CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

As the research mainly focusses on the spinnability of C/M blends in ring, compact and rotor spinning systems, literature available on the various aspects related to this area is summarized in this chapter. It mainly deals with the classification of fibres, property requirements for spinning, spinning of milkweed fibres and influence of spinning systems on the yarn structure and properties. The potential applications of milkweed fibres are also reported.

2.2 DEFINITION OF A TEXTILE FIBRE

A fibre can be defined as a “unit of matter characterized by flexibility, fineness and a high length to width ratio” (Wynne 1997). A “fibre” can also be defined as any product capable of being woven or otherwise made into a fabric. Fibres are the fundamental units or the building blocks used in the making of textile yarns and fabrics. A variety of fibres is needed to satisfy all of the many uses and the likes and needs of individuals. However, all fibres should possess certain characteristics for their commercial success such as: a high length to diameter ratio, strength, extensibility and elasticity, resistance to chemicals, heat and sunlight and ability to absorb colour.
2.3 HISTORY AND CHARACTERISTICS OF NATURAL FIBRES

Nature has provided abundance source of fibres - plant, animal, and minerals of different dimensions and properties. Historically, the natural fibres have served the mankind’s clothing needs for thousands of years. The oldest indication of fibre use is probably the discovery of flax and wool fabrics at excavation sites of the Swiss lake dwellers (7\textsuperscript{th} and 6\textsuperscript{th} centuries BC). Hemp, the oldest cultivated fibre plant, dates back to 4500 BC, which originated in Southeast Asia and spread to China. The art of weaving and spinning of linen was already well developed in Egypt by 3400 BC, indicating the fact that cultivation of flax existed even before that. Reports on spinning of cotton in India dates back to 3000 BC. The manufacture of silk and silk products originated in the highly developed Chinese culture; the invention and development of sericulture (cultivation of silkworms for raw silk production) and of methods to spin silk dates back to 2640 BC (Fisher 1981).

With improved transportation and communication, highly localized skills and arts connected with textile manufacture spread to other countries and were adapted to local needs and capabilities. Meanwhile, new plant fibres were discovered and explored for their possible usage. Industrial revolution during 18\textsuperscript{th} and 19\textsuperscript{th} centuries encouraged the invention of new machineries for processing various natural fibres, resulting in tremendous increase in fibre production (Jakubowska et al 2012). The introduction of regenerated cellulose fibres followed by the invention of completely synthetic fibres challenged the monopoly of natural fibres for textile and industrial use. With advent of increasing competition from synthetic fibres, intensive research were focussed on breeding of better natural-fibre sources with higher yields, improved production, processing methods and modification of fibre, yarn or fabric properties.
Natural fibres are hair-like raw material directly obtainable from a vegetable, animal or mineral source and are convertible into nonwoven fabrics such as felt or paper or after spinning into yarns, into woven cloth. Although nature abounds in fibrous materials, especially cellulosic types such as cotton, wood, grains and straw, only a small number can be used for textile products or other industrial purposes. Apart from economic considerations, the usefulness of a fibre for commercial purposes are determined by properties such as length, strength, pliability, elasticity, abrasion resistance, absorbency and various surface properties. Most textile fibres are slender, flexible and relatively strong. They are elastic in nature due to which they stretch under tension and tend to recover on removal of tension.

2.4 CLASSIFICATION OF TEXTILE FIBRES

The textile fibres may be divided into two major groups, namely, (a) natural fibres and (b) man-made or synthetic fibres. Figure 2.1 describes the different fibre types classified under each major group (Corbman 1985; Cook 1997).

2.4.1 Natural Fibres of Vegetable Origin

The term natural fibres covers a broad range of vegetable, animal, and mineral fibres. As the name indicates these fibres are obtained from vegetable source i.e. plants and are generally comprised mainly of cellulose: examples include cotton, linen, jute, flax, ramie, sisal and hemp (Collier & Tortora 2009). Among the vegetable fibres, the most important textile fibre is cotton, which make up nearly 50% of total fibres used all over the world. Cellulose fibres are used extensively in manufacture of both paper and cloth.
Figure 2.1 Classification of textile fibres
These fibres can be further categorized into the following:

- **Seed fibres**: Fibres collected from seeds or seed coats (cotton and kapok).
- **Leaf fibres**: Fibres collected from leaves (sisal and banana).
- **Bast fibres or stem fibres**: Fibres collected from the stem or bast surrounding the stem of their respective plant. These fibres have higher tensile strength than other fibres. E.g. flax, jute, kenaf, hemp, soybean fibre and banana fibres.
- **Fruit fibres**: Fibres collected from the fruit of the plant, e.g. coconut (coir) fibre.
- **Stalk fibres**: Fibres collected from the stalks of the plant. E.g. straws of wheat, rice, barley.

Based on the part of the plant from where fibres are collected – the fibre are classified as shown in Figure 2.2.

### 2.4.2 Natural Fibres of Animal Origin

Animal fibres generally comprise proteins and are commonly made from hair or fur. Wool refers to the hair of the domestic goat or sheep, which is distinguished from other types of animal hair in that the individual strands are covered with scales and tightly crimped and the wool as a whole is coated with an oil known as lanolin, which is waterproof and dirt proof.

Other similar animal fibres include alpaca wool, llama wool and camel hair which are generally used in the production of coats, jackets, ponchos, blankets and other warm coverings. Angora refers to the long, thick, soft hair of the Angora rabbit. Silk too is an animal fibre which is obtained from spinning of cocoons of silkworm.
Figure 2.2 Classification of vegetable cellulosic fibres
2.4.3 **Natural Fibres of Mineral Origin**

Mineral fibres are naturally occurring fibres or slightly modified fibres procured from minerals. Asbestos is a natural fibre obtained from varieties of rock. It is a fibrous form of silicate of magnesium and calcium containing iron, aluminum and other minerals. It is acid proof, rust-proof, flame-proof. However, the use of asbestos is now rapidly declining due to health risks from the asbestos dust.

2.4.4 **Man-made Fibres**

These fibres are extruded from the polymers of varying chemical composition under different spinning routes, namely, dry, wet and dry-jet wet spinning.

2.5 **SEED-HAIR FIBRES**

Unlike the bast and leaf fibres, seed-hair fibres are single celled. These fibres are attached to the seeds of certain plants for aid in wind-dispersal. The more typical seed-hair fibres are all similar in morphology to cotton, with long lengths and small diameter. Cotton fibres consist of unicellular seed hairs in the bolls of cotton plant. Innumerable products are made from cotton, primarily textile and yarn goods, cordage and automobile tire cords. Short fibres that are left on the seed after processing are termed linters. Cotton linters are commercially available and are used as raw material for the manufacture of viscose rayon. These waste fibres have similar diameters to the cotton fibre, with much shorter lengths (less than 7 mm).

2.5.1 **Cotton**

The cotton plant belongs to the natural order of the mallow family. It grows in subtropical climates. Cotton is a soft, fluffy staple fibre that grows
in a protective capsule, around the seeds of cotton plants of the genus *Gossypium*. The plant is grown in more than 70 countries. The fibre most often is spun into yarn or thread and used to make different textile materials.

Raw cotton is creamy white in colour. The fibre is a single cell, which, during growth, pushes out of the seed as a hollow cylindrical tube over one thousand times as long as it is thick. The quality of the cotton depends on the staple length, the number of convolutions and the brightness of the fibre (Basra 1999). Cotton contains carbon, hydrogen and oxygen with reactive hydroxyl (OH) groups. Cotton has 2,000-12,000 glucose residues per molecule and the molecular chains are in spiral form.

2.5.2 Kapok

Kapok is a silky fibre obtained from the fruit or pods of kapok tree. Kapok, like cotton, grows in a seed pod. The kapok tree, sometimes called the silk cotton tree, is native to the tropics. The dried fibre can be easily separated from the seeds. The fibres are contained in the outer shell. When the fruit or pod ripens, the fibres which are in small clumps loosely surrounding the seeds become entirely free from the shell. Individual kapok fibres are from 1 to 1.5 cm in length (Li 1984).

Under a microscope, a kapok fibre appears as a long narrow cell with frequent folds with a thin wall and hollow structure. The walls form a smooth, closed tube with a large cavity called lumen. Each kapok fibre is coated with a waxy substance called cutine. It is the cutine and lumen which gives kapok fibre, its buoyancy. Chemically, kapok fibre consists of cellulose, although it contains polysaccharides called pentosan and an inert plastic-like material called lignin. Kapok fibres are smooth and do not contain scales. It weighs only one-eighth as much as cotton, is as warm as wool and smooth as silk (Sunmonu & Abdullahi 1981).
The kapok fibre is white and silky. The fibre has exceptional resiliency and buoyancy, but it is too brittle to be spun readily into yarns. As a result, the uses of kapok have been limited to stuffing and insulation materials. Because of its buoyancy and resistance to wetting, kapok has been used as a filling for life preservers. Having a hollow and air filled structure, kapok can remain in water for hours without an appreciable absorption of water, while holding up considerable weight. The degree of polymerization of kapok fibre is 3300, moisture regain is 10% and specific heat of fibres is 0.324 cal/g°C (Meiwu et al. 2010).

2.5.3 Milkweed Fibres

Milkweed, a perennial plant can adapt to adverse soil conditions, is being considered as an alternative source of fibre in recent years. Milkweed belongs to the genus *Asclepias*, with over 80 distinct species of which 45 are indigenous to the United States of America (USA). It previously belonged to the family *Asclepiadaceae*, but is now classified into the subfamily *Asclepiadoideae* of the dogbane family *Apocynaceae*. Farmers and scientists joined hand-in-hand in the late 1980s to develop milkweed as an alternative fibre source (Adams et al. 1984; Heise & Vidaver 1989; Witt & Nelson 1992; Knudsen & Sayler 1993, Knudsen & Zeller 1993; Witt & Knudsen 1993).

*Asclepias* species produce their seeds in follicles. The seeds, which are arranged in overlapping rows, have white silky filament-like hairs known as silk, or floss. The follicles ripen, split open and the seeds, each carried by several dried floss, are blown by the wind (Crew et al. 1991).

Two types of fibre can be obtained from the common milkweed: the long, strong but brittle bast fibre and the seed hair fibres known as floss. It was found that, similar to rubber content (in the latex), the quality of the bast fibres varied greatly with edaphic and climatic environment (the type of soil
the plant is growing in and the season, that is, dry or wet year). Although the bast fibres are similar to flax in many aspects, the fabrics made using bast fibres are very brittle with little or no draping qualities. Though pulp produced from the fibre yielded a good paper, it proved too costly for economic utilization (Louis & Kottes 1987).

After Second World War, the use of floss gained importance though it was difficult to be spun. It was mainly considered for stuffing material and there was a shortage for kapok during the World War II. The floss is made of fibres with a large lumen and very thin walls that have an elastic springiness characteristic of the kapok fibre. The fibres also have a waxy coating that makes them water resistant.

2.5.4 Types of Milkweed Species

The important species of milkweed are:

1. *Syriaca* common milkweed
2. *Incarnata* swamp milkweed
3. *Speciosa* showy milkweed
4. *Tuberosa* pleurisy root
5. *Calotropis procera*
6. *Pergularia daemia*

All the species produce tough fibres in their stems which can be used to make cloth, twine, etc and was traditionally harvested from the dead stems in autumn and winter, a fairly simple process. Dry summers produce the strongest fibre.
2.5.4.1 *Asclepias syriaca*

*Asclepias syriaca*, called as common milkweed, belong to herbaceous plant species, to the genus *Asclepias*, thus making it as a type of milkweed. There is a line running along the length of each pod, which will split open to release its seeds when mature. The common milkweed provides two different useful kinds of fibres (stalk fibre and floss), plus six different cellulosic materials (shoots, leafy tops, flower buds, flowers, immature pods and white). Milkweeds supply tough fibres for making cords and ropes and for weaving a coarse cloth. The dried stalks are split open to release the fibres and milkweed fibres are sometimes mixed with fibres of Indian hemp (*Apocynum cannabinum*). The bark is removed and the fibres released by first rubbing between the hands and then drawing the fibres over a hard surface. Twisting the fibre opposite to each other and twining them together forms the cord. Often this is accomplished by rolling the fibres on the thigh while twisting them together (Gaertner 1979).

2.5.4.2 *Asclepias incarnata*

*Asclepias incarnata* (Swamp Milkweed and White Indian Hemp) is an herbaceous, perennial plant species native to North America. Swamp milkweed is an upright, 1 to 1.5 meter tall plant, growing from thick, fleshy, white roots. The seed floss is used to stuff pillows etc, or is mixed with other fibres to make cloth. It has also been used as a baby’s nappy. The seed floss is a kapok substitute, used in life jackets or as a stuffing material and is water repellent (Jones & Bargen 1992).
2.5.4.3  *Asclepias speciosa*

*Asclepias speciosa* is a species of milkweed commonly known as the showy milkweed. It is native to the western half of North America. Showy milkweed, including fibre can be used for cord and cloth, food, chewing gum, and numerous medicinal uses (Adams 1984). A good quality tough fibre is obtained from the bark. It is used in twine, coarse cloth, paper etc. The fibre is 10–45 mm long.

2.5.4.4  *Asclepias tuberosa*

*Asclepias tuberosa* is a species of milkweed native to eastern North America. It is a perennial plant growing to 0.3 to 1 metre tall, and the leaves are spirally arranged. This plant grows well on dry, sand or gravel soil, but has also been reported to grow on stream margins (Arya & Goel 2009).

2.5.4.5  *Calotropis procera* and *Calotropis Gigantea*

The *calotropis procera* (aak) plant, an evergreen, erect undershrub with a woody base, is available in large quantity in the sandy tracts of States like Haryana, Rajasthan, Uttar Pradesh and Gujarat within India. The floss from the bolls can be used for the preparation of cloth and for insulating material (Varshney & Bhoi 1987). Among the *Asclepiadaceae* members, akund floss are obtained from *calotropis procera* and *calotropis gigantea* mainly from the seed fibre of former, is available from the wild population in different parts of India. Australia and New Zealand were once the chief markets for Indian akund floss (Anjula & Gupta 2003). *Calotropis gigantea* and *calotropis procera* are available in waste lands and by the roadside, often on black cotton soil.
2.5.4.6  *Pergularia daemia*

The *pergularia daemia* belongs to the family of milkweed fibres (*Asclepiadaceae*). It is also known as “Veliparuthi” in Tamil, “Uttaravarum” in Sanskrit and “Utranajutuka” in Hindi. Different parts of this plant has medicinal values such as its latex used for treating toothache, stem bark for treatment of cold and fever and aerial parts of this plant are reportedly used in various pharmacological activities like hepatoprotective, infertility, anti-diabetic, analgesic, anti-pyretic and anti-inflammatory (Kirtikar & Basu 1996).

The pergularia daemia is a slender, hispid, fetid smelling perennial climber. Its fruits are (follicles) lanceolate, long-pointed, about 5 cm long, covered with soft spines and the seeds are pubescent and broadly ovate. The different stages from flowering to maturity of the pergularia daemia plant are shown in Figure 2.3. Flowering may occur each year between August and January in India, with fruits maturing from October to February (Parrotta 2001).
Figure 2.3 Various stages of *pergularia daemia* (a) Plant with leaves (b) flowering stage (c) development of pods (d) matured of pods with seeds (e) opened and split matured pods (f) fibres attached with seed
2.6 PROPERTIES AND APPLICATIONS OF MILKWEED FIBRES

The detailed comparison of properties of cotton, kapok and milkweed fibres are shown in Table 2.1.

Table 2.1 Comparison of properties of cotton, kapok and milkweed fibres

<table>
<thead>
<tr>
<th></th>
<th>Cotton</th>
<th>Kapok</th>
<th>Milkweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Family</td>
<td>Malvaceae</td>
<td>Malvaceae</td>
<td>Asclepiadaceae</td>
</tr>
<tr>
<td>Genus</td>
<td><em>Gossypium</em></td>
<td><em>Ceiba</em></td>
<td><em>Asclepias</em></td>
</tr>
<tr>
<td>Longitudinal appearance</td>
<td>Flat and ribbon like with convolutions, thick wall and small lumen</td>
<td>Smooth, Single cell, cylindrically shaped, without any convolution, large lumen</td>
<td>Smooth, Single cell, Cylindrically shaped, without any convolution, large lumen</td>
</tr>
<tr>
<td>Cross-section</td>
<td>Bean shaped, Elliptical</td>
<td>Oval to Round</td>
<td>Oval to Round</td>
</tr>
<tr>
<td>Diameter (µm)</td>
<td>12-45</td>
<td>20-43</td>
<td>20-50</td>
</tr>
<tr>
<td>Linear density (tex)</td>
<td>0.12-0.18</td>
<td>0.064</td>
<td>0.11</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>25-60</td>
<td>10-24</td>
<td>20-30</td>
</tr>
<tr>
<td>Strength (cN/tex)</td>
<td>25-40</td>
<td>8-15</td>
<td>16-25</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>5-10</td>
<td>1.5-3.0</td>
<td>1.5-3.0</td>
</tr>
</tbody>
</table>
Table 2.1 (Continued)

<table>
<thead>
<tr>
<th></th>
<th>Cotton</th>
<th>Kapok</th>
<th>Milkweed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture regain (%)</td>
<td>7-8</td>
<td>10-10.73</td>
<td>10.5-10.9</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.54</td>
<td>Wall density - 1.5 Considering lumen - 0.384, Wall thickness – 1-2 µm</td>
<td>Wall density – 1.4 Considering lumen – 0.27, Wall thickness – 1.4 µm</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>cellulose -80-90%, water - 6-8%, wax &amp; fats 0.5-1%, proteins – 0-1.5%, pectins - 4-6%, ash - 1-1.8%</td>
<td>cellulose - 35-50%, hemicellulose - 22–45%, lignin - 15–22%, wax - 2–3% proteins - 2.1%</td>
<td>cellulose - 55%, hemicellulose - 24%, lignin - 18%, extractables - 3%</td>
</tr>
<tr>
<td>Crystallinity (%)</td>
<td>72-75</td>
<td>38-40%</td>
<td>32-39</td>
</tr>
<tr>
<td>Degree of polymerization</td>
<td>9000-15000</td>
<td>3300</td>
<td>4000</td>
</tr>
<tr>
<td>Application</td>
<td>clothing, bedding, towels and furnishings.</td>
<td>padding and stuffing of upholstery, cushions, mats, life saving belts, sound proofing electrical insulation, oil spill clean up</td>
<td>padding and stuffing of upholstery, cushions, mats, life saving belts, sound proofing, electrical insulation, oil spill clean up</td>
</tr>
</tbody>
</table>

2.6.1 Structure and Chemical Composition of Milkweed Fibres

The physical properties of fibre are dependent on the fibre structure and shape. Fibre structure consists of the size, shape and position of the cellulose molecules and aggregates of molecules either as crystallites, fibrils or region of amorphous cellulose. A given cellulose molecule is composed of
glucose anhydrides polymerized into a long chain the length of which is dependent on the degree of polymerization (Hessler et al 1948). They also found that the degree of polymerization of cotton fibre with primary cell walls only and with secondary walls have the average value of 5,940 and 10,650 respectively.

Knudsen (1990), have identified the chemical composition of common milkweed fibres as 55% cellulose, 24% hemi cellulose, 18% lignin and 3% extractables. He also stated that the milkweed seed fibre has a potential application as a super absorbent, thermal insulation, fluid carrier, bulking, bonding and tactile-changing fibre.

Reddy & Yang (2009) have analyzed the characterization of cellulose fibre from common milkweed stems in terms of their composition, structure and properties. The results showed that the fibre obtained from the milkweed stem have about 75% cellulose, higher than the milkweed floss but lower than that in cotton and linen. The milkweed stem fibres have low crystallinity when compared with cotton and linen with strength similar to cotton and higher elongation than that of linen. Overall, the milkweed stem fibres have properties required for high value textile, composites and other industrial applications.

Timell & Snyder (1955) have studied the molecular properties of common milkweed fibres for α-cellulose content and found that the α-cellulose fraction was entirely composed of anhydro-glucose and the hemicellulose portion of anhydro-xylose units. In addition to the original material, it also contained minor amounts of arabinose and uronic acid residues. They also found that, the milkweed fibre had a rather interesting composition, apparently comprising only two main constituents, namely, an exceedingly high molecular weight cellulose part and a probably low-molecular weight hemi-cellulose portion, the latter consisting chiefly of
xylan. The lower D.P limit was 2500 and the upper was 8000. Despite the presence of high D.P cellulose, the fibre has low strength due to the high content of xylan.

Barth & Timell (1958) have analyzed the constitution of hemicellulose from common milkweed floss. The average degree of polymerization of the methylated hemicelluloses was 97 and the corresponding value for the native polymer was 172. On the basis of these results it is suggested that the hemicelluloses contain approximately 170 β-D-xylopyranose residues linked together by 1,4-glycosidic bonds and with, on the average of, one branching point present per molecule. Every 14\textsuperscript{th} anhydroxylose unit carries a single terminal side chain of 4-O-methyl-D-glucouronic acid attached by α-glycosidic bond to the 2-position of the xylose residues.

2.6.2 Thermal Stability of Milkweed Fibres

Gu et al (1992), have studied the thermal analysis of milkweed and several individual commercial materials of similar chemical composition. To identify the major organic volatile products of pyrolysis and to correlate gas evolution with the decomposition of the individual components (cellulose, hemicellulose and lignin) of the floss they have done a two-stage thermal process (pyrolysis-combustion) with a thermo gravimetric analyzer and a fourier transform infrared spectrometer. During pyrolysis, acetic acid, formic acid and methanol are formed in addition to carbon-di-oxide and water. The result showed that pyrolytic decomposition of the three chemical constituents of milkweed occur without any apparent synergistic interaction. The combustion of milkweed have produced CO\textsubscript{2} and H\textsubscript{2}O, but the removal of the waxy coating from the fibres results in an increased susceptibility to combustion.
Further, they stated that the fibre undergo three reactions subsequent to moisture loss: An exothermic reaction associated with the major weight loss, 58% for milkweed and 62% for extracted milkweed, between 100 and 300°C; rapid combustion between 300 and 450°C resulting in loss of most of the remaining sample mass (38% and 32%, respectively) and a small weight loss recorded at temperatures between 450 and 600°C (0.8% and 0.6%). The thermal stability of milkweed floss is of the same order as its least stable component, hemicellulose. Cellulose has a higher degradation temperature and degradation onset temperature, although lignin begins to degrade at a lower temperature than milkweed floss, it degrades more slowly as the temperature rises.

2.6.3 Moisture Property of Milkweed Fibres

Woeppel et al (1990) have studied the moisture characteristics of two species of milkweed, *Asclepias speciosa* and *Asclepias syriaca*. Moisture content, moisture regain, absorbency rate and absorptive capacity were measured on milkweed and cotton fibres in the raw state as well as after two treatments (scouring with an aqueous detergent solution and stripping in an organic solvent). They observed that *A. speciosa* and *A. syriaca* fibres were similar in moisture characteristics, indicating that fibres from these two species of milkweed should perform similarly in absorbent materials. Generally the scoured or stripped milkweed fibres exhibited superior moisture content, moisture regain, and absorptive capacity when compared to the scoured cotton fibres, but could not match the absorbency rate of the scoured cotton.

2.6.4 Application of Milkweed Fibres

The difficulty in sourcing kapok fibres resulted in the look out for alternate fibres which could be a good substitute for kapok. It was found that
the fibre best suited for use, as a substitute for kapok was milkweed fibre. An examination of the two fibres shows a striking resemblance. Both fibres have the same wide lumen and thin walls. They are almost the same size in diameter and length and possess similar physical properties. The insulating property of milkweed fibres is slightly superior to those of kapok. Neither fibre retains moisture nor is readily wetted by liquids (Woeppel et al 1990).

The light airy fibres on the common milkweed plant have been used for some time in textile structures. Composed of 100% cellulose, these are classified as seed fibres because they grow as single cells on the large seed of the plant. The limited uses of milkweed fibres are strongly related to their unique structural features. The fibres are hollow, with a thin wall relative to their diameter and are therefore lightweight. This nature of fibres has led to their use in items where good insulation or buoyancy properties are needed; as filling fibres for comforters, life vests and winter jackets. A disadvantage is the high moisture regain of milkweed, which can cause the fibre masses in these items to become damp and clump together (Knudsen & Zeller 1993).

The smooth, straight fibre contour of milkweed fibres, makes the fibres difficult to spin into yarns. They may be blended with other fibres to increase cohesion in the blended yarns, as they also have low strength because of thin fibre wall, there is little possibility to produce such yarns. Initial efforts focussed on developing milkweed floss fibres as an insulative fill material and substitute for down. It was demonstrated that a blend of milkweed floss and down produces a very good comforter and jacket fill material (National Institute of Industrial Research 2005).

Milkweed floss blended with down has insulative properties similar to down. Down is superior to milkweed floss in loftiness and compressibility, which influence product performance, but the properties of milkweed floss can be enhanced by blending with down. One of the most promising
commercial uses for milkweed floss is its use as a loose material for jackets and comforters (Gaertner 1979). He also stated that milkweed floss is a non-allergenic cellulose fibre, with a fill power of about 350 \( \text{cm}^3/\text{g} \) which is comparable to high quality goose down.

Nourbakhsh et al (2009) has studied the suitability of using Iranian giant milkweed fibres as raw material for thermoplastic composites and found that the Izod impact strength of composite significantly decreased when the milkweed fibre content is increased. The resulting properties reveal that composites with good strength could be successfully developed using giant milkweed with polypropylene as a reinforcing agent. The giant milkweed can be a valuable renewable natural resource for composite production and could be utilized as a substitute for wood.

2.7 SPINNING OF SEED HAIR FIBRES AND ITS BLENDS

Swoyer (1939) had invented the method and equipment for processing of kapok fibres as shown in Figure 2.4.

![Figure 2.4 Equipment for processing of kapok fibres](image)

The kapok fibre after being removed from the bales is passed through the picker and then to the feeding device where it is moistened or sprinkled with liquid such as water. Then a measured quantity of the fibre
passes to the first breaker of the carding machine which is provided with a woolen card. The 100% kapok fibre was carded with one-half of the usual speed of the main cylinders of the carding machine. The slivers from the first breaker are subjected to treatment in the second breaker, whereby the slivers of 100% kapok are formed, which now pass to the condenser, which forms the lighter 100% kapok roving, which are collected on the yarn rolls or spools. The yarn rolls or spools are then placed on the mule. The 100% kapok roving from the spools is then spun into yarn to the size that is to be desired and the yarn is wound on the spindles to form the cops.

From the findings of Dauda & Kolawole (2003), it is observed that the spinning of 100% kapok fibres beyond lap formation stage is not possible, while the spinning of kapok fibre blended with at least 50% cotton fibre is largely successful. With the increase in kapok content in the blend, the yarn regularity and tenacity decreases while the yarn extensibility increases with reduction in the total cost of production.

Liu et al (2011) have studied the effect of mercerization on micro-structure and the properties of kapok/cotton blended yarns. The results showed that mercerization treatment did not have an obvious effect on chemical compositions of cellulose, but did lead to decreasing the crystallinity of blended yarns and transformed certain portion of cellulose I into cellulose II. When the NaOH concentration increased from 180g/l to 250 g/l, the strength of blended yarns increased and elongations at breaking declined and the extent of changes were lessened gradually with the increase of kapok fibre content. With further increase in NaOH concentration to 280g/l, the strengths of blended yarns with high content of kapok fibre dropped dramatically and elongations at breaking increased gradually, while hygroscopicity of blended yarns increased significantly. They also concluded
that, a moderate alkali treatment condition should be chosen in mercerization process for kapok fibre

The machine for processing of milkweed pods and separation of floss from the seeds has been developed by Berkman (1940) and the processing machine was modified by Ragsdale (1990). Bargen et al (1994) has developed the equipment for milkweed floss recovery as shown in Figure 2.5.

![Milkweed floss recovery machine](image)

**Figure 2.5  Milkweed floss recovery machine**

The system consists of a pod harvester, a pod conditioner, two drying stages and a spike tooth cylinder processor. Milkweed pods are introduced into the inlet end and conveyed to a pod cracking chamber wherein a cylinder having rigid spikes projecting radially cracks the pods. The cracked milkweed pods are then conveyed to a picking chamber wherein a row of picking cylinders with spikes will pick and loosen the floss seeds from the cracked milkweed pods. The picking cylinders are arranged in parallel fashion and rotate in opposite direction. The picked, loosened floss and pods are then conveyed to a fluffing chamber which includes a rotating cylinder having a series of spikes which further fluff the loosened floss to remove the
seeds from the floss. A fan directs a current of air through the loosened and picked floss materials to lift the floss and carry it to an outlet.

The harvest rate is 0.4–0.5 hectare/hr and 90% of the pods were harvested. The pod conditioner opened 95% of the pod structure. The drying process removed 50% of the moisture in the pod within 4 hrs during the first drying stage, and further dried the pods to 10% moisture content in 48–60 h in the second stage of drying. The floss processor recovered 60% of the floss with the centrifugal separator prior to spike-tooth cylinder processing.

Louis & Kottes (1987) have successfully produced the yarn and fabric from the cotton/milkweed blends at different proportions. The milkweed generated larger waste when processing with blends of cotton/milkweed as compared with 100% cotton, presumably due to milkweed’s lack of cohesiveness. The breaking strength of yarns and fabrics made from the cotton/milkweed blends were 15-25% lower when compared to 100% cotton yarns and fabrics. They found that the fabric strength retention of the cotton/milkweed blends after DMDHEU finishing was greater when compared to cotton fabrics. The higher percentage of milkweed in the blend led to higher fabric breaking strength. The strength responses of the chemically modified milkweed blends as well as the morphological responses of the milkweed fibres to swelling might have been due to a combination of presence of lignin in milkweed and a less ordered cellulosic structure. The high moisture regain property of the milkweed blends suggests that the fabrics made from such blends would be more comfortable to be worn as apparels.

Varshney & Bhoi (1987) have produced yarns from the stem of *calotropis procera* plant. The fineness and strength of the fibre were found to be comparable with cotton. However, small staple length, high percentage of short fibres and lack of convolutions offered problems in spinning. The yarn of blend of cotton and milkweed in 1:1 proportion was inferior to cotton in
respect of strength, fineness and evenness. The properties of cloth indicated that aak cloth has high tensile and abrasion strength and more weight per square metre than cotton cloth.

Andrews et al (1989) observed that there was a 38% increase in strength for 75/25 cotton/milkweed blend yarn fabric after ammonia mercerization and 66% after sodium hydroxide mercerization. The corresponding increase for 67/33 cotton/milkweed after ammonia mercerization was 63% and 40% after sodium hydroxide mercerization respectively and the strength decreased after cross-linking. The authors further found that the advantage with presence of milkweed as increased moisture retention in the blends after swelling treatments. The effect of swelling treatments overshadowed the decrease in crystalline cellulose by replacing cotton with milkweed. Any slight decrease in crystalline size from the presence of the smaller milkweed crystalline in the blend was also overshadowed by the decrease in crystalline size produced by ammonia mercerization. Furthermore, this effect was more pronounced in the milkweed blends.

Drean et al (1993) have studied the transverse dimensions (wall thickness and linear density) of milkweed fibres, analyzed milkweed’s physical fibre properties to process different yarns blended with cotton/milkweed fibres and effect of high milkweed content and transforming these yarns into plain weave fabrics. They found that the processing difficulty increases as the milkweed increases in the blend. It appears to be impossible to spin a pure milkweed fibre yarn using a classical ring spinning process.

Cox et al (1995) worked with 100% milkweed fibre and commented that these fibres did not perform satisfactorily as a loose fill material. It was rated significantly rougher and bulkier than any other fill material. Furthermore, laundering significantly affected the 100% milkweed
fill resulting in decreased thickness and considerable decrease in insulative value. They concluded that 100% milkweed cannot be used as a loose-fill material. When milkweed was blended with down or feathers, its performance properties were enhanced. The insulative value of the 50/50 milkweed/down blend was similar to the 100% down.

Analysis of different extraction methods of fibre from the bast of *calotropis procera* were conducted by Wazir & Shah (1997) and they found that the tenacity decreased with increasing relative humidity. The best results were obtained by stripping off the bast, retting the strips in water for 24-48 h, followed by drying and fibre extraction. Bast fibres of *Calotropis procera* plant were separated by retting the stem for 8 days and maximum quantity of fibres was obtained. The yarn made of 50/50 blend of cotton and aak was inferior to cotton in respect of strength, fineness and evenness. The strength of blended yarn is 50% of the cotton yarn. The weight per square metre of the blended yarn cloth is 2.5 times greater (or lower) than 100% cotton cloth due to coarser count and greater thickness.

The diameter of the milkweed fibres ranges from 30 to 50 μm and the fibre length ranges from 9.5 to 30 mm. Like cotton, it is a single-cell fibre but without convolutions. Although the milkweed fibre does not collapse upon drying as cotton fibre, it collapses during wet processing. The relatively low percentage of cellulose in milkweed fibres is reflected in their low degree of crystallinity compared to cotton (Sakthivel et al 2005).

Sakthivel et al (2005) have investigated the spinning of milkweed fibres in the cotton spinning system and stated that 100% mudar yarn could not be produced in the cotton spinning system. The smooth, straight fibre contour of milkweed makes the fibre difficult to spin into yarns. The lack of cohesiveness of the milkweed fibres causes extreme difficulties in textile processing. Further, they stated that, the processing of 100% mudar fibres
resulted in numerous problems during spinning like lap licking, unwinding during carding and a requirement of thicker lap to get the sliver in carding. It also causes frequent stoppage and flies in carding. The 100% mudar fibres were not suitable for regular running speed for upstream processes like drawing/simplex/spinning.

Pushpanjali (2006) has studied the physio-chemical properties of calotropis procera fibre and revealed that it is quite comparable with other bast fibres namely Bhindi and Bhang in terms of length and fineness. But the tenacity of aak fibre is moderate and higher than the wool. Its reaction to various chemicals and reagents are similar to cotton. It can be easily scraped from the stems by hand de-cortication or retting and can be used for blending with other fibres in producing fabrics of different qualities.

Bahreini & Kiumarsi (2008) have investigated the spinnability and dyeing behaviour of the seed fibre milkweed and revealed that the raw milkweed fibres and the blended cotton/milkweed 75/25 become spinnable after chemical treatments such as scouring and bleaching. The color strength of 100% milkweed fibres is lower and its exhaustion value is higher than that of 100% cotton. The color, yielded on the blended fibres, has been found to be higher than those of both 100% milkweed or cotton fibres. Overall, the dyeability of stabraaq fibres with the two types of reactive dyes used, resembles that of cotton more closely and the blended fibres have gained superior dyeing properties over the cotton and kapok fibres used.

Huang (2009), have patented the invention for spinning milkweed fibre with cotton sliver and its processing method as shown in Figure 2.6. The processing device have conveyors which are arranged in a bat wool room, deseeding room, blowing room, curing room and drying room respectively and integrated in a strip box body. The meshing rolls are respectively arranged in between the bat wool room, deseeding room and blowing room and are
connected with three conveyors. The invention has the advantages that the new spinning method of milkweed fibre can easily be compared with existing technology for cotton.

![Diagram of processing milkweed fibres]

Figure 2.6 Processing of milkweed fibres

2.8 STRUCTURAL STUDIES ON SEED HAIR FIBRE SPUN YARNS

The mechanical properties of staple yarns depend not only on the physical properties of the constituent fibres, but also the yarn structure characterized by the arrangement of the individual fibres in yarn cross-section. Therefore, the arrangement of the individual fibres has attracted much attention to understand the yarn structure and the resulting yarn properties in a better way. Many properties such as yarn strength, extensibility, appearance, compactness, as well as uniformity of the structure are related to fibre distribution along yarn cross-section and the packing density analysis reveals quite valuable information regarding these properties.

2.8.1 Fibre Migration and its Measurement

The relative fibre movement at the point of yarn formation and the resultant position of fibres in the yarn structure is defined as fibre migration.
The migration behaviour of a fibre is affected significantly by the inherent properties of constituent fibres like fibre length, fibre fineness, crimp and cross-sectional shape and the special characteristics of adopted processing systems.

The tracer fibre technique was originally developed to study the fibre arrangements in fibro sliver by Morton & Summers (1949). Later this technique was adopted to study the radial position of fibres in the yarn by Morton & Yen (1952). The technique involved introduction of coloured fibres of less than 1% in proportion of total weight of fibres into the body of yarn and then optically dissolving the grey fibres by immersing the yarn samples in a solution of same refractive index, thus facilitating the dyed fibres to be scanned using a microscope. It was possible to view the yarns only from one direction using this technique. Thus, Riding (1964) adopted a different procedure to view the specimens from two directions at right angles simultaneously, in order to carry out the quantitative analysis. Hearle and his co-workers studied the occurrence of geometric mechanism in addition to the tension mechanism to influence fibre migration during yarn formation and explained the existence of irregular short term variations and regular long term variations along the yarn length (Hearle et al 1965, 1968).

2.8.1.1 Ideal migration

The fibre is said to exhibit an ideal migration if it migrates regularly and uniformly from outside to the centre of yarn and then back to the outside, assuming the yarn as circular in cross-section throughout the structure as shown in Figure 2.7. In such condition, fibres are to follow the helical path around the concentric layers of constant radius so that the density of packing is constant throughout the yarn length.
Consider ‘r’ as the helix radius of fibre which makes an angle with the yarn axis and ‘R’ as the radius of the fibre helix at the surface making the helix angle $\alpha$ with the axis. The length along the fibre is denoted by ‘h’ and the yarn length is denoted by ‘z’. The helix angle, ‘$\theta$’ of the fibre at the intermediate position will be measured using the Equation 2.1,

$$\tan \theta = \frac{2\pi r}{h} \quad (2.1)$$

Here ‘h’ is the yarn length for one complete turn of a fibre. If it is considered as the length of fibre for one complete turn, it can be determined from the relation using the Equation 2.2,

$$L = \frac{h}{\cos \theta} \quad (2.2)$$

Thus ‘L’ increases as ‘$\theta$’ increases and is maximum for the outer layer which follows the longer helical path. If the yarn is divided into different zones of equal radial spacing the area increases proportionately as the radius increases.
2.8.1.2 Factors influencing the migration behaviour of fibres

Factors which influence the fibre position in the yarn are most conveniently considered in three groups namely: fibre factors, yarn factors and factors associated with the spinning process itself (Beherey 1968). If fibre substance, cross-sectional shape, inter-fibre friction, and mechanical properties are regarded as inherent characteristics of a given type of fibre, then fibre type, staple length and denier are the three basic fibre factors which may affect the migration. Anandjiwala et al (1999) investigated the effect of fibre properties and yarn structure on the tensile properties of ring spun yarns made from a 50:50 blend of high (Pima) and low (Upland) tenacity cotton fibres spun using intimate and draw frame blending techniques. The findings revealed that intimate blended yarn had better tensile strength than draw frame blended yarn, even though more high strength Pima cotton fibres are positioned in the core of the yarn.

Balasubramanian (1970) had studied the influence of processing factors on the average disposition of fibres where the blending constituents differ widely with respect of fibre length and denier. It was found that long and fine fibres have a tendency to occupy the core, while short and coarse fibres concentrate at the surface. Further, it is showed that, when blending is done prior to the card, intimate mixing of the components is realized in the yarn even in blends composed of fibres that differ considerably in length and fineness.

Processing factors which affect the fibre migration are the particular spinning system, machine geometry and machine settings. Gupta & Hamby (1969) emphasized that the migration behaviour of staple yarns is dependent on their mean fibre position and concluded that the spindle speed and spinning tension influences the rate of migration to a lesser extent. Huh et al (2002) have studied the structural and physical properties of ring, rotor
and friction spun yarns and showed that ring spun yarn exhibits the higher fibre migration, followed by rotor and friction spun yarns. Alagha et al (1994) concluded in his study that the difference in migration characteristic of yarn on different spinning systems is due to different twisting methods and different levels of tension developed during yarn formation. Hearle et al (1972) have investigated the fibre migration in open-end yarns and concluded that the low strength of rotor spun yarns could be attributed to poor fibre alignment, inferior and shallower fibre migration within yarn body and large number of folded fibres.

2.8.2 Packing Density of Yarns

The important research focus of the yarn structure is the investigation of fibre arrangement in yarn cross section. The fibre arrangement in yarn cross section is often expressed by the fibre packing density and fibre migration index. For the evaluation of packing density, there are various approaches used by different researchers. One of the early approaches was based on mainly open and hexagonal close packing (Schwarz 1951) as shown in Figure 2.8.

![Idealized packing of fibres in yarn](image)

(a) Open packed structure  (b) Hexagonal close packed structure

Figure 2.8 Idealized packing of fibres in yarn
(a) Open packed structure (b) Hexagonal close packed structure
In open packing, fibres follow on concentric circles over a central fibre in a number of layers. The first layer consists of a single fibre and second layer has six fibres all of them touching each other as well as central fibre. The third layer is formed by fibres touching the circle that contains the second layer of fibres. Build up of layers one over the other proceeds in this manner. Open packing gives a circular yarn with air spaces between layers from 2\textsuperscript{nd} layer onwards. Close packing gives a hexagonal outline with all fibres touching each other. Yarn is not circular and closer to elliptical.

Hearle et al (1969) postulated an improved approach based on dividing the yarn cross-section into zones of equal radius by which fibre distribution is defined by yarn packing fraction. On the other hand, fibre packing density is a function of the radial distance and defined as the number of fibres per unit area perpendicular to fibre axis (Dogu 1972). However, it has been suggested that fibre packing density measurements should be based on the ratio of the cross-sectional area of fibres in a given zone to the area of that zone, since fibre-number density per unit cross-sectional area is inapplicable (Hickie & Chaikin 1974).

Driscoll & Postle (1988), later on, defined fibre distribution as the ratio of fibre volume to yarn volume at radius \( r \), generalizing the definition of yarn packing fraction suggested by Hearle and also taking into account the obliquity of the fibres to improve the earlier approaches. The similar approaches as above has been adopted by dividing yarn cross-section into several annular zones having equal areas (Neckar et al 1988) and similarly the yarn cross-section have been divided into five concentric zones having equal widths to determine packing density of MJS yarns (Punj et al 1998). Differing from above, an approach called virtual locations where fibres are virtually distributed neither in the form of a ring nor a hexagonal configuration but as a combination of these two was proposed (Grishanov et al 1997). This approach
enables the simulation of air gaps between fibres and gives a good representation of fibre location.

Hearle et al (1965) found that yarn density increases with twist and asymptotically approaches a value. Twist and count have the maximum influence on packing coefficient. With cotton increase of packing density with twist is more rapid. Barella (1950) found that yarn density approaches fibre density at the time of break during loading in tensile load tester. He also showed that the packing density is higher and diameter is lower with finer fibres. Yarn packing density increases with increase in spinning tension as the fibres get closely packed. Lower strand width at the delivery by the use of finer roving and lower ring frame draft will increase the packing density because twist flows closer to the nip. However Tyagi & Kumar (2009) found that packing density increases with spinning draft initially and afterwards drops.

2.9 SUMMARY

Survey of literature presented in this chapter covers various aspects of classification of textile fibres and seed-hair fibres. The important types of fibres coming under milkweed family are also elaborately discussed. From the foregoing discussions, it is clear that the milkweed fibres are light in weight, have smooth appearance, possess low elongation at break and are hollow in nature which presents difficulty in conversion of fibre into yarn in spinning process. The thrust of the present work is aimed at improving the spinnability of milkweed fibres by blending with cotton fibres by modifying its surface by suitable chemical treatments. The study also includes optimization of process variables in ring and rotor spinning systems for the production of cotton/milkweed blended yarns. Further, the relationship between the yarn structure and yarn characteristics and the suitable end-use application of the cotton/milkweed blended fabrics is also explored.