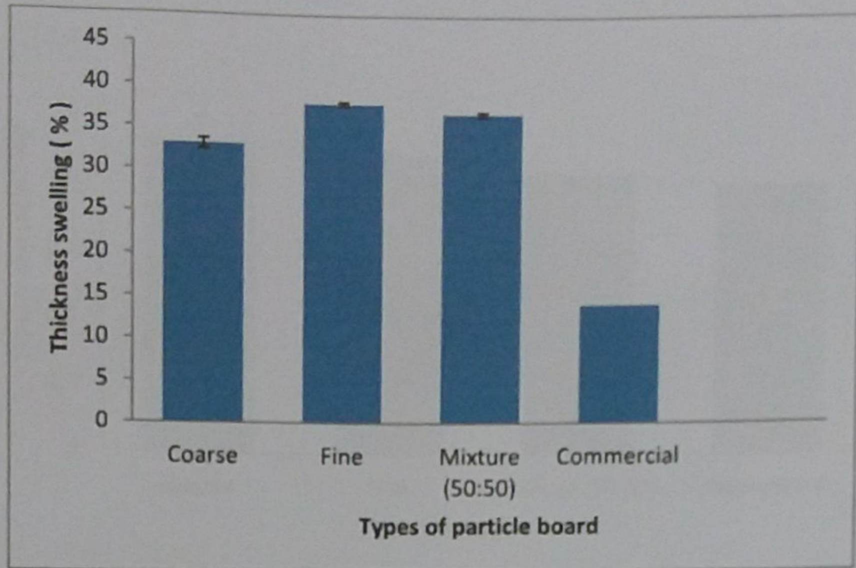

Fig. 4.4 Thickness swelling(%) of *Erythrina variegata* particleboard and commercial particleboard.

From statistical it was found that p value is less than 0.01 ($p < 0.01$). The particleboard made from course and mixture (50:50) showed the lowest and particle board only from fine material showed the highest thickness swelling. So there was a highly significant difference among the three treatments.

It was also found that after 24 hours the percentage of thickness swelling was 33.02 %, 37.91 % and 36.83% in *Erythrina variegata* particleboard and 14.11% (Reza, 2015 and Rahaman, 2016 unpublished thesis) in commercial particleboard.

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).

4.2.1.5 Linear Expansion

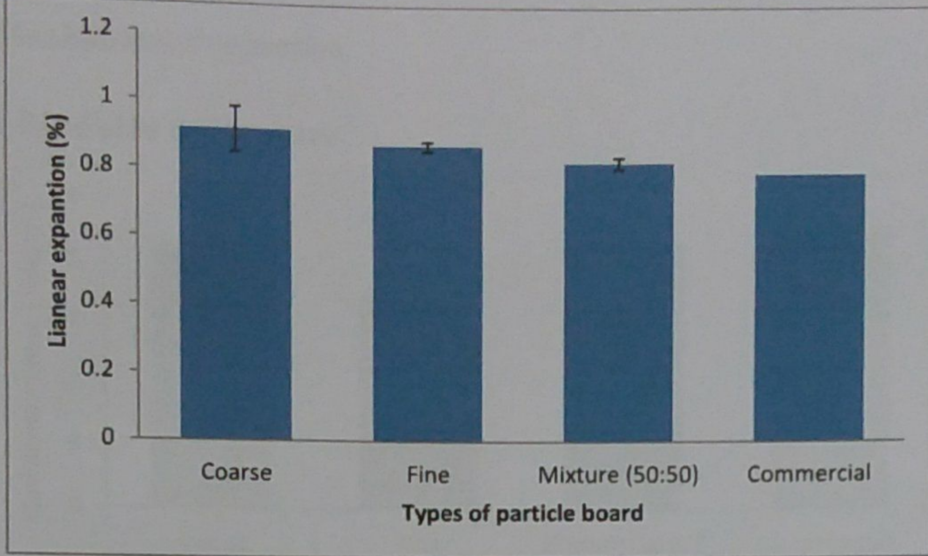

Fig. 4.5 Linear Expansion (%) of *Erythrina variegata* particleboard and commercial particleboard after 24 hours soaking.

From statistical it was found that p value is greater than 0.05 (p> 0.05). So there was no significant difference among the three treatments. The particleboard made from fine and mixture (50:50) showed the lowest and particle board only from coarse material showed the highest linear expansion.

It was found that the linear expansion of *Erythrina variegata* particleboards 0.92%, 0.87% and 0.83% and commercial particleboard was 0.79% (Reza, 2015 and Rahaman, 2016 unpublished thesis). 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)

4.2.2 Mechanical Properties

4.2.2.1 Modulus of Rupture

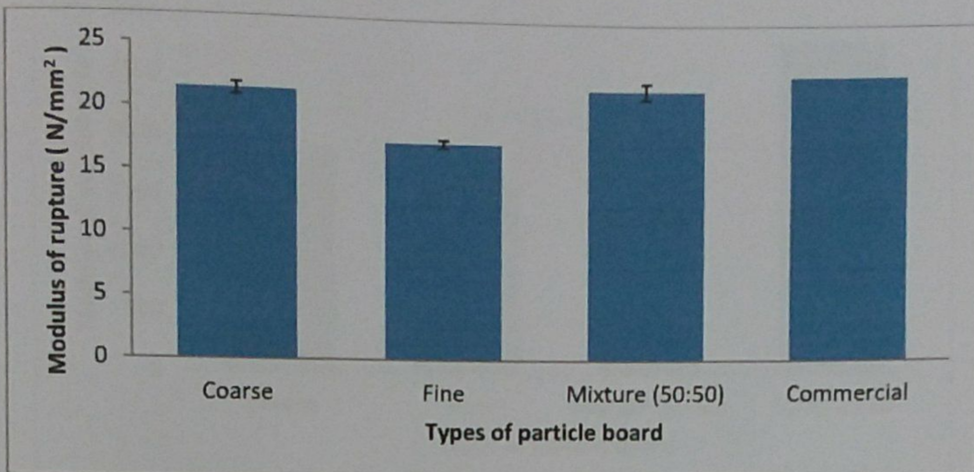

Fig. 4.6 Modulus of rupture of *Erythrina variegata* particleboard and commercial particleboard.

From statistical it was found that p value is less than 0.01 ($p< 0.01$). So there was a highly significant difference among the three treatments. The particleboard made from coarse and mixture showed the highest and particle board only from fine material showed the lowest modulus of rupture (MOR).

It was found that the MOR of *Erythrina variegata* particleboards were 21.53 N/mm², 17.50 N/mm² and 21.97 N/mm² and commercial particleboard was 23.11 N/mm ² ((Reza, 2015 and Rahaman, 2016 unpublished thesis) .

According to ANSI A208.1–1993 (NPA, 1993), the MOR of standard particleboard is 16.5- 23.5 N/mm² for high density grade, 11.0- 16.5 N/mm² for medium density grade and 3.0- 5.0 N/mm² for low density grade. According to IS: 3087-1985 (Anon, 1985), the MOR of standard particleboard is 10.98 N/mm². 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/mm² (for 18 mm thick board), 13.80 N/mm² and 17.65 N/mm², respectively.

4.2.2.2 Modulus of Elasticity

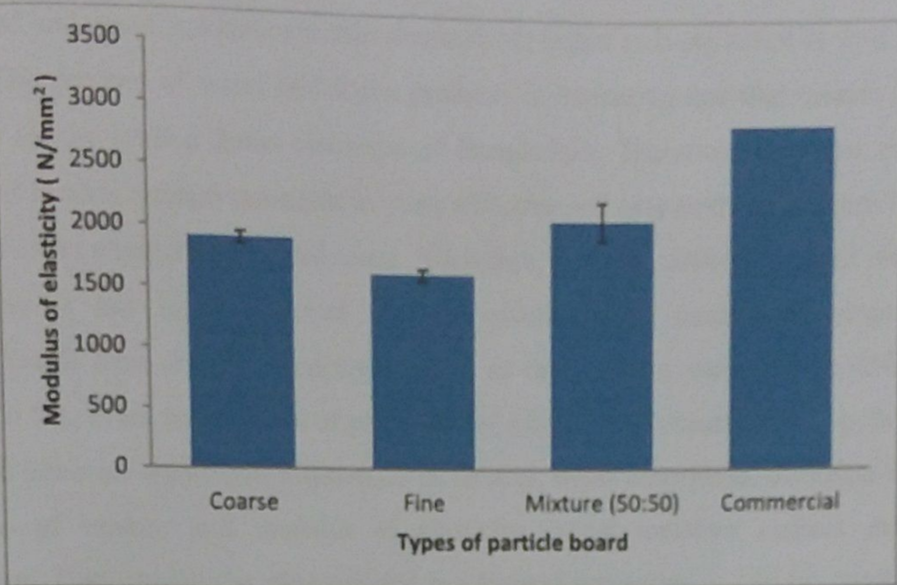

Fig. 4.7 Modulus of elasticity of *Erythrina variegata* particleboard and commercial particleboard.

From it was found that p value was less than 0.01 ($p < 0.01$). So it indicated that there was a highly significant difference among the three treatments. The particleboard made from course and mixture (50:50) showed the highest and particle board only from fine material showed the lowest modulus of rupture (MOE).

It was also found that the MOE of *Erythrina variegata* particleboards were 1912.14 N/mm², 1631.67 N/mm² and 2085 N/mm² and commercial particleboard was 2870 N/mm² (Reza, 2015 and Rahaman, 2016 unpublished thesis). According to ANSI A208.1–1993 (NPA, 1993), the MOE of standard particleboard is 2,400- 2,750 N/mm² for high density grade, 1,725- 2,750 N/mm² for medium density grade and 550- 1,025 N/mm² 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/mm² (for18mmthickboard, TheLaminexGroup, 2003).

5. Conclusion and Recommendations

5.1 Conclusion

The wood and wood products are ever demandable topics in Bangladesh as well as in the world. The demand of wood and wood products is increasing and that creates immense pressure on the limited forest resources of Bangladesh. Therefore, it is now especially important to utilize forest resources in more effective and economic ways. Particle boards are used as an alternative of solid wood. Therefore, from the above presented results and discussion it has been observed that all physical and mechanical properties of Particleboards from *Erythrina variegata L.* is of international standard like ANSI; ISO; AS/NZS; GS. From the analysis of physical and mechanical properties among three types of board there are significant differences in density, water absorption, thickness swelling, modulus of rupture and modulus of elasticity except moisture content and linear expansion. Considering the physical and mechanical properties, it can be conclude that manufacturing of particleboard using *Erythrina variegata L.* has great potentiality to meet the increasing demand for wood based products as well as the size of particles affect the properties of particleboard.

5.2 Recommendations

Particleboard board of *Erythrina variegata L.* 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 *Erythrina variegata L.* This study was conducted in a very small scale. So further research is needed regarding this work.

References:

Adams, C. F. (1975). Nutritive value of American foods in common units. Agriculture Handbook, Agricultural Research Service, US Department of Agriculture, (456).

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

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, 1979. Specification for wood chipboard and methods of test for particleboard, BS 5669. British Standards Institution 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(a). 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, 1985. 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.

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.

AWPA (Australian Wood Panels Association). 2008. Product Range and Properties. Australian Wood Panels Association Incorporated. Online document, Retrieval with Opera version 9.64, retrieved on November 02, 2009. Web address: <http://www.woodpanels.org.au/productinfo/default.asp>.

Bates, D. M. (1968). Notes on the Cultivated Malvaceae: Abelmoschus.

Bazzaz, F. A., & Sombroek, W. G. (Eds.). (1996). Global climate change and agricultural production: direct and indirect effects of changing hydrological, pedological and plant physiological processes. Food & Agriculture Org.

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

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

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.

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

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. (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).

Hamon, S., & Yapo, A. (1985, August). 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).

Harris, K. M. (2015). Effect of Chlorpyrifos Application at Different Growth Stages on Insect Pests' Incidence, Damage and Yield of Tomato (Solanum lycopersicum L) and Okra (Abelmoschus Esculentus L) (Doctoral dissertation).

Hegde, N. 1993. Cultivation and uses of Erythrina variegata in Western India. In S.B. Westley and M.H. Powell, eds. Erythrina in the New and Old Worlds. Paia, HI (USA): NFRA, pp. 77-84.

Hunt, M. O. (1962). Particleboard Industry-Facts and References.

Joseph K., Thomas S. and Pavithran C., Effect of chemical treatment on the tensile propertie of short sisal fibre-reinforced polyethylene composites. Polymer, 1996 37, 513

Little, E.L. and Skolmen, R.G. 1989. Common forest trees of Hawaii (native and introduced). Agricultural Handbook 679. Washington, DC: USDA Forest Service, pp. 142-44.

McClintock, E. 1982. Erythrinas cultivated in California. Erythrina Symposium IV. Allertonia. 3(l):139-54.

Mohanty, K.C. and Das, S.N. 1988. Nematicidat properties of Erythrina indica against Meloidogyne incognita and Tylenchorhynchus mashhoodi. Indian Journal of Nematology. 18(l):138.

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

Muniappan, R. 1993. Status of Erythrina species and the fruit-piercing moth in the Pacific. In S.B. Westley and M.H. Powell, eds. Erythrina in the New and Old Worlds. Paia, HI (USA): NFTA. pp. 340-44.

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

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

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

Raven, P.H. 1974. Erythrina (Fabaceae): achievements and opportunities. LLOYDIA (Journal of Natural Pruducts).37:321-31.Rotar, P.P., Joy, R.J. and Weissich, P.R. 1986. 'Tropic Coral': tall erythrina (Erythrina variegata L). Research Extension 072. Honolulu, HI (USA): University of Haw

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.

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.

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

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.

Appendix

Table 1: ANOVA for Density

Dependent Variable: Density

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12144.44	2	6072.222	30.70225	4.98E-06	3.68232
Within Groups	2966.667	15	197.7778			
Total	15111.11	17				

**P < 0.01

LSD for Density

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Fine	6	748.33	A
Coarse	6	700.00	B
Mixture (50:50)	6	688.33	B

Table 2: ANOVA for Water Absorption

Dependent Variable: Water Absorption

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2863.548	2	1431.774	182.3949	2.98E-11	3.68232
Within Groups	117.7479	15	7.849858			
Total	2981.296	17				

**P < 0.01

LSD for Water Absorption

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Fine	6	103.18	A
Mixture (50:50)	6	80.980	B
Coarse	6	73.48	C

Table 3: ANOVA for Moisture Content

Dependent Variable: Moisture Content

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.307733	2	0.153867	2.363987	0.128105	3.68232
Within Groups	0.976317	15	0.065088			
Total	1.28405	17				

$P > 0.05$

LSD for Moisture Content

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Fine	6	5.418	A
Mixture (50:50)	6	5.1850	A
Coarse	6	5.1117	A

Table 4: ANOVA for Thickness Swelling

Dependent Variable: Thickness Swelling

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	79.13121	2	39.56561	37.76077	1.4E-06	3.68232
Within Groups	15.71695	15	1.047797			
Total	94.84816	17				

**$P < 0.01$

LSD for Thickness Swelling

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Fine	6	37.907	A
Mixture (50:50)	6	36.827	A
Coarse	6	33.018	B

Table 5: ANOVA for Linear Expansion

Dependent Variable: Linear Expansion

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.023433	2	0.011717	1.208596	0.326098	3.68232
Within Groups	0.145417	15	0.009694			
Total	0.16885	17				

$P > 0.05$

LSD for Linear Expansion

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Coarse	6	0.9150	A
Fine	6	0.8733	A
Mixture (50:50)	6	0.8267	A

Table 6: ANOVA for MOR

Dependent Variable: MOR

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	72.95301	2	36.47651	24.35178	1.95E-05	3.68232
Within Groups	22.46848	15	1.497899			
Total	95.42149	17				

**$P < 0.01$

LSD for MOR:

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Mixture (50:50)	6	21.528	A
Coarse	6	21.527	A
Fine	6	17.495	B

Table 7: ANOVA for MOE

Dependent Variable: MOE

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	628975	2	314487.5	5.215419	0.019076	3.68232
Within Groups	904493.5	15	60299.57			
Total	1533469	17				

**P < 0.01

LSD for MOE:

Grouping Information Using the Tukey Method and 95% Confidence

B.Type	N	Mean	Grouping
Mixture (50:50)	6	2085	A
Coarse	6	1912.1	A B
Fine	6	1631.7	B