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Handbook of Textile Processors Series

The Substrates – Fibres, Yarn and Fabric

Mathews Kolanjikombil

WPI

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Dedicated to my wife

Contents

Preface

It was my long time intention to write handbooks for shop floor textile processor. During my career as a textile processor in day to day work, I had come across on many occasions, the need for ready reference books for immediate help, rather than going through highly technical books which is more theoretical and not of much help practically on the production floor. A shop floor technician needs facts and figures, recipes as guideline, precautionary measures to be taken during the process, etc., for his immediate use and help in achieving results and targets in short time. All these information given in short, may be without much detailed theory as his time on the shop floor is limited.

I have been collecting information and recipes throughout my career, most of it practically tried, and I could put it on paper after my retirement from active involvement in production work. After roughly making manuscript, I came to the conclusion that it may not be able to fix it in one book. Hence, with the consultation with the publisher, I have decided to publish it as a series of 10 books – The Substrate – Fibre, Yarn and Fabrics, Preparation of the substrate, Fabric Dyeing Vols. I and II, Yarn Dyeing, Printing, Finishing, Laboratory Testing Methods, Tables and Useful Information and Important Machineries.

The book is a compilation of information.

The present book is the first in this series, which is about the different substrates used in the day to day processing. This book gives a general description of the substrate which includes the chemical structure, manufacturing methods, fundamental properties, physical and chemical characteristics which are very important in designing processing sequences, recipes, processing parameters and their major uses.

Even though the book is written with production personnel in mind, students of textile chemistry and engineering can find this book useful in their academics.

Any suggestions for improvement of the book, including any inclusions or omissions to be done in the future editions, are welcome.

K. Mathews

1
Fibres

1.1 General

The history of textile fibre is as old as civilization, as we get reference of the usage of natural fibres thousand of years ago. During ancient times, the natural fibres like cotton, silk, wool and flax were used.

Later due to improvement in science and technology, synthetic fibres have been developed, which leads to engineer fibres as per requirements of the end use.

A fibre or textile fibre can be defined as the unit of mass which is capable of being spun into a yarn or made into a fabric by bonding or interlacing in a variety of methods including weaving, knitting, braiding, felting, twisting or webbing and which is the basic structural element for textile products. It is the smallest textile component, which may be man-made or natural. They have length at least 100 times to that of their diameter or width.

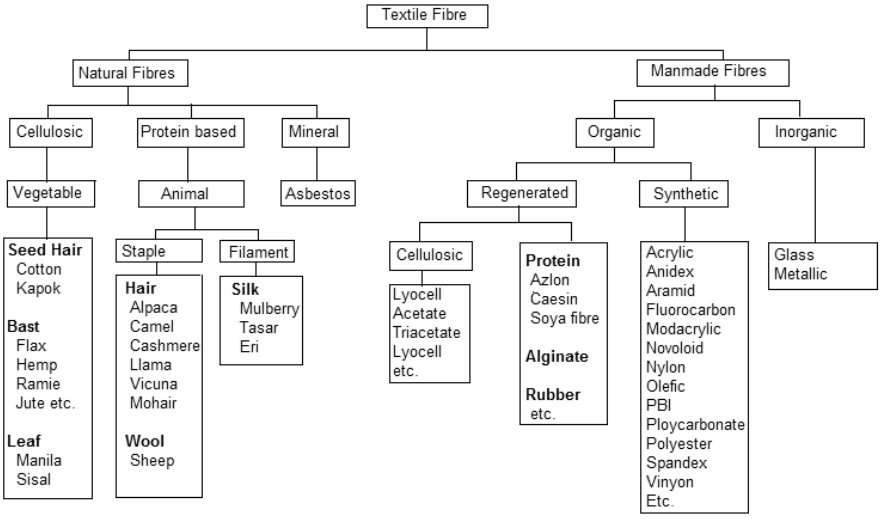
1.1.1 Classification of fibres

Fibres can be classified as follows:

1. Natural fibres
   (a) Animal fibres
   (b) Vegetable fibres
   (c) Mineral fibres
2. Man-made fibres
   (a) Organic fibres: regenerated fibres and synthetic fibres
   (b) Inorganic fibres

Fibres can also be classified based on type (natural and manufactured), length (short staple, long staple and continuous), size (ultrafine, fine, regular and coarse), etc.

Figure 1.1 summarizes the classification and examples.



Note: PBI, polybenzimidazole.

Figure 1.1. Classification and examples of fibres

1.2 Natural fibres

Any hair like raw material directly obtainable from an animal, vegetable or mineral source that can be convertible after spinning into yarns and then into fabric. Natural fibres divided into three categories based on the source of material:

1. Plant
2. Animal
3. Mineral

1.2.1 Vegetable fibres

They can be further classified as:

(a) Seed fibre occurring on the seed, e.g., cotton, milk weed, kapok, cattail.

(b) Bast fibres (phloem fibre), e.g., flax, ramie, hemp, jute, sunn, kenaf, urena.

(c) Tendon fibre from stem or leaves, e.g., abaca, pineapple, manila hemp, sisal hemp, palm, New Zealand flax, yucca, palma istle, etc.

(d) Fibre occurring around the trunk, e.g., hemp palm.

(e) Fibre of fruit/nut shells (coconut fibre – Coir).

Cotton and linen are the most important among them (Table 1.1).

Table 1.1. Vegetable fibres of commercial interest

Commercial name	Source	Botanical name	Grown area
		Bast or soft fibres	
China jute	Abutilon	*Abutilon theophrasti*	China
Flax		*Linum usitatissimum*	North and south temperate zones
Hemp		*Cannabis sativa*	All temperate zones
Jute		*Corchorus capsularis*	India
Kenaf		*Hibiscus cannabinus*	India, Iran, CIS, South America
Ramie		*Boehmeria nivea*	China, Japan, United States
Roselle		*Hibiscus sabdariffa*	Brazil, Indonesia (Java)
Sunn		*Crotalaria juncea*	India
Urena		*Urena lobata*	Zaire, Brazil
Abaca		*Musa textilis*	Borneo, Philippines, Sumatra
Cantala		*Agave cantala*	Philippines, Indonesia
Caroa		*Neoglaziovia variegata*	Brazil
Henequen		*Agave fourcroydes*	Australia, Cuba, Mexico
Istle		*Agave* (various species)	Mexico
Mauritius		*Furcraea gigantea*	Brazil, Mauritius, Venezuela, Tropics
Phormium		*Phormium tenax*	Argentina, Chile, New Zealand, India, West indies
Pineapple	Pina	*Ananas comasus*	Hawaii, Philippines, Indonesia, India, West Indies
Sansevieria		*Sansevieria* (entire genus)	Africa, Asia, South America
Sisal		*Agave sisalana*	Haiti, Java, Mexico, South America

Commercial name	Source	Botanical name	Grown area
		Seed hair fibres	
Coir	Coconut husk	*Cocos nucifera*	Tropics, India, Mexico
Kapok		*Ceiba pentandra*	Tropics
Cotton		*Gossypium* sp. Cotton.	United States, Asia, Africa
Milkweed		*Chorisia* sp.	North America
		Other fibres	
Broom root	Roots	*Muhlenbergia macroura*	Mexico
Broom corn	Flower head	*Sorghum vulgare technicum*	United States
Crin vegetal	Palm leaf	*Chamaerops humilis*	North Africa
Palmyra palm	Palm leaf stem	*Borassus flabellifer*	India
Pissava	Palm leaf base	*Attalea funifera*	Brazil
Raffia	Palm leaf	*Raphia raffia*	East Africa

1.2.2 Fibres of animal origin (natural protein fibres)

1. Animal hairs, e.g., wool (sheep), specialty hairs like alpaca, camel, cashmere, guanaco, llama, mohair (angora goat), vicuna, fur fibres like mink, muskrat, angora rabbit, etc.
2. Animal secretions, e.g., silk fibre like cultivated, dupioni, tussah (wild) and spider silk.

1.3 Man-made fibres

1.3.1 Regenerated natural fibres

1. Rayon: (a) Cuprammonium Fibres, (b) Viscose Rayon, like regular and high tenacity, high wet modulus, hollow fibres.
2. Acetate: (a) Secondary Acetate, (b) Tri-Acetate.

3. Protein: (a) Casein, (b) Zein, (c) Peanut, (d) Soyabean.
4. Miscellaneous: (a) Alginate, (b) Rubber.

1.3.2 Synthetic fibres

1. Condensate polymer fibres: (a) Nylon 6.6, Nylon 6, Nylon Type 11, 6, 10, Nromatic Type (Quina), Bicomponent Nylon, (b) Aramid like Kevlar and Nomex, (c) Polyester.
2. Addition polymer: (a) Anidex, (b) Acrylics, (c) Modacrylic, (d) Novoloid, (e) Nytril, (f) Olefin Fibres like Polyethylene and Polypropylene, (g) Saran, (h) Vinyl, (i) Vinyon.
3. Elastomers: (a) Spandex, (b) Rubber, (c) Lastrile.
4. Man-made mineral: (a) Glass, (b) Metallic.
5. Others: (a) Alginate, (b) Inorganic like Avceram, Fibrefrax, Thornel, (c) Organic like Polybenzimidazole, Teflon.

2
Cotton

2.1 General

Cotton fibres are seed hairs from plants of the order Malvales, family Malvaceae, tribe Gossypieae and genus *Gossypium*. Cotton is a soft fibre that grows around the seeds of the cotton plant and is the purest form of cellulose available in nature. After flowering, an elongated seed pod or boll is formed on the cotton plant in which the cotton fibres grow and each fibre is a single elongated cell that is flat twisted and ribbon like with a wide inner hollow (lumen).

A cotton seed pod may contain about 30 seeds and each seed contains around 2000–7000 seed hairs (fibres). The function of the hair/fibre is the disbursement of the seed, by helping it to float in the air. The outer surface is covered with a protective wax-like coating which gives fibre an adhesive quality, which is about 10% of the weight of the raw fibre consists of waxes, protein, pectate and minerals, otherwise the hair contains majority cellulose.

The following species are grown commercially:

- *Gossypium arboreum* and *Gossypium herbaceum*, known collectively as 'Desi' cottons, tree cotton, are native to India and Pakistan. These rough cottons are the shortest staple cottons cultivated (ranging from 3/8 to 3/4 in. [9.5–19 mm]) and are coarse (micronaire value >6.0) compared with the American Upland varieties. *G. herbaceum*, the original cotton of India, averages 1.2–1.8 m (3.9–5.9 ft) in height. The fibre is greyish white and grows from a seed encased in grey fuzz fibres (Fig. 2.1).
- *Gossypium barbadense*, originally of early South American origin, has the longest staple length and is commonly referred to as 'extra long staple' cotton. It is known as American Pima, Creole, Egyptian, or sea island cotton, native to tropical South America. The fibre is long and fine with a staple length usually greater than 1 3/8 in. (35 mm) and a micronaire value of below 4.0.
- *Gossypium hirsutum* is a upland cotton, native to Central America, Mexico, the Caribbean and Southern Florida, most commonly grown species in the world. The lengths, or staple lengths, of the upland

cotton fibre vary from 7/8 to 1 1/2 in. (22–36 mm), and the micronaire value (an indicator of fibre fineness and maturity but not necessarily a reliable measure of either) ranges from 3.8 to 5.0. *G. hirsutum* is a shrubby plant that reaches a maximum height of 1.8 m (5.9 ft) and is used in apparel, home furnishings and industrial products.

- *Gossypium peruvianum* and *Gossypium purpurascade* are not of much commercial importance (Fig. 2.2).

The cotton plant is a tree or a shrub that grows naturally as a perennial, but for commercial purposes, it is grown as an annual crop. Botanically, cotton bolls are fruits.

Cotton is a warm-weather plant, cultivated in both hemispheres, mostly in North and South America, Asia, Africa and India (in tropical latitudes). Mostly it is cultivated in the northern hemisphere. It is primarily grown between 37° N and 32° S but can be grown as far north as 43° N latitude in Central Asia and 45° N in mainland China. Cotton is cultivated in North and South America, the Middle East, Africa, India, China and Australia.

Recently cotton production is being shifted to more environmentally friendly techniques such as organically produced cotton. Cotton grown without the use of any synthetically compounded chemicals (i.e., pesticides, fertilizers, defoliants, etc.) is considered as 'organic' cotton. It is produced under a system of production and processing that seeks to maintain soil fertility and the ecological environment of the crop. To be sold as organic, it must be certified. Certified organic cotton was introduced in 1989–1990 and over 20 countries have tried to produce organic cotton. Since 2001, Turkey has been the largest producer of organic cotton. The top organic cotton growing countries are: Turkey, India, China, Syria, Peru, the United States, Uganda, Tanzania, Israel and Pakistan.

Gossypium barbadense

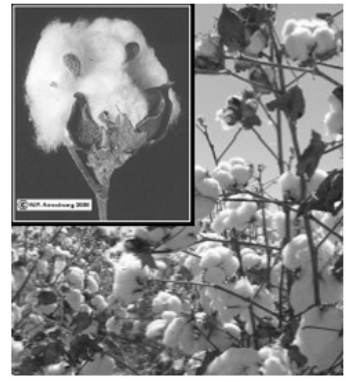
Gossypium herbaceum

Figure 2.1. Cotton of commercial importance

Cotton fibre can be classified in to three categories depending on the fibre length

1. *Long staple* – Plants with a staple length of between 30 and 65 mm. Staple cottons, well-known types such as Egyptian and Sea Island, are included in this group. Long staple cotton represents 3–5% of the world's production and are used for delicate fabrics with specific weight of less than 100 g/m^2 in the production of high-quality shirts and blouses, the best quality bed linen, underwear, etc.
2. *Medium staple* – Fibres with a staple length of between 20 and 30 mm. These medium length fibres are the most common form of cotton. Medium staple cotton (about 85% of the world production and are used in for the production of bed linen, table cloths, good quality denim (jeans) cloth as well as underwear. It is grown in Central *Asia*

Gossypium hirsutum



Gossypium arboreum

Gossypium peruvianium

Gossypium purpurascens ;

Figure 2.2. Common cotton varieties

(Uzbekistan, Tajikistan, Kazakhstan and Turkmenistan), West Africa (Chad, Mali, Ivory Coast and Burkina Faso), Europe (Greece and Spain), the Middle East (Turkey, Syria), the United States, Brazil and Pakistan.

3. *Short staple* – Fibres with a staple length of less than 20 mm from coarse, lower grade cotton, which is grown in Central Asia (Uzbekistan, Tajikistan, Kazakhstan and Turkmenistan), the United States and India. Short staple cotton is used especially for the production thick fabrics with specific weight greater than 250 g/m^2, for example, for denim, drill, flannel for work clothes, upholstery and carpets.

It has 8% moisture regain. (Raw conditioned 8.5%, saturation 20–25%, mercerized cotton 8.5–10.3%.) The fibre contains 90% cellulose and it is arranged in a way that gives cotton unique properties of strength, durability and absorbency. It is fresh, crisp, comfortable, absorbent and flexible, and it has no pilling problems and has good resistance to alkalis.

Harvesting: Harvesting is one of the final and most important steps in the production of a cotton crop, as the crop must be harvested before the inclement weather can damage the quality and reduce the yield (Table 2.1). Because of economic factors, virtually the entire crop (>99%) in the United States and Australia is harvested mechanically (Fig. 2.3). In rest of the world (~75%), hand harvesting of cotton, one boll at a time, is still quite prevalent, particularly in the less developed countries and in countries where the labour is cheaper.

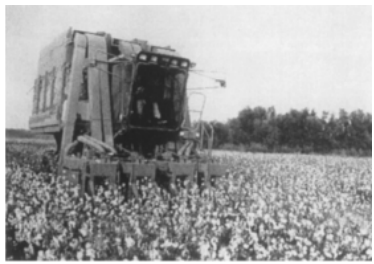
Table 2.1. Harvesting time of different geographical regions and countries of the world

Geographical region	Country	Harvesting season
North and Central America	USA	July–January
	Mexico	June–January
	Guatemala	November–March
South America	Brazil	August–January or February–May
	Argentina	February–June
	Paraguay	February–June
	Columbia	July–September or December–March
	Peru	February–October

Geographical region	Country	Harvesting season
	Venezuela	February–May
Europe	Greece	September–November
	Spain	September–November
	Uzbekistan	September–November
	China	September–November
	India	July–January or December–May
Asia and Oceania	Pakistan	September–February
	Turkey	September–December
	Australia	April–June
	Iran	October–December
	Syria	September–November
	Egypt	September–October
	Sudan	January–April or September–May
Africa	S. Africa	April–May
	Ivory Coast	October–January
	Tanzania	May–July
	Nigeria	December–February

Picking: The process of plucking cotton bolls from cotton plant is called picking.

Hand harvesting



Mechanical harvesting

Figure 2.3. Types of harvesting

Figure 2.4. Spotting

Spotting: After seed cotton is collected immature bolls are discarded (Fig. 2.4).

Figure 2.5. Ginning

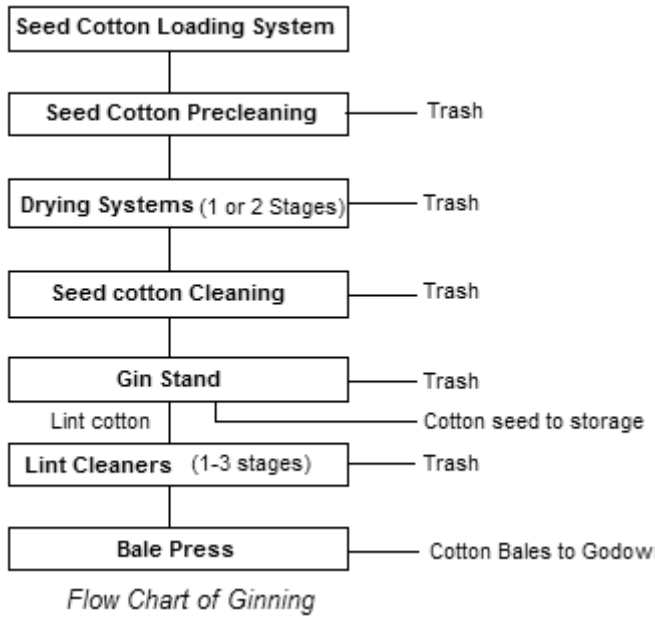
Ginning: The process of separating lint from the seed is called ginning. It is performed most often by mechanical means (Fig. 2.5). Ginning operations, which are considered a part of the harvest, are normally considered to include conditioning (to adjust moisture content), seed–fibre separation, cleaning (to remove plant trash) and packaging (Fig. 2.6).

Baling: After ginning, staple fibres are compacted by mechanical means. This is called Baling.

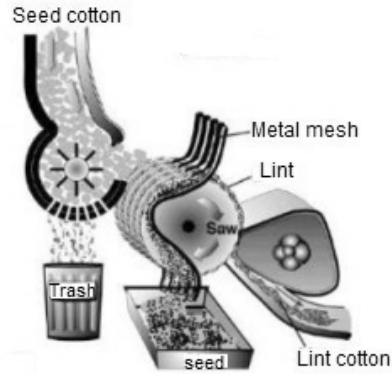
Spinning: It is the process of making yarns from unbundled fibres.

The process of spinning consists of the following steps:

- Upon arrival at the spinning mill, cotton bales are sampled according to lint quality and origin to ensure yarn homogeneity.
- They are then opened to make the lint fluffy by passage though bale openers.



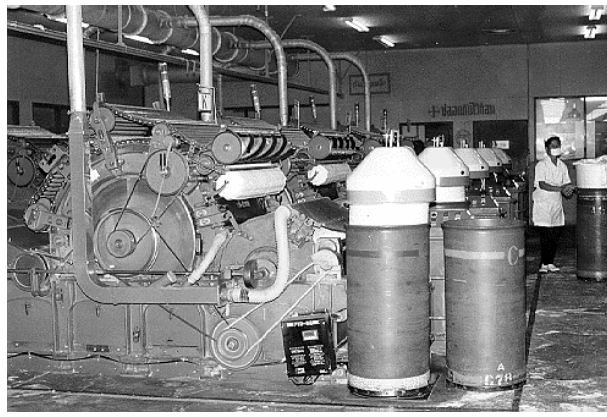
Flow Chart of Ginning



Schematic representation of Cotton Ginning

Figure 2.6. Ginning - the complete process

- *Cleaning*: Bale fibres are usually fed to air-jet (vortex) cleaners to remove extraneous matter from cotton lint.
- Carding separates fibres from each other, straightens fibres, aligns and condenses them into a single continuous strand and removes impurities (Fig. 2.7).



Carding

Combing

Figure 2.7. The process of carding and combing

- A sliver of approximately 1-m width is then obtained which is fed to several rubber rollers rotating at increasingly higher speed.
- *Bleaching*: It done using either hypochlorite or peroxide.
- Several slivers are drawn and twisted together to form the final yarn.

Cotton has poor wrinkle resistance, shrinkage, poor acid resistance, less abrasion resistance, susceptible to damage by moths and mildew, needs lots of maintenance and stains are difficult to remove. Its fibre length ranges from 1/2 to 2 in. It has 10% increase in strength when wet. It has a density of 1.54–1.56 g/cm^3. It has a twisted tube shape.

2.2 Structure of cotton fibre

As mentioned earlier, cotton fibre consists of approximately 95% cellulose. The structure of cotton cellulose is a linear polymer of β-D-glucopyranose. The noncellulosic constituents of the fibre are located principally in the cuticle, in the primary cell wall and in the lumen. Cotton fibres that have a high ratio of surface area to linear density generally exhibit a relatively higher noncellulosic content (Table 2.2).

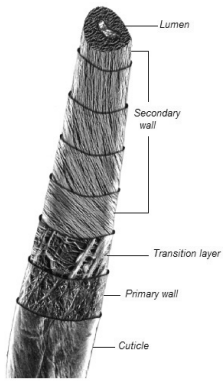
Table 2.2. Typical composition of cotton fibres

Constituent	Composition (% by dry weight)	
	Typical %	Average %
Cellulose	95	88.0–96.0
Protein (% Nx6.25)	1.3	1.1–1.9
Pectic substances	0.9	0.7–1.2
Ash	1.2	0.7–1.6
Wax	0.6	0.4–1.0
Total sugars	0.3	0.1–1.0
Organic acids	0.8	0.5–1.0
Pigment trace	Trace	Trace
Others	1.4	1.1–1.5

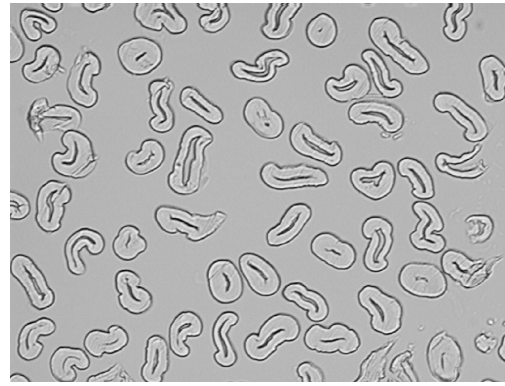
The noncellulosic constituents include proteins, amino acids, other nitrogen containing compounds, wax, pectic substances, organic acids, sugars, inorganic salts and a very small amount of pigments. After cellulosic component, the major constituent is nitrogenous compounds which are normally expressed as protein. Most of the nitrogenous material occurs in the lumen of the fibre, most likely as protoplasmic residue and a small percentage from the primary wall. Underlying the waxy cuticle is the primary cell wall, which is composed of two distinct layers. The outermost layer is comprised primarily of pectin substances (usually designated as pectin) in the form of free pectic acid (linear polymer of (1→4)-D-galacturonic acid). The innermost layer is comprised of hemicelluloses, primarily in the form of xyloglucan and cellulose. Soluble sugars (about 0.1–1.0% of fibre dry weight) found on cotton originate from two sources: metabolic residues (plant sugars) located within the dried lumen and the outer fibre surface and insect sugars (insect 'honeydew' excretion) found on the outer surface of the fibre. Cotton wax (about

0.4–1.0% of fibre dry weight) comprises the cuticle on the outer surface of the fibre. The natural wax content serves as a protective barrier both to water penetration and to microbial degradation of the underlying polysaccharides. The wax serves as a lubricant that is essential for proper spinning of cotton fibre into yarn. The quantity of wax increases with the surface area of the cotton, and the finer cottons tend to have a larger percentage of wax. The wax is a mixture of high molecular weight, primarily long-chain saturated fatty acids and alcohols (with even numbers of carbon atoms, C_{28} to C_{34}), resins, saturated and unsaturated hydrocarbons, sterols and sterol glucosides, including montanyl triacontanoate (10–15%), montanol (25%), 1-triacontanol (18%) and β-sitosterol (10%) (Fig. 2.8).

Organic acids (0.5–1.0% of fibre dry weight) in the raw fibre, exclusive of pectic acid, are primarily 1-malic acid (up to 0.5%) and citric acid (up to 0.07%), are present in the lumen as metabolic residues and are removed during the normal scouring and bleaching due to their high water solubility. The inorganic salts (phosphates, carbonates and oxides) and salts of organic acids present in the raw fibre are reported as percent ash (about 1.2% of fibre dry weight) and expressed as the oxides of the elements present (excluding chlorine, which is expressed as such). The amounts of these cations present on the



Cotton fibre bundle cross section



Cross sections of cotton fibres

Figure 2.8. Structure of cotton fibre

cotton fibre vary considerably because of maturity differences, environmental factors (e.g., rainfall) and agricultural practices, as well as the field and the handling procedures that affect deposition of material (plant parts and soil) on the fibre. During the production of cotton, the plant absorbs potassium and other metals as normal nutrients.

2.2.1 Metal content in cotton

Table 2.3. Metal content in cotton

Metal	Content in ppm
Potassium	2000–6500
Magnesium	400–1200
Calcium	400–1200
Sodium	100–300
Iron	30–90
Manganese	1–10
Copper	1–10
Zinc	1–10
Lead	n.d.
Cadmium	n.d.
Arsenic	Trace (<1)b

Metals are incorporated from the soil into plants as natural constituents. In addition to metals absorbed by plant tissue, soil and plant parts may be deposited directly onto the lint especially during harvesting. Ca, P, S, K and Fe are plant part elements and Mg, Al, Si, Fe, Cr, Se, Hg, Ni, Cu, K and Ca are soil elements. The metals are removed for the most part by proper scouring and bleaching processes that are used to prepare the fibre and fabric for dyeing and finishing (Table 2.3).

The mature cotton fibre has a noncellulosic covering called the cuticle that contains waxes, pectins and proteins. This cuticle is intermingled with the primary wall. The structure of the primary wall, which changes substantially during fibre development, is not well understood. It is responsible for maintaining the integrity of the fibre and may account for much of the strength of the cotton fibre. Most of the cuticle is dissolved and removed by industrial scouring of fabric, but it has important functions during spinning of the fibres into yarn and during weaving the yarn into fabric. One reason for scouring is that the waxes block access to the interior of the cotton fibre for molecules such as dyes.

Understanding of fibre structure requires knowledge of the structure of the cellulose molecule, the structure and perfection of its crystalline arrays, the packing of these arrays (elementary fibrils) into microfibrils, and then the arrangement of these microfibrils in the primary and secondary cell walls. The noncrystalline material is also important. Once the cellular fluid dries

after the cotton boll opens, which is called lumen, it collapses leaving fibre cross sections with irregular, kidney bean shapes, which contain biological material. That material constitutes a small percentage of the total dry weight.

2.2.2 Chemical structure of cotton

As explained earlier cellulose constitutes around 95% of cotton fibre. Hydrolysis and oxidation studies point to the fact that the cellulose in cotton fibre is a 1-4-linked linear polymer of β-D-glucopyranose. These monomers are linked together by elimination of one molecule of water between the hydroxyl groups attached to the number 1 carbon atom of one glucose molecule and the number 4 carbon atom of another (Fig. 2.9).

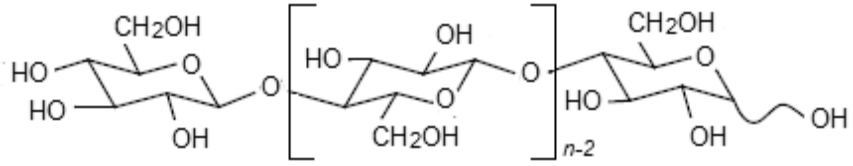


Figure 2.9. Chemical structure of cotton

The molecular cellulose chains have varying lengths. Measurements of the chain length require that cotton be in solution. Solvents for this purpose include cuprammonium hydroxide solution, phosphoric acid, nitric acid, quaternary ammonium bases, cadmium ethylenediamine hydroxide, cupriethylenediamine hydroxide, *N*,*N*-dimethylacetamide and lithium chloride (DMAC LiCl), and 1,3-dimethyl-2-imidazolidinone (DMI) and lithium chloride. DMAC LiCl, when used in conjunction with gel permeation chromatography, provides both the weight (M_w) and number average (M_n) molecular weight of cellulose in a nondegrading solvent without derivatization. In undegraded cotton fibre, the molecular chain length (degree of polymerization [DP]) may be higher than 20,000 monomeric D-glucopyranosyl units. This corresponds to a molecular weight of 3,240,000 Da. Each cellulose chain has a reducing end (O1-H) and a nonreducing end (O4-H). Reducing ends are especially reactive, but they are present in such small amounts in cellulose that they are often ignored.

Fibre strength cotton is influenced by the structural organization of the cellulose chains. Molecular weight of a polymer is one of the most important influences on its physical properties, and the determination of molecular weight distribution is critical for predicting performance of a polymer. For polymers, higher molecular weight and narrower molecular weight distribution are positively correlated with increased strength. Unfortunately, polymer

characterization techniques generally depend upon dissolving of the polymers. Attempts to identify the true molecular weight of native cellulose have been limited mostly because cellulose is difficult to dissolve. During development, the composition of the cell wall of the cotton fibre changes continuously, ending with the cessation of the fibre's metabolic activity (Fig. 2.10).

2.2.3 Molecular physical structure

The physical and to some extent chemical characteristics of cotton fibre are influenced by the molecular and supramolecular arrangement of the cellulose molecule chains. They associate each other by forming intermolecular hydrogen bonds and hydrophobic bonds. They coalesce to form microfibrils also called crystallites. There are several different forms or polymorphs (cellulose I–IV and X with recent subclasses Iα and Iβ), depending on the source and treatment. Native cotton is cellulose I. In cotton, the microfibrils can organize into macrofibrils 60–300 nm wide. The macrofibrils are organized into fibres. Cotton fibres have a complex, reversing, helical arrangement of macrofibrils. There are both different unit cells and different packing arrangements in the unit cell. Mercerization with caustic soda or ammonia can convert cellulose I partially to cellulose II and III.

The cotton fibre is a porous, hydrophilic material that accounts for the comfort of cotton clothing. The moisture absorbed from the atmosphere and held under ambient conditions is expressed either as moisture content (amount of moisture as the percentage over the oven-dried weight) or more commonly as moisture regain (amount of moisture as a percentage of the oven-dry sample). Under ordinary atmospheric conditions, moisture regain is 7–11%. Upon immersion in liquid water, the cotton fibre swells and its internal pores fill with water. Pure cotton holds a substantial percentage of its dry weight in water under conditions of centrifugation. The values are ~30% for water of imbibition and 50% for the water retention. Centrifugation conditions are less severe in the latter case. Pores accessible to water molecules are not necessarily accessible to chemical agents. Many uses of cotton, e.g., easy care fabric, depend on chemical modification to impart the desired properties.

Preparation processes of cotton materials slightly increase the accessibility to internal volume, liquid ammonia treatment of the scoured–bleached cotton decreases it slightly, caustic mercerization substantially enhances, and crosslinking to impart durable press properties reduces the accessibility to internal pore volume substantially.

2.2.4 Chemical reactions

Even though 2-OH, 3-OH and 6-OH groups of the cellulose structure (see Fig. 2.9), but the regular occurrences of intermolecular and intramolecular hydrogen bonds in the crystalline regions of cotton cellulose render the involved hydroxyl groups unavailable to chemical agents under mild reaction conditions. Thus chemical agents that have access to the interior pores of the cotton fibre thus find potential reactive sites unavailable for reaction. The order of decreasing availability of hydroxyl groups in cotton is 2-OH > 6-OH > 3-OH. These are the main positions where reactions of dyes, crosslinking, reactive dyes (esterification), etc., take place.

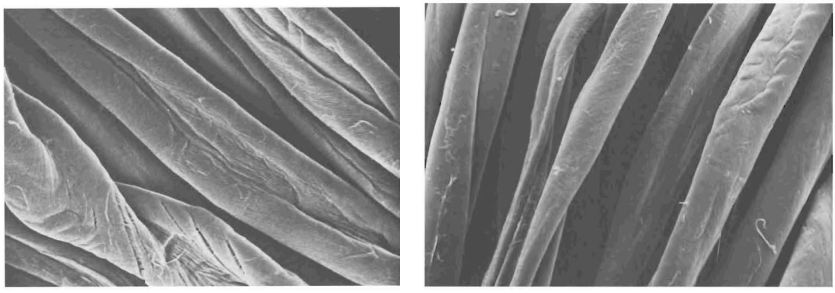


Figure 2.10. Scanning electron microscopic view of cotton unmercerized (LHS) and mercerized (RHS) (×1000)

Cellulose is readily attacked by oxidizing agents, such as hypochlorites, chlorous, chloric and perchloric acids, peroxides, dichromates, permanganates, periodic acid, periodate salts and nitrogen tetroxide.

2.2.5 Action of heat

Heat can dehydrate and decompose cotton. Heating cotton cellulose up to 120°C drives off moisture without any loss of strength. Heating to a higher 150°C has been shown to reduce solution viscosity, indicative of lowered molecular weight and tensile strength. Between 200°C and 300°C, volatile products and liquid pyrolyzate, mainly 1,6-anhydro-β-D-glucopyranose, commonly known as levoglucosan, evolve. At 450°C, only char remains.

2.2.6 Cotton fibre and yarn quality correlation

Cotton from various origin will have different characteristics, which may or may not be able to be generalized and is very confusing for a cotton buyer or

a yarn manufacturer. Essential characteristics of cotton quality and characteristics of yarn quality are given from detailed experimental investigations. Some of the important conclusions which help to find correlation between yarn quality and cotton fibre quality are given below:

- *Staple length*: If the length of fibre is longer, it can be spun into finer counts of yarn which can fetch higher prices. It also gives stronger yarn.
- *Strength*: Stronger fibres give stronger yarns. Further, processing speeds can be higher so that higher productivity can be achieved with less end breakages.
- *Fibre fineness*: Finer fibres produce finer count of yarn and it also helps to produce stronger yarns.
- *Fibre maturity*: Mature fibres give better evenness of yarn. There will be less end breakages. Better dyes' absorbency is additional benefit.
- *Uniformity ratio*: If the ratio is higher, yarn is more even and there is reduced end breakages.
- *Elongation*: A better value of elongation will help to reduce end breakages in spinning and hence higher productivity with low wastage of raw material.
- *Nonlint content*: Low percentage of trash will reduce the process waste in blow room and cards. There will be less chances of yarn defects.
- *Sugar content*: Higher sugar content will create stickiness of fibre and create processing problem of licking in the machines.
- *Moisture content*: If moisture content is more than standard value of 8.5%, there will be more invisible loss. If moisture is less than 8.5%, then there will be tendency for brittleness of fibre resulting in frequent yarn breakages.
- *Feel*: If the feel of the cotton is smooth, it will be produce more smooth yarn which has potential for weaving better fabric.
- *Class*: Cotton having better grade in classing will produce less process waste and yarn will have better appearance.
- *Grey value*: Reading of calorimeter is higher, which means it can reflect light better and yarn will give better appearance.
- *Yellowness*: When value of yellowness is more, the grade becomes lower and lower grades produce weaker and inferior yarns.

- *Neppiness*: Neppiness may be due to entanglement of fibres in ginning process or immature fibres. Entangled fibres can be sorted out by careful processing but neppiness due to immature fibre will stay on in the end product and cause the level of yarn defects to go higher.

3
Bast Fibres

Bast fibre or skin fibre is a fibre collected from the phloem (the bast surrounding the stem of a certain plant).

The bast fibres have often higher tensile strength than other kinds and are ropes, yarn, paper, composites and burlap. A special property of bast fibres is that the fibre at that point represents a weak point. They are obtained by the process called retting. Bast fibres can be of two types:

Low lignin content – linen or flax (raw and bleached) and ramie

High lignin content – jute, hemp

3.1 Flax or linen

Flax is considered to be the oldest fibre in the Western world and CIS (formerly USSR) grows most of the flax fibre. Linen has been gradually loosing its position as an apparel fabric since 1950s, but the emergence of linen fibre as a component of blends and the importance as a cool fibre has stimulated considerable interest in the fashion world now (Fig. 3.1).

Linen or flax fibres are extracted from the stem or bast of flax plant (*Linum usitatissimum* L.). Fibres held together by gummy substance called as *pectin.* Flax fibre basically composed of cellulose. Flax is difficult to grow because of the soil preparation required before sowing, and the heavy applications of artificial fertilizers required. After a slow initial growth, the plants grow as rapidly as 1 inch/day for 30–40 days. Blossoms then begin to develop and stem growth ceases.

Flax is normally a 3-month crop, although this growing time varies with climatic and other growing conditions. It is attacked by several fungal and viral diseases, usually kept under control by chemical treatments of the seed or by cultivation of resistant varieties. Harvesting is usually carried out by pulling the plant from the ground. Pulling is considered superior to cutting since flax deteriorates at the cut. Yields of fibre per acre vary from 200 to 360 kg. Major flax-producing countries are Belgium, Scotland, France, Russia and Germany. Countrai flax produces the finest and strongest yarn from Belgium. Flax plant is also cultivated for the flax seed (oleaginous flax linseed) and cultivated in counties like Canada, Argentina, the United States, Egypt, India, etc. There are different varieties of flax used for fibre production and oil production.

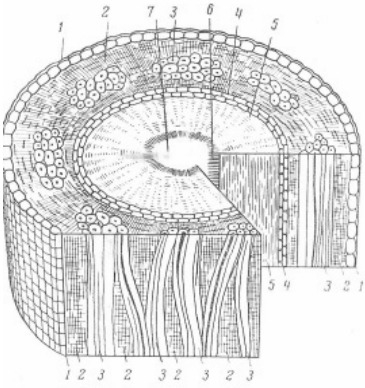

Flax plant


Flax seed


Harvesting flax


Ultimate Flax fibre (enlarged)

Figure 3.1. Flax plant and fibre



Schematic diagram of the cross section

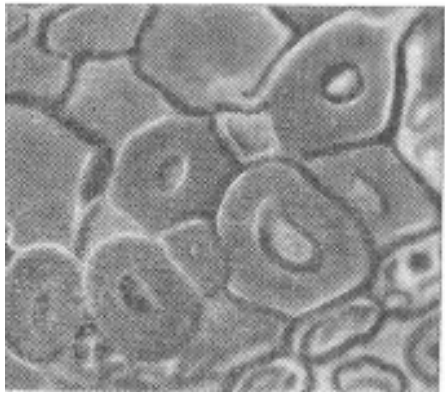

Cross section of flax fibre

Figure 3.2. Flax stem: 1. Epidermis, 2. Parechyma, 3. Bast bundles, 4. Cambium, 5. Woody tissue, 6. Pith, 7. Lumen

Inside the stalk of a flax plant, the fibres carry nutrients and water to the leaf. They are found as individually separated filaments of different lengths, which vary according to the height at which the leaf is situated in the plant. Each filament is composed of a number of single tapered-ended fibre cells evenly joined lengthwise, so that each cell underlays 50% of the preceding one and overlaps 50% of the following one, tightly tied together all along, to form single filaments of the same regular fine thickness, but of different lengths. The fibres are held together by tissues to form the stem of the plant. Like any other bast fibres the main component of the fibres is cellulose, while secondary components are waxes, fats, hemicellulose, lignin and pectin (Figs. 3.2 and 3.3).

During harvesting the flax plant is pulled out from the soil and not cut. Next process is called turning and deseeding which can be done many days after harvesting, for example, after 10 days in case of dew retting, and then bundled or baled.

Like other bast fibres, flax must be separated from the stalks by retting whereby the pectin which binds the fibres together is removed by bacterial

action. Water retting, which is essentially bacterial, is practiced in areas such as the Philippines, Taiwan and China. The bacteria take part in this process are *Clostridium* sp., *Clostridium butiricum*, *Granulobacter pectinovorum*, *Clostridium felsineum*, *Clostridium guerfelli* and *Bacillus amylobacter*. Modern times to hasten the bacterial action and decomposition and to stimulate the multiplication of the bacteria, the water heated to 30°C or by adding active bacteria cultures to the water, or even by adding pure enzymes. The process depends very much on the temperature and chemical nature of the water, but takes only 6–8 days under controlled temperature conditions.

Most of the crop grown in Russia and the United States is dew retted, which is predominantly fungal as against bacteria in case of water retting. In this method, the harvested flax straw is left in the field and allowed to remain until the combined action of the moisture from dew and microorganisms makes separation of the fibres possible. The main fungi taking part in the dew retting are *Alternaria alternata*, *Alternaria linicola*, *Cladosporium herbarum*, *Fusarium nivale*, *Cephalosporium* sp. and other, mainly pectinolytic and cellulolytic species. Dew retting has many advantages, even though it is a slow process like, homogeneity of the resulting fibre, preserve the strength of the yarn, fibre separation is easier, even preparation of the fibre helps in further processing like dyeing, etc. Main disadvantages are slow process and difficulties in spreading on the field evenly and properly aligned to get the homogenous retting process which will affect the colour and quality.

After removal of the stalks from the retting medium, thorough drying is necessary to prevent further fermentation. As a result of such retting process, the pectins glueing the bast bundles to the other parts of the stems are disintegrated, and the bundles are easily separated by subsequent treatment in breaking and scutching machines. On the contrary, excessively strong biochemical action may reduce the strength of the lamellae binding the ultimate fibres together and the technical fibre disintegrates into elementary fibres forming the so-called cotton-like flax stock (Fig. 3.4).

The retted and dried fibres are removed from the woody remainder of the stem by the process of scutching, in which the stems are first broken by passage through a series of fluted metal rollers, and the fine pieces of the woody portion of the straw, called shives, are beaten out. About a tenth of the original flax stem is useful fibre.

Cotton-like flax fibre is sometimes used in blends with cotton for manufacturing fabrics. However, it is obtained not by biochemical destruction of valuable technical fibre, which would not be feasible, but from the wastes of the primary treatment of flax (in which a certain part of bast fibres is eliminated together with shive). The bast fibre may be transformed into cotton-like fibre by boiling in alkali solutions. There is also a mechanical process of extracting technical fibre from bast stems. This process is used for obtaining

green bast. Chemical analysis of cotton is carried out on natural untreated fibre, while the analysis of flax is usually made on a half-ready product obtained from technical fibre by the wet spinning method (see Table 3.1). The content of lignin in flax fibre can be as high as 5%. It can be seen from the table that the content of cellulose in flax yarn is lower than in cotton, and the amount of impurities is greater.

Table 3.1. Chemical analysis of flax fibre

Yarn thickness tex and (count)	Cellulose	Wax-like substances	Lignin	Proteins	Pectins	Ash	Total	Unidentified impurities
68 (14.5)	73.93	2.39	2.88	2.29	2.04	1.06	84.59	15.41
56 (18)	75.8	2.9	2.7	2.52	2.34	0.86	87.12	12.88
36 (28)	78.82	1.68	2.05	2.1	1.86	0.71	87.22	12.78

The ultimate fibres of flax consist mainly of cellulose. The middle lamellae mainly consist of pectins; some lamellae also contain lignin, which is confirmed in microscopic examination of fibre cross sections by the colouring of lignin by phloroglucinol and hydrochloric acid. Lignin, though in a less amount, is contained in the flax fibre proper, particularly in the lower portions of the stem as has been found by several investigators by means of microchemical reactions and luminescent analysis of fibre and stem cross sections. Flax fibres are multicellular, with each cell having tapering ends and a narrow lumen. The fibres show longitudinal striations and nodes. The ultimate fibres are composed of elementary fibrils (microfibrils), which are spirally arranged.

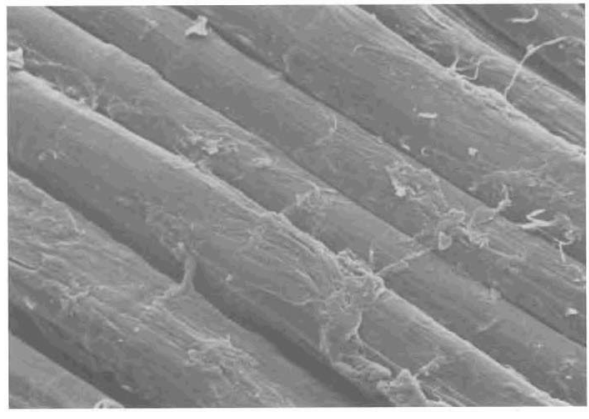


Figure 3.3. Electron microscopic view of the flax fibre (×1000)

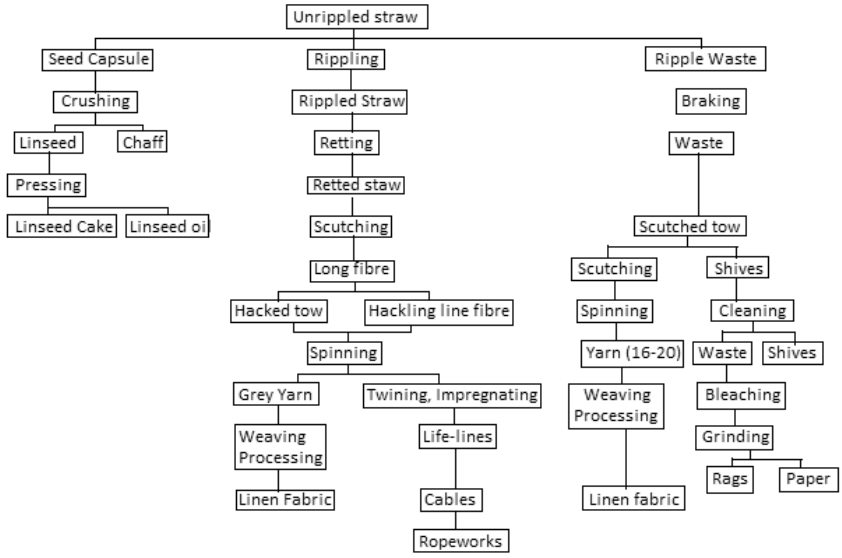


Figure 3.4. Processes involved in flax fibre production

The fibrils are held together by a bonding or gummy substances. The unretted flax contains about 16.7% hemicellulose, 1.8% pectins, 2% lignin and 1.5% fats and waxes. The polymer of flax consists with a degree of polymerization of about 18,000 cellobiose units. Flax is an assembly of ultimates cemented together within the fibres and an assembly of these fibres into bundles. The physical structure of flax ultimate fibres is characterized by displacements or 'breaks' in their surface layers (see Fig. 3.2). These displacements are the result of the multiple deformations to which bast bundles are subjected in processing, beginning with the removal of the flax stem.

These assemblies are prone to discolouration. It is the structure which makes linen feel like linen. Flax has relatively high strength. Disruption of structure by, for example, scouring referred to as cottonization.

A fibre obtained from the stem is of very high quality and is used in making cloth, sails, nets, paper, insulating material, etc. The best quality flax fibre is used for making cloth. It is soft, lustrous and flexible, although not so flexible or elastic as cotton or wool. It is stronger than cotton, rayon or wool, but weaker than ramie. Lower quality fibre is used in manufacturing of towelling, matting, rugs, twines, canvas, bags and for quality papers such as printing currency notes, upholstery tow, insulating material, rugs, twine and paper.

The seed contains 38–40% of a drying oil having wide range of applications. The paint and varnish industries consume about 80% of all the linseed oil produced. The remainder is used in items such as furniture polish, enamels,

linoleum, oilcloth, printer's inks, soap making and leather. It is also used as a wood preservative and as a waterproofing for raincoats, slickers and tarpaulins.

3.2 Jute fibre

Jute is one of the cheapest natural fibres and is second only to cotton in amount produced, and variety fibres are composed primarily of the plant materials cellulose and lignin. Jute is a long, soft, shiny vegetable fibre that can be spun into coarse, strong threads.

Jute is an annual herbaceous dicotyledonous plant that grows up to a height of 2.5 m. The stems are about 1–2 cm in diameter with few branches. The colour of the stem, petiole, leaf and pod varies in different forms. Mainly two qualities namely *Corchorus capsularis* and *Corchorus olitorius* are utilized for fibre production on a commercial scale, former one is known as 'white jute' and latter one is known as 'tossa jute'. The two species differ in the quality of fibre they yield. Fibres of *C. olitorius* are frequently softer, stronger and more lustrous than those of *C. capsularis*. Jute fibre is obtained from the bast or phloem layer of the stem. It is thus a ligno-cellulosic fibre that is partially a textile fibre and partially wood. The plant and its fibre length is about 2 m. It is generally used in geo textiles. It has a good resistance to microorganisms and insects. It has low wet strength, low elongation and inexpensive to produce bags (Fig. 3.5).

Jute is an annual plant grown in countries are Bangladesh, India, Myanmar, Nepal, China, Vietnam, Thailand and Brazil. Usually harvested 110–120 after sowing when the plants are at early pod stage. This is important because

Figure 3.5. Jute plant

fibre will be weak if it is harvested before flowering and it becomes coarse and lacks lustre if harvesting is delayed. After harvesting, it is made into bundles of 10–12 kg each and left standing in the field for 3–4 days for helping in defoliation. Next the bundles are allowed to ret in water for 15–18 days after which the fibre can be separated manually. Action of bacteria during retting break down the soft tissues around the fibre bundles and the fibres. Soft water at around 34°C and pH of 6–8 gives good retting. Retting is complete when the bark separates out easily from the core. Stopping retting at the correct point is very important, as it determines the quality of the fibre. Fibres from the retted stalks is done manually (decortication) using knives. Another system of retting followed is ribbon retting, where the outer skins of the stem is removed in the form of a ribbon and retted separately. Retting in slow-flowing clean water produces the best fibre.

Instead of retting stems of the plant, another process called ribbon retting is also followed which has certain advantages. In ribbon retting, the green bark is separated in from the stem after harvesting and retted separately. Decortication of four to six stems is done together manually. This process gives can produce longer fibres and water required is much less compared to conventional process. But other disadvantages are high labour cost, loss of fibre yield (ribboning always leaves some amount of fibre stuck on the stalk 19–30%), loss in strength and entangling of the retted fibre, longer retting period, etc.

After retting, the material is washed well to remove dirt, gum, extraneous plant materials and dried in the sun.

Fibre is situated in the outer skins of the stem of the plant in the shape of spindle of 2.5 m length and 0.02 mm diametre. The fibres are joined into bundles with middle lamellae. Within the ultimate cells of a jute fibre, the ultrafine fibrils, that are purely cellulosic, are the highly ordered regions, while the inter-fibrillar regions are less ordered regions which can make room for the presence of short chain hemicellulose molecules to a larger extent and the bulky lignin molecules to a smaller extent as the bonding material of the middle lamella, providing strong lateral adhesion between the ultimates.

After retting the jute fibre basically is a compound of lignocellulose consisting of calcium, magnesium, aluminium, iron, etc., that are present either in the free state or bonded with functional groups of cellulosic chain. Chemically they are polysaccharides, also called carbohydrates (or holocellulose), and are divided into two groups: alphacellulose (58–63%) and hemicellulose (21–24%). Alphacellulose forms the bulk of the ultimate cell walls with the molecular chains lying broadly parallel to the direction of the fibre (Figs. 3.6 and 3.7). The hemicellulose and lignin, however, are located mainly in the areas between neighbouring cells, where they form the cementing material of the middle lamella, providing strong lateral adhesion between the ultimates.

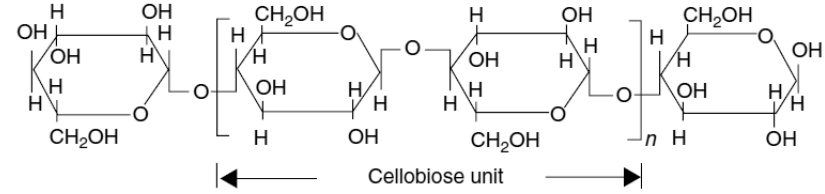


Figure 3.6. Structure of alphacellulose

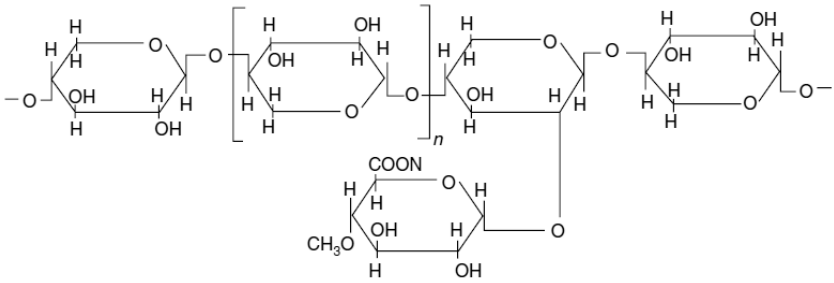


Figure 3.7. Structure of hemicellulose

The hemicellulose consists of polysaccharides of comparatively low molecular weight built up from hexoses, pentoses and uronic acid residues. Thus their three main constituents are hemicellulose-lignin 11.4–12%, alphacellulose 58–63% and hemicellulose 21–24%. In addition, analysis of the hemicellulose isolated from alphacellulose and lignin gives xylan 8–12.5%, glucoronic acid 3–4%, together with traces of araban and rhamnosan. The insoluble residue of alphacellulose has the composition glucosan 55–59%, xylan 1.8–3.0%, glucoronic acid 0.8–1.2%, together with traces of galactan, araban, mannan and rahmnosan. All percentages refer to the weight of dry fibre lignin (11.4–12%) which is not a fibrous matter and is removed by

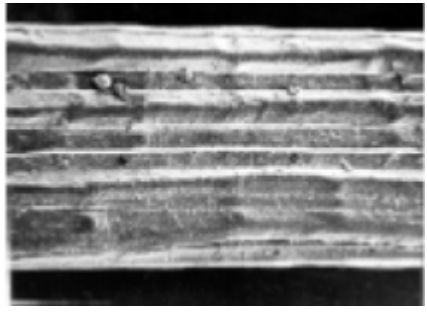


Figure 3.8. SEM view of jute fibres

chlorination by which it is converted to a soluble chlorolignin complex which is removed by a dilute alkali treatment (Fig. 3.8).

Other minor contituents (total of about 2%) are fats and waxes 0.4–0.8%, inorganic matter of 0.6–1.2%, nitrogenous matter 0.8–1.5% and traces of pigments (Table 3.2).

Table 3.2. Average physical properties of a single jute fibre

Property	Average result
Tenacity of single fibre (g/tex)	70
Linear density (tex)	1.8
Elongation at break (%)	1–2
Length breadth ratio	115–140
Specific gravity	1.5–4.0
Moisture regain at standard conditions (%)	12.5

3.2.1 Manufacture

Jute spinning system consists of two stages of carding (Breaker card and Finisher Card) forming the sliver and three stages of drawing and finally spinning stage which can be flyer spinning (or other type spinning for finer quality yarns or blends). After forming the slivers, it is passed through drawing frames in which the faller bars move on spiral screws or the push-bar method for the first stage. Slivers are doubled and fed to each drawing. The output sliver from the final drawing stage then passes to the spinning frame, where its linear density is reduced suitably for the yarn being spun, after which the required twist is inserted using an overhung flyer, with the yarn winding-onto a bobbin rotating on a dead spindle, against a friction drag. Ring or pot-spinning are also used. After the last drawing, the sliver is given a small crimp by passing through a crimp box to hold the fibre together and fed to the spinning frame (Fig. 3.9).

Jute/cotton (50/50) blended spun count of 8/10s yarn is used for making curtain fabrics, blankets, rugs, foot mats, etc. A probable spinning flow chart is given in Fig. 3.10.

Traditionally jute has been used to manufacture packaging materials like hessian, sacking, ropes, twines, carpet, backing cloth, etc., but it has been decreased over the years as it has been replaced by synthetics. Alternative use has been developed and now it is being used for products like home textiles,