Name of Study: Utilization of Banana Pseudostem for Textiles

Name of Agency: Department of Clothing and Textiles 
Faculty of Family and Community Sciences 
The Maharaja Sayajirao University of Baroda, Vadodara 

Department of Economic Analysis & Research 

National Bank for Agriculture and Rural Development, Mumbai 

2021
UTILIZATION OF BANANA PSEUDOSTEM FOR TEXTILES

Department of Clothing and Textiles
Faculty of Family and Community Sciences
The Maharaja Sayajirao University of Baroda
Vadodara
UTILIZATION OF BANANA PSEUDOSTEM FOR TEXTILES

Draft Report submitted to

Department of Economic Analysis and Research
National Bank for Agriculture and Rural Development
NABARD

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The NABARD Research Study Series has been started to enable wider dissemination of research conducted/sponsored by NABARD on the thrust areas of Agriculture and Rural Development among researchers and stakeholders. The study on ‘Utilization of Banana Pseudostem for Textiles’ completed by Maharaja Sajajirao University of Baroda, Vadodara is the twenty-first in the series. The list of studies in the series is given at the end of this report.

Banana is an important fruit crop in India and occupies about 20% area out of the total area under crops in India. Apart from the fruit yield, banana crop generates a huge quantity of waste biomass in the form of pseudostem, leaves etc. However, not much attention has been focused on effective utilization of the huge waste biomass generated from the banana crop. In India, presently this biomass is dumped on roadside or burnt or left in situ causing detrimental effect on environment. Though, the technologies for extraction of fibres and paper making from pseudostem are available, yet it has not been adopted by the industries mainly due to bulky nature leading to high transport cost. There exists a vast potential of extracting fibres from pseudostem.

In India, only 10% of the banana waste (Pseudo stems) is used for extracting fibre. It is extremely important to realize the potential of these fibres and put them into textile application. The purpose of the study was to take the banana fibres to fabric stage by softening them and making them more pliable to be spun into fine yarns and then construct a banana textile grade fabric.

Hope this and other reports we are sharing would make a good reading and help generate debate on issues of policy relevance. Let us know your feedback.

Dr. KJS Satyasai
Chief General Manager
Department of Economic Analysis and Research
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Annexure
EXECUTIVE SUMMARY

- India is an agricultural land country and farmers are the backbone of our country. Agriculture continues to be the backbone of our Indian economy as it provides 54% employment to rural as well as urban masses. In India about 60% of land mass is under various agricultural practices.
- Banana plant is considered as one of the most important fruit crop. Banana occupies 20% area among the total area under crop in India.
- After the harvest of the fruit, the plant is cut and thrown on roadside. This agro-waste is the source of banana fibre and other utility by-products.
- The extraction process includes cutting of the pseudostem, transporting of the stalks to the shed, separating each pseudostem, sheathing the pseudostem, passing it through the raspador to extract the fibre. Extracted banana fibres are washed and sun dried.
- Banana fibres packed in a bundle of 5 kgs were sent to the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara for application of softening treatment and testing its properties.
- The softening treatment used for the study includes five steps. The first step is alkalization, followed by bleaching and then re-alkalization. The fibres are then dipped in water in oil emulsion and kept overnight for batching.
- Filament fibre treatment apparatus was fabricated in the department. The apparatus had a central disc attached with a motor to rotate and along with it the fibres would also rotate. This action helps to keep the fibre immersed in the treatment solution and also helped to reduce fibre engagements. The apparatus helped to reduce 33% wastage.
- Untreated and treated banana fibres were tested for its physical and chemical properties. It was observed that the treated fibres were softer, even and pliable as compared to the untreated fibre. The increase in elongation also helps the fibre to improve its spinability.
- The treated fibres were combed and were ready for spinning.
- A group of 18 women from different remote regions of Vadodara were the part of the programme. These women had no source of income and had the willingness to work.
- Before the beginning of the training programme, phoenix charkhas were motorised to control the variable of feeding the fibres and to reduce labour.
- Training programme for “spinning of banana yarn” was carried where Mr. Nazir Kamal Ahmed was invited as a resource person for five days. The beneficiaries were thought to handle the fibres, feed them on the raspador and hold to insert the required twist in the yarn.
- Spinning workshop began immediately after the training programme i.e. from 3rd December 2019. A six month’s spinning workshop was planned, however due to the pandemic Covid-19, from March 2020 the workshop was kept on halt.
- The workshop resumed from October 2020 and continued till December 2020, to complete the proposed tenure.
• An average of 30 grams of banana yarn was obtained on each charkha where two women were engaged for spinning and one for pre-preparation.
• 100% spun banana yarn of 11’s count was obtained during the workshop.
• Fibre density of banana fibres is 1.35 that makes the fibre lighter than cotton and silk, making it more voluminous.
• Using these 11’s banana yarns for weft and 2/30’s cotton yarn for warp, six different fabric samples were outsourced.
• 100 grams of banana yarn can be used to weave 2 meters of fabric.
• Due to the pandemic situation, an online exhibition was conducted to showcase the developed banana yarn and banana union fabrics.
• There were more than 400 views for the exhibition and lot of positive response for the yarn and fabric developed.
• To sum up the responses for the visual textures of the banana union fabric, most of the people appreciated the fabric structure, and the uniqueness of the fabrics. Designers would want to develop line using these fabrics. Many were touched by the way the agro-waste was utilized and women empowered.
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Chapter 1
INTRODUCTION

For a human being there are three basic needs i.e. Food, Clothing and Shelter. Clothing serves as a second skin. From the primeval periods, man has used various types of covering for warmth, protection from cold, rain, wind and even for body adornment. Mankind started covering themselves first from animal skins, later with twisted and interlaced leaves and stem of plant. Later with the advancement in civilization, they started extracting fibres from various plants and used them for weaving cloth. Over 20,000 years, fibres have been known to human as raw material to fabricate the cloth. Textile technologists have defined textile fibre as a ‘fine strand of sufficient length, pliability and strength to be spun into yarn and woven into cloth’.

Nature offers us a wide option of material that can be called fibrous. The oldest fibre used as a raw material for clothing by historic man was obtained from natural resources. Natural fibres can be classified into vegetable and animal origin. Fibres that are obtained from either animal’s hair or skin are known as animal fibre (wool and silk). Fibres that are obtained from plant’s leaves, fruits, seed covers and stem are known as vegetable fibres (cotton, jute, sisal, coir, flax, hemp, abaca, ramie, etc). Vegetable fibres are also known by cellulosic fibres which are completely renewable and biodegradable. (Shah, J.2009)

The variety of plants that yield fibres of greater or less value, in various parts of the world, is very large. The fibre obtained from same plant quality may differ with the living conditions in the temperate zones compares to tropical zones. (Lee, G.S. 1920) India is a country of such vast extent, and so diversified in soil as well as in climate, that we may readily believe it to be capable of producing almost every kind of natural produce, and among these every known variety of fibre, which are used for variety of textile and industrial products. (Muthun S., Garden M.A. 2016)

Vegetable fibres are considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. These cellulose fibrils are aligned along the length of the fibre, irrespective of its origin i.e. whether it is extracted from stem, leaf or fruit. It appears that such an alignment renders maximum tensile and flexural strengths, in addition to providing rigidity in that direction of the fibre.

Cellulose is one of the commonest naturally occurring fibrous materials. All plant fibres are single-cell materials. Except for seed fibres most plant fibres exist in bundles of ultimate
fibres. A fibre is defined as ‘a unit of matter characterized by flexibility, fineness, and high ratio of length to thicknesses while fibre can be defined as ‘one of the unit botanical cells into which leaf and bast fibres can be distinguished’. Cellulosic naturally occurring can be traced back more than 10,000 years. About 8,000 B.C. cellulosic were used for textiles in the Middle East and China. (Kavitha M. 2015) Minor textiles in textile mean those fibres that are limited in production and also not available on the economics of a scale of a mass market. The fibres have a limited production and application.

India is an agricultural land country and farmers are the backbone of our country. Agriculture continues to be the backbone of our Indian economy as it provides 54% employment to rural as well as urban masses (Sachdeva and Chanana, 2015). Even though agriculture contribution is only 17% to India’s GPD, it is the source for nearly 60% of its population. In India about 60% of land mass is under various agricultural practices (Hiloidhari et al, 2014).

A year after cultivation of crops a massive amount of agricultural waste is produced. It is seen that after the processing of one ton of the main product, 1.5 tons is crop residue is generated. According to a survey by Govt of India, every year about 500 metric ton of crop waste is produced (Mahawar et al, 2015). Worldwide, it is a common practice of dumping it in the garbage houses where the residue is degraded or decompose by microbes and bacteria. Sometime, these crop wastes are left in the field or either burnt in open which result in environmental problems and various human health issues.

The agricultural straw and livestock manure are considered as a potential resource. Improper decomposition of agricultural wastes not only leads to environmental pollution, but also wastes of valuable biomass resources. The recycling and utilization of agricultural wastes are well thought-out to be the crucial step for environmental protection, energy structure and agricultural development for other various sectors (Wang, 2016).

Agro residues or agricultural waste are organic materials generated as by-products after cultivation and during processing of agricultural crops. Agro- residues are categorized into two types: Field residues and processed residues. Field residues are waste generated after the harvesting of crops and left behind. It includes Pineapple leaves, banana pseudostem and leaves, cornhusk, cotton seed pods, kapok seed pods, cotton stalks. Processed residues are material obtained and left after the crop are processed into a valuable resource after the
isolation from main agricultural products. Some examples are bagasse, pea peel, wheat and rice straw.

Mainly the agro-residues are used for fodder, fertilizer, and feedstock etc. there have been many studies going on utilization of agro waste in various sectors. As agro residues are non-wood lignin cellulosic and a rich source of cellulose along with lignin. In the field of textile, due to availability of cellulose, leads researchers to obtain natural fibres by maximum removal of hemicellulose and lignin. bagasse and bamboo are important stalk agro- residues, cornhusk and banana leaves are important leaf agro- residues.

Banana is one of the rhizomatous plants and grown over 129 countries around the world. Banana plant is considered as one of the most important fruit crop. Almost all part of banana plant from fruit, fruit peel, leaf, pseude-stem, stalk, and inflorescence (flower), can be utilized. They can be used as food product or in non-food related product. Some example are apart from edible fruit used as thickener, colorant and flavouring, macro and micro-nutrient source, livestock feed, fibres, bioactive compound source, and organic fertilizer. In some studies banana peel is been utilized as bio-fuel, bio-sorbents, pulp and paper, cosmetics, energy related activities, organic fertilizer, environmental cleanup and biotechnology related processes (Rana et al, 2018). Peel is also used for waste water treatment. Banana leaves are used as food wrapping, cooking, plates for eating, baskets, mats etc. Waste banana pith is used as color absorbent in textile dyes. Pith is used as food after boiling; it is also used to make cookies. Various product like jam, chips, flour, pickles from immature bud, pith and pseudostem (Mohapatra et al, 2010).

Around the 13th century, banana stems had been used as a source of fibre. The ideal condition for cultivation of banana is in warm and humid climate of the tropical region. It is a lignocellulosic fibre extracted from the pseudo-stem of the banana plant. After the fruits harvesting, the trunk are considered as a waste. Billons tons of stem and leaves are dumped away annually. Such agro waste can provides valuable sources of fibres, which leads to the reduction of other natural and synthetic fibres production which requires extra energy, fertilizer and chemical. A normal pseudostem weighs approx. 37 kg from that 1 kg of good quality fibre can be extracted. Banana fibres are good absorbent, high breathable, quickly dry with high tensile strength.

Minor fibres have high strength but also have high stiffness and low cohesiveness is a major drawback. Softening treatment can improve its hand and can be used in apparel section or
home furnishings. They are used as in several other areas like handicrafts, paper industry, packaging, geo-textiles, technical textiles, medical textiles etc. Banana is one of the probable fibres which will prove its potential as jute and linen.

**1.1 Purpose of the study**

*Nature from its precious treasure has given mankind innumerable blessing*

India is an agricultural based country and it is the backbone of Indian economy. After the harvesting of crops a massive amount of residue is generated which is consider waste and is left aside or dumped in open landfills. Agricultural residue not only occupies the field for the next crop and also creates environment pollution. These residue contain lots of nutrients, minerals which can be utilize in various sector i.e. pharmaceutical, food industry, agricultural, textiles etc. In India banana is ranked second important fruit crop next after to mango. Banana is harvested for its fruits and rest part of banana is thrown as a waste which includes pseudostem, leaves, fruit peel, and inflorescence (flower). Due to high production of banana fruit crops it generates tons of wastes and thrown in garbage occupying landfills or left open in the field which is a matter of concerns in present context. Among all pseudostems generate massive waste and occupies the crop field. Due to high amount of water present in the pseudostem burning it generate smoke and pollute the surrounding and consume times. To make proper usage of banana pseudostem there have been many research carried out apart from used as fodder, leaves as food wrapping or used as plate. The most utilization of pseudostem is to extract fibre from it. Application of banana fibre for manufacturing textiles is a new concept in India. In India, only 10% of the banana waste (Pseudo stems) is used for extracting the fibre. Banana fibres have excellent strength and lustre. It is extremely important to realize the potential of these fibres and put them into textile application. Hence, the purpose of the study was to confer the banana fibres to fabric stage by softening them and making them more pliable to be spun into fine yarns and then construct a banana textile grade fabric.
1.2 Objectives of the study

1. To utilize banana pseudostem for extraction of banana fibre.
2. To apply softening treatment on banana fibres to impart soft hand and spinability.
3. To apply softening treatment on other minor fibres.
4. To spin hand woven yarns on phoenix charkha.
5. To develop fabric samples from the spun yarns.

1.3 Scope of the study

Banana is one of the major fruits crops of Gujarat. This gives employment and income to millions of people engaged in its growing and trade. Banana production of 1.9 million tonnes has been reported with the productivity of 42.7 tonnes/ha. In Gujarat, banana crop is cultivated in 11 districts covering an area of about 60900 ha. Gujarat is ranking 3rd among the states of India with an average productivity of 58.7t/ha. Surat, Vadodara, Anand, Kheda, Junagadh, Narmada, and Bharuch are the productive belts for banana cultivation.

After the harvest of the fruit the pseudostem is discarded on the roadside. This agro-waste is the source of banana fibre extraction. Gujarat being the third largest state for production of banana, and thus producing huge amount of pseudostem finds the prime reason for this study. The extraction of fibre and skill development of banana yarn production would provide the farmers an additional source of income and spinning of yarn would give lot of employment opportunities to the people residing near these regions. Extraction of banana fibre and skill development of banana yarn spinning finds a huge scope in Gujarat state.
Chapter II

REVIEW OF LITERATURE

One of the primary responsibilities of any researcher is to have acquainted with latest literature on the subject of research. It provides the valuable information regarding the various aspects of the problem and enables the researcher to make a systematic planning of the research considering the nature of the problem of the study the relevant theoretical literature and researches on banana and other cellulosic minor fibres were reviewed. The investigator visited and collected the literature from various libraries like Smt.Hansa Mehta library, The library at the department of clothing and textiles, Faculty of family and Community Sciences, Of The Maharaja Sayajirao University of Baroda, Vadodara. Another important source of information was from research journals.

The review of literature related to the study has been broadly classified into two major sections and further in subsections:

2.1 Theoretical Review

2.1.1 Minor Fibres
2.1.2 Chemical composition and properties of some cellulosic minor fibres
2.1.3 Description of Banana plant
   2.1.3a) Origins of Banana
   2.1.3 b) Anatomy of Banana Plant
   2.1.3 c) Importance of banana in India
   2.1.3 d) Suitable climate for banana farming
   2.1.3 e) Suitable soil type for banana farming
   2.1.3 f) Banana varieties
   2.1.3 h) Planting season in banana farming
   2.1.3 g) Banana Irrigation
   2.1.3 i) Application of manure and fertilizers in banana farming
   2.1.3 j) Harvesting of banana farming
   2.1.3 k) Post harvest management of banana farming
   2.1.3 l) Medical uses
   2.1.3 m) Banana in Indian customs, Ceremonial & Rituals
2.1.4. Extraction and uses of banana fibre
  2.1.4.1. Chemical treatment
  2.1.4.1.2. Mechanical treatment

2.1.5. Types of commercial softener

2.2 Research Related Review

2.1.3. Minor Fibres:

Fibres can be classified by their chemical origin, falling into two groups or families: natural fibres and manufactured fibres. Natural fibres are classified by the source from which they are extracted. Basically there are two categories: animal sources and plant sources. Wool, silk, cashmere, mohair etc are the examples of animal sources and cotton, flax, jute etc are the examples of plant sources. People in the society are aware about cotton, silk, wool as it is being used in fashion and technical applications. However in the arena of textiles there are many unexplored natural fibres that have a potential to be textile fibre.

![Classification of Textile Fibres](https://www.whaleys-bradford.ltd.uk/textile-fibres)

**Figure 2.1:** Classification of Textile Fibres

Source: [https://www.whaleys-bradford.ltd.uk/textile-fibres](https://www.whaleys-bradford.ltd.uk/textile-fibres)
The definition of minor fibre in textiles includes those fibres that are limited in production and also not available on the economics of a scale of a mass market. (Agrawal G, 2016) Minor fibres can be used for novelty applications and ultimately the waste is being utilized as a textile fibre.

Ghosh (2015) mentioned that 700 species of plants giving fibre is used by human beings. To list a few: Ramie, Hemp, San hemp, Kenaf, Roselle, Bhindi, Jaba kusum, Swet jaba, Sthal Padma, Lata kasturi, Nettles, Sisal, Pineapple, Atasi, Abaca, Banana, Screw pines, Bhurjya Twak, Chhilka, Deola, Coast Cotton tree, Trailing Hollyhock.

2.1.3 Chemical composition and properties of some cellulosic minor fibres

Minor fibres can be classified into Cellulosic Minor Fibres (all staple) and Protein Minor Fibres. This study is limited to exploration of other cellulosic minor fibre only in which the research study is focused on banana fibre. The reasons for selection: it has capability to be used as various applications in future and cultivation and availability in India. There is a need for these fibres to be explored more as a textile fibre. These cellulosic fibres have several components namely, cellulose, hemicellulose, lignin, pectin and inorganic matters.

Cellulose

Cellulose forms the main structural basis of all vegetable fibres and consists of a long chain of 1.4 anhydro glucose unit. Cellulose makes up about 45% of the dry weight of wood. This lineal polymer is composed of D-glucose subunits linked by -1, 4 glycoside bonds forming celllobiose molecules. Cellulose can appear in crystalline form, called crystalline cellulose. In addition, there is a small percentage of non-organized cellulose chains, which form amorphous cellulose. In most of the vegetable fibres, cellulose is in intimate association with other carbohydrate constituents like some sugar residues, xylose and mannose. These chemicals are combined with cellulose through chemical bonds.

Hemicellulose

Hemicellulose are polymeric carbohydrates and make up 25-30% of total wood dry weight. The principal component of hardwood hemicellulose is Glucuronoxylan, whereas glucomannan is predominant in softwood. These are made up of relatively short chain in comparison with cellulose. Unlike cellulose, hemicellulose molecules have short side chains sticking out at intervals along its length. These side chains are acidic in nature. These side
chains are soluble in alkali. Further hemicellulose consists of many monomers like D-glucose, D-mannose, L-arabinose and D-galactose. Because of the relatively short chains with short side chains, hemicellulose and amorphous in nature. The molecules are oriented in the direction of cellulose micro fibrils. These molecules are chemically bonded to lignin by relatively weak bonds and also strongly associated with cellulose molecules. It may be possible that these molecules form an intermediate between cellulose and lignin.

**Lignin**

Lignin is the most abundant polymer in nature. It is present in cellular cell wall, conferring structural support, impermeability and resistance against microbial attack and oxidative stress. Structurally, lignin is an amorphous heteropolymer, non-water soluble and optically inactive. It consist of phenylpronane units joined together by different types of linkages. Lignin is generally regarded as three dimensional polycondensate of dehydrogenation products obtained from hydroxycinnamyl alcohols. Lignin can be divided into three types i.e. Gymnosperm or soft wood lignin, wood lignin, Angiosperm dicotyledonous or hard wood lignin and angiosperm monocotyledon lignin. It is totally amorphous and hydrophobic in nature. Lignin can be eliminated from vegetable fibres with the aid of bisulphates of alkali metals or by chlorination or by oxidation reactions. Lignin is considered to be a thermoplastic polymer exhibiting a glass transition temperature of around 170℃. It is not hydrolysed by acids, but soluble in hot alkali, readily oxidized and easily condensable with phenol.

**Pectin**

Most of the vegetable fibres contain small amount of pectin. Pectin is a collective name for hetero polysaccharides, which consist essentially of polygalacturon acid. Pectin acid has a chain structure similar to that of other carbohydrates. It is soluble in water only after a partial neutralization with alkali or ammonium hydroxide. It provides flexibility to plants. Actual pectin’s available in vegetable fibres form a very complex composition. They are mainly calcium and magnesium pectates. In practice, pectin’s are not easily eliminated from fibres; they are difficult to wash out with hot water and are completely extracted only with hot alkali solutions or by prolonged treatment with acids.

Some of the fibres have been discussed below:

**2.1.3a) Ramie**
Ramie is an herbaceous perennial plant in the nettle family *Urticaceae*, native to eastern Asia.

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

### 2.1.3.b) Coir

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

2.1.3.c) Flax

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

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

2.1.3.d) Hemp

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

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

2.1.3.e) Kapok

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

2.1.3.f) Kenaf

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

2.1.3.g) Nettle

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

2.1.3.h) Okra

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

2.1.3.i) Pineapple fibre

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

2.1.3.j) Sisal

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

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

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

2.1.3 Banana plantation and its varieties in India

2.1.3a) Origin of banana

The banana plant is the tallest and largest herbaceous flowering plant (Oneyma et al., 2016). The origins of banana are placed in tropical and subtropical region, in the jungle of Malaysia, India, Indonesia, whereas it is now grown all over the world on about 8.8 million hectares. It is the world’s oldest cultivated crop (Mohiuddin et al., 2014). It is said to be that the earliest written reference to banana is in sanskrit and dates back around 500 BC. Banana has so many varieties of wild bananas and as well of cultivated banana grown at present. Later banana have travelled with human population. The first European to know about bananas was the armies of Alexander the Great, while they were campaigning in India in 327 BC. In the middle Ages, the banana was a forbidden fruit by the Muslim and Christians. The Arabs brought them to Africa. The credit goes to African for the present name, since the word banana was derived from the Arab finger. Banana was brought along with the Portuguese to the canary island. Travelling into all these places, gradually the banana loosed its seeds, filled with flesh and diversifying.

In 1516, when Fiar Tomas de Berlanga sailed to Santo Domingo, he brought banana roots with him. From there, Banana travelled to the Caribbean and Latin American Countries. By the end of 19th century banana was traded internationally all over the world. With the technological advancement in refrigerated, development of railroads, maritime lead banana to become the most important world traded fruit.

Todays genus Musa is said to be derived from the wild species Musa acuminate (AA) and Musa balbisiana (BB). It is believed that there are 1000 varieties of bananas in the world.
addition to this, now days, it is gaining importance as a good source of fibres in the textile industry.

2.1.3b) Anatomy of Banana Plant

Banana is a tallest herbaceous plant with a pseudostem (a false stem) sheath of leaves wrapped around to form a trunk like structure and in its entire life cycle banana bears only once bunch of fruit. Banana belongs to *Plantae* kingdom. According to Carolus Linnaeus, they are classified as:-

Kingdom: *Plantae*
Division: *Angiosperm*
Order: *Zingiberales*
Family: *Musaceae*
Genus: *Musa*

![Morphology of banana plant](http://www.promusa.org/Morphology+of+banana+plant)
1. Root system
   The root system is the means by which the plant takes up water and nutrients from the soil. The roots are produced by the underground structure called a rhizome.

2. Rhizome
   The rhizome is the banana plant’s true stem. It is commonly referred to as a corm, and occasionally as a bulb, but the botanically correct term is rhizome. It is characterized by horizontal underground growth; production of roots from multiple nodes; and production of clonal plants.
   The terminal growing point of the rhizome, the apical meristem, is a flattened dome from which the leaves and the inflorescence are formed.

3. The matt
   Banana rhizomes or underground stems, grow suckers from many different points on the rhizome. Each rhizome produces many fibrous roots that intertwine to form a matt. Roots reach down 5 feet into soil and extend outward for up to 16 feet.

4. Suckers
   A sucker is a lateral shoot that develops from the rhizome and usually emerges close to the parents. A sucker that has emerged through the soil surface is called a creeper. A full grown sucker bearing foliage leaves is called maiden sucker.
   Morphologically there are two different types of suckers or sprouts emerge from the matt. The sword suckers develop into producing pseudostem. Sword suckers have narrow leaves. Water suckers are weak pseudostem with broad leaves. They produce poorly most growers. Eliminate the water suckers, leaving sword suckers to grow into replacement pseudostems. Very small sprouts, less than a foot tall is called peepers until they are identifiable as sword suckers or water suckers.

5. Inflorescence
   The inflorescence is a complex structure that includes the flowers that will develop into fruits. It is supported by the aerial true stem which is often called the floral stem.

6. Pseudostem
   Suckers grow into pseudostem, if they are allowed to remain on the matt.
The pseudostem is the part of the plant that looks like a trunk. This ‘false stem’ is formed by the tightly packed overlapping leaf sheaths. The pseudostem continues to grow in height as the leaves emerge one after the other and reaches its maximum height when the aerial true stem emerges at the top the plant.

Even though the pseudostem is very fleshy and consists mostly of water, it is quite sturdy and can support a bunch that weighs 50kg or more. (Promusa, 2015)

Plate 2.1: Banana plant cultivation
Source: Photograph taken by researcher

2.1.3 c) Importance of banana in India

Banana is the most important fruit crop in India next to mango. In the banana production, India lead with an annual output of about 30.47 million tonnes, contributing about 26.7% in
world pool of banana production (FAOSTAT, 2017). Banana occupies 13% area among the total area under crop in India (NHB 2017).

In India banana is grown all around the year. It is largely produced and majorly consumed among all the fruit in India. It is all most grown all over part of the country. Major banana producing states in India are Gujarat, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Maharashtra, Karnataka, Madhya Pradesh, Bihar, Kerala, West Bengal, Assam, Chhattisgarh, Odisha. Gujarat leads in production (4.18 million tonnes) and Karnataka leads in area under cultivation (102,000 ha) (NHB, 2017).

Most of the Banana is vegetative crop, also being cultivated through tissue culture. Sucker are being used as planting material by the farmers but due to its limitation advance in tissue culture have a great impact on the cultivation of banana crop. (Apaari, 2019).

2.1.3d) Suitable climate for banana farming

Banana, basically a tropical crop, grows well in a temperature range of 15°C – 35°C with relative humidity of 75-85%. It is grown in a warm and humid climate at an altitude of 1200m from the sea level. Bananas mature slower cooler climate and yield get reduced at lower humidity and temperature. For maximum productivity larger quantity of water is required. Four months of monsoon (June to September) with an average 650-750 mm. rainfall are most important for vigorous vegetative growth of banana.

Below 12°C temperature can injury the plant and high velocity of wind (80 Km/hr ) can damages the banana crop. (Apaari, 2019)

2.1.3e) Suitable soil type for banana farming

In Banana Farming, Soil for banana should have good drainage, adequate fertility and moisture. Deep, rich loamy soil with pH 6 to 7.5 is most preferred for banana cultivation. Ill drained, poorly aerated and nutritionally deficient soils are not suitable for banana. Saline solid, calcareous soils are not suitable for Banana cultivation. A soil that is not too acidic & not too alkaline, rich in organic material with high nitrogen content, adequate phosphorus level and plenty of potash are good for banana. (Doshi. A, 2016)
2.1.3f) Banana varieties

In India, bananas are grown in diverse agro-climatic condition with different farming practices. Therefore, India is a home of wide range of varieties of Musa cultivators. Dwarf Cavendish is majorly cultivated in India. However, around 20 cultivars viz. Dwarf Cavendish, Robusta, Monthan, Poovan, Nendran, Red banana, Nyali, Safed Velchi, Basarai, Ardhapuri, Rasthali, Karpurvalli, Karthali and Grandnaine etc Among all varities G9 gaining popularity and most preferred varieties due to its attractive bright yellow with better shelf life & quality.

Table 2.1: Important banana varieties cultivated in different states of India are given below:

<table>
<thead>
<tr>
<th>States</th>
<th>Varities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andhra Pradesh</td>
<td>Dwarf Cavendish, Robusta, Rasthali, Amritpant, Thellachakrakeli, Karpoora</td>
</tr>
<tr>
<td></td>
<td>Poovan, Chakrakeli, Monthan and Yenagu Bontha</td>
</tr>
<tr>
<td>Assam</td>
<td>Jahaji (Dwarf Cavendish), Chini Champa, Malbhog, Borjahaji (Robusta), Honda, Manjahaji, China (Manohar), Kanchkol, Bhimkol, Jatikol, Digjowa, Kulpait, Bharat Moni</td>
</tr>
<tr>
<td>Bihar</td>
<td>Dwarf Cavendish, Alpon, Chinia, Chini Champa, Malbhig, Muthia, Kothia, Gauria</td>
</tr>
<tr>
<td>Gujarat</td>
<td>Dwarf Cavendish, Lacatan, Harichal (Lokhandi), Gandevi Selection, Basrai, Robusta, G-9, Harichal, Shrimati</td>
</tr>
<tr>
<td>Jharkhand</td>
<td>Basrai, Singapuri</td>
</tr>
<tr>
<td>Karnataka</td>
<td>Dwarf Cavendish, Robusta, Rasthali, Poovan, Monthan, Elakkibale</td>
</tr>
<tr>
<td>Kerala</td>
<td>Nendran (Plantain), Palayankodan (Poovan), Rasthali, Monthan, Red Banana, Robusta</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>Basrai</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>Dwarf Cavendish, Basrai, Robusta, Lal Velchi, Safed Velchi, Rajeli Nendran, Grand Naine, Shreemanti, Red Banana</td>
</tr>
</tbody>
</table>
Utilization of banana pseudostem for textiles

<table>
<thead>
<tr>
<th>States</th>
<th>Planting Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maharashtra</td>
<td>Kharif - June – July</td>
</tr>
<tr>
<td></td>
<td>Rabi - October – November</td>
</tr>
<tr>
<td>Tamil Nadu</td>
<td>February – April</td>
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<tr>
<td></td>
<td>November – December</td>
</tr>
<tr>
<td>Kerala</td>
<td>Rainfed- April-May</td>
</tr>
<tr>
<td></td>
<td>Irrigated crop- August- September</td>
</tr>
</tbody>
</table>

Sources: [BANANA (nhb.gov.in)]

2.1.3h) Planting season in banana farming

Planting of tissue culture can be done through the year except when the temperature is too high and too low. During the drought drip irrigation can be used for planting the banana crop.

<table>
<thead>
<tr>
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<td></td>
<td>Irrigated crop- August- September</td>
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</tbody>
</table>

Sources: [BANANA (nhb.gov.in)]

2.1.3g) Banana Irrigation

Banana is a water loving plant, for maximum production it requires large quantity of water. In its entire life cycle, banana plant at least needs 900-1200 mm of water. Generally it can be fulfilled by rain and with extra supported with efficient drip irrigation. According to the seasons frequency of drip irrigation should be given with interval of 7-8 days in winter and 4-5 days in summer. The drip irrigation has also improves the water use efficiency. (Banana tissue culture)
2.1.3h) Application of manure and fertilizers in banana farming

Banana required high amount of nutrients, already soil has some amount of nutrients and minerals but it can be enhanced by adding extra nutrients in the soil. Banana crop requires 7-8 Kg N, 0.7-1.5 Kg P and 17-20 Kg K per metric tonne yield. Traditionally farmers use more of urea and less of phosphorous and potash.

In order to avoid loss of nutrients from conventional fertilizers i.e. loss of N through leaching, volatilization, evaporation and loss of P and K by fixation in the soil, application of water soluble or liquid fertilizers through drip irrigation is encouraged. A 25-30% increases in yield is observed using fustigation. Moreover, it saves labour and time and the distribution of nutrients is uniform. (Doshi .A, 2016)

2.1.3i) Harvesting of banana farming

Bananas produce one bunch of fruit in its whole life. Before harvesting of fruit from the plant there are many intercultural operations.

Desuckering: Banana produce number of suckers from the underground stem. These suckers should not be allowed to grow as it can expense the growth with main plant. Sucker can be removed by cutting them off or by detaching them off.

Bunch covering: Bunch covering done depending of its maturity stage. Bunch are covered with dry leaves, so that it can be prevent from scorching, bettle and also improves its visual qualities of the fruit.

Bunch removal: - Bunch should be hand cut with sharp sickle 30cm above the first hand. Harvested bunch should generally be collected in well-padded tray or basket and brought to the collection site. Bunches should be kept out of light after harvest, since this hastens ripening and softening. For local consumption, hands are often left on stalks and sold to retailers.(https://www.krishisewa.com/articles/production-technology/229-banana-cultivation.html)

2.1.3l) Post harvest management of banana farming

Each banana plant grows from a pseudostem, which is a bundle of the bases of the leaves of the plant. The true stem is underground, around the rhizome that produces the pseudostem above it and other suckers from which more banana plants grow. Some call this collection of
banana plants growing from the same underground structure a banana mat. After the main pseudostem produces a bunch of bananas, you should cut it to the ground because it will never produce fruit again, and even if you leave it in place, a light frost will kill it to the ground anyway. The underground portion of the banana plant remains so it can produce suckers that will grow into new fruiting pseudostems. (Doshi A, 2016)

In Ayurveda, banana has been described as having many medicinal properties and has been used for antiscorbutic, mild demulcent, astringent diet in case of diarrhoea and chronic dysentery. It is used to treat ulcerative colitis, coeliac disases, sprue, diabetes, uremia, nephritis, gout, hypertension and cardiac diseases. Tribal people residing in western ghats uses banana leaf as bandage to cover cuts, ulcers and blisters. The villagers of South India, Orrisa, Bihar etc. soak the leaves in coconut oil as a dressing. Banana fruits are acclaimed to soothe the stomach. In Haryana people has made their local medicine to cure dysentery by
mixing banana fruit with 50 gms of opium taken orally with cow’s milk. In Kerala, banana fruits are invised with small pellets of calcium hydroxide and are swallowed by woman having menses disorder like early menses, excessive menses bleeding. (Pushpangadan et al., 1986)

2.1.3l) Banana in Indian customs, Ceremonial & Rituals

From the ancient times, commonly practice by Hindu, banana plants has placed a special role in every religious ritual, customs and ceremonial such as planting tree at the entrance of the temple, marriages. In south India, banana fruits and its other part has diverse uses in rituals and worship. Banana fruits are offered as prasaad along with sweet sugar candy or jaggary. After the pooja “Prasad” are offered in banana leaf plates. Even the Pooja flower offered in temples are wrapped in banana leaf. Threads made from banana leaf sheath are used to make garlands meant for deities. Banana fruits are used as offering to God, Goddesses and to godly people in all over the country. (Pushpangadan et al., 1986)

2.1.4 Extraction and uses of bast fibres

Bast fibres can be extracted by any of the three methods:

   Chemical treatment

   Mechanical treatment

   Biological treatment or retting

2.1.4.1.a) Chemical treatment

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

2.1.4.1.b) Mechanical treatment

The mechanical process is divided into three steps.
1. Tuxing - The step involves giving a slight incision just underneath the pseudostem, and then giving a sharp pull, which brings away a strip or ribbon of the outside skin containing the fibre. These ribbons are called “Tuxies”.

2. Striping - The tuxies are fed in fibre extraction machine and pulled out. The tuxies are drawn several times between the blade and the bench before the fibre is sufficiently clean. With this all the pulp, weak fibre and pithy matter is scrapped off.

3. Drying – The fibres are sun-dried. Delay and carelessness in drying affect both the colour and strength of the fibre.

### 2.1.4.1.c) Biological treatment or retting

It is a phenomenon occurring through the combined action of bacteria and weathering which allows the degradation of the stem material (mainly pectines) surrounding the fibre bundles. There are many method of retting:-

1. Dew Retting: - in this harvested stalks are laid on the field under heavy night time dew and warm day time temperature for two to three weeks depending on the climatic conditions, fibres can be separated.

2. Water Retting: - in this harvested stalk are submerged into a stagnant water or slow moving water such as ponds, bog etc. The water penetrates to central stalk and swelling up the inner cells, bursting the outermost layer. The stalk bundles are weighed down by the heavy stone or wood for 8-14 days.

3. Chemical retting:- the dried plants are immersed in a tank filled with solution of chemicals, such as sodium hydroxide, sodium carbonate, high pH agents, pectinolytic enzymes or mineral acids. Within few hours fibres start loosening but a close monitoring required otherwise it can easily damage the fibre.

### 2.1.5 Softening Agents

Fibres can be soften either by mechanically or chemically. In mechanicals fibres are passed through number of rollers whereas in chemical softening agents are used to utilized in textile wet processing to improve fabric hand. Softening agents can make fabrics feel softer, more resilient, more flexible, and smoother than un-softened fabrics.
Chemical softening involves the use of four basic classes of softening agents:

1. Ionic Softeners - consist of ethoxylated fatty alcohols, acids, ester alcohols, polyethylenes, silicones and waxes. They do not ionize in water, due to the neutral charge they possess.

2. Silicones - are used as water repellent agents and have a high lubricating ability. They are used in small quantities due to their high cost. The drawback of silicone softeners has been the yellowing of textiles after curing or heating treatment.

3. Anionic softeners - They have a negative tail in the chemical structure when they ionize in water. These softeners include sulphates and sulphonates.

4. Cationic softeners - include chemicals like the fatty amino acids, amine oxides, and sulphobetaines. In addition to contributing to soft hand, these softeners have good antistatic properties due to the presence of two charges on the molecular structure.

5. Amphoteric softeners - These softeners are mostly used in softening cellulosic fibres and wool. Cationic softeners have a positive tail end, and they are attracted to fibres that acquire a negative charge when immersed in water, e.g. cellulosic fibres. Cationic softeners include quaternary ammonium salts, amino-amides and cyclic catatonic.

(Dosh. A, 2016)

2.2 Research Related Review

A study was conducted to investigate spinability of banana fibres through yarn formation and its analysis by Hossain M., & Begum H (2017). The main objective of the study was to find out the suitable spinning system for the banana fibres. Fibres used in this study was extracted from Kobri (AB genome, Musa paradisiaca) banana plant. With the 100 % banana fibre it was found difficult to produce web on carding machine. To overcome with this problem, Banana fibre were blended with cotton to form a carding web. By blending with cotton both ring and rotor spinning system was used to produce 70:30 cotton: banana and 50:50 cotton: banana yarns. 100 % banana was used to produce yarn in long staple (Jute spinning system). The yarns were tested for evenness, imperfections index, hairiness, strength. Results showed that quality of Rotor (Cotton–banana blended yarn) was better than ring (Cotton-banana blended yarn). Evenness in the yarn increased with the increase in the proportion of banana part. Strength of the rotor yarn was found more than ring and strength increased with the increase in the banana in blend ratio. Load
and Extension curve of 100 % banana yarn spun on jute spinning system showed that unevenness was more in yarns with the C.V % 85.34. It was concluded that rotor spinning system was more convenient system to spun banana fibre blended with cotton than ring spinning system.

Ahmed M., Chattopadhyay S., et.al, (2004) in this study researchers prepared cotton-ramie blended yarns by commercial cotton spinning system. Decorticated Ramie fibre were first treated with 1 % hydrochloric acid for 30 min at room temperature, washed thoroughly, hydro-extracted and dried. It was not possible to spin the Ramie fibre with 20-30% adhered gum. To reduce the gum content, the acid treated fibres were subjected to two- step degumming process with 1.5 % NaOH at 100°C for 60 min followed by additional treatment with 6.0 % NaOH at 100°C for 30 min. The degummed fibres were bleached with hydrogen peroxide, cut into 40 mm staple length and blended with cotton in the proportion of 35:65 (cotton: ramie). The blends were spinned using the ring spinning system. Test results showed that: the average gum content of decorticated ramie fibre reduced from 22.7 % to 2.35 % in case of degummed fibre there was 89.6 % gum removal further on bleaching the gum content reduced to 1.82 giving the further reduction by 22.5 %. By degumming and further bleaching, there was decrease in hemicellulose, lignin, pectin, ash, fat and wax but holocellulose and ∞- cellulose increased. SEM results showed that removal of gum make the fibre surface became smoother. The Lea strength of 100 % cotton yarn was higher than cotton: ramie blended yarn. Unevenness and imperfections was more in cotton: ramie blended yarn due to lack of compatibility between two fibres.

Doshi A., & Karolia A., (2016) carried out a experimental study on optimization of enzyme treatment for banana fibres. Banana fibres are extremely strong, lustrous and long length filament fibres. But being lingo-cellulosic in nature the fibres are stiff and less pliable. Banana fibres used in this study were extracted from Giant Naine banana plant variety. To soften the banana fibres, four eco-friendly enzymes: cellulase, hemicellulase, pectinase and lacase were applied individually to optimize the concentration and conditions and a final treatment was standardized for combinations. For all the treatment M:L ratio was 1:40. In individual enzyme treatments four different concentrations of cellulase was taken: 0.2%, 0.3%, 0.5% and 0.7%. It was observed that maximum weight loss was at 0.3 % concentration. The strength loss increased to a greater extends with the increase in concentration. Hemicellulase 0.5 %, 1%, 2% and 3 % was taken. Weight loss decreased after 1 % conc. Strength loss was found higher as compared to the cellulase treated fibres due to the fact that hemicellulose start degrading earlier than cellulose. Fibres were treated with four different concentrations of Laccase: 2%, 3%, 4% and
The weight loss was found less as compared to other enzymatic treatment due to the reason that laccase alone acts on only phenolic lignin which contain 10-20% of the lignin sub-structures in the plant-cell wall. Strength loss was found less in lower concentration of laccase with the increase in concentration severe strength loss was observed. Three different concentrations of pectinase was taken: 0.5 %, 0.7% and 1 %. Weight loss was same as in other enzymatic treatments but the strength loss was found high even with the low concentration. The effect of the enzymes on the fibres were measured in weight loss, strength loss and subjective evaluation by hand and based on these concentrations and conditions were optimized. Combinations of the enzymes done in a specific order (first laccase followed by hemicellulose then cellulase, pectinase) showed better results due to the reason that in lingo cellulosic fibres, lignin acts as a glue between cellulase and hemicellulase. In this combination treatment laccase first removed the lignin and simultaneously set the hemicellulase free and other enzymes removed the unwanted impurities. The optimized condition for enzymatic treatment of banana fibre was for enzyme laccase: the conc was 3% owf, time: 30 min, temperature: 55°C and pH: 5-6. For enzyme hemicellulase: the conc was 1% owf, time: 60 min, temperature: 40°C and pH: 5.5-6. For enzyme cellulase: the conc was 0.3 % owf, time: 45 min, temperature: 55°C and pH: 4.5-5. For enzyme pectinase: the conc was 0.7 % owf, time: 15 min, temperature: 55°C and pH: 5.5.

A Comparative study on the effect of chemical and enzyme treatments on softening of Sisal fibre was conducted by Bhoj.R (2017). Sisal fibre is exceptionally durable with low maintenance with minimal wear and tear. Due to the low cohesiveness it creates problems during weaving. So, the main aim of the study was to soften the sisal fibre by different chemical and enzyme treatment to make it suitable for various end applications. For enzyme treatment four different kinds of enzymes were used: Cellulase, Hemicellulase, Pectinase and Laccase. First the fibres were treated with 10% owf laccase because it helps in degradation of lignin then combination of cellulase (7%), hemicellulase (5%), pectinase (2%) was tried on pretreated laccase sample. In chemical treatment, fibres were treated with NaOH followed by bleaching with hydrogen peroxide and sodium hydroxide. It was observed that chemically treated sisal fibre have less strength loss as compared to enzyme treated fibres. This was mainly because of alkali used during chemical treatment which caused the mercerization without tension. SEM results showed that untreated sisal fibre were irregular and rough and much of the pithy material was observed whereas enzyme and chemical treated sisal fibres were smooth and clean. Whiteness index of the chemically treated fibres was increased and yellowness was decreased whereas in enzyme treatment Chemical composition indicates there was total removal of lignin.
in chemically treated fibre. Treated fibres were spun into yarn on Medleri charkha and it was observed that yarns were very uneven due to the unevenness of the fibres and the technique used in spinning. Woven samples prepared from chemically treated fibres were smoother than enzyme treated fibres. Hence it was concluded that chemical treatment have given results than enzyme treatment.

Shroff A., (2014) studied the effect of enzymes for softening of Banana, Sisal and Ramie. Researcher used hemicellulase, pectinase and cellulase enzymes for softening of the fibres. The fibres were treated with different combinations of enzymes at 6%, 15% and 22% concentration for 2,8,12 and 16 hours. It was seen that combination shows the variation in readings so the fibres were treated individually with the enzymes at 10 %, 12% concentration for 8,12 and 14 hours and it was observed that there was maximum weight loss of the banana fibre when treated with cellulase enzymes, sisal was when treated with hemicellulase at 12 % concentration for 14 hours and ramie treated with pectinase enzymes. The maximum strength loss was observed in sisal fibre due to hemicellulase enzyme. The results showed that tensile strength of all three fibres was similar to cotton. Non-woven fabrics was also prepared by blending 50:50 banana and sisal fibre by punching manually because of lack of cohesiveness property and 40:60 % of ramie and banana fibre on DILO nonwoven machine because ramie has a good cohesive property. Finally it was concluded that ramie gave the best results for the preparation of non-woven giving the most compact, smooth and flexible fabric as compared to the fabric prepared from banana and sisal fibre.

Thabede- Zwane P.L.E. (1997)treated sisal fibres to soften it to improve hand characteristics for the production of textiles. The main purpose of this study was to explore the effects of alkali degumming on the physical properties of mechanically decorticated sisal fibres and subsequently produced yarns and woven fabric and to explore the effect of commercial softeners on hand properties of fabric from degummed fibres. The fibres were treated with 5 different concentrations (6%, 7%, 8%, 9% and 10%) of NaOH for 45 mins. These treated fibres were spun into yarns using traditional methods. These yarns were then used as filling yarns were tested for breaking strength, apparent elongation, linear density and stiffness. Also fibres were evaluated for cellulose content using the staining test and observed under high magnification for physical changes on the surface. Spun yarns were tested for absorbency. The fabrics were tested for breaking strength, elongation, stiffness and absorbency and also subjective hand evaluation were obtained from panel of swazi women. Results indicated that as NaOH concentration increased, fibre breaking strength and apparent elongation decreased.
significantly but there was no significant effect on linear density or stiffness. At the yarn stage, an increase in NaOH concentration resulted in a significant decrease in yarn breaking strength, apparent elongation and linear density and an increase in absorbency. Evaluation of fabric hand were very similar for control and treated fabrics suggesting that the incorporation of cotton yarns in the weave may have more impact than improved processing. Even the use of commercial softeners did not improve fabric hand significantly. A majority of panelists suggested the fabrics could be used for making improved rugs and wall hanging.

Shetti V. (1998) pretreated cotton-banana union fabric with different chemical treatments and then treated with crosslinking and softening agents to study its effect on physical properties. The study was taken up with the purpose to study its effect of chemical pretreatments on banana union fabric, to study the effect of bleaching on chemically pretreated fabrics, to study the effect of resin finish on the pretreated, bleached fabric, to study the effect of softener on resin finished fabric, to study selected softener on bleached fabric, to evaluate the treated by Kawabata evaluation system (KES-FB), subjective evaluation and scanning electron micrographs (SEM). Cotton–Banana union fabric was pretreated with chemicals like polyethylene glycol-600, dimethyl formamide, and ethylene diamine using different concentrations. Best treated fabrics were selected. Concentration used were Polyethylene 20% v/v, dimethyl formamide 50%v/v and ethylene diamine 25% v/v. Then the fabric bleached with hydrogen peroxide using different concentrations and then 1% v/v was finalized. After bleaching resin finish was applied using Dimethylol dihydroxy ethylene Urea (DMDHEU). The finish was applied on the fabric with the help of padding mangle using single-dip-single-nip method. After all the treatments physical properties like fibre diameter, weight loss, percentage shrinkage, bending length, tensile strength, drape coefficient, wrinkle recovery, whiteness index, softening by KES-FB instrument. Among all the pretreatments polyethylene glycol pretreatment was best suitable as it reduced the desired whiteness with better strength retention to the fabric. Silicon softener was compatible with the substrate and showed improved wrinkle recovery and drapability without adversely affecting the strength of the fabric. Dimethylol dihydroxy ethylene urea resin cum softener treatment showed highest hand value ranking. It also showed improved wrinkle recovery and drape.

Zwane P.E., Cloud R. M. (2006) explored the spinability of sisal fibre treated with Sodium hydroxide (NaOH) and the potential utility of spun yarns in producing a woven fabric for different end uses. Exploratory and experimental approaches were utilized in gathering data for the project. The main purpose of the study was to explore spinability of fibres using a
traditional spinning wheel and utility of their spun yarns in producing a woven fabric for different end uses. Some of the physical properties of yarns and fabric woven from treated fibres were also determined to compare the hand qualities of softened and non-softened fabrics were determined. A traditional spinning wheel was utilized to spin the fibres into yarns with an aid liquid-based binding agent, using ratio of a 1:2 parts of water. The spun yarns were tested for properties like yarn breaking strength and elongation, yarn fineness, yarn stiffness and absorbency test of yarn. Plain- woven fabric were prepared using yarn spun from fibres treated with optimal concentration (0.25N) on a portable table loom. The warp yarns were 100% 3 ply cotton (80tex) and weft yarns were made from 100%, 2 ply sisal yarns with fibres treated NaOH. This fabric was compared to control fabric which was made up of cotton yarns were used to increase the acceptance of product and improve the hand as cotton being an acceptable and versatile natural fibre in textiles. Further, to enhance the fabric’s hand, it was treated with polyethylene cationic wax emulsion and another cationic softener. Treated fabrics were tested for tensile strength and elongation, stiffness, absorbency test and subjective hand evaluation was done by a consumer panel of 20 trained female assessors and also these assessors were further requested to indicate potential fabric uses. Results showed that treated sisal fibres were successfully spun into yarns which were finer and weaker in strength, but highly absorbent. On the other hand, the apparent elongation of yarns was decreased, indicating the brittleness of the fibres and yarn stiffness was not significantly reduced due to the use of the binding agent in the spinning process. The application of softeners has no significant effect on fabric hand when compared to control fabric. It also had decreased flexural rigidity. The potential end uses of fabric that were identified were apparel and accessories. In addition, the production 100% sisal fabric may be explored using finer yarns than that which were used in this study.

Dr. Nayak L.K et al, (2014) developed an extractor to produce good quality banana fibre for textile use. According to them considerable work has been done in the field of direct use and product development from banana fruits. However, not much attention has been focused on effective utilization of the biomass. Textile grade fibre can be extracted from this pseudostem. Though banana fibre extractors have been designed and developed at various R&D institutes and commercial organization of the country, no where quality of fibre extracted from these machines matches the desirable properties of textile grade fibre in terms of fineness, strength etc. for making fine quality yarn. Moreover, the fibres obtained from these extractors differ in quality posing problem to the processor. Hence, design and development
of an efficient extractor and standardization of the extraction process for getting good quality textile grade fibre is need of the hour. Extensive trial runs were conducted on the first up-graded extractor (with the provision of feeding mechanism & scratched roller-guide plate clearance adjustments) to study the variation of yield of fibre from green and white sheath of pseudo-stem. The fibre yields from green & white sheath were found to be 0.70% and 0.96% respectively. The overall yield of dry fibre from pseudo stem was found to be 0.80%. the CAD design of the second up-graded extractor ( with the provision of an additional roller to avoid backward dragging & delivery mechanism) were completed.

Zwane P., & Cloud R (2006) researchers in this study developed fabric using chemically-treated sisal fibres. The purpose of the study was to explore the spinability of fibres using a traditional spinning wheel and the potential utility of spun yarns in producing a woven fabric for different end uses. For the experimentation, fibres treated with NaOH were spun on traditional spinning wheel with the aid of liquid based binding agent. Spinned yarns were subjected to following tests: Yarn twist, linear density, strength and absorption test as per the ASTM test method respectively. Results showed that spun yarns of two plies with low twist of eight to 12 tpi, apparent elongation and linear density decreased whereas absorbency increased with an increase of NaOH concentration. High absorption was due to the removal of lignin and hemicellulose which was responsible for impeding water absorbency on sisal yarns. Plain woven union fabrics was prepared using yarns spun from fibres treated with optimal concentration (0.25 normality) and untreated fibres. Warp yarns in the fabrics was made from 100%, 3 ply cotton and weft consist of 100% 2 ply sisal yarns. Four different fabric sample was prepared: Control sample, degummed (alkali treated sample), degummed + softened (Polyethylene wax emulsion) and degummed + softened (Cationic softener). It was concluded that fabric made from alkaline treated fibres was more pliable, soft, smooth, slippery and compact whereas the control fabric sample was found harder, rougher, harsher and more open. It was further recommended that softened fabrics can be used for making table linen, pants and count thread embroidery.

Agrawal G., (2016) documented cellulosic minor fibres with regard to its cultivation, extraction process, applications, initiatives and schemes taken by government, non-government and other allied agencies/Institutes. Cellulosic minor fibres has outstanding properties and can play an important role as a textile material owing to their properties like tenacity, wet strength, luster and microbial properties. The information on various cellulosic minor fibres was not available from the single source of literature so it became difficult for any researcher to work on these fibres.
This study was limited to 9 cellulosic fibres which included Pineapple, Flax, Coir, Ramie, Bamboo, Kenaf, Sisal and Sun hemp on the basis of the reasons like its capability to be used in various application in future, its cultivation and availability in India. This study revealed that cellulosic minor fibres are of vital importance due to various factors which include potential to provide farm and off-farm based employment to the large section of people. Another essential factor found was utilization of the waste to generate wealth. Hence the cellulosic minor fibres have a great potential to be used as textiles and it should be promoted for environmental sustainability. The reason for limited use of these fibres is due to the difficult extraction process, processing and also the unawareness of these fibres. These fibres are capable of being used as textile fibres with the help of the modification of the fibres.
Chapter III

METHODOLOGY

The study undertaken was an experimental and exploratory on banana fibers. The main aim of the study was to soften banana fibers and spin 100% hand spun banana yarn. The spun yarns were used for weaving banana union fabrics. The chapter deals with materials and methods which were followed in fulfilling the planned objectives of the study.

The experimental procedure of the study undertaken has been subdivided into the following subsections:

3.1 Extraction of banana fibres and testing of properties
3.2 Yarn spinning workshop
3.3 Banana Union fabric construction
RESEARCH DESIGN

BANANA FIBRE

Fibre Extraction

Fabrication of FFT Apparatus for Softening Treatment of Fibre

Softening Treatment of raw fiber

Testing of Fiber Properties

FIBRE

Phoenix Charkha Spinning

Motorization of Phoenix Charkha

Training Program

Spinning Workshop (6th months)

100% Hand Spun Yarn

Testing of Yarn Properties

YARN

Handloom Fabrics

Cotton/Banana Union Fabric (Chemical treated)

• Plain weave
• 2/2 Twill weave
• Plain weave with extra weft
• Decorative Weave
• Tangaliya weave

Testing of fabric Properties

Online Exhibition of an exclusive range of Textile Grade Banana Yarns & Fabric

FABRIC
3.1 Extraction of banana fibres and testing of properties

Banana fibre extraction process was studied and the samples were procured from Sarsa, Anand, Gujarat regions of India, contact details have been mentioned in Table 3.1

Table 3.1: Contact details of organizations from where banana fiber were procured

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Contact Organization</th>
<th>Postal Address</th>
<th>Contact No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Esha Biodegradable</td>
<td>Esha Biodegradable, Sarsa, Anand</td>
<td>9275124111</td>
</tr>
</tbody>
</table>

3.2 Testing of Fiber

Bundle Fiber Strength Test: For testing the bundle fibre strength Pressley Fibre – Strength Tester was used with ASTM D 1445.

3.2.1 Determination of the physical properties of banana fiber

3.2.1 a) Determination of fiber length

To determine the length of banana fiber steel ruler was used with a holder placed at one end. Single fiber was clipped to the holder and length was measured on the other end. 50 readings were taken and average was calculated.

3.2.1 b) Determination of fiber diameter

Microscope with micrometer lens was used to measure the diameter. An average of 25 readings was taken to analyse fiber diameter.

3.2.1 c) Determination of colour and texture of the fiber

Colour and the texture of raw fiber was analyzed by naked eyes and the feel by hands. For testing the whiteness index, CIE standard and ASTM D1925 standard was used to measure yellowness index, using spectrophotometer.

3.2.1 d) Determination of moisture regain of the fiber

To determine the moisture regain, the fibers of known weight were exposed to 65±2 % RH at 27±2°C temperature for five days. The samples were weighed in condition state (W1). The
samples were then dried at 110°C in oven, up to the constant weight (W2). From these two weight difference, moisture regain was calculated using equation:

\[
\text{Moisture regain} = \frac{\text{Weight of moisture (W1−W2)} \times X}{100 \ \text{Oven dry weight (W2)}}
\]

3.2.1.2 Determination of strength of banana fiber

3.2.1.2 a) Bundle fiber strength test

For testing the bundle fibre strength Pressley Fibre – Strength Tester was used with ASTM D 1445. The test was carried out in the Department of Textile Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

3.2.1.2 b) Single fiber strength test

Using ASTM D 3822 standards single filament strength was tested. LlyodInstron Tensile testing instrument was used. The sample length was kept 20 cm. The instrument worked on constant rate of extension (CRE) principle. The test was carried out in the Department of Textile Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

3.2.1.3 Determination of fiber fineness

Following ASTM D7025 standard filament fiber fineness was tested. The Tex was determined by using average weight of 20 readings of 100 cm length of the fiber and calculations were done by using the formula:

\[
\text{Tex} = \frac{W \times L}{L}
\]

Where, \( W \) = Weight of the fiber
\( L \) = Length of the sample
\( L \) = the unit length of the sample

The count of the filament fibers was also determined by indirect system of yarn numbering using Beesley’s yarn balance. The instrument consists of a hook and a pointer at two ends. A standard balance was hung on the notch of the beam yarn. Template was used to cut the length of filament fibers based on linen count system. These fibers were added on the hook
until the pointer is opposite the datum line. The count is the number of short length filament fibers used to balance the beam.

3.2.1.4 Determination of fiber evenness

The evenness of the filament fiber was evaluated by microscopic observation. An average of 200 readings for fiber diameter was taken at different intervals. 40 slides were prepared and five readings from each slide were taken and plotted as graph for evaluation.

3.2.2 Material Characterization of fiber

3.2.2.1 Determination of chemical composition of banana fiber:

Chemical constituents of the raw fibers were determined as per the scheme suggested by Garner (1967). The procedure was carried out in the sequence mentioned below:

a) Estimation of water soluble components

A weighted sample of grey fibers was boiled in distilled water for five hours, using material liquor ratio of 1:30. Samples were then filtered in sintered glass crucible of no. 1 porosity, oven dried at 100°C for 30 minutes, and then weight was taken on electronic balance. The water soluble component was calculated using oven dry weight. The formula used for calculation:

\[
\text{Water soluble components (\%)} = \frac{W_1 - W_2}{W_1} \times 100
\]

Where, \( W_1 \) is the initial weight of the sample

\( W_2 \) is the weight after the removal of water soluble component

b) Estimation of Fats and Waxes:

After the removal of the water soluble component from the sample it was extracted in the Soxhlet apparatus with 2:1 alcohol (methanol)/benzene solution for 4 hours. Sample was then washed with alcohol dried and weighted (\( W_3 \) gms). The results was expressed as percentage of the oven dry weight of the original sample.
Fats and waxes (%) = \( \frac{W_2 - W_3}{W_1} \times 100 \)

Where, \( W_3 \) is the weight after the removal of fats and waxes

c) **Estimation of Pectin Content:**

The defatted fiber samples was then extracted by boiling for 1 hour in 1% ammonium oxalate solution and then washed with distilled water until the washing are free from oxalate. The loss in weight owing to the removal of pectinous material is recorded as a percentage of the oven dry weight of the original sample using formula:

Pectin content (%) = \( \frac{W_3 - W_4}{W_1} \times 100 \)

Where, \( W_4 \) is the weight after the removal of pectin content

d) **Estimation of Hemicellulose Content:**

After the pectin removal, the fibers were extracted in the Soxhlet apparatus with 2% Caustic soda solution for 1 hour and then wash thoroughly with distilled water. The loss in weight due to the removal of hemicellulose is estimated as percentage of oven dry weight of the original sample using equation:

Hemicellulose content (%) = \( \frac{W_4 - W_5}{W_1} \times 100 \)

Where, \( W_5 \) is the weight after the procedure (removal of hemicellulose content)

e) **Estimation of Lignin Content:**

After the hemicellulase removal, fibers were subjected for 2 hours under reflux boiling in water bath with 50:1 material liquor of 0.7% Sodium Chlorite solution, at 4 pH using acetic acid. Then these fibers were filtered in sintered glass crucible of no.1 porosity. Later the samples were washed with 750 ml of distilled water then with 250 ml of 2% sodium bisulphate solution, and finally with 1000 ml of distilled water. The samples were dried at
105°C. The lignin content of oven dry weight of the original sample was calculated by formula:

\[
\text{Lignin content (\%) } = \frac{W_5 - W_6}{W_1} \times 100
\]

Where \( W_6 \) = weight of the sample after the lignin removal.

f) Estimation of Cellulose Content:

After the removal of non-cellulosic components, cellulose was measured by weight differences using formula:

\[
\text{Cellulose content (\%) } = \frac{W_6}{W_1} \times 100
\]

Where, \( W_6 = \) Weight of the sample after lignin removal (Doshi A., 2017)

3.2.3 Determination of microscopic properties of banana fiber

Longitudinal and cross section was viewed under microscopic with a magnification of 15X power. Slides were prepared for longitudinal view, and readings were taken. For cross section, the bundle of fibers was inserted in a hollow pipe of very fine diameter and was sliced. The slice was observed under the microscope.

3.3.3 Standardization of chemical treatment for banana fibers

i) Alkalization and Bleaching Treatment

To begin the treatment, banana fibers were scoured, which is also termed as alkalization for lignocellulosic fibers. The fibers were treated with 4 % sodium hydroxide at 80°C to 90°C for 60 min and bleached with the optimized bleaching recipe. Time of treatment with sodium hydroxide was studied based on bundle fiber strength and the hand of the fiber. Fibers treated for 2.5 hours with NaOH treatment.

Alkalization for 2.5 hours was accompanied with the combination of bleaches for 25 minutes.

ii) Treatment with oil emulsion

After bleaching fiber were followed with alkalization for 1 hour.
For softening treated fibre were immerged in oil emulsion

- Rice bran oil: 20% w/v
- Non-ionic emulsifier: 5ml/1000ml of water

3.3.3 Fabrication of instrument for treating banana fibers

While treating the fibers in bulk for spinning of yarn, lot of entanglements was a major issue. Thus to overcome this problem, an equipment was fabricated in the Department of Clothing and Textiles. This fabricated instrument was termed as FFT (Filament Fiber Treatment) apparatus.

3.4 Spinning and testing of yarns

3.4.1 Yarns spun on phoenix charhka (hand spun yarns)

For the present study, banana fibers were spun on Phoenix Charhka. This was purchased from Phoenix Products, Belgaum. At significant research finding some modification was done. In modification each charhka was installed with motor to convert into semi-automatic machine.

3.4.2 Training Workshop

Under the project 18 ladies were to be trained for combing and spinning. 5 days training workshop was planned. During these practice days focus was laid on feeding mechanism, as this step was manual and could be responsible for unevenness and also thickness to certain extent, of the yarn. One person’s task was to comb the fiber and second person’s task was ply the fibers and the third person would feed the fibers in the charhka. Three people working on charhka, aids in speeding up the spinning process and also help to obtain finer yarns.

3.4.3.1 Determination of yarn fineness:

Following ASTM D7025 standard yarn fineness was tested. The Tex was determined by using average weight of 20 readings of 100 cm length of the fiber and calculations were done by using the formula:

\[
\text{Tex} = \frac{W \times l}{L}
\]
Where, \( W \) = Weight of the fiber

\( l \) = Length of the sample

\( L \) = the unit length of the sample

The count of the yarn was also determined by indirect system of yarn numbering using Beesley’s yarn balance. The instrument consists of a hook and a pointer at two ends. A standard balance was hung on the notch of the beam yarn. Template was used to cut the length of filament fibers based on linen count system. These yarns were added on the hook until the pointer is opposite the datum line. The count is the number of short length yarns used to balance the beam.

**3.4.3.3 Determination of yarn strength and elongation:**

Using ASTM D 3822 standards yarn strength was tested. LlyodInstron Tensile testing instrument was used. The sample length was kept 20 cm. The instrument worked on constant rate of extension (CRE) principle. The test was conducted in Department of Textile Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

**3.4.3.4 Determination of yarn twists (TPI):**

The yarn twist was calculated on twist tester. The sample length was 10”, test length with tension arrangement. 10 readings were taken for each yarn at varied distance.

**3.5 Construction of fabrics**

Union samples were constructed from 100 % banana hand spun yarn used as weft. The fabrics were made using cotton warp. Total six samples were constructed. Weaving was outsourced.

**3.5.1. Evaluation of properties of constructed fabric:**

**a) Determination of fabric Count:**

Fabric count (the number of yarns/inch) helped to describe the closeness of the weave. Following ASTM D 3775-98 fabric count was determined by counting number of threads in one inch in warp and weft direction using pick glass. Average of 10 readings were taken.
b) **Determination of fabric thickness:**

Following ASTM D 1777-96, fabric thickness was measured on Universal thickness tester. 10 readings were taken from the different places of the fabric. Average of these 10 readings were taken.

c) **Determination of Fabric weight per unit area:**

Sample of 5 X 5 cm. were cut and weighted. GSM was calculated using formula:

\[
\text{GSM} = \frac{\text{Weight in grams of the sample} \times 100 \times 100}{5 \times 5}
\]
Chapter IV

RESULTS AND DISCUSSION

Increasing awareness on a global level on the benefits of using natural fibre has been the lead cause for development of agro based fibres. One of such potential fibre is banana fibres. However due to its inherent drawback of stiffness, softening is required. The fibers were treated and were used to spin yarn. A group of 18 women were trained for fibre combing and spinning. The spun yarns were used to construct the fabric samples. The results have been given and discussed under the following sub section

4.1 Extraction process of banana fibre
4.2 Physical and Chemical properties of banana fibres.
4.3 Fabrication of softening apparatus.
4.4 Softening of banana fibres
4.5 Yarn spinning workshop
4.6 Fabric construction
4.7 Exhibit of banana yarn and fabrics
4.8 Fibre to fabric conversion data

4.1 Fibre Extraction process

Banana plants are classified as herbaceous perennials. These plants live for many years, but they do not have woody tissues. Banana plant stalks are made up of several layers of leaves and stems. Banana plants are rhizomes. Many young plants can emerge from a mature banana rhizome, allowing the plant to continue for an indefinite period as stalks developed, flower, and fruit and then die. It takes around 8 to 12 months for the plant to produce fruit. After the harvest of the fruit the pseudostem is cut.

For the present study banana fibres were procured from Esha Biodegradable – Tarisha Farm at Sarsa, Anand, were of G9 variety. Grand Nain bananas (also spelled Grande Naine) are banana cultivars of Musa acuminate. It is one of the most commonly cultivated bananas and a source of commercial Cavendish bananas. It takes around 8 to 12 months for the banana plant to bear the fruit.
Generally during the month of June the harvesting of the plants is carried out. After the harvest of the fruit, the pseudostem is cut. An average of 70 to 80 MT per hectar of pseudostem is generated. It takes approximately two day on one raspador to extract banana fibre from 70 to 80 MT. Due to this agro-waste, the farmers face several issues:

- The pseudostem is thrown on the roadside to be dried. As these pseudostem contains high amount of water hence, can only be burned after drying.
- They may cause several health issues lying unused for a long period of time.
- The farmers have to pay an additional cost to discard the pseudostem, away from their field.

To overcome these problems, the banana pseudostem which is an agricultural waste can be utilized to extract banana fibres.

- Disposal problem of banana pseudostem resolved
- Extraction of banana fibres
- Several bi-products obtained
- Additional Income Generation
Cutting: After the harvest of the banana fruit, the banana pseudostem is cut. Banana plant leaves are huge, depending on the variety. Stalks can range in sizes from 2.5 feet to 12 feet long. Labours are appointed on daily wages to cut the stem.

Plate 4.2: Cutting of Banana Plants on the Field
(Courtesy: Esha Biodegradable, Sarsa)
Transportation: After cutting the pseudostem, they are loaded on a truck and are bought to the shed, where extraction of the fibres would take place.

Plate 4.3: Banana stalks transportation to the shed
(Courtesy: Esha Biodegradable, Sarsa)

Sheathing: Banana stalk are collected under the shade near the farm. There are around 12-15 layers of pseudostem in a plant. Each sheath is separated as shown in the picture and are cut to lay straight.

Plate 4.4: Separating of layers of banana pseudostem
(Courtesy: Esha Biodegradable, Sarsa)
Extraction of banana fibres

Banana fibre extraction process is a crucial step in obtaining banana fibres. The type of Raspador used has an impact on the quality of fibres obtained. Hence, the number of blades in a raspador is an important parameter to consider during purchase of banana fibre extracting machine.

Two people are employed on one raspador. The process of extraction includes feeding of banana pseudostem in feed roller and is pulled back. The same process is carried out from the reverse side. Each stem weights 25 – 30 kgs and 250 to 300 grams of banana fibre is obtained from it. The person employed for this activity needs to be very careful during feeding of the stalk. Besides banana fibre there are other bi-products obtained during the process. All of these by-products can be utilization value.

- Edible central core
- Banana sap as liquid fertilizer or mordant for dyeing
- Scutcher waste as vermin-compost
**Figure 4.2:** Schematic diagram of Banana fibre in Raspador machine


**Plate 4.6:** Extraction of banana fibre on Raspador

(Courtesy: Esha Biodegradable, Sarsa)
Washing and Drying: After the extraction of banana fibre, the fibres are washed in tap water and sun dried. The dried fibres are packed in a bundle of 5 Kgs each. These fibres were bought to the Department of Clothing and Textiles for application of softening treatment. The raw fibres were studied for their properties.

Plate 4.7: Close view for extraction of banana fibre
(Courtesy: Esha Biodegradable, Sarsa)

Plate 4.8: Rinsing of extracted fibre
(Courtesy: Esha Biodegradable, Sarsa)
4.2 Testing of Fiber

4.2.1 Physical properties of banana fibre
Banana fibres are classified as natural, bast fibres obtained from pseudostem of banana plant. Banana fibres are filament fibres of lignocellulosic nature.

4.2.1.a) Length and Width of raw banana fibre:
Average length of banana filament fibres was observed between 90 cm to 110 cm. The diameter was 18µm. It was observed that the length to breath ratio was 1:50,000 whereas silk is also a natural filament fibre with length to breath ratio 1:33,000. Fact associated with this aspect ratio is the higher the ratio, the finer the fibre. Hence banana fibres are not very fine fibres naturally.

4.2.1.b) Colour and Strength:
Raw banana fibres are coffee creamy to light brown in colour. They possess rough texture, majorly due to the pithy material remains on the fibres. The fibres still have a natural lustre. Banana fibres have excellent tensile strength, better than cotton. Average bundle strength of raw banana fibres is 42 gms/tex. Where as a single filament fibre strength is 356.51 gf and extension at maximum was 2.16mm. Like any other fibre, banana fibres also have better bundle strength than single filament fibre. Banana fibres are naturally strong fibre, but posse’s poor elongation property.

4.2.1.c) Moisture regain of raw banana fibre:
Moisture regain of banana fibre was 10.63, which is close to cotton fibre. Moisture affects mechanical properties, including breaking strength, elongation and elastic recovery of fabrics. This degree to which fibre strength is influenced by moisture is closely related to moisture regain. For cellulosic and lignocellulosic fibres the strength increases as the relative humidity increases; and moisture regain is directly proportional to relative humidity.

4.2.1.d) Fineness and Evenness of raw banana fibre
Linen count of raw banana fibre was 105 Linen. On converted from indirect system to direct system, the value obtained was 157.59 denier / 97’s.
The evenness of the filament fibre was evaluated by microscopic observation. Graph obtained by plotting the readings in given in Graph 4.3.
Graph 4.1: Evenness of raw banana fibre

From the above shown graph, wide range of variation in the readings of the diameter was observed. Most of the readings fall in the ranges between 13 µm to 57 µm and there are several points where the diameter is above 40µm. The mean (average) of the fibre diameter was 19.35 µm; however the standard deviation was 8.6. Hence, it can be concluded that raw banana fibre is uneven.

Determination of chemical composition of banana fiber:

The chemical composition of untreated banana fibre obtained by elemental analysis is mentioned in Table 4.1

Table 4.1: Chemical composition of raw banana fibre

<table>
<thead>
<tr>
<th>Chemical Constituent of banana fibre</th>
<th>Percent value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water soluble</td>
<td>9</td>
</tr>
<tr>
<td>Cellulose</td>
<td>64</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>9</td>
</tr>
<tr>
<td>Lignin</td>
<td>9</td>
</tr>
<tr>
<td>Pectin</td>
<td>2</td>
</tr>
<tr>
<td>Fats and waxes</td>
<td>2</td>
</tr>
</tbody>
</table>
From the chemical composition data, it can be concluded that banana fibres have high content for lignin and hemicellulose. Hence, to use banana fibre for textile application, softening method was required.

**Chemical Structure of Lignocellulosic fibre**

Banana fibres are lignocellulosic in nature. Lignocellulose is a complex structure made of three basic compounds; cellulose, hemicelluloses and lignin. Figure 4.1 shows the arrangement of lignocellulose in a plant cell. Inside the lignocellulose complex, cellulose retains the crystalline fibrous structure and it appears to be the core of the complex. Hemicellulose is positioned both between the micro- and the macro-fibrils of cellulose. Lignin provides a structural role of the matrix in which cellulose and hemicellulose is embedded.

![Figure 4.3: Positioning of Lignocellulosic Components in a Plant Cell Wall](http://www.intechopen.com)

**4.2.2 Determination of Microscopic properties**

**Microscopic view of banana fibre:**

Under the microscope, the longitudinal section of banana fibre is roughly cylindrical with surface irregularities due to the pithy material attached to it. The fibre has striations, and at some points its splits into two or more sections and furthermore joins back. This observation
was made when the fibres were examined from one end to the other. To certain extend, the unevenness of banana fibre can be attributed to this characteristic of being in bundle and separating at random points. However, a single fibre is relatively smooth and straight. The ends of the fibres are slightly tapered and blunt. Pronounced cross marking were seen on the entire length of the fibre. The cross section appears as serrated and polygonal. The cell wall is thin. The lumen is large and distinct. It is round and uniform in diameter.

![Longitudinal section of raw banana fibre](Plate 4.9)

![Cross section of raw banana fibre](Plate 4.10)

**Plate 4.9:** Longitudinal section of raw banana fibre

**Plate 4.10:** Cross section of raw banana fibre

### 4.3.1 Fabrication set up for treatment unit

The FFT (Filament Fibre Treatment) apparatus worked on simple principle of rotation. The apparatus was made from aluminium vessel. The capacity of the vessel was 100 litres. A disc was attached in the centre of the vessel which was 10 inches above the base and was attached to a motor. The capacity of the motor was 50 rpm, which was modified.
This disc was an important part of FFT apparatus that actually performs the operation. During the treatment the disc rotates continuously and produces strong rotating currents within the water due to which the fibres also rotate inside the vessel. The rotation of the fibres within water containing the bleach enables the bleaching action evenly. Thus the disc produced most important function of rubbing the fibres with each other as well as with water without any entanglements. After treating the fibres, they were combed and weighted. Combing removed the pithy material from the fibre. Along with the pithy material, filament fibres were also removed due to entanglements. It was observed that less wastage was generated after treating banana fibres in FFT apparatus. Due to fewer entanglements, the waste generated after combing also reduced. The apparatus let the fibres rotate without entangling with each other. This observation was measured by weighing the combed waste. Hence, it can be concluded that any treatment can be made more effective in terms of generating less wastage by utilizing the FFT apparatus. Approximately 33% – 35% of fibres can be saved and utilized for planned end use.

Table 4.3 Effective of FFT apparatus on post treatment weight loss

<table>
<thead>
<tr>
<th>Weight of fibres before bleaching</th>
<th>Weight of fibres after bleaching and combing</th>
<th>Weight of fibre after bleaching in FFT apparatus and combing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Kg</td>
<td>300 grams</td>
<td>400 grams</td>
</tr>
<tr>
<td>Percent improvement to reduce waste</td>
<td></td>
<td>33%</td>
</tr>
</tbody>
</table>

Plate 4.13: A) Untreated banana fibre  B) Treated banana fibre
Plate 4.14: A) Fabricated filament fibre treatment Apparatus

Plate 4.14: B) Fabricated filament fibre treatment Apparatus
4.3 Softening Treatment

Year 2009 was declared as International year of Natural Fibres. Since then, a marked awareness about the use of minor fibres has been observed. Extraction of banana fibres has been observed at many places across the country. These fibres are have been utilized in handicraft industry. Banana fibres are potential fibres and can be utilized in textiles as well.

The prime importance of the present study is to apply a softening treatment on banana fibres to obtain more pliable, soft, even fibres with better elongation to be spun into a yarn.

Softening treatment was optimized during the Ph.D work of Amrita Doshi guided by Prof. Anjali Karolia has been utilized in the present work. The table given below mentions the recipe for softening treatment.

**Table 4.2: Recipe for chemical treatment**

<table>
<thead>
<tr>
<th>Series of treatment</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alkalization</strong></td>
<td>4% NaOH for 90 min at 80°C to 90°C</td>
</tr>
<tr>
<td><strong>Bleaching</strong></td>
<td>Bleach: H₂O₂ : NaOCl: 100:1</td>
</tr>
<tr>
<td></td>
<td>pH: 9-10</td>
</tr>
<tr>
<td></td>
<td>Alkali: NaOH</td>
</tr>
<tr>
<td></td>
<td>Alkali concentration: 4%</td>
</tr>
<tr>
<td></td>
<td>Time: 25 min</td>
</tr>
<tr>
<td></td>
<td>Temperature: 80°C to 90°C</td>
</tr>
<tr>
<td><strong>Re-alkalization</strong></td>
<td>4% NaOH for 60 min at 80°C to 90°C</td>
</tr>
</tbody>
</table>
Treatment with oil emulsion

- Rice bran oil: 15% w/v
- Non-ionic emulsifier: 5ml/1000ml of water
- Water: M: L:: 1:20

Plate 4.11: Banana fibres immersed in solution for step 1 of the softening treatment

Plate 4.12: Banana fibres at the last stage of softening treatment
4.4 Spinning and testing of Yarn

4.4.1 Training Workshop

- The major Criteria for sample selection were as follows:-
  ➢ No Education boundaries were there but they must be above 18 Years.
  ➢ Heterogeneous Social composition rather than Homogeneous groups ( can be from different social group, gender etc.)
  ➢ A sample of 18 people would be optimum for the fieldwork.
  ➢ Adhar card was mandatory.
- On 25th meeting was conducted with 18 people who were going to be trained for the program. A small presentation of the targeted work was also given. Banana fibres were also given to them to experience it so that they could develop an insight of fibre on which they are going to work.
- The training workshop was conducted for 5 days i.e. from 27 November to 1 December, 2019.
- To instruct the whole training program, a resource person from the Phoenix Product was invited, Mr. Nazir Kamal Ahmed, an expertise in the field of conducting training workshop on spinning of Banana Fibre in Andhra Pradesh.
- The main aim of the training was to demonstrate spinning of banana fibre on Phoenix Charkha to trainees.
- On the first day of training program, it was kept simple and firstly started with introduction of trainer with the participants and then each participant was allowed to introduce themselves to the trainer and also among themselves.
- After the introduction, then trainer began to explain the concept of spinning and what are the major topics to be covered during the 5 days of the training.
- The key topics that were covered in the training program:-
  - Parts of charkha
  - Feed mechanism
  - Handling of the fibre
  - Combing and sorting of fibre
  - Difference between Coarser yarn and finer yarn
  - Amount of Pressure and twist required on the fibre during spinning
The timing of workshop were from 10:00 am to 17:00 pm with two break consisting of 45 minutes of lunch break between 12:00 to 13:00 and one half an hour tea break from 3:30 pm to 4.00 pm.

All the trainees were segregated into groups of 6 having 3 members on each group per Charkha and their roles.

Firstly they were given cotton yarn for practice to understand the concepts of twist, yarn count, how to maintain the denier and how to join two yarn then they were given raw untreated banana fibre.

Only for the 5 day training program, lunch was provided by the organizer only.

At the last of training program, each participant was asked for the feedback and doubts were made clear.

Plate 4.16: Mr. Nazir Kamal Ahmed demonstrating the trainees

4.4.2 Spinning workshop

The six months spinning workshop was planned from 3 December, 2019 to 3 May, 2020. However, due to pandemic situation spinning workshop which started in December was put on halt from March 2020. The workshop resumed from 1st October 2020 and continued till December 2020.

In first two week of training program, trainees worked with untreated banana fibre then they were gradually moved toward treated banana fibre.

The main objective of the spinning program is
→ To spun 100% fine banana yarn
→ To test the physical properties and its suitability in textiles
→ To calculate its production planning and cost of the yarn.

- So the first objective was to spun the 100% fine banana yarn acquired during this 6 month of spinning workshop. After then its physical properties (microscopic view, its shape, length, yarn tensile strength) was to be study and depending on the result find its best suitability in textiles (apparel, furnishing etc).

Plate 4.17: Trainees spinning yarn in Phoenix Charkha
Plate 4.18: Trainees working under project “Utilization of Banana Pseudostem for Textiles”

4.4.2. Testing of Fiber

4.4.2 a) Properties of untreated and treated banana fibres

- Weight loss
- Tensile strength
- Fibre fineness
- Chemical composition

4.4.2 b) Weight loss

The performance of the treated fibres were analysed by weight loss parameter. Weight loss was due to removal of unwanted impurities. Hence it was a positive sign that the treatment was effective. Percent weight loss of treated fibres has been given in Table

<table>
<thead>
<tr>
<th>Sr.No</th>
<th>Sample</th>
<th>% Weight loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raw</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Chemical Treated</td>
<td>27</td>
</tr>
</tbody>
</table>

Weight loss indicated that impurities were removed after the treatment. Percent weight loss of treated fibre was 27%. This indicated that chemical treatment was more effective in removal
of unwanted material than the enzyme treatment. Weight loss was majorly due to removal of non-cellulosic material like lignin, hemicellulose and pectins.

4.4.3 Tensile strength

a) Bundle fibre strength test:
Bundle fibre strength of raw, enzyme treated and chemical treated banana fibres have been given in Table 4.4. The table also gives percent strength loss of the treated fibres.

Table 4.5: Bundle strength of untreated and treated banana fibres

<table>
<thead>
<tr>
<th>S.No</th>
<th>Sample</th>
<th>Bundle Strength (gm/tex)</th>
<th>%Strength loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raw</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Chemical Treated</td>
<td>40</td>
<td>5%</td>
</tr>
</tbody>
</table>

It was observed that percent strength loss of the treatments was into acceptable limits. The criteria for considering the limits of strength loss is generally 5-6%, however it is also dependent on the industrial requirement. Another factor that was taken into account was during blending, the strength of the treated banana fibre should be comparable to the strength of the fibre that it has to be blended with. Average bundle strength of cotton fibre is 30-35 gms/tex, and raw banana fibre was 38 – 40 gms/tex. Hence, banana fibres are stronger that cotton. Post-treatment strength of banana fibre also was closer to raw cotton fibres. Hence, this percent loss of banana fibres after both the treatment is acceptable.

b) Single fibre strength and elongation
The work of rupture, obeying Hooke’s law, and work factor was less than 1/2 as all the three curves are concave in nature. Work of rupture is used to measure toughness of the material which indicated the resistance of the material to sudden shock.
From Table 4.4, it was observed that the Initial young’s modulus of the treated fibre was lower than the untreated fibres. The lower the value of Initial young’s modulus, the greater is the extensibility. Hence, treated fibres had greater extensibility, which was an important property required for spinning.
Table 4.6: Average load elongation and stress strain values of banana fibres

<table>
<thead>
<tr>
<th>Fibre Sample</th>
<th>Maximum Load (gf)</th>
<th>Extension at max. (mm)</th>
<th>Stress (gm/den)</th>
<th>Strain (%)</th>
<th>Initial Youngs modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>409.51</td>
<td>2.16</td>
<td>2.26</td>
<td>2.16</td>
<td>1.04</td>
</tr>
<tr>
<td>Treated</td>
<td>220.50</td>
<td>2.68</td>
<td>2.26</td>
<td>2.68</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The stress strain curve obtained for untreated and treated banana fibres has been given in Graph 4.2. It was observed that in case of treated fibres the strength was higher than the untreated fibres till lower strain values. Also elongation of the chemical treated fibres increased. The elongation obtained in the chemical treated fibres aided for spinning.

Graph 4.2: Stress strain curve of untreated and treated banana fibres

4.4.4 Fibre fineness

The denier of untreated and treated banana fibres was calculated and the values were obtained in denier and Linen count, which is used for dry spun (hemp, jute and silk). The values obtained are given in Table 4.6.
Table 4.7: Fineness of untreated and treated banana fibre

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Denier</th>
<th>Linen count Dry spun Indirect System (‘Linen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated banana fibre</td>
<td>157</td>
<td>105</td>
</tr>
<tr>
<td>Chemical treated banana fibre</td>
<td>75</td>
<td>198</td>
</tr>
</tbody>
</table>

The denier of untreated banana fibre was 157 which were reduced to 75 after treatment. Fibre diameter decreased due to removal of hemicellulose, pectin and lignin. The treatment was effective in improving the fineness of banana fibres because alkali treatment separated the fibre bundles into elementary fibre by degrading the cementing material.

4.4.5 Chemical composition

The chemical composition of untreated and treated banana fibre was carried out to analysis the change in the constituents of the treated fibres. The percent removal of hemicellulose was 68%. Lignin removal was 40%. The results of chemical composition test are given in Table.

Table 4.8: Chemical composition of Untreated and Treated banana fibres

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Untreated banana fibre</th>
<th>Treated banana fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water soluble</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Fats and Waxes</td>
<td>1.95</td>
<td>2</td>
</tr>
<tr>
<td>Pectins</td>
<td>1.85</td>
<td>1.2</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>15</td>
<td>4.8</td>
</tr>
<tr>
<td>Lignin</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Cellulose</td>
<td>62.2</td>
<td>77</td>
</tr>
</tbody>
</table>

4.5. Process of yarn spinning on Phoenix charkha

Banana fibres were spun on Phoenix Charkha (Plate 4.7). It is a double drive charkha. Phoenix Charkha is a pedal driven machine for spinning coarse long-staple fibres like banana pseudostem fibres at the cottage level. Movement of the pedal was manual and this could be one of the uncontrolled factors in the unevenness of the yarn. To avoid this factor, motor was attached to the charkha to put the flywheel in rotation. Due to the motor attached the
movement of the pedal and thus the charkha could be kept constant. The only uncontrolled factor during the spinning of banana yarns was the feeding of the filament fibres. There were two pulleys coaxially coupled to the flywheel and these pulleys drive a bobbin and a flyer simultaneously. The difference in diameter between pulleys created difference in RPM between rotation of the bobbin and rotation of the flyer. The differential in the RPM decides the twist per inch (TPI) imparted to the yarn. When banana fibres were fed into the charkha with help of a pair of rollers pressed against each other, the fibres were guided for spinning action with the help of a rotating flyer. It is a simple instrument and can be easily used by farmers and their family members to generate additional income.

The process of spinning on phoenix charkha takes place in the following steps:

1. Banana fibres were loosely tied in a bundle (like hank) of 30 grams, to avoid entanglements. One bundle was opened at a time and fibres were loosened manually so that they can be picked up easily during spinning.

2. Feeding of the filament banana fibres manually. The feeding tray is triangular in shape; top angle is facing towards passing the filament further for spinning. Fibres were fed from two sides (Figure 4.12) of the triangle in alternate pattern. This helps to avoid cluster formation at the joining of the filament fibres.

![Feeding mechanism of yarns on phoenix Charkh](image.png)

**Figure 4.4:** Feeding mechanism of yarns on phoenix Charkh
3. During the time of feeding the fibres, RBO oil emulsion is sprayed on banana fibres. Oil emulsion improves cohesiveness and reduces friction. Hence a better quality of yarn can be obtained. Filament fibres were further preceded towards the flyer.

4. The flyer inserts twist in the yarn. Each flyer rotation creates one turn in the roving. In the final analysis therefore, since the flyer rotation speed is kept constant, twist per unit length of roving depends upon the delivery speed, and can be influenced accordingly. Formation of twist takes place in the flyer assembly.

5. Yarns were further guided towards the bobbin through the thread guide. The spindle also rotated and thus the yarn is wound on bobbin.

Properties of hand spun yarn
Yarn fineness
Fineness of yarn was important to obtain fine fabric. The values have been given in Table 4.15. It can be observed that the yarns become finer after treatment.

Table 4.9: Fineness of spun yarn

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of Yarn</th>
<th>Count (Ne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raw</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Chemical Treated</td>
<td>11</td>
</tr>
</tbody>
</table>

4.4.2. c Yarn strength
Banana fibbers are extremely strong fibres. It was essential to maintain the strength after treatment. The untreated and treated fibres were spun into yarns on phoenix charkha and their tensile properties were tested on Instron tensile strength tester which is shown in Table 4.16.

It was observed that maximum load was taken by untreated banana yarn, reduced for chemical treated, however it important to know that the denier of both the treated yarns had also reduced. Hence to compare the strength of all the three yarns nullifying the denier effect, stress strain graph was plotted.
Table 4.10: Yarn (spun on phoenix charkha) strength and elongation

<table>
<thead>
<tr>
<th>Yarn Sample</th>
<th>Maximum Load (gf)</th>
<th>Extension at max. (mm)</th>
<th>Stress (gm/den)</th>
<th>Strain (%)</th>
<th>Initial Youngs modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>2076</td>
<td>4.04</td>
<td>1.21</td>
<td>4.04</td>
<td>0.29</td>
</tr>
<tr>
<td>Chemical treated</td>
<td>889.5</td>
<td>3.14</td>
<td>1.70</td>
<td>3.1</td>
<td>0.36</td>
</tr>
</tbody>
</table>

4.5 Construction of Banana Fabrics

The development of the banana fabric samples was outsourced. Below shown are the pictures of the developed samples along with the fabric specifications

Plate 4.19: 100% Hand Spun Banana Yarn of 11’s count
Plate 4.20: Plain Weave Banana Union fabric

Plate 4.21: Close View of Plain Weave

<table>
<thead>
<tr>
<th>Plain weave banana union fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp Count</td>
</tr>
<tr>
<td>Weft Count</td>
</tr>
<tr>
<td>Fabric Count</td>
</tr>
<tr>
<td>Fabric GSM</td>
</tr>
<tr>
<td>Fabric thickness</td>
</tr>
</tbody>
</table>
Plate 4.22: Close view of Left hand 2/2 Twill Weave

Plate 4.23: Close of Right Hand 2/2 Twill weave

<table>
<thead>
<tr>
<th>Twill weave banana union fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warp Count</strong></td>
</tr>
<tr>
<td><strong>Weft Count</strong></td>
</tr>
<tr>
<td><strong>Fabric Count</strong></td>
</tr>
<tr>
<td><strong>Fabric GSM</strong></td>
</tr>
<tr>
<td><strong>Fabric thickness</strong></td>
</tr>
</tbody>
</table>
Plate 4.24: Plain weave with extra weft technique

Plate 4.25: Close view of Plain weave with extra weft technique

<table>
<thead>
<tr>
<th>Banana union fabric with extra weft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp Count</td>
</tr>
<tr>
<td>Weft Count</td>
</tr>
<tr>
<td>Fabric Count</td>
</tr>
<tr>
<td>Fabric GSM</td>
</tr>
<tr>
<td>Fabric thickness</td>
</tr>
</tbody>
</table>
Plate 4.26: Decorative weave

Plate 4.27: Close View of Decorative Weave

<table>
<thead>
<tr>
<th>Banana union fabric with towel weave</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Warp Count</strong></td>
</tr>
<tr>
<td><strong>Weft Count</strong></td>
</tr>
<tr>
<td><strong>Fabric Count</strong></td>
</tr>
<tr>
<td><strong>Fabric GSM</strong></td>
</tr>
<tr>
<td><strong>Fabric thickness</strong></td>
</tr>
</tbody>
</table>
Plate 4.28: Tangalia Weave

Plate 4.29: Close View of Tangaliya Weave

<table>
<thead>
<tr>
<th>Banana union fabric with Tangaliya weave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp Count</td>
</tr>
<tr>
<td>Weft Count</td>
</tr>
<tr>
<td>Fabric Count</td>
</tr>
<tr>
<td>Fabric GSM</td>
</tr>
<tr>
<td>Fabric thickness</td>
</tr>
</tbody>
</table>
4.7 Exhibit of banana yarn and fabrics

Due to the pandemic Covid-19, an online exhibition was conducted on 04/01/2021 Monday. The mode was youtube live. There were more than 400 visits for the exhibition. An attempt was made to let the viewers get the visual texture of banana yarn and fabrics developed. The preliminary properties of the yarn and fabrics developed were also mentioned during the exhibit. The yarns and fabrics were also exhibited in the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara.

The work was well appreciated, as most of the people reported that this was the first time such fine variety of spun banana yarn and fabrics were seen. The fabric was found unique and was very aesthetically appealing to all the viewers. The fabric structure was also delightful. It was reported that the designers would want to develop a line using this potential fabric. Besides the fabric, there were a lot of appreciations for the concept of women empowerment through skill development of yarn spinning.
### 4.8 Fibre to fabric conversion data

<table>
<thead>
<tr>
<th>Activity</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana fibre extraction in one day (8 hours of work) on one raspador</td>
<td>25 kg to 30Kg of fibre</td>
</tr>
<tr>
<td>Treated, combed banana fibres obtained after treating 1 Kg of fibre</td>
<td>500 grams</td>
</tr>
<tr>
<td>Amount of yarn spun on phoenix charkha in one day (2-3 women employed on one charkha)</td>
<td>30 grams</td>
</tr>
<tr>
<td>Amount of banana yarn required to weave 1 meter of fabric (banana yarn only in weft)</td>
<td>50 grams</td>
</tr>
</tbody>
</table>
Utilization of banana pseudostem for textiles

Banana Fibre to Fabric - Costing Sheet

**Extraction of 1 Kg of Banana Fibre**

Four times of Banana pseudostem biomass is generated for every ton of banana fruit generation. Banana fruit : Biomass :: 1:4

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Kg of pseudostem</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting cost</td>
<td>10</td>
</tr>
<tr>
<td>Transportation to extraction unit</td>
<td>70</td>
</tr>
<tr>
<td>Shearing cost</td>
<td>10</td>
</tr>
<tr>
<td>Extraction</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturing Overheads</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>5</td>
</tr>
<tr>
<td>Water for washing</td>
<td>5</td>
</tr>
</tbody>
</table>

Total cost of Banana fiber - Rs 110/Kg

**Softening Treatment of Banana Fibre**

Time of treatment is 3.5 hours followed by overnight batching

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Reagents</td>
<td>35</td>
</tr>
<tr>
<td>Oil</td>
<td>30</td>
</tr>
<tr>
<td>Aluminium foil</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturing Overheads</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>5</td>
</tr>
<tr>
<td>Gas for heating</td>
<td>10</td>
</tr>
</tbody>
</table>

Treatment cost of Banana fiber - Rs 125/Kg

**Combing of Treated Banana Fibers**

<table>
<thead>
<tr>
<th>Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>200/Kg</td>
</tr>
</tbody>
</table>

**Spinning of Banana Yarn**

From 1 Kg of treated fibre 500 gms of softened banana fiber is obtained

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 gms of treated banana fibre</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 people</td>
<td>210 X 4 = 840</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manufacturing Overheads</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>5</td>
</tr>
</tbody>
</table>

Cost of spinning 60 grams of banana yarn is Rs 845/-

**Weaving Cost**

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 gms Banana yarn</td>
<td>704</td>
</tr>
<tr>
<td>30 gms Cotton Yarn</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labor</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Construction cost of 1 meter of banana union fabric is Rs. 764

The operations mentioned below are summarized to calculate the cost of 1 meter of Banana Union Fabric

Extraction 110
Softening 125
Combing 100
Spinning 704
Weaving 60

Therefore construction cost of 1 meter of Banana union fabric is Rs. 1099/-
Chapter V
SUMMARY AND CONCULSION

India is an agricultural land country and farmers are the backbone of our country. Agriculture continues to be the backbone of our Indian economy as it provides 54% employment to rural as well as urban masses. In India about 60% of land mass is under various agricultural practices Banana plant is considered as one of the most important fruit crop. Banana occupies 20% area among the total area under crop in India. After the harvest of the fruit, the plant is cut and thrown on roadside. This agro-waste is the source of banana fibre and other utility by-products. The extraction process includes cutting of the pseudostem, transporting of the stalks to the shed, separating each pseudostem, sheathing the pseudostem, passing it through the raspador to extract the fibre. Extracted banana fibres are washed and sun dried. Banana fibres packed in a bundle of 5 kgs were sent to the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara for application of softening treatment and testing its properties. The softening treatment used for the study includes five steps. The first step is alkalization, followed by bleaching and then re-alkalization. The fibres are then dipped in water in oil emulsion and kept overnight for batching. Filament fibre treatment apparatus was fabricated in the department. The apparatus had a central disc attached with a motor to rotate and along with it the fibres would also rotate. This action helps to keep the fibre immersed in the treatment solution and also helped to reduce fibre engagements. The apparatus helped to reduce 33% wastage. Untreated and treated banana fibres were tested for its physical and chemical properties. It was observed that the treated fibres were softer, even and pliable as compared to the untreated fibre. The increase in elongation also helps the fibre to improve its spinability. The treated fibres were combed and were ready for spinning. A group of 18 women from different remote regions of Vadodara were the part of the programme. These women had no source of income and had the willingness to work. Before the beginning of the training programme, phoenix charkhas were motorised to control the variable of feeding the fibres and to reduce labour. Training programme for “spinning of banana yarn” was carried where Mr. Nazir Kamal Ahmed was invited as a resource person for five days. The beneficiaries were thought to handle the fibres, feed them on the raspador and hold to insert the required twist in the yarn. Spinning workshop began immediately after the training programme i.e. from 3rd December 2019. A six month’s spinning workshop was planned, however due to the pandemic Covid-19, from March 2020 the workshop was kept on halt. The workshop resumed from October 2020 and continued till December 2020, to complete the proposed tenure. An average of 30 grams of banana yarn was obtained on each charkha where two women were engaged for spinning and one for pre-preparation. 100% spun banana yarn of 11’s count was obtained during the workshop. Fibre density of banana fibres is 1.35 that makes the fibre lighter than cotton and silk, making it more voluminous. Using these 11’s banana yarns for weft and 2/30’s cotton yarn for warp, six different fabric samples were outsourced. 100 grams of banana yarn can be used to weave 2 meters of fabric. Due to the pandemic situation, an online exhibition.
was conducted to showcase the developed banana yarn and banana union fabrics. There were more than 400 views for the exhibition and lot of positive response for the yarn and fabric developed. To sum up the responses for the visual textures of the banana union fabric, most of the people appreciated the fabric structure, and the uniqueness of the fabrics. Designers would want to develop line using these fabrics. Many were touched by the way the agro-waste was utilized and women empowered.
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environmental risk, crucial pathways, influencing factors, policy mechanism, *The Tenth International Conference on Waste Management and Technology*, 12-17


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9. www.maps of india
Annexure I

Invitation for online exhibition

Bananas on the Loom - An Exhibit

The first ever online exhibition on Textile Grade Banana Yarn and Fabrics
Date: 4th Jan 2021
Time: 2.15 pm
Link: https://youtu.be/skINiMSEK9I
Annexure II

Newspaper coverage – Gujarat Samachar dated 3/12/2020
Annexure III

Newspaper coverage – Sandesh dated 5/01/2021
Annexure IV

Gujarati magazine – Chitralekha dated Dec, 2020
Utilization of banana pseudostem for textiles

Annexure V

UTILIZATION OF BANANA PSEUDOSTEM FOR TEXTILES

Funded by
NABARD

Department of Clothing and Textiles
Faculty of Family and Community Sciences
The Maharaja Sayajirao University of Baroda
DISCLAIMER

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<td>1.</td>
<td>Whither Graduation of SHG Members? An exploration in Karnataka and Odisha</td>
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<tr>
<td>2.</td>
<td>Study on Strengthening the value chain of TDF Wadi Projects in Andhra Pradesh</td>
<td>Administrative Staff College of India, Hyderabad</td>
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<td>3.</td>
<td>Developing a roadmap of Social Enterprise Ecosystem as a precursor for a viable Social Stock Exchange in India</td>
<td>Grassroots Research and Advocacy Movement (GRAAM)</td>
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<td>4.</td>
<td>Sustainability of Old Self Help Groups in Telangana</td>
<td>Mahila Abhivrudhi Society, Telangana</td>
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<td>5.</td>
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<td>7.</td>
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