# CHAPTER II

# REVIEW OF LITERATURE

One of the essential prerequisite of any research study is to get acquainted with latest literature on the subject of research. Hence, an attempt was made to review the relevant theoretical literature and researches on banana and other minor fiber. The investigator visited and collected the literature from various libraries like SITRA (The South India Textile Research Association), Coimbatore; ATIRA Ahmadabad Textile Industry's Research Association) and Smt. Hansa Mehta Library, and the department library of The M.S. University of Baroda. Another important source of information was internet and exchange of e-mail.

The review of literature collected was categorized and discussed under the following subsections:

**2.1 Theoretical Review**

- 2.1.1. Chemical composition and properties of some cellulosic minor fibers
- 2.1.2. Banana plantation and its varieties in India
- 2.1.3. Extraction and uses of banana fiber
  - 2.1.3.1. Chemical treatment
  - 2.1.3.2. Mechanical treatment
- 2.1.4. Structure of lignocellulosic fibers
  - 2.1.4.1. Cellulose
  - 2.1.4.2. Hemicellulose
  - 2.1.4.3. Lignin
  - 2.1.4.4. Pectin
- 2.1.5. Mechanisms of chemical modification
- 2.1.6. Enzymes activity on textiles and its classification
- 2.1.7. Regenerated fibers
- 2.1.8. Types of commercial softeners

**2.2 Research Review**

- 2.2.1 Researches on banana fiber
- 2.2.2 Researches on natural cellulose fibers

### 2.1.1 Chemical composition and properties of some cellulosic minor fibers

Fibers are classified by their chemical origin, falling into two groups or families: natural fibers and manufactured fibers. Manufactured fibers are also referred to as manmade or synthetic fibers. The classification system used in the United States is dictated by the Textile Fiber Products Identification Act (TFPIA). Figure 2.1 gives a breakdown of textile fibers by these groupings, and the Appendix compares the properties of some of the most commonly used fibers.

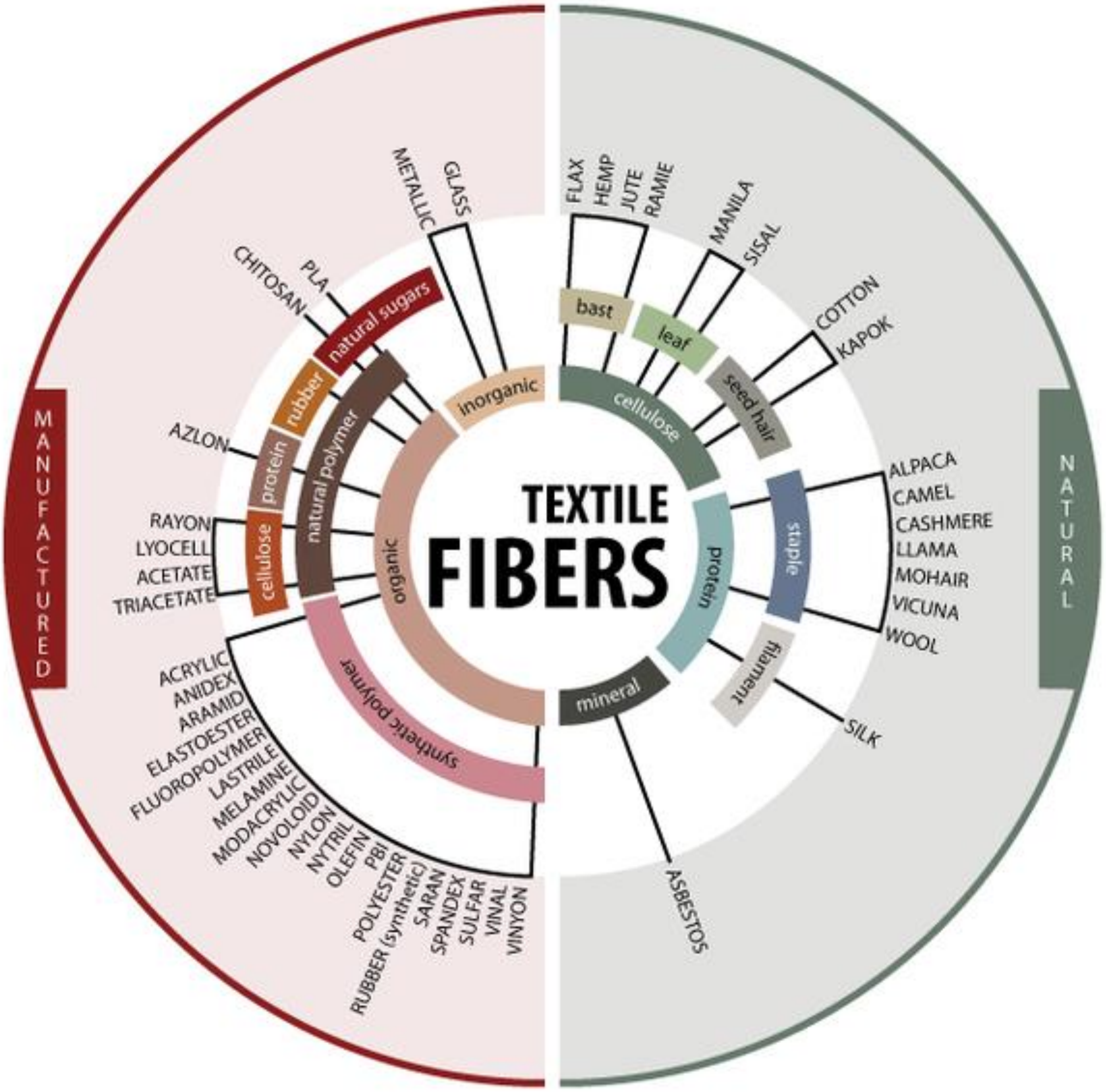

**Figure 2.1**: Classification of Textile Fibers

Source: http://gpktt.weebly.com/classification-of-textile-fibers.html

According Ghosh (2010) mentioned that there are 700 species of plants giving fiber to be used by human beings. To list a few: Ramie, Hemp, sun hemp, Kenaf, Roselle, Bhindi, Jaba kusum, Swet jaba, Sthal padam, Lata kasturi, Nettles, Sisal, Pineapple, Atasi, Abaca, Banana, Screw Pine, Bhuriya Twak, Chhilka, Deola, Coast cotton tree, Trailing Hollyhock.

Bast fibres are processed for use in carpet, yarn, rope, geotextile (netting or matting), traditional carpets, hessian or burlap, paper, sacks, etc. Bast fibres are also used in the non-woven, moulding, and composite technology industries for the manufacturing of non-woven mats and carpets, composite boards as furniture materials, automobile door panels and headliners, etc. Some of the cellulosic minor fibers have been given below:

### 2.1.1.a) Abaca

Abaca or Manila hemp is extracted from the leaf sheath around the trunk of the abaca plant (*Musa textilis*). The commercial fibres are utilized in the form of strands, and the strands in turn are composed of bundles of individual fibres. Individual fibres, when removed from the strands by boiling in an alkali solution, are smooth and fairly uniform in diameter. The lumens are large in relation to wall thickness. Cross-marking is rare, and fibre tips pointed and often flat and ribbon –like. The technical fibres are 2 to 4 m long. The single fibres are relatively smooth and straight and have narrow pointed ends. Individual fibre diameters range from 14 to 50 µm and the lengths from 2.5 to 13 mm. chemically; abaca comprises 76.6% cellulose, 14.6% hemicelluloses, 8.4% lignin, 0.3% pectin and 0.1% wax and fat. Abaca is considered as one of the strongest of all natural fibres, being three times stronger than cotton and twice that of sisal, and is far more resistant to saltwater decomposition than most of the vegetable fibres. Abaca is a lustrous fibre and yellowish white in colour.

### 2.1.1b) Bamboo

Bamboo is an abundant resource and it has always been used in agriculture, handicraft, paper-making, furniture and architecture. Recently attempts have been made to produce textile fibre from bamboo. Since a single bamboo fibre is 2 mm in length, it is used in textile production in the form of a fibre bundle. Bamboo is a very-fast growing grass. Environmental friendly fibres extracted from bamboo, which is renewable, fast growing, degradable, and does not occupy cultivated land are economically efficient and especially useful to grow in hilly areas.

After degumming through a chemical treatment, the cellulose content in the bamboo fibre reached more than 70%. Comparing chemical structure of hemp, jute and bamboo, lignin and hemicellulose contents in bamboo are far higher than that of the flax fibres, and almost as much as that of the jute fibres (Hemicellulose content: bamboo 12.49%, jute 13.53%, flax11.62; lignin content: bamboo: 10.15%, jute 13.30%, flax 2.78%). Lignin in bamboo fibre bundles is reason for yellow colour of fibres and coarse fibre fineness.

Cross section of single bamboo fibre is round with a small round lumen. The bamboo single fibre width is 6–12 µm and the length 2–3 mm and it is smaller than that of flax (12–20 µm,17–20 mm, respectively).The fine structure and mechanical properties of fibres within a maturing vascular bundle of moso bamboo Phyllostachys pubescens was studied by Wang with co-workers. Almost axially oriented cellulose fibrils were found in the fibre cell walls. This fibrilar arrangement maximizes the longitudinal elastic modulus of the fibres and their lignification increases the transverse rigidity.

Because of high and different content of non-cellulose substances in various plant fibres thefibres' crystallinity is different. When comparing crystallinities of some plant fibres, the crystallinity of ramie is the highest, follows flax and cotton and the lowest crystallinity is observed for bamboo fibres and jute fibres. These structural differences are reflected on fibre properties, i.e. density, moisture regain, tenacity, dyeing and thermal properties, etc.

Bamboo fibre is a cellulose fibre extracted or fabricated from natural bamboo, and possibly other additives, and is made from the pulp of bamboo plants. It is usually not made from the fibres of the plant, but is a synthetic viscose made from bamboo cellulose. In the US, the Federal Trade Commission (FTC) has ruled that unless a yarn is made directly with bamboo fibre — often called “mechanically processed bamboo” — it must be called "rayon" or "rayon made from bamboo. Bamboo is very resilient and durable as a fibre. In studies comparing it to cotton and polyester, it is found to have a high breaking tenacity, better moisture-wicking properties, and better moisture absorption.

### 2.1.1.c) Coir

Coir or coconut fibre is a natural fibre extracted from the husk of coconut and used in products such as floor mats, doormats, brushes and mattresses. Coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. Uses of brown coir (made from ripe coconut) are in upholstery padding, sacking and horticulture. White coir, harvested from unripe coconuts, is used for making finer brushes, string, rope and fishing nets. Coir fibres are found between the hard, internal shell and the outer coat of a coconut. The individual fibre cells are narrow and hollow, with thick walls made of cellulose. They are pale when immature, but later become hardened and yellowed as a layer of lignin is deposited on their walls. The two varieties of coir are brown and white. Brown coir harvested from fully ripened coconuts is thick, strong and has high abrasion resistance. It is typically used in mats, brushes and sacking. Mature brown coir fibres contain more lignin and less cellulose than fibres such as flax and cotton, so are stronger but less flexible. White coir fibres harvested from coconuts before they are ripe are white or light brown in colour and are smoother and finer, but also weaker. They are generally spun to make yarn used in mats or rope. The coir fibre is relatively waterproof, and is one of the few natural fibres resistant to damage by saltwater.

### 2.1.1.d) Flax

Flax fibres are obtained from the stems of the plant *Linum usitatissimum*. Fibres are running at the surface of the plant stem, which is about 1 m height and 2 – 3 mm thick in the diameter. Like cotton, flax fibre is a cellulose fibre; however its structure is more crystalline, making it stronger, and stiffer to handle, and more easily wrinkled. Flax fibre properties are controlled by the molecular fine structure, which is affected by the plant growing conditions and the retting procedure that is applied. The process of retting tends to separate the bundles of flax fibres into individual fibres, although many fibres remaining together in bundles. Flax fibres are not as pure as cotton in terms cellulose content; indeed they contain only about 60 - 70% of cellulose. In addition they contain other substances such as hemicelluloses 17% and lignin 2-3%, as well as waxes 2%, pectins 10% and natural colouring matters. Flax fibres have a soft handle and have fairly lustrous appearance. The length of fibres varies between 6 – 65 mm, but on average they are about 20 mm long. Their diameter is about 20 µm.

Flax fibres are not as twisted as cotton fibres, but both have a lumen in the centre. Several dislocations that are areas of the cell wall in natural fibres where the direction of the micro fibrils differs from the micro fibril angle of the surrounding cell wall. These deformations are due to extraction procedures. The shape of fibres varies from polygonal to oval and irregular. Fibres cross-section form depends on variety, plant growth conditions and maturity. Flax fibres are amongst the strongest in the group of naturally occurring fibres (55 cN/tex and about 20% stronger in wet state), but they do not stretch much. Flax fibres elongation at break is only 1.8% and their moisture regain is 12%.

### 2.1.1.e) Hemp

Hemp is the bast fibre obtained from stems of *Cannabis sativa L* plants. It grows easily to a height of 4 m without agrochemicals and captures large quantities of carbon. The most important components of fibres are cellulose (77%), pectin (1.4%) and waxes (1.4%). Pectin is found in the middle lamellae and glues the elementary fibres to form bundles. The lignin (1.7%) is an incrusting component of the fibre. It is incrusting cellulose and contributes to the hardness and strength of fibres. It is located in the middle lamellae and fibre primary cell wall. Other components of hemp fibres are tannin, resins, fats, proteins etc. The content of these components is much higher in hemp than in cotton.

Therefore the processing of those fibres requires different technology. The diameter of the cell varies considerably from 16 to 50 μm, with broad flat lumen. The length of the individual or elementary fibres is ranging from 2 to 90 mm. Elementary fibres are thick walled and the cross-section of fibres is polygonal with rounded edges. In longitudinal view, the fibre is roughly cylindrical, with surface irregularities and lengthwise deformations caused by dislocations. The ends of fibres are slightly tapered and blunt. Hemp fibres are coarser when compared to flax and rather difficult to bleach. The fibres have an excellent moisture resistance and rot only very slowly in water. Hemp fibres have high tenacity (53-62 cN/tex); about 20% higher than flax, but low elongation at break.

### 2.1.1.f) Kapok

Kapok (*Ceiba pentandra*) is a highly lignified organic seed fibre, containing 35-50% of cellulose, 22–45% of hemicelluloses, 15–22% of lignin and 2–3% of waxes. It also contains smaller quantities of starch, about 2.1% of proteins, and inorganic substances. Kapok contains 70–80% of air and provides excellent thermal and acoustic insulation. The absolute density of a kapok cell wall is 1.474 g/cm3, whilst the density of fibres by considering about 74% of lumen is only 0.384 g/cm3. Kapok is a smooth, unicellular, cylindrically shaped, twist less fibre. Its cell wall is thin and covered with a thick layer of wax. A wide lumen is filled with air and does not collapse like cotton. Kapok fibres are transparent with characteristic air bubbles in the lumen. The cross section of fibres is oval to round. The kapok cell wall structure differs from other natural cellulosic fibres. A primary cell wall, which is directly related to the superficial properties of fibres, consists of short microfibrils, which are oriented rectangular to the surface of fibres. In the secondary cell wall microfibrils run almost parallel to the fibre axis. Kapok fibres are 10–35 mm long, with a diameter of 20–43 μm. The cell wall thickness is about 1–3 μm. The tensile strength is 0.84 cN/dtex (93.3 MPa), Young's module 4 GPa, and breaking elongation 1.2%.Due to its wide lumen, kapok has an exceptional capability of liquids retention. Its excellent thermal and acoustic insulating properties, high buoyancy, and good oil and other non-polar liquids absorbency distinguish kapok from other cellulosic fibres. Kapok is mainly used in the form of stuffing and nonwovens; it is rarely used in yarns, mostly due to low cohesiveness of its fibres and their resilience, brittleness, and low strength. New potentials of kapok are in the field of technical textiles, yachts and boats furnishing, insulating materials in refrigeration systems, acoustic insulation, industrial wastewaters filtration, removal of spilled oil from water surfaces, and reinforcement components in polymer composites.

### 2.1.1.g) Kenaf

Kenaf fibres are obtained from *Hibiscus cannabinus*. Kenaf contains two fibre types: long fibre bundles situated in the cortical layer and short fibres located in the ligneous zone. Elementary fibres are short; their fibre length ranges from 3 to 7 mm, with average diameter of 21 μm. The cross-sections are polygonal with rounded edges and the lumens are predominantly large and oval to round in shape. The lumen varies greatly in thickness along the cell length and it is several times interrupted. Kenaf fibres contain about 45-57% of cellulose, 21.5% hemicelluloses, 8-13% lignin and 3-5% pectin. Kenaf fibres are coarse, brittle and difficult to process. Their breaking strength is similar to that of low-grade jute and is weakened only slightly when wet. There are many potential specific utilization possibilities for kenaf whole stalk and outer bast fibres, including paper products, textiles, composites, building materials, absorbents, etc

### 2.1.1.h) Nettle

*Urtica dioica*, often called common nettle, stinging nettle (although not all plants of this species sting) or nettle leaf, is an herbaceous perennial flowering plant in the family *Urticaceae*. It is native to Europe, Asia, northern Africa, and western North America, and introduced elsewhere. Nettle stems contain a bast fibre that has been traditionally used for the same purposes as linen and is produced by a similar retting process. Unlike cotton, nettles grow easily without pesticides. The fibres are coarser, however. Historically, nettles have been used to make clothing for 2,000 years, and German Army uniforms were almost made from nettle during World War I due to a potential shortage of cotton. More recently, companies in Austria, Germany, and Italy have started to produce commercial nettle textiles. The fibre content in nettle shows a high variability and reaches from below 1% to 17%. Under middle-European conditions, stems yield typically between 45 and 55dt / ha, which is comparable to flax stem yield. Due to the variable fibre content, the fibre yields vary between 0.2 and 7dt / ha, but the yields are normally in the range between 2 and 4dt / ha. Fibre varieties are normally cloning varieties and therefore planted from vegetative propagated plantlets. Direct seeding is possible, but leads to great heterogeneity in maturity. Nettles may be used as a dye-stuff, producing yellow from the roots, or yellowish green from the leaves.[

### 2.1.1.i) Okra

Okra, known as ladies' finger, gumbo, is a flowering plant in the mallow family. It is valued for its edible green seed pods. Bast fibre from the stem of the plant has industrial uses.

### 2.1.1.j) Pineapple fibre

Pineapple fibre is white, creamy and lustrous as silk fibre and is 10 times as coarse as cotton and the fibre can easily retain dyes. India is the sixth largest producer of pineapples in the world. The major pineapple producing states in India are West Bengal, Assam, Karnataka, Bihar, Tripura and Kerala. In India, the manual process employed for extracting fibre is very laborious. Also, there is a great need for marketing activities to promote pineapple fabric in India. Pineapple plants are largely grown in tropical America, in Far-East Asian countries and Africa. In Philippines and Taiwan, the pineapple plant is largely used as a source of fibre. In India, also the pineapple plant is used as a source of fibre. Pineapple fibre is used for making cloth and is also at times combined with silk or polyester to create textile fabrics. Pineapple fibre is also used for table linens, bags, mats and other clothing items. It finds different uses across the various parts of the world. There is huge potential for pineapple fabric, given its diverse uses and eco-friendly properties

### 2.1.1.k) Raphia

The Raffia palms (*Raphia*) are a genus of about twenty species of palms native to tropical regions of Africa, and especially Madagascar, with one species (*R. taedigera*) also occurring in Central and South America. Raffia fibre is widely used throughout the world. It is used in twine, rope, baskets, placemats, hats, shoes, and textile. The fibre is produced from the membrane on the underside of each individual frond leaf. The membrane is taken off to create a long thin fibre which can be dyed and woven as a textile into products ranging from hats to shoes to decorative mats. Plain raffia fibres are exported and used as garden ties or as a "natural" string in many countries. Especially when one wishes to graft trees, raffia is used to hold plant parts together as a more "natural" rope. Raffia fibres have many uses, especially in the area of textiles and in construction. In their local environments, they are used for ropes, sticks and supporting beams, and various roof coverings are made out of its fibrous branches and leaves.

### 2.1.1.l) Ramie

Ramie is an herbaceous perennial plant in the nettle family *Urticaceae*, native to eastern Asia.

Ramie fibres are extracted from the stem of the plant *Boehmeria nivea* of the nettle family. Individual fibre cells in stems are bound together in fibre bundles by waxes, hemicelluloses, lignin and pectins that are difficult to remove. Therefore the efficiency of the retting process usually used for e.g. hemp fibres extraction is not sufficient to extract ramie fibres from stems. But, a combined microbial and chemical treatment is very effective and economical. Chemical composition of ramie fibres is: cellulose (91-93%), hemicelluloses(2.5%), pectin (0.63%) and lignin (0.65%). Ramie fibres exhibit excellent mechanical properties, i.e. the best in the group of bast fibres (45-88 cN/tex) and, as most of the natural cellulose fibres the strength increases by 25% when fibres are wet. The ultimate fibre length is between 120-150mm and fibre diameter is 40-60 μm. Fibres are durable and they have good resistance to bacteria, mildew and insect attack. The main disadvantage of ramie is its low elasticity (elongation at break is 3-7%), which means that it is stiff and brittle. Fibres are oval to cylindrical in shape and their colour is white and high lustrous. Fibres surface is rough and characterized by small ridges, striations, and deep fissures. Ramie fibre can be easily identified by its coarse, thick cell wall, lack of twist, and surface characteristics.

### 2.1.1.m) Sisal

The sisal fibre is a “hard” fibre extracted from fresh leaves of sisal plant *Agave sisalana*. It is usually obtained by a decortications process, in which the leaf is crushed between rollers and then mechanically scraped. The length of the sisal fibre varies between 0.6 and 1.5 m and its diameters range from 100 to 300 μm. Cellulose content in sisal fibres is about 70%. The fibre is composed of numerous elongated fibre cells that are narrowed towards both ends. Fibre cells are linked together by middle lamellae, which consist of hemi-celluloses, lignin and pectin. A sisal fibre in cross-section is built up of about 100 fibre cells.

The cross section of sisal fibres is neither circular nor fairly uniform in dimension. The lumen varies in size but is usually well defined. The longitudinal shape is approximately cylindrical. Physically, each fibre cell is made up of four main parts, namely the primary wall, the thick secondary wall, the tertiary wall and the lumen. The fibrils are, in turn, built up of micro-fibrils with a thickness of about 20 μm. The microfibrils are composed of cellulose molecular chains with a thickness of 0.7 μm and a length of a few μm. Sisal fibre is fairly coarse and inflexible. The tensile properties of sisal fibres are not uniform along its length.

The fibres extracted from the root or lower parts of the leaf have a lower tensile strength and modulus. The fibres become stronger and stiffer at midspan, and the fibres extracted from the tip have moderate properties. The lower grade fibre is processed by the paper industry because of its high content of cellulose and hemicelluloses. The medium grade fibre is used in the cordage industry for making ropes, baler and binders twine. The higher-grade fibre after treatment is converted into yarns and used by the carpet industry.

### 2.1.1.n) Water hyacinth fiber

Water hyacinth fibre is obtained from the stems (stalks) of the water hyacinth plant. Water hyacinth is available across all the parts of the world. In India this weed was introduced in 1896 as an ornamental piece at the botanical garden in Bengal. India has not yet fully explored the potential of this plant except for some groups in South India. In India, water hyacinth is traditionally used for manufacturing paper (under cottage industry), baskets, and matting and for animal fodder. It is also used as vermi-compost in some parts of the country. Water hyacinth is generally considered as an ecological hazard.

(Elenga 2013) (Mosier 2005) (Jacob 2008) (http://gpktt.weebly.com/classification-of-textile-fibers.html) (https://en.wikipedia.org/wiki/Bast_fibre)

**Table2.1**: Chemical composition of cellulosic and lignocellulosic fiber (Mosier 2005)

| Fiber | Cellulose | Hemicellulose | Lignin | Pectin |
|---|---|---|---|---|
| Cotton | 92 | 6 | - | <1 |
| Jute | 72 | 13 | 13 | - |
| Flax | 81 | 14 | 3 | 4 |
| Sisal | 73 | 13 | 11 | 2 |
| Hemp | 74 | 18 | 4 | 1 |
| Coir | 43 | <1 | 45 | 4 |
| Ramie | 76 | 15 | 1 | 2 |
| Straw | 40 | 28 | 17 | 8 |
| Kepok | 50 | 28 | 20 | 2 |

**Table 2.2**: Physico mechanical properties of selected plant fibers(Elisa2014)

| Properties | Jute | Flax | Cotton | Sisal | Manila | Coir | Mesta | Banana | Pineapple | Ramie | Sunhemp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A.) Ultimate cell | | | | | | | | | | | |
| Length (mm) | 0.8-6 | 25-65 | 15-60 | 0.5-6 | 3-12 | 0.5-4 | 2-11 | 0.9-4 | 3-9 | 20-25 | 5-20 |
| Breath (µ) | 525 | 10-35 | 15-20 | 5-40 | 10-32 | 7-30 | 13-34 | 12-33 | 4-8 | 15-80 | 12-36 |
| L/B Ratio | 110 | 1700 | 1300 | 150 | 250 | 95 | 140 | 100 | 450 | 3500 | 450 |
| B.) Filament | | | | | | | | | | | |
| Fineness (Tex) | 1.25-5 | 2.5-6 | 0.1-0.3 | 16-35 | 20-35 | 25-50 | 3.5-5.5 | 3-12 | 2.5-6 | 0.4-0.8 | 5.5-17 |
| Tenacity (g/tex) | 30-50 | 45-55 | 20-45 | 40-45 | 35-45 | 15-25 | 30-45 | 30-40 | 25-45 | 40-65 | 30-40 |
| Breaking Elongation % | 1-2 | 2.5-3.5 | 6.5-7.5 | 2.5-4.5 | 2-3 | 8-20 | 1-2 | 1.8-3.5 | 2.5-4 | 3-4 | 2.5-3.5 |
| Flexural rigidity (dyne/cm$^2$) | 3-6 | 1.8-2.5 | 0.3-1 | 125-175 | 150-200 | 150-200 | 3.5-6.5 | 20-50 | 2.5-40 | 0.8-1.2 | 125-175 |
| C.) Bundle | | | | | | | | | | | |
| Tenacity (g/tex) | 13-35 | 30-36 | NA | 22-36 | 20-35 | 20-35 | 16-30 | 20-30 | 20-30 | 28-40 | 15-35 |
| Density (g/cc) | 1.45 | 1.55 | 1.55 | 1.45 | 1.45 | 1.45 | 1.47 | 1.35 | 1.5 | 1.56 | 1.53 |
| Moisture regain | 12.5 | 7 | 7 | 11 | 9.5 | 9.5 | 13 | 15 | 13 | 6.5 | 10.5 |
| Degree of cryatallinity | H | VH | NA | NA | NA | NA | H | NA | NA | VH | H |

## 2.1.2 Banana plantation and its varieties in India

### 2.1.2 a)Origin of banana

Bananas have thrived on the Asian subcontinent for thousands of years. As early as the 13th century, however, tropical fruits were a novel concept amongst Europe's aristocracy. Marco Polo regaled Europeans with tales of strange and unusual fruits, including the banana. In the US, the 100th anniversary celebration of the Declaration of Independence featured a banana as its exotic showpiece.

In India, bananas are integral parts of the culture. The god Vishnu proclaimed of the fruit, "As the bark and leaves of the kadali tree are to be seen in its stem, so thou art the stem of the universe and all things visible to thee.” Even today, followers of Shiva and Vishnu believe banana plants are auspicious. Upon attending an Indian wedding, one may see a banana stalk near the stage symbolizing fertility, and women desiring a son thereafter may worship the plant during the month of Kartik.

Bananas originate in Southeast Asia and the South Pacific. According to an article published by The University of California, Santa Cruz, archeologists pinpoint the Kuk valley of Papua New Guinea as the first site of banana domestication circa 8,000 BCE. Since then, several regions domesticated other banana varieties via hybridization and centuries of refinement. The same article theorizes bananas first appeared in India around 6,000 BCE. Around this period, the fruit flourished throughout the tropics of Australia, Malaysia, and Indonesia.

### 2.1.2. b) Importance of banana in India

Banana is one of the major and economically important fruit crops of India. Banana occupies 20% area among the total area under crop in India. Most of Banana is grown by planting suckers. The technology development in agriculture is very fast, it results in developing Tissue Culture Technique.

### 2.1.2.c) Suitable climate for banana farming

Banana, basically a tropical crop, grows well in a temperature range of 15ºC – 35ºC with relative humidity of 75-85%. It prefers tropical humid lowlands and is grown from the sea level to an elevation of 2000m. In India this crop is being cultivated in climate ranging from humid tropical to dry mild subtropics through selection of appropriate varieties. Chilling injury occurs at temperature below 12ºC. High velocity of wind which exceeds 80 km /hr. damages the crop. Four months of monsoon (June to September) with an average 650-750 mm. rainfall are most important for vigorous vegetative growth of banana. At higher altitudes, banana cultivation is restricted to a few varieties like ‘Hill banana”.

Deep, rich loamy soil with pH between 6.5 – 7.5 is most preferred for banana farming. Soil for banana should have good drainage, adequate fertility and moisture. Saline solid, calcareous soils are not suitable for banana cultivation. A soil which is neither too acidic nor too alkaline, rich in organic material with high nitrogen content, adequate phosphorus level and plenty of potash is good for banana.

### 2.1.2.d) Suitable soil type for banana farming

In Banana Farming, Soil for banana should have good drainage, adequate fertility and moisture. Deep, rich loamy soil with pH 6 to 7.5 is most preferred for banana cultivation. Ill drained, poorly aerated and nutritionally deficient soils are not suitable for banana. Saline solid, calcareous soils are not suitable for Banana cultivation. A soil that is not too acidic & not too alkaline, rich in organic material with high nitrogen content, adequate phosphorus level and plenty of potash are good for banana.

### 2.1.2.e) Banana varieties

In India, banana is grown under diverse conditions and production systems. in your banana farming ,Selection of varieties, therefore is based on a large number of varieties catering to various kinds of needs and situations. However, around 20 cultivars viz. *Dwarf Cavendish, Robusta, Monthan, Poovan, Nendran, Red banana, Nyali, Safed Velchi, Basarai, Ardhapuri, Rasthali, Karpurvalli, Karthali* and *Grandnaine* etc..*Grandnaine* is gaining popularity and may soon be the most preferred variety due to its tolerance to biotic stresses and good quality bunches. Bunches have well spaced hands with straight orientation of figures, bigger in size. Fruit develops attractive uniform yellow colour with better self life & quality than other cultivars.

### 2.1.2.f) Planting season in banana farming

Planting of tissue culture Banana can be done throughout the year except when the temperature is too low or too high. Facility of drip irrigation system is important. There are two important seasons in India; Mrig Baug (*Kharif*) month of planting June – July and Kande Baug (*Rabi*) month of planting October – November.

### 2.1.2.g) Banana irrigation

Banana, a water loving plant, requires a large quantity of water for maximum productivity. But Banana roots are poor withdrawal of water. Therefore under Indian condition banana production should be supported by an efficient irrigation system like drip irrigation. Water requirement of banana has been worked out to be 2000mm per

Annum. Application of drip irrigation improved water use efficiency. Irrigate the plants immediately after planting. Apply sufficient water and maintain field capacity. Excess irrigation lead to root zone congestion due to removal of air from soil pores, thereby affecting plant establishment and growth. And hence drip method is must for proper water management in Banana.

### 2.1.2.h) Application of manure and fertilizers in banana farming

Banana requires high amount of nutrients, which are often supplied only in part by the soil. Nutrient requirement has been worked out on all India basis is to be 20 kg FYM, 200gm N; 60-70gm P; 300gm K/plant. Banana requires heavy nutrition. Banana crop requires 7-8 Kg N, 0.7- 1.5 Kg P and 17-20 Kg K per metric tonne yield. Banana responds well to application of nutrients. Traditionally farmers use more of urea and less of phosphorous and potash.

In order to avoid loss of nutrients from conventional fertilizers i.e. loss of N through leaching, volatilization, evaporation and loss of P and K by fixation in the soil, application of water soluble or liquid fertilizers through drip irrigation is encouraged. A 25-30% increases in yield is observed using fustigation. Moreover, it saves labour and time and the distribution of nutrients is uniform.

### 2.1.2.i) Harvesting of banana farming

Banana should be harvested at the physiological maturity stage for better post harvest quality. The fruit is climacteric and can reach consumption stage after ripening operation maturity indices: These are established on the basis of fruit shape, angularity, grade or diameter of the median figure of the second hand, starch content and number of days that have elapsed after flowering. Market preferences can also affect the decision for harvesting a slight or full mature fruit.

Removal of bunch: Bunch should be harvested when figures of second hand from top are 3/4 rounded with the help of sharp sickle 30cm above the first hand. Harvest may be delayed upto 100-110 days after opening of the first hand. Harvested bunch should generally be collected in well padded tray or basket and brought to the collection site. Bunches should be kept out of light after harvest, since this hastens ripening and softening. For local consumption, hands are often left on stalks and sold to retailers.

### 2.1.2.j) Post harvest management of banana farming

Each banana plant grows from a pseudostem, which is a bundle of the bases of the leaves of the plant. The true stem is underground, around the rhizome that produces the pseudostem above it and other suckers from which more banana plants grow. Some call this collection of banana plants growing from the same underground structure a banana mat. After the main pseudostem produces a bunch of bananas, you should cut it to the ground because it will never produce fruit again, and even if you leave it in place, a light frost will kill it to the ground anyway. The underground portion of the banana plant remains so it can produce suckers that will grow into new fruiting pseudostems. **(**http://www.agrifarming.in/banana-farming)

**Table 2.3**: District wisearea, production &productivity of banana in Gujarat (2010-11)

**Source:**http://nhb.gov.in/report_files/banana/BANANA.htm

| **Districts in Gujarat** | **Area (Hectors)** | **Production (M.T.)** | **Productivity (M.T./Ha)** |
|---|---|---|---|
| Bharuch | 15200 | 990280 | 65.15 |
| Anand | 14045 | 877391 | 62.47 |
| Baroda | 9390 | 569130 | 60.61 |
| Narmada | 6000 | 384000 | 64.00 |
| Junagadh | 1800 | 81000 | 45.00 |
| Bhavnagar | 1600 | 88000 | 55.00 |
| Tapi | 1600 | 88000 | 55.00 |
| Kutch | 1000 | 52690 | 52.69 |
| Baroda | 9390 | 569130 | 60.61 |
| Kheda | 806 | 36270 | 45.00 |
| Valsad | 770 | 43120 | 56.00 |
| Navsari | 460 | 25760 | 56.00 |
| Panchmahal | 300 | 9150 | 30.50 |
| Sabarkantha | 204 | 6149 | 30.14 |

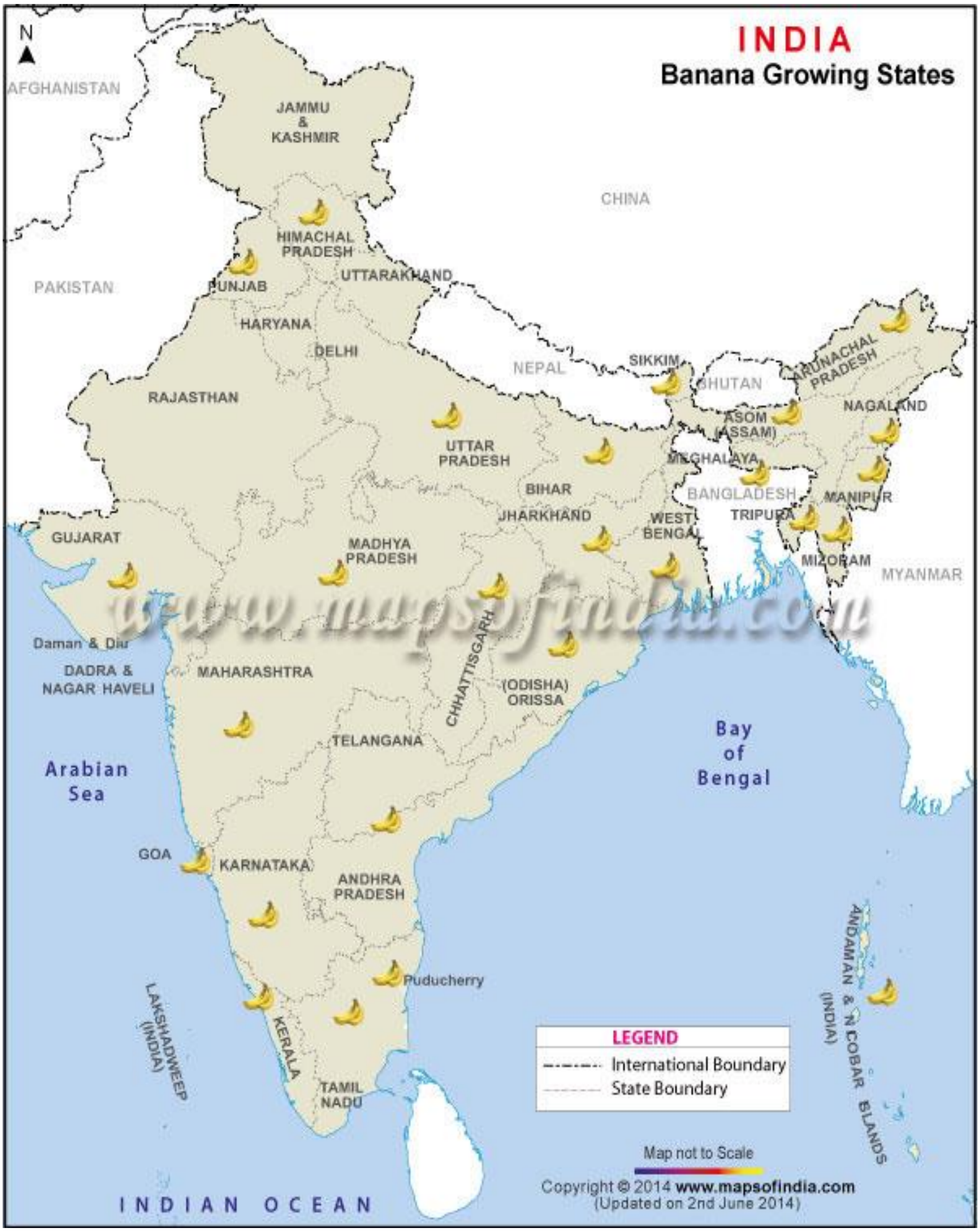

**Plate2.1**: Banana growing states in India

**Source:**http://www.mapsofindia.com/indiaagriculture/fruits-map/banana-producing-states.html

### 2.1.3 Extraction and uses of bast fiber

**2.1.3.1**Bast fibers can be extracted by any of the three methods:

Chemical treatment
Mechanical treatment
Biological treatment or retting

#### 2.1.3.1.a)Chemical treatment

In chemical treatment the gums or resins which adhere to the fiber can be removed either by direct application of chemicals or by a combination of retting and decortications method along with chemical application. The usual method is to boil the material with caustic soda or other alkalis or potassium soaps. The process separates the gum in the leaves or the bark from the fibers. It also destroys much of the colouring matter. The boiling might be at the atmospheric pressure or at high pressure. As the pressure is increased, the fibers expand; but they lose their strength and damage in other ways too.

#### 2.1.3.1.b) Mechanical treatment

The mechanical process is divided into three steps.

1. Tuxing - The step involves giving a slight incision just underneath the pseudoste, and then giving a sharp pull, which brings away a strip or ribbon of the outside skin containing the fibre. These ribbons are called “Tuxies”.
2. Striping - The tuxies are fed in fibre extraction machine and pulled out. The tuxies are drawn several times between the blade and the bench before the fibre is sufficiently clean. With this all the pulp, weak fibre and pithy matter is scrapped off.
3. Drying – The fibres are sun-dried. Delay and carelessness in drying affect both the colour and strength of the fibre.

#### 2.1.3.1.c) Biological treatment / Retting

It is a phenomenon occurring through the combined action of bacteria and weathering which allows the degradation of the stem material (mainly pectins) surrounding the fibre bundles.

Retting methods

i. **Dew retting**: is most effective in climates with heavy night time dews and warm daytime temperatures. In this procedure, the harvested stalks are windrowed in the field, where the combined action of bacteria, sun, air, and dew produces fermentation, dissolving much of the stem material surrounding the fibre. Within two to three weeks, depending upon climatic conditions, the fibre can be separated. Dew-retted fibre is generally darker in colour and of poorer quality than water retted fibre.

ii. **Water retting**: bundles of stalks are submerged in water. The water, penetrating to the central stalk portion, swells the inner cells, bursting the outermost layer, thus increasing absorption of both moisture and decay-producing bacteria. Retting time must be carefully judged; under-retting makes separation difficult, and over-retting weakens the fibre. Natural water retting employs stagnant or slow-moving waters, such as ponds, bogs, and slow streams and rivers. The stalk bundles are weighted down, usually with stones or wood, for about 8 to 14 days, depending upon water temperature and mineral content.

iii. **Chemical retting** involves immersion of the dried plants in a tank with a solution of chemicals, such as sodium hydroxide, sodium carbonate, high pH agents, pectinolytic enzymes or mineral acids. The fibers are loosened in a few hours, but close control is required to prevent deterioration and damage to the fibres. Chemical retting is more expensive and does not produce the superior quality fibre obtained from the biological retting process.

According to Philippines, there are two methods for extraction of Banana fiber, namely Bacnis method and Loenit method.

i. In the Bacnis method, Banana Fiber is produced from waste stalk of Banana plant. The outer sheath is tightly covered layers of fiber. The fiber is located primarily adjacent to the outer surface of the sheath and can be peeled-off readily in ribbons of strips of 5 to 8 cm wide and 2 -4 mm thick, the entire length of sheath. This stripping process is known as tuxying the strips being called tuxies. Two methods of tuxying are employed in Philippines. In the first methodcalled Bacnis method, the trunks are pulled apart and the sheath separated according to their position in stalk. They are then flattened and the fiber is stripped from the stem by cutting the pulpy portion and pulling away the tuxy

**Plate 2.2**: Mechanical extraction of banana fibers a) Tuxing b) Stripping c) Drying

**Source:**http://www.ecoideaz.com/innovative-green-ideas/producing-banana-fiber-and-paper-from-waste

ii. In Loenit method, the tuxies are pulled off the stalk from one sheath at a time. In either of these methods tuxies are tied into bundles of 23 to 27 kg and brought to the stripping knife for cleaning. In this process tuxies are pulled under a knife blade, which is pressed tightly against the tuxy in order to scrape away the plant tissue between the fibers. The clean fiber is then air dried and made up into bundles for subsequent grading and bailing.

In addition to hand stripping, machines are used where the trunks from which the dark outer sheaths have been removed, are cut into sections of 120 to 180 cm in length. The sections are then crushed between rolls and the pulpy tissues are scraped away, one half the length at a time, by two large revolving drums, the rim of which are fitted with scrapping blade which scrape the sheath while it is pressed against a bed plate, oven dried, graded and baled.(http://www.nhm.nic.in/archive/bananafibre.pdf) (Jayaprabha2011)

### 2.1.3.2 Application of Banana fibers

In the recent past, banana fiber had a very limited application and was primarily used for making items like ropes, mats, and some other composite materials. With the increasing environmental awareness and growing importance of eco-friendly fabrics, banana fiber has also been recognized for all its good qualities and now its application is increasing in other fields too such as apparel garments and home furnishings. However, in Japan, it is being used for making traditional dresses like kimono, and kamishimo since the Edo period (1600-1868). Due to its being lightweight and comfortable to wear, it is still preferred by people there as summer wear. Banana fiber is also used to make fine cushion covers, Necties, bags, table cloths, curtains etc. Rugs made from banana silk yarn fibers are also very popular world over.

### 2.1.4 Structure of lignocellulosic fiber

The main components of the lignocellulosic materials are cellulose, hemicellulose and lignin. Cellulose is a major structural component of cell walls, and it provides mechanical strength and chemical stability to plants. Solar energy is absorbed through the process of photosynthesis and stored in the form of cellulose. Hemicellulose is a copolymer of different C5 and C6 sugars that also exist in the plant cell wall. Lignin is polymer of aromatic compounds produced through a biosynthetic process and forms a protective layer for the plant walls. Apart from the three basic chemical compounds that lignocellulose consists of, water is also present in the complex. Furthermore, minor amounts of proteins, minerals and other components can be found in the lignocellulose composition as well. The composition of lignocellulose highly depends on its source. There is a significant variation of the lignin and hemicellulose content of lignocellulose depending on whether it is derived from hardwood, softwood, or grasses.

Lignocellulosic biomass has a complex internal structure. It is comprised of a number of major components that have, in their turn, also complex structures. To obtain a clear picture of the material, an analysis of the structure of each main component is made in this section, concluding with the description of the structure of lignocellulose itself. Also addressed are the physical properties of each of the components of lignocellulose, and how each of these components contributes to the behaviour of the complex structure as a whole.

### 2.1.4.1 Cellulose

Cellulose is the β-1,4-polyacetal of cellobiose (4-O-β-D-glucopyranosyl-D-glucose). Cellulose is more commonly considered as a polymer of glucose because cellobiose consists of two molecules of glucose. The chemical formula of cellulose is $(C6H10O5)_n$ and the structure of one chain of the polymer is presented below Fig 2.2.

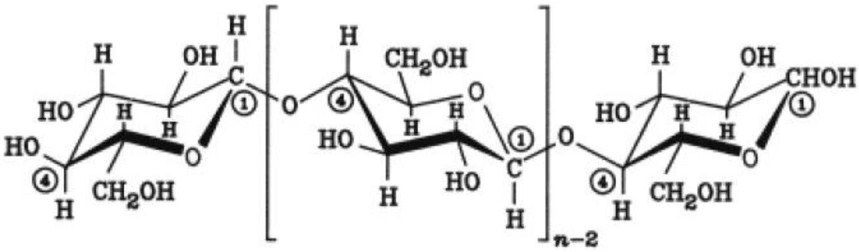

**Figure 2.2**: Structure of Cellulose molecule

**Source**:Hendrickx (2007)

Cellulose is found in both the crystalline and the non-crystalline structure. The coalescence of several polymer chains leads to the formation of microfibrils, which in turn are united to form fibres. In this way cellulose can obtain a crystalline structure. Fig 2.3 illustrates structure as well as the placement of cellulose in the cell wall.

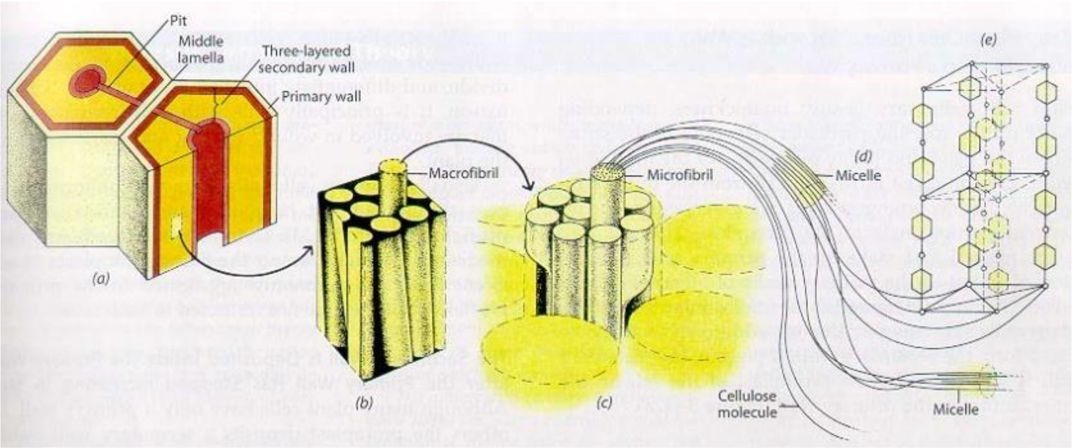

**Figure 2.3**: Formation of micro and macrofibrils and their position in the cell wall

**Source**:Hendrickx (2007)

Cellulose is a relatively hygroscopic material absorbing 8-14% water under normal atmospheric conditions (20 °C, 60% relative humidity). Nevertheless, it is insoluble in water, where it swells. Cellulose is also insoluble in dilute acid solutions at low temperature. The solubility of the polymer is strongly related to the degree of hydrolysis achieved. As a result, factors that affect the hydrolysis rate of cellulose also affect its solubility that takes place, however, with the molecule being in a different form than the native one. At higher temperatures it becomes soluble, as the energy provided is enough to break the hydrogen bonds that hold the crystalline structure of the molecule. Cellulose is also soluble in concentrated acids, but severe degradation of the polymer by hydrolysis is caused. In alkaline solutions extensive swelling of cellulose takes place as well as dissolution of the low molecular weight fractions of the polymer.

### 2.1.4.2Hemicellulose

The term hemicellulose is a collective term. It is used to represent a family of polysaccharides such as arabino-xylans, gluco-mannans, galactans, and others that are found in the plant cell wall and have different composition and structure depending on their source and the extraction method. The most common type of polymers that belongs to the hemicellulose family of polysaccharides is xylan.

As shown in Fig 2.4, the molecule of a xylan involves 1->4 linkages of xylopyranosyl units with α-(4-O)-methyl-D-glucuronopyranosyl units attached to anhydroxylose units. The result is a branched polymer chain that is mainly composed of five carbon sugar monomers, xylose, and to a lesser extent six carbon sugar monomers such as glucose.

Important aspects of the structure and composition of hemicellulose are the lack of crystalline structure, mainly due to the highly branched structure, and the presence of acetyl groups connected to the polymer chain.

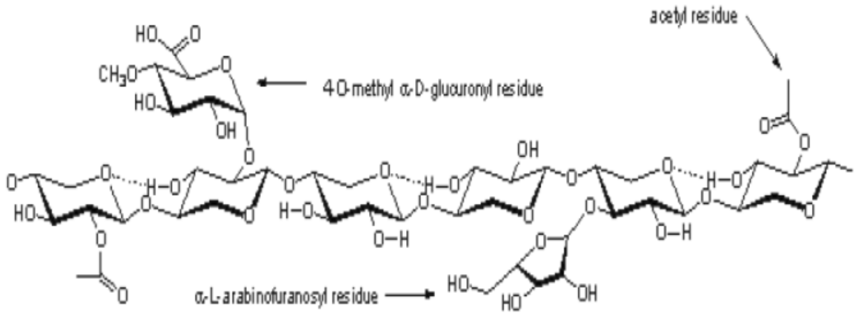

**Figure 2.4**: Schematic representation of Hemicellulose

**Source**:Hendrickx (2007)

Hemicellulose extracted from plants possesses a high degree of polydispersity, polydiversity and polymolecularity (a broad range of size, shape and mass characteristics). However, the degree of polymerization does not exceed the 200 units whereas the minimum limit can be around 150 monomers. Hemicellulose is insoluble in water at low temperature. However, its hydrolysis starts at a temperature lower than that of cellulose, which renders it soluble at elevated temperatures. The presence of acid highly improves the solubility of hemicellulose in water.

### 2.1.4.3 Lignin

Lignin is the most complex natural polymer. It is an amorphous three-dimensional polymer with phenylpropane units as the predominant building blocks. More specifically, p-coumaryl alcohol, coniferyl alcohol and sinapyl alcohol Fig 2.5are the ones most commonly encountered.Dividing higher plants into two categories, hardwood (angiosperm) and softwood (gymnosperm), it has been identified that lignin from softwood is made up of more than 90% of coniferyl alcohol with the remaining being mainly p-coumaryl alcohol units. Contrary to softwoods, lignin contained in hardwood is made up of varying ratios of coniferyl and sinapyl alcohol type of units.

The property of polydispersity, just as with hemicellulose, characterizes lignin as well. Different branching and bonding in otherwise similar molecules are encountered. Fig. 2.6 presents a model structure of lignin from spruce pine.

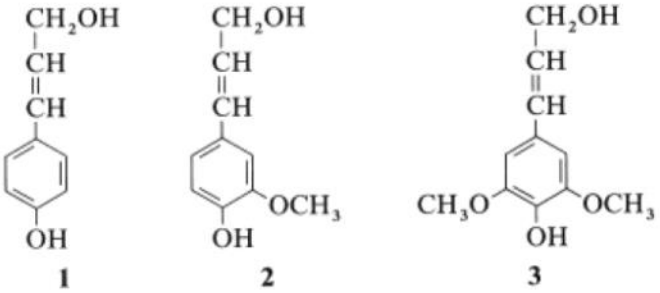

**Figure 2.5**: 1)P-coumaryl- ,2) coniferyl- and 3) sinapyl alcohol: dominant building blocks of the three dimensional polymer lignin

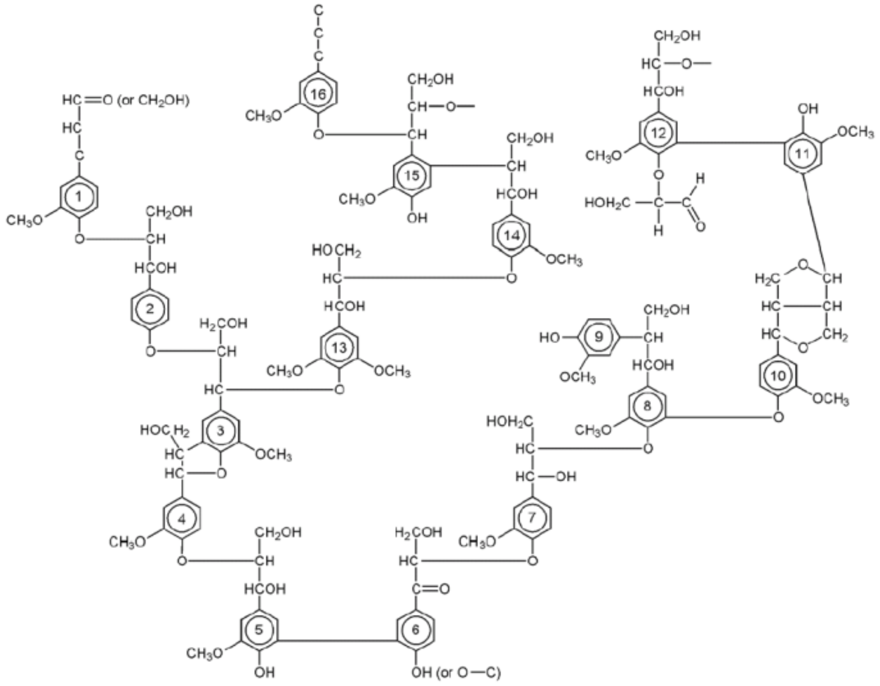

**Figure 2.6**: Model structure of *spruce* Lignin

**Source**:Hendrickx (2007)

Solvents that have been identified to significantly dissolve lignin include low molecular alcohols, dioxane, acetone, pyridine, and dimethyl sulfoxide. Furthermore, it has been observed that at elevated temperatures, thermal softening of lignin takes place, which allows depolymeristation reactions of acidic or alkaline nature to accelerate.

### 2.1.4.4 Lignocellulose

As mentioned above, lignocellulose is a class of biomass that consists of three major compounds cellulose, hemicellulose and lignin. It also includes water and a small amount of proteins and other compounds, which do not participate significantly in forming the structure of the material. Inside the lignocellulose complex, cellulose retains the crystalline fibrous structure and it appears to be the core of the complex. Hemicellulose is positioned both between the micro- and the macrofibrils of cellulose. Lignin provides a structural role of the matrix in which cellulose and hemicellulose is embedded.

Considering that cellulose is the main material of the plant cell walls, most of the lignin is found in the interfibrous area, whereas a smaller part can also be located on the cell surface.

**Table 2.4**: Overview of linkages between the monomer units that form the individual polymers lignin, cellulose and hemicellulose, and between the polymers to form lignocellulose

| **Bonds with different components (intrapolymer linkages)** | |
|---|---|
| Ether bond | Lignin, hemicellulose |
| Carbon to carbon | Lignin |
| Hydrogen bond | Cellulose |
| Ester bond | Hemicellulose |
| **Bonds connecting different components (interpolymer linkages)** | |
| Ether bond | Cellulose-lignin |
| | Hemiccellulose-lignin |
| Ester bond | Hemicellulose-lignin |
| | Cellulose-hemicellulose |
| Hydrogen bond | Hemicellulose-lignin |
| | Cellulose-lignin |

#### Chemical interaction between components

There are four main types of bonds identified in the lignocellulose complex. Those are ether type of bonds, ester bonds, carbon-to-carbon bonds and hydrogen bonds. These four bonds are the main types of bonds that provide linkages within the individual components of lignocellulose (intrapolymer linkages), and connect the different components to form the complex (interpolymer linkages). The position and bonding function of the latter linkages is summarized in Table 2.4. and 2.5.

**Table 2.5**: Functional groups in components of lignocellulose

| Functional Group | Lignin | Cellulose | Hemicellulose |
|---|---|---|---|
| Aromatic ring | Present | | |
| Hydroxyl group | Present | | |
| Carbon to carbon linkages | Present | | |
| Ether (glucosidic) linkage | Present | Present | Present |
| Ester bond | | | Present |
| Hydrogen bond | | Present | Present |

### 2.1.5 Mechanics of chemical modification

The inherently polar and hydrophilic nature of lignocellulosic fibers and the nonpolar characteristics of most thermoplastics result in compounding difficulties leading to nonuniform dispersion of fibers within the matrix, which impairs the properties of the resultant composite. This is a major disadvantage of natural fiber-reinforced composites.

Another problem is that the processing temperature of composites is restricted to 2008C as vegetable fibers undergo degradation at higher temperatures; this restricts the choice of matrix material. Another serious drawback is the high moisture absorption of natural fibers leading to swelling and presence of voids at the interface, which results in poor mechanical properties and reduces dimensional stability of composites. Another restriction to the successful exploitation of natural fibers for durable composite application is low microbial resistance and susceptibility to rotting. These properties pose serious problems during shipping, storage, and composite processing. The nonuniformity and variation of dimensions and of their mechanical properties (even between individual plants in the same cultivation) poses another serious problem. It is quite clear that the advantages outweigh the disadvantages and most of the shortcomings have remedial measures in the form of chemical treatments.

Chemical modification seemed to be the one that gave rise to continuous covalent bonds between cellulose surface and matrix. They also looked into a novel strategy which did not involve a chemical modification but the formation of a physical sleeve of polymer around the fibers. Surface modifications include (i) physical treatments, such as solvent extraction; (ii) physico-chemical treatments, like the use of corona and plasma discharges or laser, g-ray, and UV bombardment; and (iii) chemical modifications, both by direct condensation of the coupling agents onto the cellulose surface and by its grafting by free-radical or ionic polymerizations. The common coupling agents used is silanes, isocyanates, and titanate-based compounds. In this paper, we will focus on some of the chemical treatments adopted for natural fibers. A few common modifications are explained below.

**(**Hendrickx 2007) (Nagarathnamma 1999) (Vardhini2016)

### 2.1.5.1 Effect of NaOH on cellulose

Hashim (2012) in a review paper explained that mercerization is an alkali treatment process. It is widely used in textile industry. The standard definition of mercerization as proposed by ASTM D1965 is: the process of subjecting a vegetable fiber to an interaction with a fairly concentrated aqueous solution of strong base, to produce great swelling with resultant changes in the fine structure, dimension, morphology and mechanical properties.

The effect of alkali on cellulose fiber is a swelling reaction, during which the natural crystalline structure of the cellulose relaxes. Native cellulose (i.e. cellulose as it occurs in nature) shows a monoclinic crystalline lattice of cellulose-I, which can be changed into different polymorphous forms through chemical or thermal treatments.The type of alkali and its concentration will influence the degree of swelling, and hence the degree of lattice transformation into cellulose-II. It has been reported that Na+ has got a favourable diameter, able to widen the smallest pores in between the lattice planes and penetrate into them. Consequently, sodium hydroxide (NaOH) treatment results in a higher amount of swelling. This leads to the formation of new Na–cellulose-I lattice, a lattice with relatively large distances between the cellulose molecules, and these spaces are filled with H2O molecules. In this structure, the OH-groups of the cellulose are converted into O – Na-groups, expanding the dimensions of molecules. Subsequent rinsing with water will remove the linked Na-ions and convert the cellulose to a new crystalline structure, i.e. cellulose-II, which is thermodynamically more stable than cellulose-I. NaOH can cause a complete lattice transformation from cellulose-I to cellulose-II. Addition of aqueous sodium hydroxide (NaOH) to natural fiber promotes the ionization of the hydroxyl group to the alkoxide. The following reaction takes place as a result of alkali treatment:

$$\text{Fiber} - \text{OH} + \text{NaOH} \longrightarrow \text{Fiber} - \text{O} - \text{Na} + \text{H2O}$$

As reported in much literature, natural fiber chemical constituent consists of cellulose and other non cellulose constituent like hemicellulose, lignin, pectin and impurities such as wax, ash and natural oil. This non cellulose material could be removed by appropriate alkali treatments, which affect the tensile characteristic of the fiber. Mercerization was found to change fiber surface topography, and the fiber diameter was reported to be decreased with increased concentration of sodium hydroxide concentration. Mercerization treatment also results in surface modifications. Hashim (2012) reviewed the effect of NaOH on different fibers given in Table 2.6.

### 2.1.5.2 Acetylation

Acetylation is a rather attractive method of modifying the surface of natural fibers and making it more hydrophobic. It has been shown to reduce swelling of wood in water and has been studied more than any other chemical reaction of lignocellulosic materials (Figure 2.7). The main principle of the method is to react the hydroxyl groups (OH) of the fiber with acetyl groups (CH3CO), therefore rendering the fiber surface more hydrophobic. The hydroxyl groups that react are those of the minor constituents of the fiber, i.e. lignin and hemicelluloses, and those of amorphous cellulose.

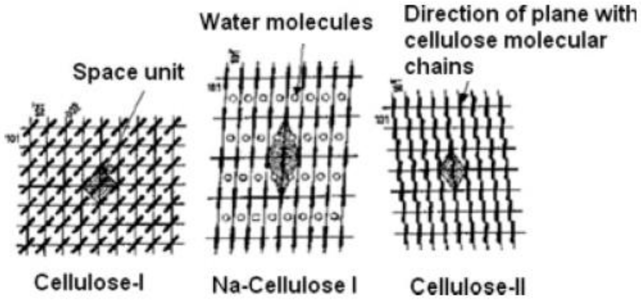

**Figure 2.7**: Lattice structure of cellulose I and cellulose II

**Source: (**Manyam 2013)

**Table 2.6**: Effect of NaOH on different fibers (Jayaprabha 2011)

| Fiber | Conc. | Effect |
|---|---|---|
| Pineapple and Sisal | 5% and 10% | At 10% NaOH, excess delignification occurred. Thus, fiber become weaker |
| Sisal | 0.25,0.5,1.0, 2.0, 5.0 & 10% w/w | NaOH treatment decrease fiber density. 10% treatment results a rougher surface than untreated |
| Hemp & Kenaf | 6% | Cell wall densification identification from small positive change in fiber density observation |
| Kenaf | 3%, 6%, 9% | 3% NaOH was ineffective to remove impurities on fiber surface, 9% NaOH show cleanest fiber surface |
| Pineapple | 2% w/v | Decrease in tensile strength and Young modulus were probably due to decrease in the degree of crystallinity and crystallite orientation |
| Kenaf, Flax & Hemp | 5% | NaOH treated kenaf and hemp composite absorb more water then silane only or alkali and silane treated samples |
| Coir | 2, 4, 6, 8 & 10% | Denser NaOH solution provided more Na+ and OH- ions to react with the substances on the fiber, causing greater amount of lignin, pectin, fatty acid and the cellulose to leach out, this would be detrimental to the fiber strength. |
| Ramie5% w/v | | Alkali treated composite exhibited better tensile properties than silane treated composite |
| Hemp | 5% | Show higher tensile strength (75.5MPa) and Young modulus (8.2GPa) |

The hydroxyl groups in the crystalline regions of the fiber are closely packed with strong interchain bonding, and are inaccessible to chemical reagents. The acetylation of the OH group in cellulose is represented below.

$$\text{Fiber} - \text{OH} + \text{CH}_3\text{CO} - \text{O} - \text{OC} - \text{CH}_3$$

$$\xrightarrow[\text{conc.H}_2\text{SO}_4]{\text{CH}_3\text{COOH}} \text{Fiber} - \text{O} - \text{CO} - \text{CH}_3 + \text{CH}_3\text{COOH} \qquad (2)$$

Acetylation has been shown to be beneficial in reducing moisture absorption of natural fibers. Reduction of about 50% of moisture uptake for acetylated jute fibers and of up to 65% for acetylated pine fibers has been reported in the literature. Acetylation has also been found to enhance the interface in flax/polypropylene composites.

### 2.1.5.3 Silane Treatment

These chemicals are hydrophilic compounds with different groups appended to silicon such that one end will interact with matrix and the other end can react with hydrophilic fiber, which act as a bridge between them. The uptake of silane is very much dependent on a number of factors including hydrolysis time, organofunctionality of silane, temperature, and pH. Alkoxy silanes are able to form bonds with hydroxyl groups. Silanes undergo hydrolysis, condensation, and the bond formation stage. Silanols can form polysiloxane structures by reaction with hydroxyl group of the fibers. The chemical reaction is given in Fig. 2.8.(Manyam 2013)

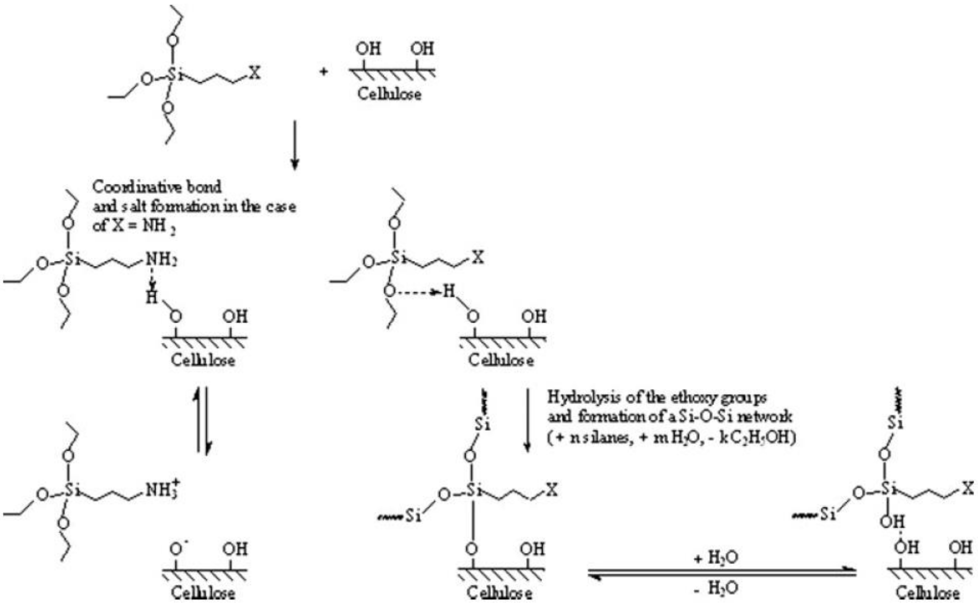

**Figure 2.8**: Scheme of interaction of silanes with cellulose fiber

**Source: (**Manyam 2013)

### 2.1.6 Enzymes activity on textiles and its classification

Celullases are used to remove fibrils from the surface and increase the smoothness of the fiber, although this treatment can also damage the fibers and reduce their mechanical properties. Pectinases are used in the textile industry for retting and degumming fiber crops, as they are capable of breaking down complex molecules of plant tissues into simpler ones, such as galacturonic acid; on the other hand, endoglucanases only act on amorphous celluloses. Hemicellulases are able to reduce water absorption by pentosan hydrolysis; xylanase and mannanase are used to dissolve hemicellulose (mainly xylan and glucomannan, respectively).

Enzymes were discovered in the second half of the nineteenth century, and since then have been extensively used in several industrial processes. Enzymes are generally globular proteins and like other proteins consist of long linear chains of amino acids that fold to produce a three dimensional product. Each unique amino acid sequence produces a specific structure, which has unique properties. Enzymes are extremely efficient and highly specific biocatalysts. Commercial sources of enzymes are obtained from three primary sources, i.e., animal tissue, plants and microbes. These naturally occurring enzymes are quite often not readily available in sufficient quantities for food applications or industrial use. However, by isolating microbial strains that produce the desired enzyme and optimizing the conditions for growth, commercial quantities can be obtained. This technique, well known for more than 3,000 years, is called fermentation. Most of the industrial enzymes are produced by a relatively few microbial hosts like Aspergillus and Trichoderma fungi, Streptomyces fungi imperfecti and Bacillus bacteria. Yeasts are not good produces of extracellular enzymes and are rarely used for this purpose. There is a large number of microorganisms which produce a variety of enzymes. Due to constantly increasing level of pollutants governments of many countries imposing stricter limitations on release of pollutants. Therefore there is ever increasing demand for clean processes i.e. processes which either cause no pollution or less pollution. Textile industry particularly the chemical processing sector always has a major share in the global pollution. Enzymes play key role in such alternative processes. Use of enzymes in textile started as long as a century ago. Today enzymes have become an integral part of the textile processing. There are two wellestablished enzyme applications in the textile industry. Firstly, in the preparatory finishing area amylases are commonly used for desizing process and secondly, in the finishing area cellulases are used for softening, bio-stoning and reducing of pilling propensity for cotton goods.

Enzymes, classification, action and properties Enzymes are biocatalyst, and by their mere presence, and without being consumed in the process, enzymes can speed up chemical processes that would otherwise run very slowly. After the reaction is complete, the enzyme is released again, ready to start another reaction. Usually most enzymes are used only once and discarded after their catalytic action. Enzymes are very specific in comparison to inorganic catalysts such as acids, bases, metals and metal oxides. Enzyme can break down particular compounds. The molecule that an enzyme acts on is known as its substrate, which is converted into a product or products.

For each type of reaction in a cell there is a different enzyme and they are classified into six broad categories namely hydrolytic, oxidising and reducing, synthesising, transferring, and isomerising. The essential characteristic of enzymes is catalytic function. Consequently, the original attempt to classify enzymes was done according to function. The International Commission on Enzymes (EC) was established in 1956 by the International Union of Biochemistry (IUB), in consultation with the International Union of Pure and Applied Chemistry (IUPAC), to put some order to the hundreds of enzymes that had been discovered by that point and establish a standardized terminology that could be used to systematically name newly discovered enzymes. The EC classification system is divided into six categories of basic function:

EC1 *Oxidoreductases*: catalyze oxidation/reduction reactions.
EC2 *Transferases*: transfer a functional group.
EC3 *Hydrolases*: catalyze the hydrolysis of various bonds.
EC4 *Lyases*: cleave various bonds by means other than hydrolysis and oxidation.
EC5 *Isomerases*: catalyze isomerization changes within a single molecule.
EC6 *Ligases*: join two molecules with covalent bonds.

Each enzyme is described by a sequence of four numbers preceded by “EC”. The first number broadly classifies the enzyme based on its mechanism. Enzymes can work at atmospheric pressure and in mild conditions with respect to temperature and acidity (pH). Most enzymes function optimally at a temperature of 30ºC-70ºC and at pH values, which are near the neutral point (pH 7). Enzyme processes are potentially energy saving and save investing in special equipment resistant to heat, pressure or corrosion. Due to their efficiency and specific action, the mild conditions in which they work and their high biodegradability, enzymes are very well suited for a wide range of industrial applications. Enzymes work only on renewable raw materials. Fruit, cereals, milk, fats, cotton, leather and wood are some typical candidates for enzymatic conversion in industry. Enzymes are used in the textile industry because they accelerate reactions, act only on specific substrates, operate under mild conditions, are safe and easy to control, can replace harsh chemicals and enzymes are biologically degradable i.e. biodegradable.

Properties of enzymes used in textiles

1. Enzyme accelerates the reaction: An enzyme accelerates the rate of particular reaction by lowering the activation
2. Energy of reaction: The enzyme remains intact at the end of reaction by acting as catalyst.Enzymes operate under milder condition: Each enzyme has optimum temperature and optimum pH i.e. activity of enzymeat that pH and temperature is on the peak. For most of the enzyme activity degrades on the both sides of optimum condition
3. Alternative for polluting chemicals: Enzymes can be used as best alternative to toxic, hazardous, pollution making chemicals. Also some pollutant chemicals are even carcinogenic. When we use enzymes there is no pollution.
4. Enzyme acts only on specific substrate: Most enzymes have high degree of specificity and will catalyse the reaction with one or few substrates. One particular enzyme will only catalyse a specific type of reaction. Enzymes used in desizing do not affect cellulose hence there is no loss of strength of cotton.
5. Enzyme are easy to control Enzymes are easy to control because their activity depends upon optimum condition.
6. Enzymes are biodegradable: At the end of reaction in which enzymes used can drain the remainingsolution because enzymes are biodegradable and do not produce toxic waste on degradation hence there is no pollution. (Ashok 2012) (Rita2008) (Elisa 2014)

### 2.1.7 Regenerated fibers

There has always been a desire to find a cheap substitute for silk. Towards to end of the 19th century scientists found a way to produce an artificial fibre which looked like silk. The first soluble cellulose derivative with fibre forming properties, cellulose nitrate was prepared in 1832. Later, it was found to be soluble in mixture of alcohol and ether, and several more or less attempts were made to produce fibres but the processes were never fully developed. In 1885 Count Hilaire de Chardonnet patented the product which was named as "Chardonnet Silk". Yarns and Fabrics made from this silk were put up in Paris Exhibition in 1889. Commercial production of the first man made textile fibers began in chardonnet's factory in Besancon in 1891.

The solubility of cellulose in aqueous ammonia containing copper oxide was discovered in 1857. By 1897, the process had been developed to the extent that fiber production was possible. Commercial production of cuprammonium rayon or "Bemberg silk" began in Wuppertal in 1904.

Thus, the years leading up to 1900 can be seen as the birth of the man-made fiber industry, soon after "Artificial silk" stockings, arrived after world war. At first, the cellulose were produced only as artificial silk (continuous filament) yarn but, during the twenties, staple viscose rayon fibers were developed in Germany, where they were called Zellwolle (cellulose-wool). Further developments of viscose process led to cellulose man-made staple fibers with properties very similar to cotton.

Regenerated cellulose is a class of materials manufactured by the conversion of natural cellulose to a soluble cellulosic derivative and subsequent regeneration, typically forming either a fiber.

According to Sushil Hada , TRADC, Birla Cellulose Clothing is the penultimate necessity for mankind after food & shelter. Majority of this clothing requirement is currently been fulfilled by cotton fibres. However, with the increasing consumer affluence, there has been a demand for better quality, high fashion and environment friendly products.

Recently, textile industry has noticed several breakthroughs in cellulosic and synthetic fibres backed by advanced technology and innovations. Viscose fibres have come across as a viable solution to cater to the clothing needs of the evolved customer.

According to the FIbre Organon, widely read publication on the fibre industry, global fibre consumption has grown at CAGR of 2.7% during 2007 -2013, whereas viscose alone has grown at 8.4% CAGR. This indicates that Viscose is becoming the preferred choice of evolved consumer. Birla Cellulose is the pioneer and leader in producing viscose fibre. Towards meeting the customer and consumer demand for better quality, & new application development, Birla Cellulose TRADC (Textile Research and Development Centre) has constantly innovated and advanced its offerings.

### Viscose

Viscose has a unique cross-section and a brilliant lustre. It is more absorptive and softer, making it more pleasant to the skin. With its lustre, sheen, drape, smoothness and breathability, this fibre is extremely well suited for blending with other fibres. It is also available in a wide range of cut lengths and titre combinations. It is 100% natural, soft feel, high uniform, high absorbency, high moisture regain, and biodegradable. Viscose has a unique cross-section and a brilliant lustre. It is more absorptive and softer, making it more pleasant to the skin. With its lustre, sheen, drape, smoothness and breathability, this fibre is extremely well suited for blending with other fibres. It is also available in a wide range of cut lengths and titre combinations.

### Modal

Modal fibre – Usually referred as 2nd generation fibre, has been confirmed as high wet modulus (HMV) fibre which satisfies a minimum value of tenacity in the wet stage of 5% elongation, by the Bureau of International Standard Fibre Association (BISFA). Bean shaped cross section, high wet modulus, and better fibre tenacity, allows Birla Modal fibre to render excellent softness , shade brilliancy and dimensional stability especially for ladies wear, night wear, undergarment and bed sheet for high class for a fashion product in 100% modal & blend with cotton etc. These superior physical properties make the fabric last longer with and enduring look and feel. Modal fibers are defined in International Standard ISO 206: 999 (E) as high wet modulus, high breaking strength regenerated cellulose fibers produced by using particular viscose rayon, and regeneration bath compositions which allows greater molecular orientation during stretch and coagulation of the fibers.

**Excel**

Excel fibre - With the generic name of Lyocell, this is the 3rd generation fibre produced from solvent spinning process. Solvent is used to dissolve pulp with almost negligible impact on environment. -High wet and dry strength, brilliant lusture & absorbency with a natural source. Birla Excel is most suitable for wash look effect product, home textile, ladies tops and is blend friendly with cotton, linen etc. (http://www.textilevaluechain.com/index.php/article/technical/item/489-technological-advancement-in-viscose-fibre)(http://mytextilenotes.blogspot.in/2012/09/learning-about-viscose-modal-and-tencel.html)

Production process of all the three fibers is almost same; however they are fibers of three different generations and the major difference is in their physical properties mentioned in Table2.7

**Table 2.7**: Physical properties of cotton and regenerated fibers

| Property | Cotton | Viscose | Modal | Excel |
|---|---|---|---|---|
| Tenacity | | | | |
| Dry (gpd) | 2.8-3.5 | 2.7 | 3.9 | 4.6 |
| Wet (gpd) | 3.2 | 1.35 | 2.5 | 3.8 |
| Wet / dry | 1.14 | 0.5 | 0.5-0.7 | 0.84 |
| Elongation % | 8 | 20 | 15 | 13 |
| Moisture % | 7.5 | 13 | 13 | 13 |
| Initial wet modulus (gpd) | 1.10 | 0.25 | 0.7 – 0.8 | 1.45 |

### 2.1.8. Softening Agents

Softening of fibers can be achieved mechanically or chemically. Mechanical softening involves the use of a number of pairs of rollers that modify the yam characteristics. Chemical softening agents are utilized in textile wet processing to improve fabric hand. A softening agent is “an auxiliary that when applied to textile material brings about an alteration in hand, resulting in the goods being more pleasing to the touch". Softening agents can make fabrics feel softer, more resilient, more flexible, and smoother than un-softened fabrics.

Orientation of softener molecules on the fiber surface also influences the hand. Depending on the medium from which a softener is applied, the softener may orient itself either in a perpendicular or parallel manner to the fiber surface. For example, application of a softener using an organic solvent will lead to non ionic forces between softener and fiber chemical structure.

Softeners reduce the inter-fiber and inter-yam friction in both static and dynamic friction. The effect of softeners results in ease of movement of fibers during the spinning process. The reduction in friction through the use of softening agents contributes to a softer hand in fabrics. Consequently, fabrics a) become easier to press because the iron glides more easily over the fabric, b) have improved sewability because the needle passes with ease, c) have fewer fibers tom during cutting, although cutting with scissors can be problematic due to slippage d) form fewer permanent creases in wet processing, e) have relaxed fibers in dry textiles, and f) result in good recovery from any type of applied strain on the fabric.
Chemical softening involves the use of four basic classes of softening agents:

**Nonionic softeners** Consist of ethoxylated fatty alcohols, acids, ester alcohols, polyethylenes, silicones and waxes. They do not ionize in water, due to the neutral charge they possess. Ethoxylates contribute to a soft hand, to absorbency, and to antistatic properties of a fabric. Linear esters have good lubricating properties, but do not have antistatic properties. Polyethylenes are widely used on cotton and its blends to improve their tensile properties. Polyethylenes have the ability to surround individual cotton fibers, and they are stable to heat treatment.

**Silicones** are used as water repellent agents and have a high lubricating ability. They are used in small quantities due to their high cost. The drawback of silicone softeners has been the yellowing of textiles after curing or heating treatment. This problem has been addressed by production of modified silicone softeners which improve hand and durable press properties, and reduce yellowing of textiles.

**Anionic softeners** have been in existence for a long time. They have a negative tail in the chemical structure when they ionize in water. These softeners include sulphates and sulphonates. Due to low affinity of anionic softeners to most fibers, attachment of anionic softeners is by a weak electrical attraction rather than by chemical bonding which results in poor durability. Anionic softeners also have good heat stability.

**Amphoteric softeners** include chemicals like the fatty amino acids, amine oxides, and sulphobetaines. In addition to contributing to soft hand, these softeners have good antistatic properties due to the presence o f two charges on the molecular structure. Although on the expensive side, amphoteric softeners are generally compatible with other classes of softeners. They can be combined with other softeners to improve textile properties without major adverse effects.

**Cationic softeners** were discovered early in the turn of this century, but they were not used in the textile industry until the 1930's. These softeners are mostly used in softening cellulosic fibers and wool. Cationic softeners have a positive tail end,and they are attracted to fibers that acquire a negative charge when immersed in water, e.g. cellulosic fibers. Cationic softeners include quaternary ammonium salts, amino-amides and cyclic catatonics. Cationic softeners are used widely because they give desired effects at lower concentrations than anionic and nonionic softeners. They have low water solubility and are often supplied in the form of pastes or emulsion. Despite the wide use of these softeners, they have limitations too. Treated products change colour when exposed to heat. Cationic softener build-up on textile fibers reduces water absorption, especially with fabric softeners used after home laundering of textiles.

## 2.2 Review related to banana fibers

### 2.2.1 Researches related to treatment of banana fiber with alkalis

Effect of alkali treatment on banana fibers was studied by Vardhini et.al. (2016). Alkali treatment of banana fibres was used for lignin removal. The effects of various experimental parameters, such as alkali concentration, time and temperature, on lignin removal of banana fibres was ascertained by response surface methodology using Box-Behnken design. The optimum conditions for lignin decomposition are identified as alkali concentration 11g/L, treatment time 150 min and temperature 90 ºC. There were changes in fibre composition due to alkali treatment under optimum conditions. The removal of lignin from mechanically extracted banana fibre was at least 40% in the optimum conditions. There is 20% increase in the cellulose content. The hemicellulose contents are also reduced by half of the actual content. The surface morphology reveals that there is a separation in the fibre bundles.

Barreto et.al. (2010) studied the structure characterization of the banana fiber modified by alkaline treatment was studied. Some important properties of this fiber changed due to some chemical treatments, such as the crystalline fraction, dielectric behaviour, metal removal (governed by solution pH) and biodegradation. The results showed that treated banana fiber is a low cost alternative for metal removal in aqueous industry effluents. Thus, for regions with low resources, the bio sorbents are an alternative to diminish the impact of pollution caused by local industries, besides being a biodegradable product. It was observed by XRD that chemical treatment with NaOH increased the crystalline fraction of the banana fiber, due to partial removal of the lignin (amorphous phase). The vibrational modes obtained by IR spectroscopy did not suffer significant changes after this alkaline process and the main bands appeared approximately in the same range wave number.

Brindha et al. (2012) experimented with fibers extracted from Banana varieties scoured with 2% NaOH solution at 100C for 45min and analyzed for their physico-chemical and mechanical properties. The moisture regain, cellulose content, modulus and tenacity of the fibers of all varieties were increased after scouring process. The fiber from the variety rasthali had high moisture content (13.21%), cellulose content (83.02%), modulus (3293.16gf/den) and tenacity (48.66gf/den) when treated with 2% NaOH solution. Thus, the scouring can increase the fiber quality for their usage in industries like paper and textile.

Ebisike et.al (2013) carried out a study to investigate how naturally-occurring fibers can be extracted by chemical retting method. In this study, banana fibers were obtained through chemical retting using banana trunk. The retting was conducted in four different media of different concentrations; 0.0M NaOH(aq), 0.01M NaOH(aq), 0.05M NaOH(aq) and 0.1M NaOH(aq) solutions respectively. In the pH study of the process, the pH of all the retted solutions converged at the range 6.71 to 7.60 while the optimum pH was found to be 7.39. The moisture content and moisture absorption calculated from the study showed moisture content of 94.88% and moisture absorption of 14.92%. Fiber yields of 0.25% to 0.55% were obtained from the four solutions studied. This, in large scale production will find application in composite development for various applications and an appropriate scenario of conversion of waste to wealth.

Banana fibers have been successfully extracted from banana harvest waste using various concentrations of sodium hydroxide as retting media. The study showed that irrespective of the route taken for fiber retting, optimum pH for retting is in the neutral pH region (around pH 7). It is also observed that the higher the concentration of the retting solutions, the longer it takes the retting solution to reach the region of the optimum pH (7.39). A fiber yield of 0.25% to 0.55% was obtained. With large cultivation or plantation of banana, after harvest, large quantity of fibers from banana waste of commercial significance for application in new materials development like body parts of cars, partitioning panels, ceiling boards, plumbing yarn, etc. can be obtained. This will be an appropriate scenario of conversion of waste to wealth.

### 2.2.2 Researches related to treatment of banana fibers with enzymes

An attempt has been made by Ortega et al. (2016) to study the effect of enzymes on banana fiber and to use them for banana yarn spinning. The aim of the paper was to show the viability of using banana fibers to obtain a yarn suitable to be woven, after an enzymatic treatment, which is more environmentally friendly. Extracted long fibers are cut to 50 mm length and then immersed into an enzymatic bath for their refining. Conditions of enzymatic treatment were optimized to produce a textile grade of banana fibers, which were characterized. *Biopectinase M01* (made of pectinase and hemicellulase) and *Biopectinase K* (made of poligalacturonase) were used. The optimum treating conditions were found with the use of Biopectinase K (100% related to fiber weight) at 45 ″C, pH 4.5 for 6 h, with bath renewal after three hours. The first spinning trials showed that these fibers were suitable to be used for the production of yarns.

Ganan et al. (2004) in his article has updated that extraction processes of natural fibers can be performed by different procedures that include mechanical, chemical and biological methods. Each method presents different advantages or drawbacks according to the amount of fiber produced or the quality and properties of fiber bundles obtained. In this study, biological natural retting was satisfactorily used for obtaining banana fibers from plant bunches. However, the most important contribution of this work refers to the description of the hierarchical microstructural ordering present in banana fiber bundles in both bundle surface and inner region. The chemical composition of banana fiber bundles has been evaluated by FTIR spectroscopy. Through exposure time, the fiber bundle configuration presents small variations in composition. The main changes are related to hemicellulose and pectins as they confirm the outer walls of the bundle. Hierarchical helicoidal ordering in the bundle surface as well as orientation on the longitudinal axis of the bundle were observed by optical microscopy (OM) and scanning electron microscopy (SEM) for 3-4 microm surface fibers and 10-15 microm inner elementary fibers, respectively. With increasing exposure time, fiber bundle walls lose integrity, as reflected in their mechanical behaviour.

India is the world's largest producer of banana. The fiber has limited application in textiles due to its high stiffness and less cohesive properties. Shroff and Karolia (2015) conducted a research with the aim to remove noncellulosic gummy materials from banana fiber thus softening it and prepare nonwovens through needle punch method. Grey banana fibers were treated with hemicellulase, pectinase and cellulase enzyme individually by varying its concentration and time. This optimised treatment was treated with different combination of enzymes, and then standardised. The effect of the enzymes on the fibers was measured in weight loss, strength loss and whiteness index of the fiber. Subjective analyses by touch and feel method, SEM analyses were also done. The best softened fibers were then processed for preparation of nonwovens through needle punch method at NIRJAFT Kolkata.

Rasmina et al. (2011) investigated the upper and lower portions of Musa sapientum pseudo-stem sheaths. They were exposed in four types of treatments: pectin decomposing bacteria, magnesium oxide (MgO), both pectin decomposing bacteria and MgO and control. The bioaugmentation of pectin decomposing bacteria together with MgO additions were found to enhance retting process and reduced retting periods 52% and yielded better strength on the fibres. The lower portion pseudo-stem sheaths gave the higher strength than upper portion. Colour changed showed that the bioaugmentation of pectin bacteria enhanced the degradation colouring compound in banana fibres.

Akubueze et al. (2015) in the study illustrated the process technology for the production of biodegradable agro- sack from banana and plantain fibres of Nigerian origin for packaging a wide range of industrial and agricultural based produce such as cotton linters, cocoa, onions, potatoes, grains, oil seeds etc. Un-utilized banana/plantain stems were retted and extracted in a controlled system, using natural and microbial retting techniques. A consortium of bacteria species such as; Bacillus cereus, Bacillus licheniformis, Bacillus subtilis and Bacillus polymyxa isolated from soil and retting water of the stems were used, with six to ten (6-10) days of accelerated retting period as against twenty eight to thirty five (28-35) days of natural retting. The extracted fibres were carded and successfully spun into yarn using a spinning wheel, woven into fabric by interlacing warp and weft yarns in a 0.68m by 0.74m and 1.64m by 1.32m weaving frame respectively. The resultant fibres possess sufficient strength, uniformity, fineness and some level of flexibility which enable it to withstand the strains and stress of spinning and weaving process.

### 2.2.3 Studies related to banana union fabrics

A study was conducted on value addition and product diversification of minor fibre fabrics (Jute & Banana) using hand block printing, by Malhan (1999). The objective of the study was to print the Jute & Banana blends with Bagru and Sanganeri style of printing. The printed fabrics were converted into novelty products and were further evaluated for market acceptability. It is interesting to know that back in 2000 no products of Jute & Banana were easily available in market. However Jute was still seen home furnishing. The printing of the fabric was a successful attempt and products like cushions covers, lamp shades, table mats, table covers, tray and trolley covers, wall hangings, partition panels and bed spreads were prepared and they were liked by consumers. However these products would cater to niche market only.

Owing to certain deficient in some functional requirements of KVIC woven cotton Banana union fabric, a study was conducted on Cross linking and softening of chemically pre-treated Cotton Banana union Fabric by Sheth (1998). The fabric was pre-treated, bleached, resin finished and then silicon and cationic softeners were applied. The pre-treatment were successful as they provided space for further treatments which was proved by increase in yarn diameter.

A study was conducted on dying and printing of Cotton Banana union fabric. The fabric was pre-treated and bleached then printed and dyed with reactive dyes. The pre-treatment improves dye ability of the fabric. However there is no effect of pre-treatments for batik technique. In discharge printing, due to pre-treatment the dye ability of fabric increased. However the best visual effect results were obtained with screen printing. (Sheth 1998)

Another study was conducted by Shukla (1998) to study change in physical properties (strength, elongation, and stiffness) due to effect of ageing and accelerated heat, with resin and an addictive along with resin. It was observed the pre-treatment are more beneficial for cellulose as compared to bast substrate. However ageing showed more degradation. Due to the application of resin, cross linkings were formed which results decrease in fabric strength. On addition of additives there is reduction of cross linkage which helps to maintain strength loss.

Long back in 1997 an effort was made in the department of Clothing and Textiles by Arora (1997) to weave banana union fabric. Although spinning a banana yarn was not a success, however designed Cotton Banana, Rayon Banana union fabric were well produced. Innovative variations in the woven fabrics were created by dyeing, using ply yarns on plaited yarns in weft. The researcher reported that banana fibers can be effectively used and could be utilized for apparel purpose.

Raval (1999) studied the effect of eco-friendly pigment printing on Cotton, Banana and Jute fabric. A comparison of eco-friendly pigment printing was also done with chemically pre-treated Cotton Banana Jute. Beautiful shades were obtained with colours (Red, Yellow, and Blue) on all the three fabrics. However, researcher reports that the pre-treated gave better brighter and darker shades on Banana union fabric followed by 100% cotton and Jute cotton fabric.

### 2.2.4 Researches on banana fiber properties

Preethi and Balakrishna (2013) explored different varieties of banana plant. Banana is one of the important fruit crop cultivated in tropical parts of the world. Banana farming generates huge quantity of biomass all of which goes as waste and the above ground parts like pseudostem and peduncle are the major source of fibre. Banana fibre can be used as raw material for industry for production of range of products like paper, cardboards, tea bags, currency notes and reinforced as polymer composite in high quality dress materials. Fibre from pseudostem and peduncle of four commercial cultivars of Tamil Nadu viz., G*rand Naine*, *Poovan*, *Monthan* and *Nendran* were extracted using banana fibre extraction machine. The highest pseudostem and peduncle fibre recovery were obtained from *Poovan* (2.71% and 1.09%, respectively) and the lowest from *Grand Naine* (1.07% and 0.63%, respectively). Cellulose is the major component of the fibre. The highest cellulose content was recorded in *Nendran* peduncle fibre (60.27%) followed by *Nendran* pseudostem fibre (59.23%). The other non- cellulosic substances like hemicellulose, lignin and pectin were high in *Monthan* pseudostem fibre (15.75, 21.56 and 4.08%, respectively). Mechanical properties like tex and fibre diameter decides the fineness. Fine fibres were obtained from pseudostem of *Nendran* (24.23 tex and 0.119 mm, respectively). The breaking load, breaking extension and tenacity were found to be good in peduncle fibres of *Nendran* cultivar (332.33 g, 2.01% and 39.56 g/tex).

Mukhopadhyay et al. (2008) examined the relationship between the banana yarn diameter and their properties. Banana fibers obtained from the stem of banana plant (*Musa sapientum*) have been characterised for their diameter variability and their mechanical properties, with a stress on fracture morphology. The nature of representative stress strain curves and fracture at different strain rates have been analysed through SEM. Banana fibers have shown high variability along the length and between fibers, which is a characteristic of natural fibers. The standard deviation has been found to decrease with increasing diameter of fibers. The diameter variability had a normal distribution. The tenacity of banana fibers was a function of the testing speed. At lower strain rate, an increase in strain facilitates the amorphous to crystalline sharing of load. At higher speeds however, the faults dominate with catastrophic failure at the highest strain rates. Some of the stress strain curves showed signs of strain hardening. Banana fiber at present is a waste product of banana cultivation and either not properly utilized or partially done so. The extraction of fiber from the pseudostem is not a common practice and much of the stem is not used for production of fibers. The behaviour of the fibers also gives important hint regarding their subsequent behaviour as reinforcement in composites. There is scope for further research to completely characterise the banana fibers and facilitate proper applications in natural fiber reinforced composites.

Basak et al. (2015) described an experiment in which flame retardancy was imparted in cellulosic cotton textile using banana pseudostem sap (BPS), an eco-friendly natural product. The extracted sap was made alkaline and applied in pre-mordanted bleached and mercerized cotton fabrics. Flame retardant properties of both the control and the treated fabrics were analysed in terms of limiting oxygen index (LOI), horizontal and vertical flammability. Fabrics treated with the non-diluted BPS were found to have good flame retardant property with LOI of 30 compared to the control fabric with LOI of 18, i.e., an increase of 1.6 times. In the vertical flammability test, the BPS treated fabric showed flame for a few seconds and then, got extinguished. In the horizontal flammability test, the treated fabric showed no flame, but was burning only with an afterglow with a propagation rate of 7.5 mm/min, which was almost 10 times lower than that noted with the control fabric. The thermal degradation and the pyrolysis of the fabric samples were studied using a thermogravimetric analysis (TGA), and the chemical composition by FTIR, SEM and EDX, besides the pure BPS being characterized by EDX and mass spectroscopy. The fabric after the treatment was found to produce stable natural khaki colour, and there was no significant degradation in mechanical strengths. Based on the results, the mechanism of imparting flame retardancy to cellulosic textile and the formation of natural colour on it using the proposed BPS treatment have been postulated.

Raghavendra et al. (2013) examined that natural fiber reinforced bio-degradable composites are good alternative for conventional materials. Natural fibers are cheaper in cost, environmental friendly and biodegradable. In the present work composites are made using short Banana fibres and natural rubber. Composites are prepared using vulcanizing technique at 1500c. And composites obtained were determined for mechanical properties like tensile strength, tear strength were studied. The effect of different lengths of fiber content with natural rubber was determined.

## Researches on natural cellulose and lignocellulosic fibers

Maria (2011) made an observation that alkaline pre-treatment of lignocellulosic materials causes cellulose swelling, decrease of polymerization degree and crystallinity, increase of internal surface area, disruption of the lignin structure, separation of structural linkages between lignin and carbohydrates. Advantages of Alkaline pre-treatment: - the employment of lower temperatures and pressures than other pre-treatment technologies, - in comparison with acid processes, alkaline ones cause less sugar degradation; - many of the caustic salts can be recovered and/or regenerated.

Kaushik et al. (2012) studied the use of natural fibers as replacement to man-made fiber in fiber-reinforced composites have increased and opened up further industrial possibilities. Sisal fibers were modified using alkali and benzoyl peroxide solution of different concentration for different time intervals. Morphological changes, thermal stability and crystallinity of fibers were investigated using scanning electron microscope (SEM), TGA and XRD technique. Thermal stability of sisal fibers decreased on mercerization. Whereas, sisal fibers treated with benzoyl peroxide had enhanced thermal stability. XRD studies, sisal fibers show enhanced crystallinity. Morphology of sisal fiber was changed by chemical treatments. The surface of sisal fiber becomes rougher after treatments in comparison with smooth and clear surface of raw sisal fibers. The removal of surface impurities on plant fibers may be an advantage for fiber to matrix adhesion as it may facilitate both mechanical interlocking and the bonding reaction due to the exposure of the hydroxyl groups to chemicals such as resins.

Kiron reviewed different types of spinning systems in his blog titled as An Overview of Developments in Yarn Spinning Technology. Ring spinning is currently the most widely used yarn production method. Initially developed in America in the 1830s, its popularity has survived the emergence of much faster spinning technologies. In addition to the superior yarn quality, ring spinning is extremely versatile. It is capable of producing yarns with wide ranges of linear density and twist from a great variety of fibre materials. It is also used for doubling and twisting multifold and cabled yarns.

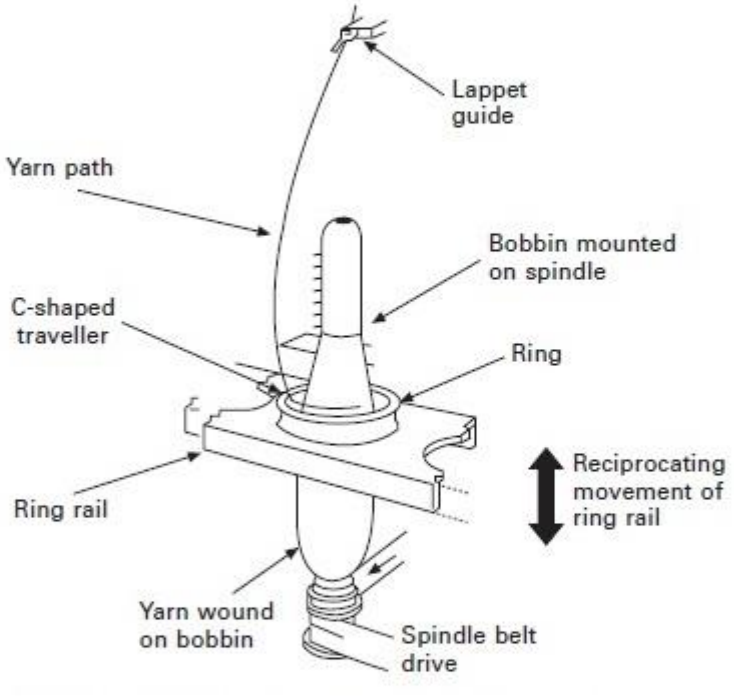

**Figure 2.9**: Ring spinning System

The technology behind ring spinning has remained largely unchanged for many years, but there have been significant refinements. Changes, which on their own offered only slight advantages, provided the following synergies when combined:

1. The introduction of longer frames reduced the relative costs of automatic doffing.
2. The combination of spinning frame and winding (link winders) further enhanced the adoption of automation.
3. The introduction of automatic doffing meant that doffing time was reduced and thus package (and ring) size was less critical.
4. The introduction of splicing on the winder meant that yarn joins became less obtrusive — again offering the potential of smaller package.
5. Smaller rings meant that for a limiting traveller velocity (40 meters per second [m/s]), higher rotational speeds (and hence twisting rates) could be achieved. These combinations meant that the potential maximum speed of ring spinning was raised from about 15,000 to 25,000 revolutions per minute.

Monteiro et al. (2011) studied tensile stress of eight lignocellulosic fibers: sisal, ramie, curaua, jute, bamboo, coir, piassava and buriti. It is shown that, for all of these fibers, the tensile strength holds an inverse relationship with the fiber diameter. Statistically this relationship conforms to a hyperbolic type of analytical equation, which discloses the possibility of unusually high strength fibers to be selected in association with very small diameters. In the paper, use of lignocellulosic fibers in automobiles had also been mentioned. Fig 2.10 gave a glimpse of it.

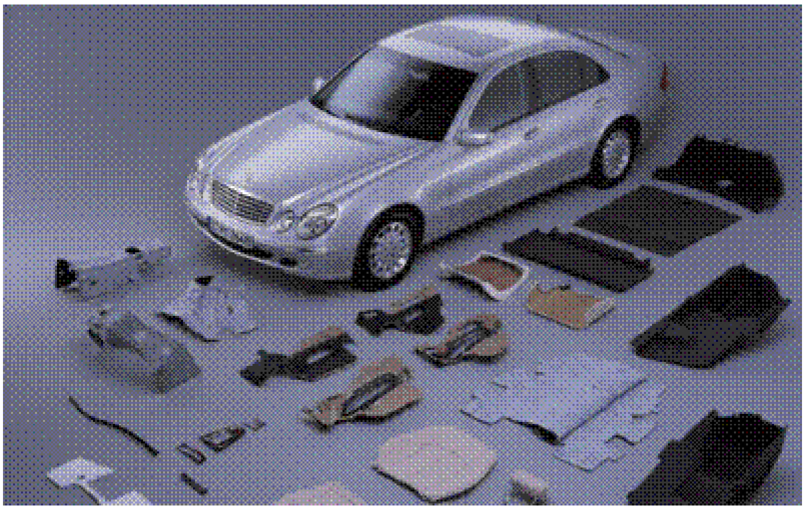

**Figure 2.10**: Automobile components made of natural fiber reinforced composites (Monteiro 2011)

Elenga et al. (2013) in his article had explained the gradual dissolution of non cellulosic components. The objective of the study was to evaluate the effect of alkali treatment at room temperature on its microstructure, structure, composition, thermal behaviour, mechanical properties and colour. The fibers were soaked in three NaOH solutions (2.5%, 5%, 10% by weight) for 12 hours. It was found that the fibers treated with 5% NaOH solution exhibited enhanced textile strength and increased yellowness.

Mosier et al. (2005) reviewed process parameters and their fundamental modes of action for promising pre-treatment methods. Alkali pre-treatment processes utilize lower temperatures and pressures compared to other pre-treatment technologies. Alkali pre-treatment may be carried out at ambient conditions, but pre-treatment time is measured in terms of hours or days rather than minutes or seconds. Unlike acid-catalyzed pre-treatments, a limitation occurs because some of the alkali is converted to irrecoverable salts or incorporated as salts into the bio-mass by the pre-treatment reactions. Alkali pre-treatments use sodium, potassium, calcium, and ammonium hydroxide as reactants. Sodium hydroxide has received the most attention. Lime (calcium hydroxide) has the additional befits of low reagent cost and safety and being recoverable from water as insoluble calcium carbonate by reaction with carbon dioxide

A study was conducted by George et al. (1994) on light and wash fastness characteristics of chemically pretreated Jute based fabrics dyed with Reactive Dye. The specific objectives of the study were to study the degree of fixation of dichlorotriazinyl (cold brand), monochlortriazinyl (hot brand) and Vinyl Sulphone based reactive dyes and to study the colour fastness characteristics on exposure to light and wash. The dye samples were then tested for light and wash fastness. The results revealed that NaOH treatment has improved not only dye fixation has improved not only dye fixation but also fastness properties to light and wash, whereas another ethylene diamine treatment had negative implications on dye fixation characteristics which resulted in only staining of the pre-treated fabrics with the dye. The dimethyl formamide treated fabrics were seen to have considerable loss of weight, strength and abrasion resistance. Thus it could be concluded that the pre-treatments can be effectively used to induce desirable qualities in jute and jute based fabrics to make them more durable and to increase the aesthetic appeal.

A study was conducted by Sharma et al. (1993) on designing and construction of skirts from jute and jute multifibre fabrics. The main objective of this study was to determine the wear characteristics of jute and jute multifibre fabrics. Various standard tests for determining wear characteristics were carried out. For the construction of skirts, the designs were divided into 4 major categories namely straight, gathered, and flared and multi- gored. Results reveal that percent weight loss was found to be least in jute- polypropylene fabric and maximum weight loss was found in jute-viscose fabric. Based on the observed preliminary data and wear characteristics of jute and jute multifibre fabrics, jute cotton and jute - viscose fabrics showed the most favourable properties for the construction of skirts.

A study was conducted by Gupta (1992) on a study on the physico-chemical modified jute and jute- multifiber fabric. The main objective of study the physical subjected to ageing and accelerated heat and the study effect of cross linking agent - DMDMEU on the physical properties of pretreated fabrics. The pretreated samples were subjected to ageing and the samples were also resin finished using DMDHEU and magnesium chloride. The results revealed that the tests conducted on different fibres after pretreatment and on the pretreated sample subjected to ageing, accelerated heat and resin finishing showed improvements in particular wear characteristics, such as abrasion resistance, strength retention, crease recovery angle and resistance to heat treatment indicating less damage on the fabrics.

Amongst cellulosic minor fibres Ramie possess excellent absorbency properties. In order to make changes in the tensile strength and stiffness Gupta (2000) has applied resins and softeners individually and in combination. It was applied on 100% ramie and cotton ramie blended fabrics, which was further evaluated for its fixation and surface modification. Combination treated samples produce smooth, fine and soft handle, also decrease in bending rigidity was seen due to formation of cross linkages by the softeners.

Value addition and product diversification are important for handicraft products using minor fibers. Bhagwate (2006) did experimental study on product development from kenaf fibres. Wherein, she developed utility, aesthetic appealing and acceptable products using Kenaf fibres and the ropes. They were pretreated to remove the lignin and to make fibres whiter. Six different techniques like weaving, finger weaving, quilting, macramé, stuffing and tying and braiding to make various products. Out of the whole range of handicraft products developed wall piece with macramé technique, shoulder bag with weaving technique were preferred. Thus it was the successful efforts made by her and the products will have the market, it will also have the employment generation in the rural areas.

An experimental study on bio-softening of cellulosic minor fibres for non-woven application was carried by Shroff (2013) with three different fibres – Ramie, Sisal and Banana. Pectins, waxes, lignin and hemicellulose were removed using three eco-friendly enzymes like hemicellulase, pectinase and cellulaseto soften fibre.

Combination of enzymes gave better result than the single enzyme treatment on the fibres. Further 100% and different blended non-woven fabrics were prepared at National Institute of Research on Jute and Allied Fiber Technology, Kolkata. Among the all, Ramie non-woven fabric gave best results as it was compact, smooth, flexible and had even surface.

According to Kundu and Verma (2013) the properties such as low breaking extensibility, stiffness, messiness and long staple fibre differentiate the manufacturing of jute yarn from cotton system. The main functions of jute spinning units are to convert jute fibres to yarns for different end uses. The types of jute yarn manufactured can be classified according to the application/use to which they are put ie, fine yarns, hessian yarns, carpet, sacking yarns, etc. These yarns can be further classified into warp and weft yarns, the warp yarns normally being superior to the weft yarns as they have to withstand the cycles of stress during weaving while the weft yarns act more as filler and undergo less strain during weaving process. Jute yarns of various dimensions are plied together to make twines, ropes, cordages, etc as per requirement and use. These are used for the purpose of tying, knotting, binding, etc particularly agricultural commodities. It was not possible to produce jute yarn finer than 138 tex (4 lb/spy) by conventional techniques. But, later on after development of apron draft ring spinning system it is easier to produce yarn as fine as 60 tex (1.75 lb/spy). This type of jute yarn has the prospect of being used in high quality jute textiles.

Bel-Berger et al. (1999) blended kenaf (*Hibiscus cannabinus L.*) with cotton (*Gossypium hirsutum L.*), new high-end uses for kenaf have been identified. Kenaf fibers, bast fibers similar to jute, are typically separated by mechanical, chemical, or bacterial means. Mechanically separated fibers are usually too stiff to be blended with cotton and cannot be made into good yarns. Fibers processed chemically and bacterially were blended with cotton and made into fabrics and evaluated. The retted kenaf ribbons were carded to produce straightened fibers which were cut into uniform lengths, blended with cotton, converted into yarns which were then made into fabrics to compare the retting treatments' effects on fabric hand and appearance. In order to further improve the hand of the retted kenaf/cotton blend fabrics, the fabric needed to be softened with routine finishes used in the textile industry. The effects of different fabric treatments such as enzymes, bleaching and mercerization on blended light weight and heavy weight cotton/kenaf fabrics were compared and measured for softness of hand. This collaborative effort resulted in cotton/kenaf blend fabrics that were aesthetically appealing and had a soft hand. The light weight blend fabrics had a linen look and, after treatment, were suitable for use in apparel without any type of lining. Mercerization was an adequate means to improve hand and appearance of the heavy weight fabrics, resulting in excellent examples of upholstery fabrics. Cotton enhanced the kenaf fibers and resulted in a higher value end product.

Bakri et al. (2016) throughout this research, the fundamental characterization of functional groups bond structure and the behavior of natural fiber before and after treatment were understood. Fibers were obtained by extracting it from the bamboo, betel nut and hemp plants. The Infrared spectrum of natural fiber were obtained and tested using Fourier transform infrared (FTIR) spectroscopy in the range of 400 cm-1 to 4000 cm-1 for untreated and alkali treated fibers. It was prepared quantitatively and qualitatively according to ASTM E168-06 and ASTM E1252-98 standards. Based on the Infrared spectral, the functional groups of the plant fiber were then collected and classified. The effect of chemical treatment was evaluated and discussed. Based on the result obtained, the bond structure of certain functional groups (i.e. hemicellulose, cellulose, and lignin) was removed and changed due to the alkaline treatment.

Andreaus et al. (2014) observed that despite of the amazingly grown interest in cellulases due to their importance for biomass hydrolysis, their main industrial use is still related to textiles. The main applications of cellulases are the removal of surface fibre fibrils from cellulosic fabrics to avoid pilling and improve fabric appearance and the ageing of indigo-dyed denim garments. Cellulolytic enzymes are also used in detergents to aid in the removal of fibre encrusted dirt and soil and to increase colour brightness of the washed garments and may be used for the treatment or recovery of cellulosic textile waste.

Elisa (2014) investigated the application of enzymes such as laccase and xylanase for the preparation of cellulose from lignocellulosic material is an option for those industries seeking to reduce the use of chlorine-containing bleach agents, thus minimizing the environmental impact of their processes. Mixed hydrolytic and oxidative enzyme systems have been well described in the context of biopulping, and thus provide good precedent regarding effectiveness, despite the susceptibility of xylanase to inactivation by laccase-generated oxidants. In nature, three key enzymes are broadly recognized for their ability to oxidize lignin: LiP, MnP, and laccase. Of these three enzymes, laccase exhibits the greatest potential for commercial development for several reasons. First, unlike LiP and MnP, laccase does not require the presence of a cofactor. Second, laccase does not require a low, steady supply of hydrogen peroxide for activity; oxygen serves as the terminal electron acceptor for this enzyme.

Plant fibers are rich in cellulose and they are a cheap, easily renewable source of fibers with the potential for polymer reinforcement. The presence of surface impurities and the large amount of hydroxyl groups make plant fibers less attractive for reinforcement of polymeric materials. A study was conducted by Mwaikambo et al. (2002) where hemp, sisal, jute, and kapok fibers were subjected to alkalization by using sodium hydroxide. The thermal characteristics, crystallinity index, reactivity, and surface morphology of untreated and chemically modified fibers have been studied using differential scanning calorimetry (DSC), X-ray diffraction (WAXRD), Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM), respectively. Following alkalization the DSC showed a rapid degradation of the cellulose between 0.8 and 8% NaOH, beyond which degradation was found to be marginal. There was a marginal drop in the crystallinity index of hemp fiber while sisal, jute, and kapok fibers showed a slight increase in crystallinity at caustic soda concentration of 0.8–30%. FTIR showed that kapok fiber was found to be the most reactive followed by jute, sisal, and then hemp fiber. SEM showed a relatively smooth surface for all the untreated fibers; however, after alkalization, all the fibers showed uneven surfaces. These results show that alkalization modifies plant fibers promoting the development of fiber–resin adhesion, which then will result in increased interfacial energy and, hence, improvement in the mechanical and thermal stability of the composites.

Alkali use on cellulosic fibers enhances the dissolution of lignocellulosic material and leads to increased surface area, decreased degree of polymerization, and separation of structural linkages between lignin and cellulose. Chemical fiber extraction with 1.75N, 2.25N, and 1.0 N, NaOH solutions has been successfully carried out on kenaf, sisal and bagassee, the waste product from sugar cane after the juice has been extracted. Higher concentrations of NaOH , high steam pressure, and longer treatment times increased the amounts of gum removed from sugar cane rind and resulted in fibers with lower strength and rigidity. According to alkali use on jute dissolved hemicellulose, made fibers slightly more even in size with reduced spinning end breakage rate, and contributed to improved yam processing. Weak concentrations of alkali solution which were used in the latter study did not significantly change the fiber fineness or strength.

Ramaswamy et al. (1995) reviewed, the degumming process using 1.75N of NaOH increased breaking strength, elongation, and moisture regain of kenaf fibers. When an enzyme was used with degumming treatment, fibers were weakened significantly, and finer fibers were produced. Degummed kenaf fibers produced the strongest, most pliable and spinability fibers, with the lowest residual gum content than non degummed kenaf fibers. The degumming process in the study on kenaf supported the boiling fibers in optimum NaOH solution result in the removal of gums in the amorphous regions of fibers, and allowed for the rearrangement of molecules thus increasing crystallinity. The above effect of alkali was also confirmed by who used NaOH for pretreatment on sisal for grafting purposes. Results showed an increased in grafting yield due to fiber swelling. Degumming using NaOH on sisal, banana and pineapple fibers and the breaking strength of sisal and pineapple fibers first increased with increasing concentration then decreased after reaching a certain level. With banana fibers, the breaking strength decreased with increasing concentration from the onset. On all three fibers water absorption increased after the degumming process.

Elisa (2014) studied the application of enzymes such as laccase and xylanase for the preparation of cellulose from lignocellulosic material is an option for those industries seeking to reduce the use of chlorine-containing bleach agents, thus minimizing the environmental impact of their processes. Mixed hydrolytic and oxidative enzyme systems have been well described in the context of biopulping, and thus provide good precedent regarding effectiveness, despite the susceptibility of xylanase to inactivation by laccase-generated oxidants. This paper examines the progress towards development of sequential and simultaneous mixed enzyme systems to accomplish delignification. Even though the effectiveness of mixed hydrolytic and oxidative systems might be moderated when used simultaneously due to the inactivating effect of the redox mediator on the enzymes, in practice it would be beneficial to combine the treatments. Fiber is expected to have a protective effect, and lignin will provide an alternate target for the oxidized mediators. The identification of hemicellulases more robust to the oxidative environment generated by the LMS is an opportunity not yet exploited. For example, while most xylanases are readily inactivated by the tryptophan modifying agent NBS, the P. citrinium xylanase was not inactivated by even a ten-fold molar excess of this oxidant. The xylanase from C. subvermispora may also exhibit stability in an oxidative environment, since the enzyme is produced along with laccase and MnP during biopulping. Inactivation studies have not been reported for the C. subvermispora xylanase, nor has sequence and structural information been published. In consideration of simultaneous enzyme application, enzymes of similar pH optima and thermal stability would be required; alternatively, a complement of enzymes of varying pH optimum may be useful. In wood degradation by C. subvermispora, the pH gradually decreases from 5.0 to near 3.5, so the production of laccase isozymes of different pH optima ensures that oxidation occurs over this pH range. Different substrates are also known to exhibit different pH optima.

Ramie is commonly known as china grass, green ramie or rhea. It is referred to as bast fiber. The fiber has limited application in textiles due to its high stiffness and less cohesive properties reported Shroff (2015). The aim of the study was to remove noncellulosic gummy materials from the fiber thus softening it and prepare nonwovens through needle punch method. Grey ramie fibres were treated with hemicellulase, pectinase and cellulase enzyme individually by varying its concentration and time. This optimised treatment was further treated with different combination of enzymes, which was later standardised. The effect of enzymes on the fibers was measured in weight loss, strength loss and whiteness index of the fiber. Subjective analyses by touch and feel method, SEM analyses was also done. The best softened fibers were processed for preparation of nonwovens through needle punch method at NIRJAFT, Kolkata

Sisal occupies 6th place among the plants, representing 2% of the world’s production of plant fibers. The fiber has limited application in textiles due to its high stiffness and less cohesive properties. The aim of the study was to remove noncellulosic gummy materials from sisal fiber thus softening it and prepare nonwovens through needle punch method. Shroff (2015) treated grey sisal fibers with hemicellulase, pectinase and cellulase enzyme individually by varying its concentration and time. This optimised treatment was further treated with different combination of enzymes, and was standardised. The effect of the enzymes on the fibers was measured in weight loss, strength loss and whiteness index of the fiber. Subjective analyses by touch and feel method, and SEM analyses were also done. The best softened fibers were then processed for preparation of nonwovens through needle punch method at NIRJAFT, Kolkata.

Chiliveri (2016) demonstrated the simultaneous production and optimization of pectinolytic enzymes (pectate lyase and polygalacturonase) under SSF from *Bacillus tequilensis* SV11-UV37 using wheat bran as a substrate, which is commercially viable and cost-effective. Optimization by one variable-at-a-time-approach showed a maximum yield of pectate lyase (1371.25 U/gds) and polygalacturonase (85.45 U/gds) with wheat bran using 80 % (v/w) moisture, 0.7 mm particle size, 20 % (v/w) inoculum, 1 % (w/w) pectin at 37 °C, pH 6 and 72 h of incubation. In addition, optimization using central composite design achieved 1.6-fold improvement in both pectate lyase (1828.13 U/gds) and polygalacturonase (105.55 U/gds) yield at optimum levels of pectin (3 %, w/w), inoculum size (20 %, v/w) and moisture level (80 %, v/w). Further, Retting studies concluded that the enzyme mixture was efficient in separating the whole fiber from kenaf and part (>75 %) from sunn hemp. In degumming of sunn hemp fibers, amount of galacturonic acid released and percentage weight loss was higher in successive alkali and enzymatic treatment than their independent treatments. The scanning electron microscopic analysis also confirmed that alkali followed by enzymatic treatment effectively removed non-cellulosic gummy material from the fiber; hence, this enzyme mixture may find feasible applications in the fiber and textile industry.

Moran (2008) studied two different procedures for cellulose extraction from sisal fibers. They were evaluated by means of TGA, FTIR, DSC and XRD, it was possible to characterize the obtained cellulose and analyze the presence of lignin and hemicellulose. No component extraction could be ensured after TGA analysis. FTIR spectra confirmed the removal of hemicelluloses and lignin; these results were based on the characteristic peaks of lignocellulosic materials. Furthermore, XRD tests showed that the crystallinity was the same for all the celluloses studied, confirming the previous conclusions. DSC curves showed the superposition of the peaks corresponding to the fusion and the degradation. These techniques allowed concluding that the obtained material was cellulose with no significant quantities of hemicellulose or lignin. When comparing Procedures I and II in terms of productivity, environmental impact, fiber quality and size distribution, many differences showed up. It was noticed that the first one was less environmentally aggressive, while the second one involved less process time and drove to fibers with more homogeneous diameter distribution.

From scanning electron microscopy; different morphologies were observed at every stage of each procedure. After cellulose was obtained, a simple acid hydrolysis conducted to nanofibers, which was confirmed by AFM images. These fibers will be used in future works in the production of biodegradable nanocomposites with enhanced properties.

Various agricultural residues, such as corn fiber, corn stover, wheat straw, rice straw, and sugarcane bagasse, contain about 20–40% hemicellulose, the second most abundant polysaccharide in nature. Various pre-treatment options as well as enzymatic saccharification of lignocellulosic biomass to fermentable sugars were reviewed by Badal (2003). Our research dealing with the pretreatment and enzymatic saccharification of corn fiber and development of novel and improved enzymes such as endo-xylanase, b-xylosidase, and a-L-arabinofuranosidase for hemicellulose bioconversion is described. The barriers, progress, and prospects of developing an environmentally benign bioprocess for large-scale conversion of hemicellulose to fuel ethanol, xylitol, 2,3-butanediol, and other value added fermentation products are highlighted.

The environmental and industrial safety condition increased the potential for the use of enzymes in textile processing to ensure eco-friendly production. Laccase enzymes formulation has been used in textile processing like different processes such as bio-bleaching, dyeing, rove scouring, dyeing, finishing, neps removal, printing, wash-off treatment, dye synthesis & effluent treatment. The discharge printing by using laccases helps to avoid the hazardous reducing chemicals like sulphoxylic acid derivatives and tin salts, in particular stannous chloride. The bio-bleaching is helps the decolorising textile material by using laccase enzyme which don't increasing effluent load. Laccases are also use for washing off process which decreasing use of synthetic detergent. Laccase enzymes does not affecting fiber polymer which means less fabric damages found after processing. Laccase enzymes development further more steps in eco-friendly processing. (Garje 2011)