KIGELIA PINNATA: EXPLORING AND EXPERIMENTING FOR TEXTILE APPLICATION

April 2023

Shagun Rao
B.Sc (Hons.)

KIGELIA PINNATA: EXPLORING AND EXPERIMENTING FOR TEXTILE APPLICATION

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (Family and Community Sciences)

By
Shagun Rao

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

April, 2023

CERTIFICATE

This is to certify that the research work presented in this dissertation entitled **"Kigelia Pinnata: Exploring and Experimenting for Textile Application"** in pursuit of a Masters Degree in Clothing and Textiles is her original bonafide work.

Guide	Student
Prof. (Dr.) Madhu Sharan	Ms. Shagun Rao

Prof. Uma Iyer

I/C Head

Department of Clothing and Textiles

Faculty of Family and Community Sciences

The Maharaja Sayajirao University of Baroda

Vadodara

Contents

Acknowledgment

I would like to take this opportunity to express my sincere gratitude to all those who have helped me throughout my research journey and have contributed to the successful completion of this dissertation.

First and foremost, I would like to thank my dissertation supervisor Prof. (Dr.) Madhu Sharan, Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, for the invaluable guidance, feedback, and cheerful enthusiasm throughout the research process. Their expertise and insights were instrumental in shaping my research and helped me to produce quality work.

I would like to express my gratitude to former Dean Prof. (Dr.) Anjali Karolia, Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda for immense support by extending all the department facilities during the study.

A heartly thanks to Prof Uma Iyer, Dean, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara for extending all possible help to undertake and complete this research.

A special thanks to Dr. Shatrughan Sinha, MRID, The Maharaja Sayajirao University of Baroda, for providing the raw material, without which this research wouldn’t have been possible.

I am heartly grateful to all my teachers Dr. Hemlata Raval, Dr. Rajni Yadav, Dr. Sukriti Patel, Dr. Reena Bhatia, Ms. Kanika Choudhary, Ms. Deepti Kothari for their constant support and encouragement throughout, and specially to Dr. Falguni Patel for her valuable suggestions and guidance.

A special thanks to Sidharth Bhai, Sachin Bhai, Ela Ben, and Heena Ma’am, Nishant bhai for their technical assistance and coordination.

I am also grateful to Mr. Bakul Shah from the Sardar Bhavan Trust, for his time and guidance for the spinning of this new fibre into a yarn.

Thanks to Ms. Aisha Kazi, Weaving Superintendent, Weaver’s Service Centre, Shahibaug, Ahmedabad, for her technical assistance with handloom only because of which the fabric weaving was possible.

Appreciative to the PhD scholars Ms. Sumi Haldar and Ms. Thangjam Roshini for their guidance in textile testing and pep talks throughout the journey of this research.

I would also like to express my gratitude to my friends Hitiksha, Dolly, Janvi, Krishna, Priyanka, Aastha who have provided encouragement, motivation, and moral support throughout my studies. Their understanding and support were essential in helping me to overcome the challenges of completing the dissertation.

At last but not the least l would like to express my gratitude towards my mum, dad and sister, for supporting my decisions, their love and encouragement kept me focused and motivated throughout this challenging journey.

Once again, I extend my deepest appreciation to all those who have supported me during this journey.

Thank you.

Abstract

India is primarily an agricultural country. In agriculture, there is always a residue along with the crops which is called agro-waste. Agriculture residue is divided into two categories: field residues and process residues. Field residue includes stems, stalks, leaves, seed pods, and so on. At present most of these residues are either left to decay or burned, even though some of them have inherent properties that, when studied scientifically, can be an innovative source of useful products. This type of exploration of agro-waste has two benefits: one is that it produces innovative products, and the other is that it reduces the number of landfills that would otherwise occupy land. There have always been an urge for the eco-friendly fibres having a sustainable source as well as a sustainable process. Hence, with the same aim the study presented here was undertaken to investigate Kigelia pinnata stalks for the exploration and experimentation of fibres that have been discarded as agro-waste.

Kigelia is a genus of flowering plants in the Bignoniaceae family, native to tropical Africa and introduced to India for ornamental purposes. All parts of the plant have its numerous applications. Each part possesses numerous medicinal properties such as anti-inflammatory, antibacterial, analgesic, antioxidant. It has been classified as a medicinal crop. So, if there is an use of waste then this can be eco-friendly plantation. The tree bears flowers and fruits on a stalk which emerges from the branches. After the fruit falls off, the stalk is of no utility to the tree, and hence it eventually dries up and is treated as agro-waste. The fibres present in the stalks have a potential to be utilized as a textile fibre.

Therefore, in the present study the researcher has tried to explore the fibre from the base of its availability of raw materials from which the fibre is extracted, method of extraction, testing of extracted fibre, its spinnability, testing of the spun yarn and the application of the yarn in fabric construction.

The availability of the Kigelia pinnata stalks was identified by literature and field survey. The fibre was extracted using water retting, the yield was 15 gm. The material characterization showed good content of cellulose (65.32 %).

100% Kigelia pinnata yarn was prepared after softening treatment and spinning was done by indigenous hand spinning with S direction twist. The Twist per Inch (TPI) was 1.57 and the breadth of fibre was 8 μm. Union fabric was constructed at the Weaver's Service Centre, Ahmedabad. The fabric thickness was recorded as 1.068 mm, the fabric count being 40 x 36 and the GSM was 2.99 gm, which comes under the category of light weight fabrics. The results indicate that the fibre has the potential to be used as a functional and household textile. Bulk production of this fibre will help the textile industry in developing a novel sustainable fibre. Its utility is suggested to be suitable for making decorative household products, utility gifting as well as technical textile appropriate for making composites, upholstery blinds, partitions, as well as in automobiles. The unique inherent antibacterial property of this fibre can find its application in the field of functional medical textile as well.

List of tables

List of figures

List of plates

CHAPTER I

INTRODUCTION

In today's world, sustainability in industries extends beyond the use of organic materials and efficient processes. This concept of sustainability is widely used in every industrial arena including clothing and textile sector. According to Muthu, P.V. (2014), “A sustainable textile product is the one that is created, produced, transported, used and disposed of with due consideration of environmental impacts, social aspects and economic implications.” There has been explorations, experimentation and debates for sustainable products.

Since the last decade, in textile area there has been an increase in the use of synthetic fibres such as carbon, aramid, nylon, polyester, acrylic, rayon, and others, the life cycle of which causes pollution and has a negative impact on living beings as well. Most textile industries produce a large amount of hazardous waste, putting natural bodies at risk. As a result, there is an urgent need to find out the alternatives that do not harm the environment and assist in not only sustaining the textile industries but the entire eco-system.

Other than textile industry, agriculture also produces waste in immense quantities with diverse characteristics. The accumulation of agricultural waste is in the excess of 2 billion tons worldwide. This makes it imperative to investigate how agro-industrial waste utilization can be advanced to the next phase to maximise benefits from the sector. Improper management of these wastes leaves undesirable footprints in environment as well as on the economic health of many nations.

This ecological awareness has made scientists and academicians find an alternate source of materials to replace synthetic materials. The globe faces the challenge of shifting toward sustainable consumption and forming an ecologically friendly market. India itself generates over 500 million tons of agricultural and agro-industrial residues every year, according to official data of the Ministry of New and Renewable Energy (MNRE 2020).

The utilization of agricultural waste in textiles is an emerging area of research and development. Agricultural waste refers to the by-products of agricultural processes, such as crop residues, husks, stems, leaves, and seeds. These materials can be transformed into a variety of textile products, including fibres, yarns, fabrics, and nonwovens. One of the most promising uses of agricultural waste in textiles is the production of sustainable and eco-friendly fibres. These fibres are often created through a process known as “regenerated cellulose”, which involves breaking down the agricultural waste into its component fibres and then reforming them into new materials. Other than this, there are several other ways by which agricultural waste can be utilized in textiles, in the form of fibres, natural dyes, biopolymers, composites.

There are many resources of natural materials from plants, minerals, and animals, based on the place of origin (Ramesh et al., 2020). In recent years, a noticeable shift from the synthetic sources to the natural and much more sustainable sources has been experiment and explored. There has been an increase in the utilization of plant fibres for versatile applications. These fibres have shown a great potential especially in the industrial sector due to their remarkable properties like low density, biodegradable, availability, low cost, considerable mechanical strength, easy processing, and eco-friendly advantages. Studies have even shown that the plant fibre have been considered as promising replacement for synthetic fibres in fibre-reinforced polymer composites (Ilangovan et al., 2020). Currently, there use are being explored in clothing as well as technical industries in the fields of automobiles, household applications, industrial applications (trays and pallets), acoustic insulators, interior railway coaches, packaging goods, sports equipment, aerospace applications (wing boxes, cabin control panel boards, interior structures), automobile components like brake pads, many lightweight applications, etc. (Ganesh et al., 2021).

India is the country that is blessed with a rich biodiversity. From the towering Himalayan mountains in the north to the tropical rainforests in the south, India boasts a diverse range of ecosystems that support a vast array of flora and fauna. There are many vegetation which are the source of fibres. These sources needs to be explored and experimented to get fibres for textiles use. A species “Kigelia pinnata” is commonly found in the states of Kerala, Tamil Nadu, Karnataka, Gujarat and Maharashtra in India is also one of unexplored source for fibres. It is a popular ornamental plant and is often grown in gardens and parks for its striking appearance.

Kigelia is a genus of flowering plants in the Bignoniaceae family. Kigelia pinnata, the only species in the genus, a native species to tropical Africa, was introduced in India for its extraordinary appearance for ornamental purposes. The Kigelia produces a fruit that can grow up to 2 feet long, weighs about 7 kg, and resembles sausage. The genus name comes from the Mozambican Bantu name, kigeli-keia, while the common names sausage tree and cucumber tree refer to the long, sausage-like fruit. (Roodt 1992).

Figure 1: Kigelia pinnata stalks with fruits

(Source: https://www.flickr.com/photos/asienman/23885350751/sizes/m/)

It is a tree growing up to 20 m tall. The bark is grey and smooth at first, peeling on older trees. It can be as thick as 6 mm on a 15-cm branch. The wood is pale brown or yellowish, undifferentiated, and not prone to cracking (Roodt 1992).

Figure 2: Kigelia pinnata tree

(Source: https://upload.wikimedia.org/wikipedia/commons/)

The tree is evergreen where rainfall occurs throughout the year, but deciduous where there is a long dry season. The leaves are opposite or in whorls of three, 30–50 cm long, pinnate, with six to ten oval leaflets up to 20 cm long and 6 cm broad; the terminal leaflet can be either present or absent. The flowers (and later the fruit) hang down from branches on long flexible stems (2–6 metres long). Flowers are produced in panicles; they are bell-shaped (similar to those of the African tulip tree but broader and much darker and waxier), orange to maroon or purplish green, and about 10 cm wide. Individual flowers do not hang down but are oriented horizontally. Some birds are attracted to these flowers and the strong stems of each flower make ideal footholds. Their scent is most notable at night indicating that they are adapted to pollination by bats, which visit them for pollen and nectar. They also remain open by day however, and are freely visited by many insect pollinators, particularly large species such as carpenter bees.

Figure 3: Kigelia pinnata fruit

(Source: https://cdn.shopify.com/s/files/1/0047/9730/0847/)

The fresh fruit is poisonous and strongly purgative; fruit are prepared for consumption by drying, roasting or fermentation. In central Kenya, the dried fruits are used to make an alcoholic beverage called Muratina which is a core component in cultural events in Central Kenya. Kigelia is also used in a number of skin care products. (Roodt 1992).

After the fruit ripens and dries up, the long stalk is of no utility that eventually has to be discarded for new growth.

The aim of this research was to explore and experiment this agro-waste for its utilization in the field of textiles. The fibres obtained from this agro waste will be eco-friendly and can be alternative to synthetic fibres in some proportion.

1.1. PURPOSE OF THE STUDY:

Agricultural waste or agro-waste refers to the waste generated during agricultural processes such as harvesting, processing, or storage of crops. Eco-conscious modification of agro-waste involves processing and modifying the waste in a sustainable manner to make it useful for creating textile items.

The utilization of agro-waste for textile items has several benefits. It helps to reduce the amount of waste generated from agricultural processes (which would otherwise end up in landfills or contribute to environmental pollution), it reduces the dependence on non-renewable resources like petroleum-based fibres, which are commonly used in textile production, also, it promotes sustainability by creating a circular economy" where waste is repurposed and given a new life.

Therefore, the study aims for the utilization of agro-waste of Kigelia pinnata stalks by its eco-conscious modification since it is sustainable and environmental-friendly approach of textile production, hence promoting the efficient use of resources, reduce waste, and support circular economy.

1.2. OBJECTVES:

- To explore Kigelia pinnata stalks and its availability in Vadodara city.
- To extract fibres from Kigelia pinnata stalks and establish the identification features of the novel fibre
- To test the fibre properties based on physical, chemical and biological parameters.
- To find out the best possible use of fibres based upon the results for its application in textiles.

CHAPTER II

REVIEW OF LITERATURE

One of the most important prerequisites for any research study is to get familiarised with the research area in depth. It provides valuable information about the various aspects of the problem and allows the researcher to plan the research in a systematic manner. As per the nature of the study's problem, the relevant theoretical literature and researches on cellulosic minor fibres were reviewed. Other than the internet and interaction with researchers involved in similar researches, the investigator visited and collected literature from various libraries such as Smt. Hansa Mehta library, Department of Clothing and Textiles library, Faculty of Family and Community Sciences, T.K Gajjar library of The Maharaja Sayajirao University of Baroda.

The collected literature review was classified and discussed in the following sections and subsections:

2.1. Theoretical Review:

- 2.1.1. Sustainability in textiles
- 2.1.2 Minor Fibres
- 2.1.3. Retting of stalk fibres
- 2.1.4. Kigelia Pinnata

2.2. Research Review:

- 2.2.1. Researches on Natural Cellulosic Fibre
- 2.2.2. Researches on Fibre Retting

2.1.1. Sustainability in textiles

Sustainability is a systemic concept, relating to the continuity of economic, social, institutional, and environmental aspects of human society. It is intended to be a means of configuring civilization and human activity so that society, its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals indefinitely. Sustainability affects every level of organization, from the local neighbourhood to the entire planet. (Curteza, A. 2018)

Sustainable living means taking no more potentially renewable resources from the natural world than can be replenished naturally and not overloading the capacity of the environment to cleanse and renew itself by natural processes. Resources are sustainable if they cannot be used up; for instance, oil resources are gradually decreasing, whereas the wind can be harnessed to produce energy continuously. Meeting human needs without overwhelming nature or society is called sustainability.

Sustainability is based on a simple principle: everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to ensure that we have and will continue to have the water, materials, and resources to protect both human health and our environment.

Health-conscious consumers have traditionally favoured natural fibres (primarily cotton) over synthetic clothing; Cotton is one of the most environmentally friendly crops grown. Consumers now have their choice of an increasing selection of clothing, bedding and other products made from organic Cotton, Wool, Linen, Hemp and Flax. The Organic Trade Association acknowledges that the growing sector of apparel is making producers and customers environmentally conscious about products made by organic fibre. (Sami, 2013).

The main problem with synthetic polymers are that they are non-degradable and non-renewable. Since their invention, the use of these synthetic fibres has increased oil consumption significantly, and this continues today; arguably, polyester now is the most used of all fibres, taking over from cotton. Oil and petroleum are non-renewable (non-sustainable) resources and at the current rate of consumption, these fossil fuels are only expected to last for another 50–60 years; the current petroleum consumption rate is estimated to be 100,000 times the natural generation rate. An even more important problem with the use of fossil energy is the huge translocation of carbon from the ground into the atmosphere accompanied by emissions of sulphur and nitrogen oxides as well as all kinds of hydrocarbons and heavy metals. Fossil fuels are also the dominant global source of anthropogenic greenhouse gases (GHG), rising concentrations of which are widely understood to drive global warming; a growing majority of the scientific community believes this will lead to an unstable and unpredictable climate. Global warming can lead to more frequent and more extreme weather events such as floods, droughts, heatwaves, wind-storms, ice-storms, hurricanes, and cyclones. Other negative effects are an increase in air pollution; increase in water- and food-borne diseases; the arrival of diseases like malaria, dengue fever, and yellow fever; an increased number of wildfires; the loss of land by sea level rising; the forced migrations of people, plants and animals that can result in a serious reduction in the number of species; drop in prosperity and even starvation. Even climate change sceptics have expressed support for increased efforts to better understand the issues of even more concern is the ability of polymeric fibres to remain unchanged in the environment as such polymers do not degrade very readily, which has exacerbated the already existing ecological and environmental problems of waste building; the volume in waste disposal and landfill is very high. Landfills are decreasing in number, making less space available to discard waste.

To improve this, organic textile must cover the cultivation of raw material, mass production, manufacturing, processing, packaging, labelling, and distribution of organic textiles globally. The final product would be in the form of fibres, yarns, fabrics, and garments, including home textile products. The garment industry is sustainable with the basic requirements framed by the Global Organic Textile Standard (Lo et al., 2012).

Organic fibres:

Processing of sustainable organic fibre starts with fibre extraction and yarn production followed by bleaching, dyeing, softening, printing and drying. Organic or green decorticated fibre production depends on skilled labourers, an integrated infrastructure and the sustainability of the fibre. It leads to the market price for each fibre: for example, Anjengo yarns may yield around Rs. 25/kg, whereas Vycome is quoted at Rs. 17.50/kg. Export prices for finished coir products such as hand-loomed mats and matting, rugs and carpets range between Rs. 70 and 80/kg (Sengupta and Singh, 2013). This industry is under increasing economic and technical pressure because of inefficiencies within the system, competition from power loom cloth, a lack of quality and shrinking markets. Public sector support is being introduced to enhanced investment from the commercial sector with changes to mechanized coir extraction and the motorized spinning of yarn, in an effort to accommodate the social changes required. Greater productivity can be raised within the industry upon which the community depends.

The source from which they are extracted determines how natural fibres are categorised. Three categories of fibres—natural, regenerated, and synthetic—have been established. For natural fibres, there are two types: sources from animals and sources from plants. Category of animal sources include wool, silk, cashmere, mohair, etc., while of plant sources include cotton, flax, jute, etc. Cotton, silk, and wool are familiar materials because they are used so frequently in clothing and other technical applications.

There are 700 different plant species that produce the fibre that humans use. To name a Few Ramie, San Hemp, Hemp, Kenaf, Roselle, Bhindi, Jaba Kusum, Swet Jaba, Sthal Padma, Nettles, Sisal, Pineapple, Atasi, Abaca, Banana, Screw Pines, Bhurjya, Twak, Chhilka, Deola, Coast, Cotton Tree, Trailing, Hollyhock. They are referred to as minor fibres.

Minor fibres in textiles are defined as those that are produced in small quantities and are not economically feasible for a mass market (Agrawal G., 2016). Minor fibre can be applied for novelty applications.

Some of the Cellulosic Minor Fibres explored and used from bast are discussed further:

2.1.2. Cellulosic minor fibres.

Flax:

Flax is a bast fibre found in the stem of the plant *'Linum usitatissimum'*. The plant is cultivated in cold and humid conditions. So, the plantation is possible in cold countries. The major source of supply of Flax is from the old U.S.S.R. The other countries which have flax growing areas are Argentina, Japan, North Ireland, Egypt, France, U.S.A, Australia, Canada and New Zealand. Like jute, flax is an annual plant. The plant from which the fibre is extracted grows in moist and cold condition. The plant grows up to 170 cm in height and 1.5 cm diameter. The tree matures by changing from green to yellow. After maturity, it is harvested for its extraction of the fibre.

Harvesting may be done when:

- Flowering is almost over, and the stalk is green or
- The fruit has set, or
- The seed pods have ripened, and the stalk is yellowish brown.

Initial harvesting gives poor yield with soft fibre. Late harvesting gives a coarse fibre with higher yield. Like jute fibres, the flax fibre bundles are surrounded by gummy materials.

The retting can be of four types: (1) dew retting, (2) stagnant water retting, (3) running water retting, (4) chemical retting.

The flax fibre is thick and regular, with a dull lustre. Its length ranges from about 10 cm to 100 cm, with an average length of about 50 cm. Because flax is a strand of cells, its thickness is determined by the number of cells in each fibre cross-section. Flax cells are approximately 25mm long and 10 μm to 20 μm thick. 15000:1 is the longest and best flax length to breadth ratio. Short flax fibres may have a length-to-breadth ratio of 1500:1 or less. The cross markings on flax fibres, known as nodes, give them their distinctive microscopic appearance. A single flax fibre cell can contain up to 800 nodes. The width or thickness of the fibre cell is indicated by the length of the node. Fibres are composed of 71.2% cellulose, 18.6% hemicellulose, 2.2% lignin, 2% pectin, and 2.3% wax. Flax is the most durable natural fibre available. The fibre's tensile strength ranges from

6.5 gm/den to 8.0 gm/dem. 1.50 gm/cc is the density. The moisture regain is 12%. Flax fibres are used in a variety of applications including household clothing, fabrics, lace sheetings, canvas, threads, twines, papermaking, and certain industrial applications such as fire hoses. S.P. Mishra (2018).

Kenaf fibre:

Kenaf, also known as Bimli, is a 3- to 4-metre-tall erect herbaceous plant with a straight slender glamorous stem. It is a member of the hibiscus genus, which contains numerous species found throughout the tropical and subtropical world. There are approximately 40 species found in India, many of which are well-known and popular for a variety of reasons such as food and medicine, fodder, religious and ritualistic requirements, and as decorative plants. (Ghosh. G.K, 2015). Harvesting time is critical in bast fibre crops such as jute and kenaf. A proper harvesting stage results in a higher yield as well as better fibre quality. Decortication and retting methods are used to extract the fibres. Two improved microbial retting techniques have been developed by the Central Research Institute for Jute and Allied Fibres, Baratpur, Kolkata, through the use of a microbial retting consortium for efficient retting during water scarcity situations using the least amount of groundwater. Mechanical-microbial/ribbon retting and Micro- Pond retting are two methods. Kenaf has two types of fibres: long bundles in the cortical layer and short bundles in the ligneous zone. Elementary fibres are short, with fibre lengths ranging from 3 to 7 mm and an average diameter of 21 m. The cross-sections are polygonal with rounded edges, and the lumens are oval to round. The lumens vary greatly in thickness along the cell length and are interrupted several times. Kenaf's chemical composition is 45-57% cellulose, 21.5% hemicellulose, 8-13% lignin, and 3-5% pectin. Kenaf can be used to make ropes, twines, cordages, fabrics, oil and liquid absorbent materials, and as a potential substitute for wood pulp and fossil fuels. (Agrawal. G, 2016).

Okra fibre:

Okra is one of the most widely grown vegetables in India. Hibiscus esculentus is the botanical name for it. Bhindi is thought to be of African origin. It is grown all over India, up to an elevation of 1000 metres. The plants have a stunning appearance that is white, light cream, or yellow, silky, strong, and pliant. After harvesting, the stems are crushed between two rollers to extract the juice, which can then be sold to the sugarcane industry as a clarifier. Following that, the stems are left in the field, while the leafy tops are removed. The stalk is then retted in either stagnant or slow running water for 6 to 10 days, depending on the maturity of the stalk and the temperature of the water. After retting, the stalks are rinsed with water and brushed to clean and separate the fibres. (Ghosh. G.K, 2015).

Okra fibre contains 67.5% alpha-cellulose, 15.4% hemicellulose, 7.1% lignin, 3.4% pectin matter, 3.9% fatty and waxy matter, and 2.7% aqueous extract. N. Jain et al., 2012. Given the quality of the fibre, if spun properly, it can be woven into textile intended for winter garments such as jackets, denims, and jeans. (Ghosh. G.K, 2015).

Water Hyacinth

The water hyacinth (Eichhornia crassipes) is a free-floating perennial plant that can grow to be 3 feet tall. It has eye-catching light blue to violet flowers on a terminal spike. Water hyacinth is a voracious invader that can form thick mats. If these mats cover the entire surface of the pond, they can deplete the oxygen and kill the fish. Water hyacinths must be kept under control so that they do not cover the entire pond. Water hyacinth has the advantage of being abundantly available, growing quickly without the need for sowing, weeding, or fertilising, and requiring no land space. It is free, and harvesting it is an act of environmental benevolence. The water hyacinth plant grows quickly and abundantly, producing a large amount of biomass. Has protein-rich leaves that are as valuable as those found in potatoes or clover. The plant has a fibrous stem and an abundance of potassium. Water hyacinth is edible, not only to animals but also to humans. In Thailand, soups contain stalks and leaves. It has tough, fibrous roots that purify water by absorbing the nitrogen and phosphorus on which it thrives, as well as many other polluting substances, such as minerals. It absorbs toxic chemicals such as lead, mercury, and strontium 90 at 10,000 times the concentration found in the surrounding water. Water hyacinth grows over a wide variety of wetland types from lakes, streams, ponds, waterways, ditches, and backwater areas. In India water hyacinth potential states are Delhi, Uttar Pradesh, Bihar, West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, and Gujarat. Water hyacinth grows in all types of fresh water. Water hyacinth has been widely introduced in North America, Asia, Australia, Africa, and New Zealand. They can be found in large water areas such as Louisiana or in the Kerala backwaters in India. In many areas, E. crassipes, in particular, is an important and pernicious invasive species. Water hyacinth fibre has a chemical composition of 63.75+0.24% cellulose, 12.330.08% hemicellulose, 20.67+0.13% lignin, 2.620.05% ash, and 0.65+0.02% other extractives. The water hyacinth fibre has greater water absorbency than that of cotton and other natural fibre. Water hyacinth fibre is used for preparing fibre boards, ropes and baskets.[1]

Raffia:

Raffia palms (Raphia) are a genus of about twenty palm species native to tropical Africa, particularly Madagascar, with one species (R. taedigera) also found in Central and South America. Raffia fibre is widely used all over the world. It is used in twine, rope, baskets, placemats, hats, shoes, and textile.

The membrane on the underside of each individual frond leaf produces the fibre. The membrane is removed to reveal a long, thin fibre that can be dyed and woven into a variety of textile products ranging from hats to shoes to decorative mats. Plain raffia fibres are exported and used as garden ties or as a "natural" string in many countries. Especially when one wishes to graft trees, raffia is used to hold plant parts together as a more "natural" rope. Raffia fibres have many uses, especially in the area of textiles and in construction. They are used for ropes, sticks, and supporting beams in their native environments, and their fibrous branches and leaves are used to make various roof coverings. [6]

Ramie

Ramie is a herbaceous perennial plant native to eastern Asia in the Urticaceae family. Ramie fibres are derived from the stem of the nettle plant Boehmeria nivea. Individual fibre cells in stems are held together in fibre bundles by waxes, hemicelluloses, lignin, and pectins, all of which are difficult to remove. As a result, the efficiency of the retting process commonly used to extract hemp fibres, for example, is insufficient to extract ramie fibres from stems. However, a combined microbial and chemical treatment is both effective and cost-effective. Ramie fibres are composed of cellulose (91-93%), hemicelluloses (2.5%), pectin (0.63%), and lignin (0.65%). Ramie fibres have excellent mechanical properties, ranking above all of bast fibres (45-88 cN/tex), and, like most natural cellulose fibres, their strength increases by 25% when wet. The ultimate fibre length is 120-150mm, and the fibre diameter is 40-60 μm. Fibres last a long time and are resistant to bacteria, mildew, and insect attack. Ramie has a low elasticity (elongation at break is 3-7%), which makes it stiff and brittle. Fibres are oval to cylindrical in shape and white with a high lustre. The surface of the fibres is rough, with small ridges, striations, and deep fissures. Ramie fibre is distinguished by its coarse, thick cell wall, lack of twist, and surface characteristics.

Sisal

The sisal fibre is a "hard" fibre derived from the fresh leaves of the Agave sisalana plant. It is typically obtained through the decortication process, in which the leaf is crushed between rollers and mechanically scraped. The sisal fibre's length ranges from 0.6 to 1.5 m, and its diameters range from 100 to 300 m. Sisal fibres contain approximately 70% cellulose. The fibre is made up of many elongated fibre cells that are narrowed at both ends. Middle lamellae, which are composed of hemicelluloses, lignin, and pectin, connect fibre cells. A sisal fibre is made up of approximately 100 fibre cells in cross-section. Sisal fibre cross sections are neither circular nor uniform in dimension. The size of the lumen varies, but it is usually well defined. The longitudinal form is roughly cylindrical. Each fibre cell is composed of four major components: the primary wall, the thick secondary wall, the tertiary wall, and the lumen. The fibrils are composed of micro-fibrils with a thickness of about 20 m. The microfibrils are made up of cellulose molecular chains that are 0.7 μm thick and a few μm long. Sisal fibre is fairly coarse and rigid. The tensile properties of sisal fibres vary along their length. The tensile strength and modulus of fibres extracted from the root or lower parts of the leaf are lower. At midspan, the fibres become stronger and stiffer, and the fibres extracted from the tip have moderate properties. Because of its high cellulose and hemicellulose content, lower grade fibre is processed by the paper industry. In the cordage industry, medium grade fibre is used to make ropes, balers, and binders twine. After treatment, the higher-grade fibre is converted into yarns and used in the carpet industry.

2.1.3. Retting of stalk fibres

Natural fibres have begun to pace towards becoming the main alternative source in the modern world industry. It is used various applications from composite reinforcement, textile and even medical. Recently in 'environmental- friendly-era' natural fibres has definitely gain its place in the heart of most industries as it is biodegradable and most crucially, renewable (Yusri. Y., et al., 2013). There are plenty of sources which can be extracted into natural fibres such as Flax, Kenaf, jute, sisal, pineapple leaf, banana and others.

Retting is a microbial process, sometimes termed degumming to release separate the fibre from the non-fibre stem tissues (woody part), and removal of non-cellulosic components like pectin, hemicelluloses, lignin, waxes and fats. The individual fibres are cleaned of non-fibre materials by mechanical processing. Insufficient retting, or under-retting, results in poor separation of the non- fibre materials (i.e., shive) from the fibres which reduce fibre yield, processing efficiency, and ultimate fibre quality. On the other hand, over-retting can occur resulting in poor fibre quality. Retting is very importance in fibre yield and quality (Brunsek et al, 2015).

Retting is a natural microbial process, and it is also involves the degradation of non-fibrous matter which acts as glue between the fibres in woody plant parts and fibres without damaging the fibre cellulose. This process allows easy separation of individual fibre strands and the woody core. Since retting is a biological process, it requires both moisture and a warm temperature for microbial action to occur (Hulle et al 2015).

Natural Retting:

Natural retting is a preferential retting process to separate the fibre from lignocellulosic biomass without damaging the fibre cellulose. Retting is the microbial freeing of plant fibres from their surroundings (Mignoni. R. 1999). The process takes up to three weeks. Retting microbes consume the non- fibrous cementing materials mainly pectin and hemicellulose. Its increase softens the leaves by the destruction of the less resisting intercellular adhesive substances. When fermentation has reached the appropriate stage, the fibres can be separated quite easily from the leaves. If retting process is allowed beyond this point, fibres decline in quality. Under-retting causes incomplete removal of gummy materials such as pectin substances, and extraction of fibre becomes difficult. Therefore, the progress of retting must be observed carefully at intervals to avoid fibre damage. Though the natural retting takes more time, the process is economical. There are two traditional types of retting include water retting and field or dew retting. In water retting, plant leaves are immersed in water (river, pond or tanks). In field or dew retting, the crop is spread in the field where rain or dew provides moisture for retting. Water retting produces fibres of greater uniformity and higher quality than fibres extracted by field retting (Steyn, 2006). The process allows easy separation of individual fibre strands and the woody core. Since retting is a biological process, it requires both moisture and a warm temperature for microbial action to occur (Ashish Hulle et al 2015)

Dew retting:

During the dew retting process, stems of the plant were being cut and evenly distributed in the fields, where the presence of bacteria, sunlight, atmospheric air, and dew causes breakdown of stem cellular tissues and adhesive substances that surrounded the fibres. The places that have a warm day and heavy might dew are preferred for the dew retting process to promote colonisation of fungi. (Ashish Hulle et al 2015)

Chemical retting:

Chemical retting degrades non-cellulose components, but cellulose degradation happens when over-retting. Retting duration, chemical concentration, and retting temperature have been reported that affect the quality of retted fibres. Besides, uses of chemicals and production of wastewater have increased the cost as well as polluting environments. (Ashish Hulle et al 2015)

Enzymatic Retting:

Microbial retting is not a new process. This traditional method is mainly achieved by the pectic enzymes produced by bacteria. During retting, the bacteria multiply and produce extracellular pectinases, which release the bast fibre from the surrounding cortex by dissolving the pectin. Nowadays, with the advancement of biotechnology tools, such enzymes can be commercially produced, thus making enzymatic retting a more popular choice to produce long fibres. (Ashish Hulle et al 2015)

2.1.4. Kigelia Pinnata

Kigelia pinnata is found throughout South Central and West Africa. It is found all over India, but West Bengal has the highest concentration. The plant can grow up to 20 metres tall and is either evergreen (where rainfall occurs all year) or deciduous (where there is a three-month dry season). The bark of the tree is grey, smooth, and flakes in older specimens. Young leaves are brownish red and pinnately opposite or crowded near the tips of branches. Long, loose, pendulous sprays of 5-12 flowers bloom. Petals are a deep, velvety red with yellow veining around the edges. The flowering season is in the spring or summer. It is grey and rounded at the apex and found from December to June.

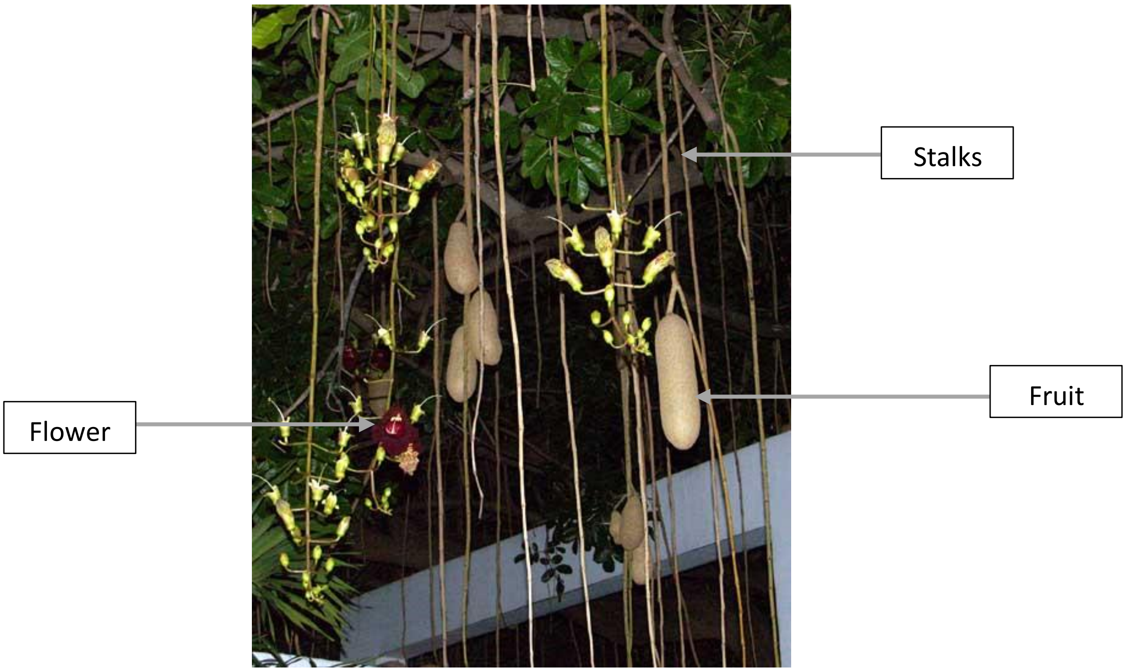


Figure 4: Kigelia pinnata

Medicinal properties and other traditional uses

The kigelia plant have medicinal properties not only because of its perceived characteristics such as bitterness, astringent taste, or smell but also because of forces that it seems to emit in connection with its location, orientation, and association with other plants. It has a long history of use by rural and African countries particularly for medicinal properties. Several parts of the plant are employed for medicinal purposes by certain aboriginal people. In Malwi during famine the seeds are roasted to eat. Baked fruits are used to ferment beer and boiled ones yield a red dye. Most commonly traditional healers used it to treat a wide range of skin ailments like, fungal infections, boils, psoriasis, and eczema. It also has internal application including the treatment in dysentery, ringworm, tapeworm, post-partum haemorrhage, malaria, diabetes, pneumonia and toothache. The Tonga women of Zambezi valley regularly apply cosmetic preparation of Kigelia fruits to their faces to ensure a blemish free complexion. In the folk medicine, the fruits of the plant are used as dressing for ulcers, purgative and to increase the flow of milk in lactating women. Roots are said to yield a bright yellow dye. The Shona people tend to use the bark or root as powder or infusion for application to ulcers, drunk or applied in the treatment of pneumonia, as a gargle for toothache, and the leaves in a compound applied for backache. In West Africa, the root and unripe fruit is used as a vermifuge and as a treatment for haemorrhoids and rheumatism. (Roodt, 1992)

The bark is traditionally used as a remedy for syphilis and gonorrhoea. The fruits and bark ground and boiled in water are also taken orally or used as an enema in treating children’s stomach ailments– usually worms. Unripe fruit is used in Central Africa as a dressing for wounds, haemorrhoids, sand rheumatism. Venereal diseases are commonly treated with the tree extracts usually in palm wine as oral medication. (Roodt 1992)

K. Pinnata is an interesting example of a plant, used in traditional medicine for many years, but which is now attracting interest and use far beyond its original geographical range. Experiments into the effect of Kigelia extracts and some of the pure compounds contained therein, on microorganisms and cancer cells have shown that the traditional use of this plant is given considerable justification. The chemical constituents of the plant provide molecules, which could be of immense medicinal applications. Considering the many medicinal purposes for which it is used, there is enormous scope for future research on K. Africana.

2.2. Research Review

2.2.2. Researches on Natural Cellulosic Fibre

Bora, R. & Padmini, T. (2019) conducted a experimental study on the fibre extraction from Calatropis gigantea stem with different retting methods and its comparison. Calotropis gigantea is a common weed in open waste lands, roadsides, and railway lines, as well as village surroundings Considering this prospect a study was carried out to optimise the fibre extraction process with different retting methods like water retting, chemical retting (urea, sodium hydroxide) and enzyme extraction process. Among all methods chemical retting with sodium hydroxide method showed highest fibre yield with 5.2%. It was found that Calotropis fibre was completely soluble in strong acids but partially soluble in NaOH and Na_2CO_3 solution. Calotropis fibres could withstand the solvents at room temperature. The fibre obtained by water retting method had longer fibre length though the decreased after scouring and bleaching process. Thickness, fineness, and bundle strength of fibre extracted with enzyme was higher than the other methods. Raw fibre extracted by chemical retting with urea has the highest elongation though it has been decreased after scouring and bleaching. Moisture regains of Calotropis fibre after scouring and bleaching was higher than raw fibre and cotton fibre due to the removal of impurities.

Savavanan, N., Sampath, P. S., et. al., (2016) studied the extraction and characterization of new cellulose fibre from the agro-waste of Langeria Siceraria (Bottle Gourd) plant. The study explored the extraction and characterization of natural fibre from the agro-waste of Lagenaria siceraria (LS) plant stem (commonly known as “bottle gourd”) by decortication and water retting. It was found that the extracted fibre from the waste stems has high cellulose content (79.91 %) with good tensile strength (257–717 MPa) and thermal stability (withstand up to 339.1°C). The immense percentage of crystalline index (92.4%) with the crystalline size (7.2 nm) as well as low density (1.216 g/cm3) of the LS fibre renders their possibility to use as an effective reinforcement material in lightweight eco-friendly composites for various industrial applications.

Saikia, D., Baishya, B., et. al. (2020) carried out experimental research on the extraction of bast fibres from odal (Sterculia villosa) and its evaluation of physical characteristics. Odal is one of the fast-growing plant species abundantly available in the North-eastern Region of India. The study was an attempt to extract the fibres from Odal bark and to evaluate the physical properties of the fibres. Extraction of Odal fibre was carried out by decortications process. Later fibres were subjected to water retting in various time duration. The yield of fibre after twenty-one days was found highest as 2.8% with good fibre quality whereas, the lowest 2.0% was recorded in seven days of retting. The highest length of fibre was recorded in retted Odal fibre as 2.31mm. The maximum wall thickness and diameter was recorded in retted Odal fibre as 1.46 mm and 5µm respectively. The maximum tensile strength (2.92 g/tex) was observed in retted Odal fibre and the least was noticed in bleached Odal fibre (1.48 g/tex). Retted Odal fibre had showed highest elongation (2.22 %). Bleached Odal fibre posed highest density (1.40gm/cc). With the growing scarcity of biodegradable fibres, these plant fibres could suitably be used as alternative source of synthetic fibres. Odal fibres have good potential for exports owing to their economics, aesthetic appeal and improved overall properties.

Abraham, E., Deepa, B., et. al., (2016) did the extraction of nanocellulose fibrils from lignocellulosic fibres with a novel approach. The objective of this work was to develop a simple process to obtain an aqueous stable colloid suspension of cellulose nano fibrils from various lignocellulosic fibres. For the preliminary analysis, three different fibres were studied: Banana (pseudo stem), Jute (stem) and Pineapple leaf fibre (PALF). To study the feasibility of extracting cellulose from these raw fibres, steam explosion technique was adopted along with mild chemical treatment. The processes include alkaline extraction, bleaching, and acid hydrolysis but with a very mild concentration of the chemicals. The chemical constituents of the fibre in each processing step were determined by ASTM standard procedures namely, for Cellulose (ASTM D 1103-55T), for hemicellulose (ASTM D 1104-56), for lignin (ASTM D 1106-56), for moisture content (ASTM D 4442-92). The cellulose, hemicellulose, lignin and moisture contents of the fibre in the untreated raw, steam exploded, and acid hydrolysed stages were determined. Morphological, spectroscopic, and thermal analyses of the fibres were carried out by FTIR, XRD, SEM, SPM, and TGA and it was observed that the isolation of cellulose nanofibres occurs in the final step of the processing stage and they possessed improved thermal stability for various advanced nanotechnological applications.

Vanishree, S., Mahale, G., et. al. (2018) conducted research on the extraction of sunnhemp fibre and tested its properties. The objective of the study was to extract sunnhemp fibre from stalks of sunnhemp plants which were considered as agriculture waste after harvesting seeds. Sunnhemp (Crotalaria junceae) stalks have been rippled and stacked for about 20-30 days to dry the stalks. The dried stalks were then pre-treated with different retting agents, viz. urea and compost culture wherein urea treated stalks produced higher fibre yield (extraction per cent) with lower retting period. Fibre was extracted by water retting (tank) method. Physico-chemical properties, microstructure and solubility tests of extracted sunnhemp fibre were performed. Results revealed that the urea treated stalks produce higher fibre yield with lower retting period. Urea treated sunnhemp stalks gave relatively longer, finer and stronger fibres than the compost culture treated and control stalks. Lower per cent of lignin was observed in compost culture treated stalks. Sunnhemp fibre constituted of oblong shaped cross-section with elongated lumen. Like cellulosic fibres, sunnhemp fibre was soluble in concentrated acids and was least affected by solvents.

Singh, J. K., & Rout, A. K. (2022), did the characterization of raw and alkali-treated cellulosic fibres extracted from Borassus flabellifer L. The objective of the study was to explore the extraction procedure and characterization of natural cellulosic fibres extracted from Borassus flabellifer L. leaf. The obtained fibres were treated with sodium hydroxide solution to overcome the drawback of hydroxyl bonding. The essential properties of raw and treated fibre such as chemical composition, density, tensile strength, surface roughness, elements, functional group analysis, crystallinity index, crystallite size, maximum degradation temperature, and thermal stability were studied. It was observed from the test results that the alkali treatment improved the cellulose content while the hemicellulose, lignin, and wax content were reduced. The treatment improved the tensile strength, while the fibre density and weight decreased. The XRD analysis of raw and treated fibre confirmed the crystallinity index (50.34% from 46.58%) and crystallite size (2.72 nm from 2.36 nm) were improved after alkalization. The outcome of FTIR analysis confirmed the amorphous contents in borassus leaf fibres (BLF) were condensed due to the alkalization. The SEM analysis showed that the impurities and wax content of the outer surface of BLF were removed after alkali treatment. The result of TG analysis confirmed that the thermal stability temperature of alkali treated fibre had increased from 261 to 285 °C. The DTG analysis proved that the maximum fibre degradation temperature of alkali-treated BLF was increased from 316 to 365 °C. Thus, the surface modified fibres was found appropriate materials for use as reinforcement in light weight high performance polymer composites.

Rafiquah, A., Abdan, K., et al. (2020) studied the effect of extraction on the mechanical, physical and biological properties of pineapple leaf fibres. The aim of this comparative This aim of this research was to indicate different extraction methods to obtain PALF (Pineapple leaf fibres) and studied on its physical and mechanical properties. PALF can be extracted in various ways such as manual, mechanical, and retting process. Manual extraction process of pineapple leaf fibre was time consuming and laborious. It also produced very low yield and difficult for mass production. However, manual extraction produced good quality fibres compared with mechanical extraction. The colour of PALF was creamy white. The fibre structure also looks finest and smooth. Mechanical properties of PALF, extracted by using mechanical machine, showed higher tensile strength compared to the extracted fibre through hand scrapping technique. In retting method, many chemicals were involved and it was time consuming. Fibre extracted by retting method could provide mechanical strength and stiffness to the fibres.

Senthamaraikannan, P., Saravanakumar, S. S., et. al. (2016) investigated the physico-chemical properties of new cellulosic fibres from the bark of Acacia planifrons. This investigation was aimed at understanding the physico-chemical properties of Acacia planifrons fibres (APFs). The crystalline structure of APFs was analysed by X-ray diffraction. The crystallinity index (65.38%) was calculated. The chemical functional group of APFs was confirmed by Fourier transform-infrared spectroscopy, the thermal stability measured by thermogravimetric analysis, and surface characterization established by atomic force microscopy. The high amount of cellulose in APFs provide high strength to the fibres, and the lower density (660 kg/m3) of APFs would make them suitable for lightweight composite applications. The thermal stability analysis of APFs showed that they are thermally stable up to 270°C. The AFM results revealed that APFs require surface treatment to improve surface roughness. The properties determined for APFs were suitable for reinforcement in preparation of polymer composites.

Saravanakumaar, A., Senthilkumar, A., et. al. (2018) studied the impact of alkali treatment on physico-chemical, thermal, structural and tensile properties of Carica papaya bark fibres. This study aims to examine the effect of sodium hydroxide (NaOH) treatment on the physico-chemical properties, structure, thermal, tensile and surface topography of Carica papaya fibres (CPFs). The surface of raw CPFs was modified by soaking with 5% NaOH solution for 15, 30, 45, 60, 75 and 90 min. The 5% (w/v) NaOH with 60 min soaking period was the optimal alkali treatment of CPFs. Chemical analysis revealed there was elimination of hemicellulose and lignin in optimally treated CPFs. The FTIR spectra of both fibres had supported this evidence. Optimally treated CPFs has relatively higher tensile strength (530 ± 11.2 MPa) than the raw CPFs (548 ± 14.6) due to increase in the cellulose content. XRD analysis confirmed that the crystallinity index (CI) and crystallite size (CS) of the optimally treated CPFs improved (56.34% to 60.43%) and (15.4 nm, 18.15 nm) respectively. AFM results showed more prominent hills and valleys in the surface morphology of the optimally treated CPFs which confirmed the rough surface compared to the raw CPFs. The findings of the investigation ensured that the optimally treated CPFs are considered as suitable alternative reinforcements for polymer composites.

Akubueze, E. U., Ezeanyanaso C. S., et al. (2019) investigated the extraction and characterization of bast fibres from roselle (Hibiscus sabdariffa) stem for industrial application. Two extraction methods for obtaining bast fibres from Hibiscus sabdariffa stem such as Bacterial retting (BR) method and chemical retting (CR) method was explored. Bacterial retted (BR) and chemically retted

(CR) Roselle (Hibiscus sabdariffa) fibre was Light brown in colour, with 16.07-20.2 diameter(μm), 2.10-2.8 fibre length (mm), 9.54-11.00% moisture, 0.93-2.50% ash, 55.55- 60.40% cellulose, 33.70-27.04% hemicellulose, 10.50-11.40% lignin, 145.60-177.55 MPa strength, 20.70-24.90 GPa modulus, 0.5-0.7% elongation at break for bacterial retting (BR) method whereas for chemical retting (CR) method was dark brown in colour, 16.07-20.2 diameter(μm), 2.10-2.8 fibre length(mm) 12.90 14.50% moisture, 1.00-2.70% ash, 48.56-56.62% cellulose, 38.07-31.85% hemicellulose, 12.50-11.64% lignin, 135.15-159.05MPa strength, 19.85- 23.70GPa, 0.4-0.6% elongation at break. The results showed that fibres produced by bacterial retting (BR) had better quality than chemical retting (CR) in terms of mechanical properties and flexibility, but the time involved in bacterial retting (BR) was too long to be considered for today's industrial process integration. More advancement in biotechnology with combined enzymatic and chemically retting can give shorter time with high quality fibres. The bast fibres from Roselle (Hibiscus sabdariffa) stem was also a unique natural fibre in the class of Jute and Kenaf.

Agrawal N (2018) experimented with pineapple fibres for its use in woven textiles. In this study researcher tried to explore pineapple fiber by studying its physical properties and carried various chemical, enzymatic and oiling treatments to soften the fiber at the same time retaining the strength, enhancing its color and spinability. Fibers were scoured with alkali i.e. Na_2CO_3 with 4% cone for 1 hour at 70-80°C using 1:40 liquor ratio with 10-12 pH followed by bleaching with H_2O_2 for 1 hour at 80°C using 1:40 liquor ratio with 3-4 pH. It was observed that pineapple fiber have inherent property of excellent strength of 4.35 gm/den. After scouring and bleaching there was increase in tensile strength of 4.91 gm/den and 4.72 gm/den respectively. For enzymatic treatment, fibers were treated with cellulase and pectinase at 1% conc for 2, 4 and 8 hour respectively. It was observed that pectinase enzyme treatment for 4 hours have given a good results with the increase in tensile strength of 5.93 gm/den. SEM results showed in scoured and bleached fibers there was increase in brightness, fibers were more crystalline, aligned, and smooth in texture as compare to raw fibers. Chemical treatment (Scoured + bleached) was selected as an optimized treatment because of whiteness, good tensile strength and it was further selected to prepare yarns. Union fabric samples was prepared using weft as 100 % pineapple and warp as 100% cotton on table loom. Blended fabrics was prepared on machine loom using yarn in three different ratios of 90:10, 70:30 and 50:50 viscose/pineapple. Hence the study revealed that pineapple fiber it can be used for making apparels and other upholstery products.

Doshi A. and Karolia A. (2016) conducted an experimental study to optimise enzyme treatment for banana fibres. Banana fibres are filament fibres that are extremely strong, lustrous, and long in length. However, because the fibres are lingo-cellulosic in nature, they are stiff and less pliable. Banana fibres were extracted from the Giant Naine banana plant variety for this study. To soften the banana fibers, four eco-friendly enzymes were used: cellulase, hemicellulase, pectinase, and lacase. The concentrations and conditions were optimised individually, and a final treatment was standardised for combinations. The M:L ratio was 1:40 for all treatments. Cellulase concentrations of 0.2%, 0.3%, 0.5%, and 0.7% were used in individual enzyme treatments. Maximum weight loss was observed at 0.3% concentration. The strength loss increased to a greater extend 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 5%.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. Pectinase was used at three different concentrations: 0.5%, 0.7%, and 1%. Weight loss was similar to other enzymatic treatments, but strength loss was found to be significant even at low concentrations. The effect of the enzymes on the fibres was measured in terms of weight loss, strength loss, and subjective evaluation by hand, and the concentrations and conditions were optimised based on these results. Combinations of enzymes done in a specific order (first laccase, then hemicellulose, then cellulase, pectinase) produced better results because lignin acts as a glue between cellulase and hemicellulase in lingo cellulosic fibres. Laccase first removed the lignin while simultaneously freeing the hemicellulase, and other enzymes removed the unwanted impurities in this combination treatment. The optimal conditions for enzymatic treatment of banana fibre were for enzyme laccase: the cone was 3%owf, the time was 30 minutes, the temperature was 55°C, and the pH was 5-6. For the enzyme hemicellulase, the cone was 1% owf, the time was 60 minutes, the temperature was 40°C, and the pH was 5.5-6. For enzyme cellulase, the cone was 0.3% owf, the time was 45 minutes, the temperature was 55°C, and the pH was 4.5-5. For the enzyme pectinase, the cone was 0.7% owf, the time was 15 minutes, the temperature was 55°C, and the pH was 5.5.

Sharan, M., & Haldar, S. (2019) conducted research on an experimental study on lotus petiole (Nelumbo Nucifera Gaertn.) for its textile applications. The study's goal was to investigate the fibre right from the beginning, which is the availability of raw materials from which the fibre is extracted, interaction with people associated with the (cultivation and marketing of lotus), method of extraction, testing of extracted fiber, spinability of the extracted fiber, testing of spinned yarn, application of spinned yarn in woven textile, and finding out the application of residual waste for bio-fuel. Total 309 gm of fibre was extracted 100% Lotus hand spun yarn was prepared on box peti charkha. Union fabrics were created in Bhujodi (Kutch) from 100% Lotus hand spun yarn as a weft and cotton as a warp, while the other was created from 100% lotus hand spun yarn as a weft and silk as a warp. To compare the properties, 100% cotton warp and weft, 100% silk warp and weft. The results indicated that it could be used as a textile fibre. The mass production of this fibre will aid the textile industry in the development of eco-friendly fibre. Furthermore, test results of residual waste for biofuel application show that waste has an inherent gross calorific value (GCV) of 3420 K.Cal/Kg, which can be used as a bio-fuel.

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

Cheng C., Guo R., et.al..(2017) executed an experimental study on effect of treatment time with hydrogen peroxide under microwave radiation on components, surface morphology, whiteness, moisture regain, removal rate of impurities, fineness, tensile strength and breaking elongation of lotus fibers. Fresh lotus stem were washed, dried and cut into 5 cm lengths and 2g fibers were placed in 100 ml of NaOH solution and treated under microwave radiation. Stems were then washed in deionized water to neutral pH. After that fibers were extracted and dried at 50 C. While analyzing the components, the content of waxes and water-soluble substances of lotus fibers treated with hydrogen peroxide for 25 min increased to 0.03 to 3.48%. The pectin content before treatment was 8.51% and after treatment was 3.49% only. Hemicellulose in Lotus fibers decreased from 19.29 to 9.12% with the increase in treatment time from 0 to 25 min. Lignin decreased from 32 to 25% with the increase in treatment time from 0 to 25 min. Lignin decreased from 32 to 25% with the increase in treatment time from 0 to 25 min. The cellulose content in lotus fiber increased from 33.01 to 60.92% due to removal of non-cellulosic impurities. Removal rate of impurities increased rapidly from 53 to 73% when the treatment time increased from 0 to 10 min and then it reached 77% for 25 min. From the SEM study, it was observed that the surface of raw lotus fibers was smooth with many longitudinal grooves and diameter ranges from 75 to 80 micrometer whereas the fibers after treatment with hydrogen peroxide for 5 to 15 min was rough with numerous protuberances and diameter changed from 45 to 55 micrometer. The cross-section shape of fibers was irregular and full of wrinkles. The crystallinity and CI of lotus fibers after treatment increased from 40.94 to 62.60 % and 46.40 to 60.64%. Hence this study opens the opportunity for the use of microwaves in preparation of lotus fibers.

A study was conducted to investigate spinability of banana fibers 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 fibers. Fibers used in this study was extracted from Kobri (AB genome, Musa paradisiaca) banana plant. With the 100 % banana fiber it was found difficult to produce web on carding machine. To overcome with this problem, Banana fiber 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 fiber blended with cotton than ring spinning system.

Rambabu V., Kona S., Naidu A.L., Rao T.S.V. (2018). experimenting mechanical properties of okra and jute fibers with ground nut shell, ash as reinforced composites with Epoxy (LY516) and Epoxy (XIN100IN) raisins matrices. Natural fibers are rapidly used as the reinforcement material in polymer matrix composites due to their advantages like low density environment friendly, higher stiffness etc. the present study aimed used two different polymers as the matrix material. Okra and jute fibers are used as a reinforcement material. Jute and okra fibers are marinated with 5% NaOH for half an hour. The fibers were cleaned and kept in HCI to remove the NaOH contain. The fibers kept in oven for an hour at 70°C. after two different epoxy-based matrix material were prepared and fibers are oriented in unidirectional composites. For composition, total 8 samples were prepared. To prepared, and to measure mechanical performance tensile, compression, hardness number and impact test were conducted. The results showed mechanical properties of natural fibers (okra and jute) along with groundnut shell, ash (3% and 5% wt.).

Reinforced with two different polymers were compared and observed good interphase of fiber/matrix improved mechanical properties. Jute fibers obtained better strength in both matrices; okra fibers reinforced composites have higher tensile strength. These materials are suitable for structural application.

Duman M.N., Kocak E.D., Merdan N. & Mistik I. (2017). studied non-woven production from agricultural okra wasted and investigated their thermal conductivity. In this study okra stem waste were used for the production of the fiber. For production of the fiber, specially designed machine (100 kg/hr capacity) was used. The fibers were left in the waster container for two days. The purpose was to separate residues from the fibers and remove completely. The fibers were treated with 10% NaOH and 60° C for 10,20, 30 and 40 minutes then fibers were washed and neutralized with 5% acetic acid solution for 5 minutes and dried at 100° C for 2 hours. The tensile strength and elongation value of okra fibers were tested with INSTRONE 4411 testing machine. Diameter was also measured with microscope. Then prepared needle punch non-woven samples. The thermal properties of both non-woven had been investigated. As per results, it was observed that the heat transfer capacity was higher in treated okra fibers as compared to untreated okra fibers.

Khan G.M.D., Yilmaz N.D. & Yilmaz K. (2017). studied okra fibers: Potential material for bio composition in which they stated okra plant is a renewable, bio degradable cost efficient and low-density source for production of bast fibers and also other industrial cost-efficient ecofriendly materials. In research they focus on the fiber extraction process, composition of fibers and morphology and other performance properties of fiber, also added the fiber modification techniques and other application. Researchers found that okra bast fiber has high content of cellulose, excellent mechanical strength and stiffness also good thermal resistance. Okra bast fibers same as jute, hemp and ramie minor fibers. Furthermore, okra bast fiber reinforced bio composites successfully fabricated with different matrices includes biodegradable corn starch, poly (lactic acid), P (vinyl alcohol), urea formaldehyde resin etc. different methods of processing are applicated. The results are indicated bio composite exhibited better mechanical properties, water resistance and thermal properties at optimized processing condition.

2.2.3. Researches on fibre retting

A research on accelerated retting cum softening of coconut fibre was conducted by Basu G., Mishra L., et al. (2015). The aim of the research was to analyse the difference in the properties of the coconut fibre when subjected to a different method. Treatment of the raw coconut fibre with a combination of Sodium Sulphide, Sodium Hydroxide, Sodium Carbonate, reduce retting time from 6 to 12 months to 2 hr. Chemical treatment decreased the linear density (about 36%), diameter (about 35%), and flexural rigidity (about 72%), ultimately softer fibre. The treatment showed positive results towards mechanical proprieties. Fine structure analysis of the treated fibres was done by FTIR, XRD, TGA, and SEM. Component analysis validated the beneficial modification with improved properties. The chemical constituent, FTIR and TG analyses revealed enhancement of cellulose content and reduction in lignin, hemicelluloses. Resultant crystallinity index of the treated coconut fibre was enhanced by 36% compared to the raw fibres. SEM showed that chemical retting was most efficient in removal of impurities. The effluent obtained from chemical retting was suitably treated to make it safe for discharge.

Banik S. (2015) studied the fungal dry retting, an eco-friendly and water saving technology for retting of jute. The study was aimed to overcome the shortcoming of traditional Jute retting. Four pectinolytic fungi were used for these fungal dry retting of Jute, viz. Aspergillus tamarii, A. flavus, A. niger and Sporotrichum thermophile. This fungal dry retting was found to be an aerobic process unlike conventional water retting. Hence it is environment pollution free, faster, water saving and able to produce good quality Jute fibre with strong and unbroken full-length jute stick as desired by the jute farmers. In field trial, the average fibre strength was 27.7 g tex, fibre fineness was 2.8 tex and fibre grade between TD-4 and TD-5. The fungi had no adverse effect on the succeeding crop rice. Eight-pound regular yarn was prepared from these fibres having normal textile properties. It was concluded that this new concept of waterless retting technique by pectinolytic fungi may solve the present water crisis for retting of Jute and other allied bast fibres.

A comparative study was undertaken by Omenna, E. C., Adeniyan, O. N., et. al. (2016) on the effect of chemical and stream retting on the Kenaf fibre quality.

This research was conducted to investigate the comparative effect of chemical (1% urea and 2% urea solutions), control and stream retting on the kenaf fibre quality. It normally takes about 14 - 28 days to complete water retting process and this makes it impossible for the Kenaf and Jute farmers to produce enough fibres that meet the yearning demands. Results revealed that the treatments (1% and 2% urea) significantly reduced the retting periods from 14 -28 days to 6 -7 days. The retting periods of 1% and 2% urea treatment was statistically similar and significantly lower ($P<0.05$) than that of the stream and control. Thus, the microbial activities in 1% and 2% urea were more efficient in reducing the retting periods. The pH of the retting water from the urea treated samples were (4.65 and 4.25) more acidic than others. There were significantly higher ($P>0.05$) degree of hardness in 1% and 2% urea liquor than others with its corresponding higher chemical oxygen demand, oxygen demand and biochemical oxygen demand at 20^{o}C. There was no difference in colour appearance of Kenaf fibers from 1% and 2% urea treatments while the control and stream retted fibers had the same dull white appearance. The fiber from 1% urea had the highest tensile strength and tensile modulus (89.95MPa and 0.152GPa respectively) followed by 2% urea (74.99MPa and 0.139GPa). Therefore, the chemical retting has produced clean, consistently long and smoother surface fiber than the stream and control. Chemical retting may reduce the risk of environmental pollution caused by stream retting as the chemical retting liquor is a good potential source of plant nutrients and may be used as liquid fertilizers.

Wateka, C., Githinji, D. N., et. al. (2016) studied the combined effect of water retting and sodium hydroxide concentration on properties of Luffa Cylindrica fibres. In this study, the extraction of Luffa cylindrica fibres together with the combined effect of water retting and alkali treatment on its tensile properties were reported. The fibres were extracted from mature fruits of Luffa cylindrica through aerobic water retting process over a duration of 2 weeks, 4 weeks and 8 weeks. The extracted fibres were oven dried to a moisture content of 9.74±1.1% and tested in tension at gauge lengths of 10 mm. The fibres were characterized in terms of moisture regain, lignin content, hemicellulose content, and cellulose content. The combined effect of water retting and sodium hydroxide (NaOH) concentration on the fibre's breaking load, elongation, tenacity and linear density was also investigated. It was observed that the luffa cylindrica fibres had a moisture regain of 10.81%, lignin content of 12.03%, cellulose content of 65.69%, and hemicellulose content of 19%. The linear density of the fibres retted for 2-8 weeks was 572–470 dTex. The breaking load of the fibres retted for 2-8 weeks was 1444.19-417.04 cN and 997.81-298.05 cN after treatments with 0% -16% NaOH. The fibre elongation was 4.0-24% after 2-8 weeks of retting and 4.3-14.5 % after treatments with 0% -16% NaOH. Tenacity of luffa cylindrica fibres was 6.0-25.25 cN/Tex after 2-8 weeks of retting and 5.9-20.22 cN/Tex after treatments with 0% -16% NaOH. From the study it was established that, an increase in aerobic water retting and concentration of NaOH had a positive effect on the tensile properties of the luffa cylindrica fibres.

Sow, S., Ranjan, S., et. al. (2021) conducted a research on improving retting methods of jute to enhance fibre and quality and retting waste management. The aim of this was to find out an efficient way of enhancing both the fibre as well as managing the waste generated out of the process. Adoption of modified conventional method of retting, mechano-microbial retting and in-situ retting with microbial formulation helped to produce quality fibre. In areas where the water is scarce, ribbon retting techniques should be introduced and farmers should be made aware as it reduced time of normal retting by 4-5 days, saved water, space and the cost of retting process up to 50% over the traditional method. Further commercialization of microbial cultures was recommended, and their use should be promoted. By following these techniques, farmers could ret their Jute in lesser time with very less quantity of water along with improvement in fibre quality and get more net income than conventional method of retting.

A comparative study was conducted by Suparna, D., Majumdar, B., et. al. (2018) on the conventional and improved retting of jute with microbial formulation. The aim of the study was to analyse the chemical and structural differences as well as the environmental impact of the two techniques of extraction. This study was carried on conventional and improved retting of jute (Corchorus olitorius L. and C. capsularis L.) with a talc based microbial formulation was carried out for three consecutive retting trials in the same water. Due to introduction of the microbial formulation by three different strains of Bacillus pumilus in the improved method, retting duration reduced by 6–7 days, fibre recovery increased by 9.7–12%, with the improvement in fibre quality (colour, lustre, fibre strength etc.) as compared to conventional method. Moreover, the root content which was not desirable for quality fibre production was high (16–20%) in conventionally retted fibre as compared to fibre obtained from improved retting (3–4%). The polygalacturonase (3.6–5.3 IU ml-1), pectin lyase (142–185 U ml-1) and xylanase activities (5.2–7.5 IU ml-1) recorded in retting water after each retting of improved method was higher by more than 2 times as compared to conventional one. These higher enzymatic activities in the retting water resulted in reduced retting duration and improvement in fibre recovery and quality. Further, the quality jute fibre extraction from repeated retting in the same stagnant water was possible by using the highly efficient microbial formulation. This technology has the potential to meet the demand of quality jute fibre by jute industries and to increase the net income of poor jute farmers with meagre initial input.

Khan R. I. (2016) evaluated the brassica fibre for textile and spinning properties. The aim of the study was to extract, characterize and modify the fibre materials from B. napus stems for textile and apparel applications. In order to find the optimum retting conditions for retting time, four different retting parameters were evaluated including; retting temperature, material liquor ratio, water exchange and the reuse of retted water. It was discovered that the virgin-retted fibres from Brassica plants exhibit most of the required textile properties including dye absorbency, strength, and thermal behaviour. However, the virgin-retted were not spinnable. In order to modify the Brassica fibres for spinnability, three treatment methods were applied: 1) alkali, acid and softener treatment; 2) pectinase enzyme treatment; and 3) enhanced enzyme treatment. Treatment was done according to Method 5 of the American Association of Textile Chemists and Colorists (AATCC). Brassica fibers obtained from treatments 2 and 3 showed similar spinning properties. The treatment demonstrated superior spinning properties to Brassica fibres obtained from treatment one. To determine the variability of the cultivars upon textile and spinning properties, seeds from twenty different Brassica cultivars consisting of three different species, B. napus, B. juncea L. and B. rapa L., were collected, planted, and harvested upon reaching physiological maturity. The virgin water-retted fibre samples were then treated with pectinase enzyme, and different spinning properties (stiffness, softness, individual fibre entity) and textile properties (fibre decomposition temperature, tenacity, and dye absorbency) of enzyme-treated samples were evaluated. The research suggested that producing fibres from canola stubble and stems could be an additional income source for canola growers.

Patel, B. Y., & Patel, H. K. (2022) conducted a research on retting of banana pseudostem fibre using Bacillus strain to get excellent mechanical properties as biomaterial in textile and fibre industry. The aim of the research was to soften banana fibres (Musa paradisiaca L) by utilising a variety of chemical (NaOH & HCl) and bacterial treatments. Physical properties (Hygroscopicity, Density, Linear density), chemical (cellulose, Hemicellulose and Lignin) and mechanical parameters (Peak load, Breaking Elongation, Tenacity) of the treated fibres were measured. The tenacity (g/tex) of microbial treated (Bacillus licheniformis) (7 days) fibre was found to be greater, at 6.33, but the average peak elongation (%) of (Bacillus Subtilis) was found to be higher, at 8.2. The lignin % of untreated Banana fibres (15.98%) was reduced in fibres treated with 5N of NaOH (10.75%), 5N HCl (8.73%), Bacillus aryabhattai (11.4%), Bacillus licheniformis (12.54%) and Bacillus Subtilis (13.56%). In contrast to raw banana fibre, the mechanical qualities of treated fibres showed positive results. The study found that treating banana fibre with NaOH, HCl and Bacillus sp. had a substantial impact on the physiochemical parameters. SEM and FTIR methods were used to validate the efficiency of the bacterial treatment.

CHAPTER III

METHODOLOGY

The present study is an exploratory and experimental in nature. The dried stalk of Kigelia Pinnata tree was the source for the fibres, which was conventionally discarded as agricultural waste. Researcher started from the base, that is, searching of the raw material for extraction of the fibre, followed by extraction, treatment, testing of fibres, spinning of yarns and fabric construction. The aim of the study was to explore and analyse the characteristics of the fibre for the application in textiles.

3.1 Research Design

3.2. Procurement of Kigelia Pinnata stalks

3.3. Extraction process and yield

3.4. Testing of fibre:

a. Identification Tests
    - Microscopic appearance
    - Burning characteristics

b. Material characterization of the fibre

c. Physical property of the fibre
    - Fibre length
    - Fibre fineness
    - Fibre Diameter
    - Length to breadth ratio
    - Single fibre strength
    - Moisture content and regain.

d. Chemical property
    - Solubility analysis

e. Biological property
    - Quantitative antimicrobial test

3.5. Yarn Testing:

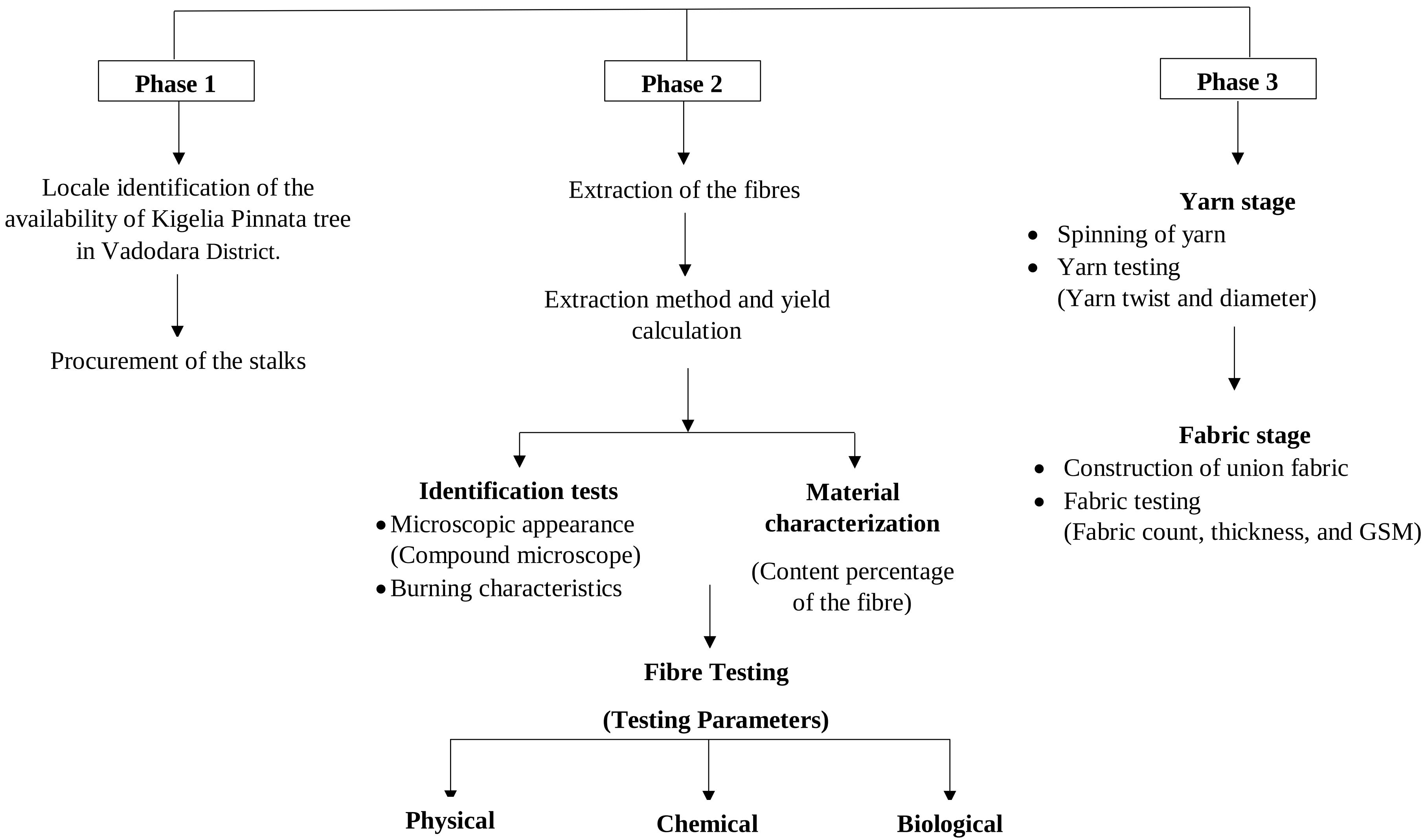
- Yarn twist
- Yarn diameter
- Yarn count

- Kigelia pinnata fabric

3.7. Fabric Testing:

- Fabric count
- GSM
- Fabric thickness

Research Design



3.2. Procurement of Kigelia pinnata stalks:

From literature and survey, it was found that Kigelia pinnata tree were there in Vadodara. The trees with the stalks were present in the Kamatibaug area and the MRID campus of The Maharaja Sayajirao University of Baroda. The permission could not be obtained to collect the raw material from Kamatibaug, the researcher procured it from MRID only.

3.3. Extraction process and yield:

Step 1: The extraction process was initiated by pounding the dried stalks so that the bark and the hollow core can be separated.

Plate 1: Dried stalks before and after pounding

Step 2: Next, the pounded mass was rubbed against a rough surface to remove the dry waste.

Step 3: The extraction was done was by water retting, followed by cleaning of the fibre with a plastic bristled brush and the fibres were dried.

Plate 2: Cleaning process with a plastic bristled brush

3.3.2. Yield of fibre

For the yield of the fibre, initial weight of the material obtained after pounding and removal of dry waste (W_0) and weight of the fibre obtained after retting and cleaning (W_1) were noted. The percent yield was calculated using the formula below:

$$\text{Yield (\%)} = \frac{W_0 - W_1}{W_0} \text{ x } 100 \qquad \ldots(1)$$

Where, W_0 is the weight of the pounded mass, and

W_1 is the weight of the fibre obtained after retting.

3.4. Testing of fibre:

a. Identification Tests

Fibre identification was done through microscopic appearance, burning and solubility tests.

- Microscopic appearance

Longitudinal and cross-sectional views were observed under the compound microscope with the magnification of 10X and 40X.

- Burning test

The burning behaviour of the fibre with its reaction of heat was carefully observed. The odour evolved after burning was also noticed.

b. Material characterization of the fibre:

Chemical constituents of the raw fibre were determined as per the scheme suggested by Turner and Doree. The procedure was carried out in the following sequence:

- Estimation of water-soluble components:

A weighted sample of 2 gm of fibres 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:

$$\text{Water soluble components (\%)} = \frac{W_1 - W_2}{W_1} \text{ x } 100 \qquad \dots (2)$$

Where, W_1, is the initial weight of the sample,

W_2 is the weight after the removal of water soluble component.

- 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 (methanoyl/benzene solution for 4 hours.

Sample was then washed with alcohol dried and weighted (Ws gms). The results was expressed as percentage of the oven dry weight of the original sample.

$$\text{Fats and waxes (\%)} = \frac{W_2 - W_3}{W_1} \text{ x } 100 \qquad \dots (3)$$

Where, W_1, is the initial weight of the sample,

W_2 is the weight after the removal of water soluble component,

W_3 is the weight after the removal of fats and waxes.

Plate 3: Soxhlet setup

- Estimation of Pectin Content:

The defatted fibre samples were then extracted by boiling for 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 pectineus material is recorded as a percentage of the oven dry weight of the original sample using the following formula:

$$\text{Pectin content (\%)} = \frac{W_3 - W_4}{W_1} \text{ x } 100 \qquad \ldots (4)$$

Where, W_1, is the initial weight of the sample,
W_3 is the weight after the removal of fats and waxes, and
W_4 is the weight after the removal of pectin content.

- Estimation of Hemicellulose Content

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

$$\text{Hemicellulose (\%)} = \frac{W_4 - W_5}{W_1} \text{ x } 100 \qquad \ldots (5)$$

Where, Where, W_1, is the initial weight of the sample,
W_4 is the weight after the removal of pectin content, and,
W_5 is the weight after the procedure (removal of hemicellulose content)

- Estimation of Lignin Content:

After the hemicellulose removal, fibres 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 fibres 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:

$$\text{Lignin (\%)} = \frac{W_5 - W_6}{W_1} \text{ x } 100 \qquad \ldots (6)$$

Where, Where, W_1, is the initial weight of the sample,

W_5 is the weight after the procedure (removal of hemicellulose content), and W_6 weight of the sample after the lignin removal.

- Estimation of Cellulose Content:

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

$$\text{Cellulose content (\%)} = \frac{W_6}{W_1} \text{ x } 100 \quad \text{... (7)}$$

Where, W_1, is the initial weight of the sample, and,

W_6 = Weight of the sample after lignin removal.

c. Physical properties of the fibre

- Determination of Fibre Length

To determine the length of fibre, it was first placed against the dark surface and the length was measured with the steel ruler. An average of 50 readings was taken.

- Determination of Fibre fineness:

Following ASTM D 7025 standard, fibre fineness was tested. In the direct system of yarn numbering, denier was determined by taking the average weight of 10 readings of 10 cm length of the fibre and calculations was done by using the formula:

$$\text{Denier} = \frac{W \text{ x } I}{L}$$

Where, W = Weight of the fibre

L = Length of the sample

1 = unit length of the system

The count of the fibres was also determined by indirect system of yarn numbering by using Beesley's yarn balance. The instrument consisted of hook at one end and the pointer at other end. A standard weight (0.040 gm) was hung on the notch of the beam. Template was used to cut the length of fibres based on cotton count system. The fibres were kept on the hook until the pointer reached the datum line. The count is the number of short length filament fibres used to balance the beam.

- Determination of fibre diameter:

Compound microscope with micrometer lens was used to measure the fibre diameter. An average of 50 readings was taken to determine the fibre diameter.

- Determination of single fibre strength:

Following ASTM D 3822 standard, single fibre strength was tested. LLOYD tensile testing instrument was used. The sample length was 10 cm. Instrument worked on constant rate of elongation principle (CRE). Capacity of the instrument was 2500 N. Pulling speed was 100 mm/min. The test was carried out in the Department of Textile Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

Plate 4: LLYOD Tensile Tester

- Bundle fibre strength:

  Following the ASTM D1445 the bundle strength of the fibre was determined using the instrument called the stelometer. The instrument worked on the principle of constant rate of loading. The sample was conditioned in the standard conditions. Gauge length was 3.2 mm, rate of loading 1 kg/ sec and weight capacity of 13 kg. The was carried out in testing lab of the Department of Clothing and Textiles, Faculty of

Family and Community Sciences, The Maharaja Sayajirao University of Baroda.

Plate 5: Stelometer for bundle strength

- Moisture Testing:

To determine the moisture content and regain, fibres weighing 10 gm were kept in oven for 4 hours. After 4 hours, samples were taken out from the oven and weighted. From the differences in two weights, moisture content and regain were calculated using below mentioned formula: (Booth J.E,1996).

$$\text{Moisture regain (R)} = \frac{100 \times W}{D}$$

$$\text{Moisture content (M)} = \frac{100 \times W}{D+W}$$

Where, D = Oven dry weight

W = Weight of water

R = Regain

M = Moisture content

d. Chemical Properties of the fibre

Solubility testing was done by treating the fibre with acids and alkalis in both hot and cold conditions. Samples of fibre were taken in test tube and treated with different chemicals and solubility was observed for each and recorded.

e. **Biological Properties of the fibre**

This parameter was tested under the standard of quantitative antimicrobial test ASTM E3151-18, wherein the biological inhibition was observed for both gram-positive (*Bacillus*) and gram-negative (*E.Coli*) microphages.

3.5. Yarn testing:

3.4.1. Spinning of extracted yarn:

The extracted fibres were hand-spun by Mr. Bakul Shah at Bhoomi Pujan office, Fatehpura, Vadodara. Thus, the hand-spun yarns were prepared.

Extracted yarns were treated with 5% NaOH ofw (on fibre weight) for softening and improving hand of the fibres so that cohesiveness can be obtained, since, good cohesiveness assist for the pliability and assists spinnability. To start spinning, 2-3 fibre bundles of similar length were given a twist so as to form a yarn, followed by the end-to-end joining was done to obtain a continuous length. The twisted yarn was winded over a pern.

Plate 6: Hand spinning of yarn

Testing of yarns:

Yarn testing was done at the testing lab of Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara.

Standard conditions maintained for testing: Relative Humidity : 65 ± 2 Temperature : 20 ± 1ºC
Conditioning: Yarns were exposed to above laboratory conditions for 24 hours

- Yarn Twist:

  The amount and direction of twist was tested on the manually operated twist tester. The sample length was 10 inches with tension arrangement. An average of 10 readings was taken.
- Yarn diameter:

  The diameter of the yarn was observed by micrometre arrangement using compound microscope. An average of 10 reading was taken.
- Yarn count

  Following ASTM D 7025 standard, yarn fineness was tested. In the direct system of yarn numbering, denier was determined by taking the average weight of 10 readings of 10 cm length of the fibre and calculations was done by using the formula:

$$\text{Denier} = \frac{W \text{ x } I}{L}$$

Where, W = Weight of the fibre

L = Length of the sample

1 = unit length of the system

3.6. Fabric Stage:

3.6.1. Construction of Fabric:

Union fabric was constructed from 100 % Kigelia pinnata hand spun yarn in weft direction, and 100% cotton as a warp. Weaving was done on the handloom by the researcher at the Weaver’s Service Centre, Shahibaug, Ahmedabad, Gujarat.

Table 1: Details of the loom

Type of loom	Table loom
No. of shaft	4
Loom width	14 inches
Reed number	36

3.5.2. Fabric Testing:

- Fabric Count:

  Fabric count (the number of yarns/inch) describes the compactness of the weave. Following the ASTM D 3775-98 fabric count was determined by counting the number of warp and weft threads using pick glass. An average of 10 readings was taken.

- Fabric thickness:

  Testing standard ASTM D 1777-96 was used to measure fabric thickness using universal thickness tester. An average of 10 readings was taken.

Plate 7: Thickness Tester

- Fabric GSM (weight per unit area)

  Sample of 5 X 5 cm was cut and weighed. GSM was calculated using this formula:

$$\text{GSM} = \frac{\text{Weight in grams of the sample x 100 x 100}}{\text{5 x 5}}$$

CHAPTER: IV
RESULTS AND DISCUSSIONS

The results and discussion of the study have been discussed under the following sections:

4.1. Procurement of Kigelia pinnata stalks:

4.1.1. About the Kigelia pinnata

4.1.2 Availability of the Kigelia pinnata stalks in Vadodara.

4.2. Fibre stage:

4.2.1. Extraction and Yield of fibre

4.2.2. Identification tests

4.2.3. Material characterization of the fibre

4.2.4. Physical property of the fibre

4.2.5. Chemical property of the fibre

4.2.6. Biological property of the fibre

4.3. Yarn Stage:

4.3.1. Spinning of the extracted yarn

4.3.2. Testing of the yarn

4.4. Fabric Stage:

4.4.1 Construction of the union fabric

4.4.2. Testing of the properties of the fabric

4.1. Procurement of Kigelia pinnata stalks:

4.1.1. About the Kigelia pinnata

Kigelia pinnata belongs to the genus Kigelia, which is a genus of flowering plants in the family Bignoniaceae.

Botanical classification:

Kingdom: Plantae

Clade: Asterids

Order: Lamiales

Family: Bignoniaceae

Genus: Kigelia

Species: Pinnata

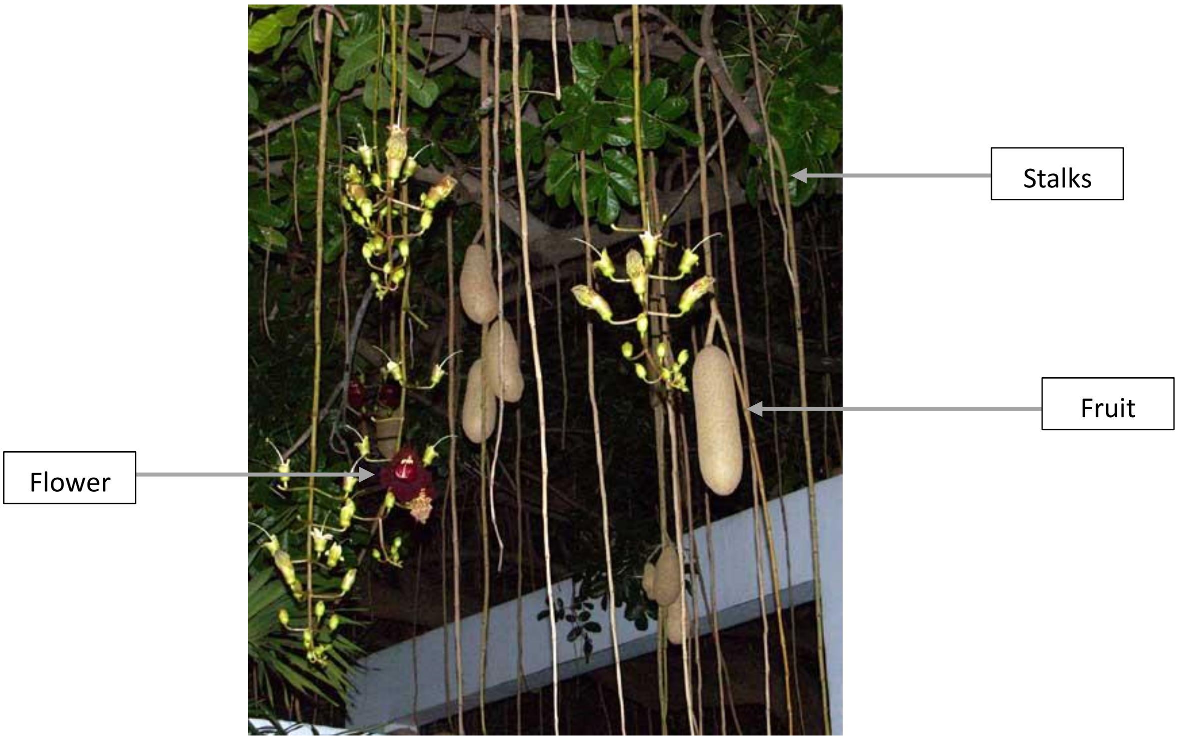


Figure 5: Kigelia pinnata

(source: https://www.flickr.com/photos/asienman/23885350751/sizes/m/)

Morphology:

Kigelia pinnata is pollinated by bats, but insects are also attracted to the flower colour and fragrance. Seed germination improves after 1 year of storage. Soaking the seeds in boiling water for 1 min aids germination, a success rate of 80% has been recorded. Truncheons cut from the tree can be planted directly into soil and root readily. It occurs along watercourses, in riverine fringes, alluvial and open woodland, high-rainfall savanna, shrubland, and in rain forest loamy red clay soils, sometimes rocky, damp or peaty, from sea level up to 3000 m altitude. It can reach a height of 20 m, and its features include a grey bark that is smooth at first but peels as it ages; wood that is light brown or yellowish, undifferentiated, and not prone to cracking; and enormous, cylinder-shaped fruits that can measure up to 0.6 m in length and 4 kg in weight. The tree is evergreen where rainfall occurs throughout the year, but deciduous where there is a long dry season. The flowers bloom in the spring and are irregularly shaped like bells, measuring 9 to 13 cm long. They are yellowish on the outside and purple on the inside. The fruits are oblong-shaped, measuring 30 to 50 cm long, and they hang on the stalk for several months. These stalks were used as the raw material for the fibre extraction. (Roodt 1992)

Figure 6: Kigelia pinnata tree in the wild
(source: https://upload.wikimedia.org/)

The tree is widely grown as an ornamental tree in tropical regions for its decorative flowers and unusual fruit can cause serious injury to people.

Medicinal uses:

Sausage tree or Kigelia pinnata is one of the most valuable tree, which all parts has medicinal properties and used to treat many diseases. .In traditional medicine the various parts of the tree are used for medicinal purposes such as treatment of the kidney stones, skin diseases, dysentery, parasitic infestation, postpartum bleeding, diabetes, pneumonia, toothache, rheumatism, CNS depression, worm infestation, genital infections, etc. Based on the anecdotal reports of antimelanoma activity, crude dichloromethane extract of Kigelia pinnata bark and fruit were tested and showed cytotoxic activity in vitro against cultured melanoma and other cancer cell lines. [5]

Figure 7: Kigelia Pinnata tree in a rural area
(Source: https://www.cabidigitallibrary.org/cms/10.1079/)

Non-medicinal use:

The leaves of Kigelia pinnata have been positioned as an important nutritional resource, comparable to other green leafy vegetables such as spinach. They are consumed by lactating women in various parts of Africa to enhance the volume and quantity of breastmilk. The dried leaves contain levels of essential amino acids that may provide beneficial health benefits as other minerals and nutrients including calcium, magnesium and iron. The tree produces good quality timber and the wood is reported to be easy to work with. Canoes are also prepared from the tree. The boiled fruits are also used to produce a red dye and the roots are reported to produce a yellow dye. It is used in cosmetic preparation meant to maintain blemish free complexion. [5]

Plate 8: Kigelia pinnata tree at the MRID campus, Vadodara

Distribution:

Native to Africa; cultivated in various other tropical countries, such as India, where the major distribution is in the region of West Bengal, Kerala, Tamil Nadu, Karnataka, Gujarat and Maharashtra. [5]

Kigelia pinnata has been nominated as a key species for domestication for future use as medicinal crop. So once these trees are grown for medicine, the wastage that is, stalk, will be available in stock and raw material for fibre extraction will be available. [5]

4.1. Procurement of the Kigelia pinnata stalks:

The availability of the tree in Vadodara was identified in the Kamatibaug garden as well as in the MRID campus of The Maharaja Sayajirao University of Baroda, Vadodara. Kamatibaug garden being the corporation property, the permission was obtained from Vadodara Municipal corporation who could not be obtained on time so, the researcher procured the stalks from MRID campus. There were two trees which were around 25-30 years old (as informed by the staff of the institute). The stalks of the tree were never the point of attraction for the students or staff for any specific use. The tree was the source of shade and greenery only.

Plate 9: Stalks of Kigelia pinnata

Source of fibre was the stalks and those were found at the height of 4 – 5 m from the ground. These would otherwise fall off and be treated as waste with no other visible use. The researcher obtained 15 stalks, weighing 40 g, over the course of three visits to the campus.

The stalks were between 1 – 2 metres long and completely dried.

4.2. Fibre Stage:

4.2.1. Extraction Method and calculation of Yield percentage:

The stalk, which was the source for raw material, is that portion of the tree which supports the growth of the flower which forms in a fruit and when it ripens, the fruit falls off, and the stalk remains. Due to the reason that these stalks have no utility other than being treated as agro-waste, this study was undertaken to utilize them as a novel and eco-friendly source of a fibre, having enough raw material for future use as well.

Plate 10: stalks before pounding

- Process after collecting the stalks:

The stalks (15 in number) obtained were pounded with a hammer, to separate the dried hollow core from the bark and the fibres.

Plate 11: Stalks after pounding

This process was done keeping 3 stalks together to speed up the process, after which the pounded material was rubbed against a rough surface to remove as much dry waste as possible. The obtained mass to be used as raw material was weighed which was 2 gm (W_0). The extraction of fibre was done by water retting, followed by the cleaning of the fibres by a plastic bristled brush. The fibres were then dried and weighed which was 0.8 gm (W_1). Yield percentage was calculated.

- Yield percentage:

  Using the formula no. 1 from chapter III,

$$\text{Yield (\%)} = \frac{W_0 - W_1}{W_0} \text{ x } 100$$

$$\text{Yield (\%)} = \frac{2\text{ g} - 0.8\text{ g}}{2\text{ g}} \text{ x } 100 = 40\%$$

Hence, the yield of the fibre extracted from the pounded mass was 40 %.

As a fibre obtained from agro-waste the percentage yield was good enough for carrying out further exploration. Due to this reason only water retting was done.

Water retting has its own advantages, as the process is chemical free and water from rainwater harvesting be utilized making it more sustainable.

4.2.2. Identification tests:

To determine the class of this novel fibre, a number of identification tests were done.

a. Microscopic appearance:

Longitudinal view:

Bundle: straight and regular appearance with striations of the bundle was observed under the 10x and 40x magnification. The longitudinal structure of the fibre was similar to that of hemp as seen in the figure , which also a bast fibre.

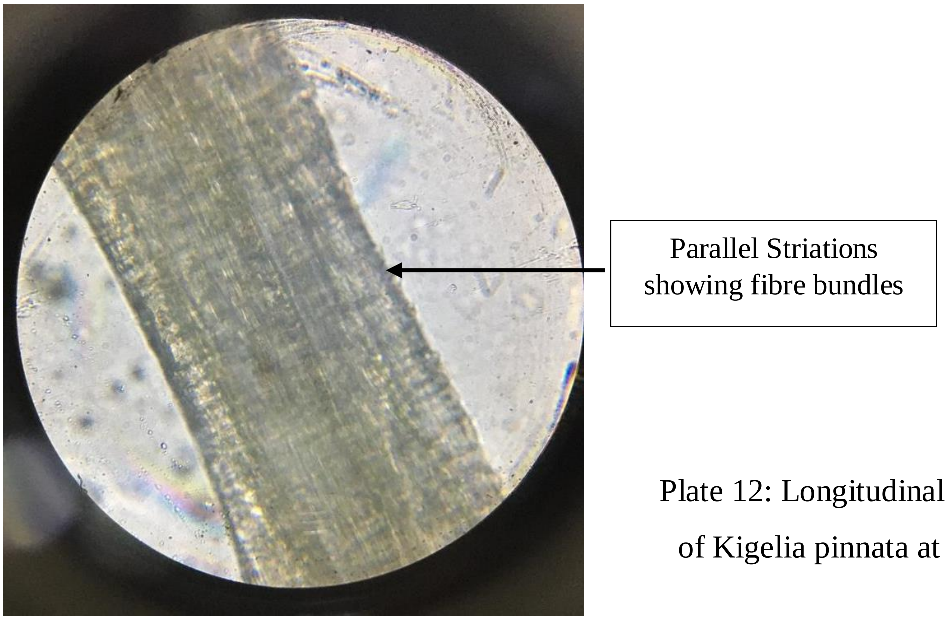


Plate 12: Longitudinal view of Kigelia pinnata at 40x

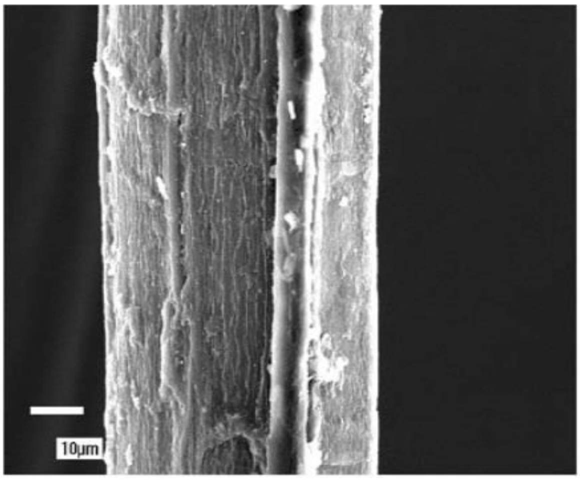


Figure 8: Longitudinal SEM of hemp fibre

(Source:https://www.researchgate.net/figure/a-Longitudinal-and-b-cross-sectional-view)

Cross-sectional view:

Cross-sectional view was observed by arranging the fibre bundles inside a rubber tube, reinforced with adhesive and later the tube was thinly sliced in circular shape and placed in compound microscope and observations were made.

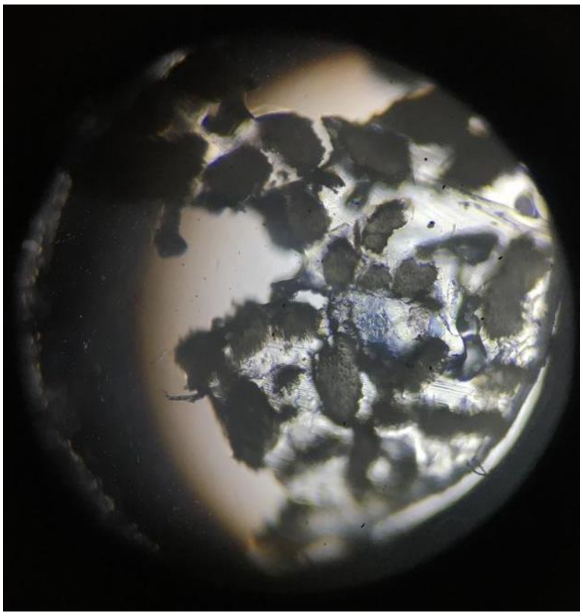


Plate 13: Cross sectional view of Kigelia pinnata at

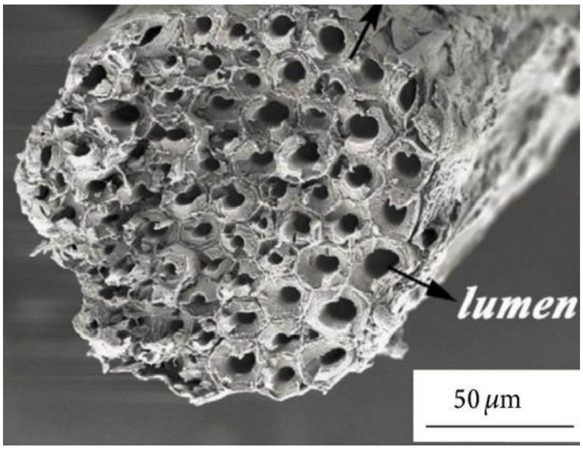


Figure 9: Cross sectional SEM of Hemp

(Source:https://www.researchgate.net/figure/a-Longitudinal-and-b-cross-sectional-view)

While observing this disc under the magnification of 40x, porous and roughly circular bundles were seen. Circular bundles infer to the properties namely smooth, slippery appearance also, high bending stiffness, and low pliability, flexibility but has good thermal properties and comfort. [2]

b. Burning Characteristics

Table 2: Burning test of Kigelia pinnata fibre

Name of the fibre	**Reaction to flame**	**Burning behaviour**	**Odour of flame**	**Leaving flame**	**Type of Ash**
Kigelia Pinnata	Does not shrink away from flame, ignites easily on contact with flame	Burns readily, with a yellow flame and light grey smoke	Burning paper	Continues to burn with an after-glow	Soft grey, powdery ash

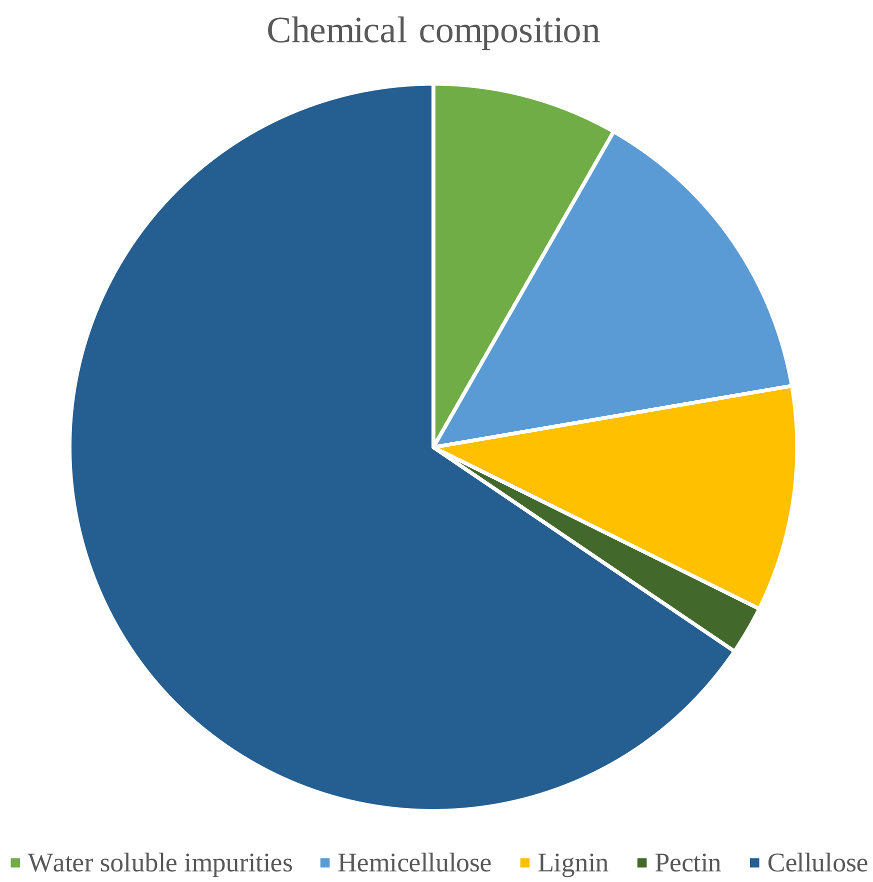
Since the fibre belongs to the class of natural cellulosic, its burning nature is like that of the other fibres such as Jute, Hemp, Banana etc.

4.2.3. Material characterization

The chemical composition of the fibre obtained by the elemental analysis was done by the process mentioned in chapter 3. The results are given in the table:

Table 3: Chemical composition of the fibre

Sr. No	**Chemical composition**	**Percent Value (%)**
1.	Water soluble impurities	8.23
2.	Hemicellulose	14
3.	Lignin	10
4.	Pectin	2.15
5.	Fats and wax	0.3
6.	Cellulose	65.32



Graph 1: Chemical composition

The chemical composition signifies the fine structure of a fibre. Different components are responsible for different properties. Water soluble impurities vary depending on the geographical conditions, here the fibre has high water impurities. Hemicellulose is characterized by a complex structure made of several polysaccharides with linear or branched structures which is responsible for the strength of the fibre, here, the hemicellulose content is high which contributes to the high strength of the fibre. Lignin is a complex phenolic polymer which is responsible for the cell wall rigidity of the fibre, due to the higher percentage of lignin precent in the fibre, it has harsh feel, here the lignin percentage is less as compared to Hemp and Jute. Pectin is component responsible for the colour of the fibre, due to its less percentage, the colour of the fibre is observed as yellow to yellowish-brown. Due to the less percentage of fats and waxes, the fibre has lesser cohesiveness, hence, poor spinnability in its raw form, which can be improved by further treatment. The fibre has high cellulose content which leads to its eco-friendliness.

4.2.4. Physical Properties

- Fibre Length:

  There was a lot of variation in the length of the extracted fibre because it is a bundle fibre. Hence, they were divided into 3 categories, short, medium, and long. For each category an average of 20 readings was taken and the average length was determined.

  Table 4: Length and category of Kigelia pinnata fibre

Length (cm)	Category
7 cm	Short
18 cm	Medium
45 cm	Long

  Length of short fibre was recorded as 7 cm, medium length was 18 cm and long length was of 45 cm. Fibre shorter than 15mm tend to have insufficient length to be twisted into yarn structure and fibres longer than 150 mm tend to require specialized spinning machinery for the conversion into yarn structure. Therefore, the fibre length of all the three categories may be sufficient to be twisted into yarn structure. (Gohl E & Vilensky L, 1987).

- Fibre Diameter:

  The diameter of the fibre was observed between the range of 8-10 µm and the average diameter was 8 µm. Fibres or filaments finer than 10 microns tend to become too delicate for ready conversion into yarn structure. (Gohl E & Vilensky L, 1987).

  As observed from table no. 3 below, the diameter of the Kigelia pinnata fibre was 8 µm which was similar to that of Coir and Sisal. The properties of the Kigelia pinnata fibre also coincides with the properties of Coir and Sisal.

Table 5: Diameter of natural plant fibers

Sr. No.	Plant Fibres	Diameter (μm)
1	Cotton	14 – 21
2	Flax	17 – 21
3	Hemp	15 – 30
4	Jute	14 – 20
5	Sisal	7 – 47
6	Abaca	10 – 30
7	Coir	7 – 30
8	Pineapple	25 – 30
9	Kapok	15 – 43
10	Nettle	20 – 80
11	Kenaf	13 – 33
12	Sansevieria	13 – 40
13	Ramie	16 – 120
14	Henequen	8.3 – 33.2
15	Mauritius	15 – 32

(Source: ASTM D 1909-04 (1961) Standard Table of Commercial Moisture Regains for Textile Fibers1 West Conshohocken, PA)

- Length to diameter ratio:

  Since there was a lot of variation in the length of the fibre, different the length to diameter ratio was obtained for different category of length.

Table 6: Length to breadth ratio

Length	**Diameter (μm)**	**Length to breadth Ratio**
7 cm (Short)	8	8750 : 1
18 cm (medium)	8	22500 : 1
45 (long)	8	56250 : 1

There was a lot of variation in the length of the fibres, the highest ratio obtained was of 56250 : 1. The fact associated with this ratio is higher the ratio finer the fibre, lower the ratio coarser the fibre. The smallest ratio of fibre length to diameter (thickness) is about 350 : 1. Anything less than this indicates a fibre which will probably not permit twisting into a yarn structure. But a ratio of 1000:1 or more indicates a fibre which should readily spin into a yarn structure. From the above observation it can be inferred that Kigelia pinnata fibre may readily be subjected to spinning.

- Fibre fineness:
  For fineness in the direct system, denier was obtained and converted into tex. Count was also calculated by indirect system as per cotton count. The values are as follows:

Table 7: Fineness of the fibre

Denier	**Tex**	**Cotton count (Ne)**
283	31	**19**

In the direct system, lower the denier finer the fibre and higher the denier coarser the fibre, whereas, according to the indirect system, lesser the count coarser the fibre, and higher the count finer the fibre. Therefore, the fibre is coarse in character. Textile grade yarn can be developed by subjecting the fibre to suitable treatments as well as exploring different spinning systems.

- Single fibre strength:
  Load, stress, and % strain values of the fibre are tabulated in table. An average of 5 readings was taken:

Table 8: Single fibre strength

Fibre sample	**Maximum Load (gf)**	**Extension at maximum (mm)**	**Stress gm/ den**	**Strain (%)**
Kigelia pinnata	805.037	6.545	2.844	13.091

It was observed that the fibre has excellent strength, which moderate elongation property due to its harsh nature.

- Bundle fibre strength
  The bundle strength was calculated in terms of gm/ tex. The average of 5 readings were taken. The bundle strength for Kigelia pinnata fibre was 2884.15 gm/tex.

- Fibre Moisture:

  Moisture greatly affects the physical properties of the fibre, all the properties namely dimensional property, mechanical properties including breaking strength, elongation, crease recovery and electrical properties. The amount of moisture depends on the relative humidity and temperature. Moisture content of the fibre was 13.1% and regain was 14.5% which is more than cotton and rayon and closer to Jute, Sisal, Hemp and Banana.

Table 9: Moisture regain of natural regenerated fibres

Sr. No.	Fibre	Moisture regain (%)
1	Cotton (Raw)	8.0
2	Cotton (Mercerized)	8.5
3	Flax	12.0
4	Hemp	12.0
5	Jute	13.75
6	Ramie (Raw)	7.5
7	Ramie (Scoured)	7.8
8	Silk	11.0
9	Wool	13.6
10	Rayon	11.0

(Source:https://www.textileschool.com/390/properties-of-vegetableplant- cellulosic-fibres)

- Colour of the fibre:

  Due to the presence of pectin which the organic compound responsible for colour, it was observed that the colour was off white to yellowish-brown. For colour improvement, bleaching can be done using various reagents.

Plate 13: Kigelia pinnata fibres

4.2.5. Chemical properties:

The reaction of fibre when subjected to different chemicals help to identify type of the fibres, as well as knowing the fine structure which can indicate the affinity the fibre has for pH, functional groups etc. The chemical analysis is also helpful in determining the type of wet processing which can be used for certain fibre. The fibres were subjected to various acids, alkalies, and other regents in both hot and cold conditions.

Table 10: Chemical properties of the fibre

Sr. No.	**Chemical**	**Results**
1.	60% Sulphuric Acid (cold)	Not Dissolved
2.	60% Sulphuric Acid (on heating)	Not dissolved
3.	72% Sulphuric Acid (cold)	Not dissolved
4.	72% Sulphuric Acid (on heating)	Disintegrated when subjected to heating for 15 mins.
5.	99% Sulphuric Acid (cold)	Not dissolved
6.	99% Sulphuric Acid (on heating)	Dissolved when subjected to heat for 10 mins.
7.	Sodium Hypochlorite	Not dissolved
8.	Acetic Acid	Not dissolved
9.	Acetone	Not dissolved
10.	Hydrochloric Acid	Not dissolved
11.	Formic Acid	Not dissolved
12.	DMF (cold)	Not dissolved
13.	Meta Cresol	Not dissolved
14.	Sodium Hydroxide	Not dissolved

It was observed that the fibre was quite resistant towards the action of alkalis and even acids, only concentrated sulphuric acid on heating because of to the high lignin content in the raw fibres. Acid could dissolve the fibre because the fibre was natural cellulosic, and acids degrade cellulose.

4.2.6. Biological Properties:

Antimicrobial testing is required for textile fibers because textiles are often in close contact with the human body and can easily become contaminated with bacteria, viruses, and other microorganisms. These microorganisms can cause unpleasant odors, stains, and even health problems. This testing ensures that textiles are safe for use and can effectively inhibit such microbial activities. Bacteria are a large group of minute, unicellular, microscopic organisms, which can be gram-positive or gram-negative depending upon the staining methods. Gram positive bacteria include *Staphylococcus, Streptococcus, Enterococcus*, etc, and gram-negative bacteria include *E. coli*, *Pseudomonas aeruginosa, Klebsiella pneumoniae, Haemophilus influenzae* etc.[3] The fibres were subjected to both gram positive (*bacillus*) and gram negative (*E.coli*) microphages, and the inferences was made that the fibres were resistant towards the gram positive microbes.

Plate 14: Gram positve testing with *Bacillus*

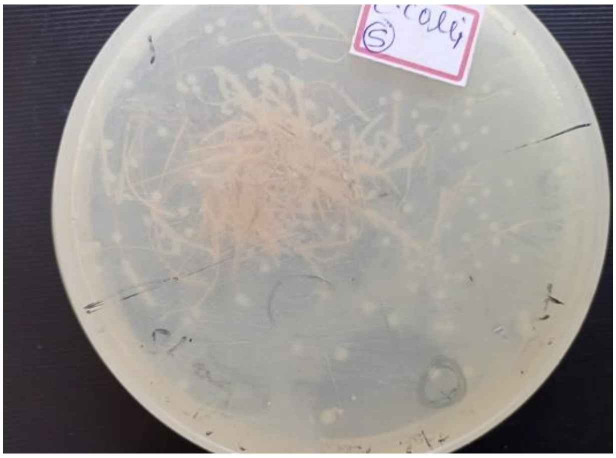


Plate 15: Gram negative testing with *E. Coli*

Bacillus species are rod-shaped, endospore-forming aerobic or facultatively anaerobic bacteria The spores are resistant to heat, cold, radiation, desiccation, and disinfectants. This bacterium is periodically associated with endocarditis, meningitis, and infections of wounds, the ears, eyes, respiratory tract. Due to these unique antimicrobial properties, further this fibre can be explored in functional medical textiles.

4.3. Yarn Stage:

4.3.1. Spinning of extracted yarn:

Spinning is the process of twisting together of drawn-out strands of fibres to form yarn. For better spinnability, the fibres must have good cohesiveness so that they can be held together without addition of any twist. The fibres obtained from Kigelia pinnata could be classified in harsh category. Due the harsh nature of the fibre it was difficult to join them to form a continuous length for spinning. To achieve continuous length the 3 fibre bundles were joined end-to-end. The continuous length of fibres thus obtained were subjected to hand spinning on a box/ peti charkha (a manual hand driven charkha, commonly used for spinning cotton fibres).

Plate 16: Hand spinning of yarn

The difficulties faced during this process was that the fibres were not able to hold the twist which may be due to the smooth surface which lacked cohesiveness and on increasing the number of twists it was breaking because of the brittle nature and stiffness. So, to overcome these difficulties the fibres were subjected to softening by 5% NaOH treatment keeping the material and liquor ratio as 1: 40 at 80^{o}C for 60 mins. After which the 3 fibre bundles were twisted by hand, and end-to-end joining of these twisted bundles was done. The fibres were twisted in both the S and Z direction. While trying to twist the fibres in both S and Z directions, S direction twist was found to be more stable. The fibres with Z twist were getting untwisted. A total of 35 metres of yarn with S twist was spun.

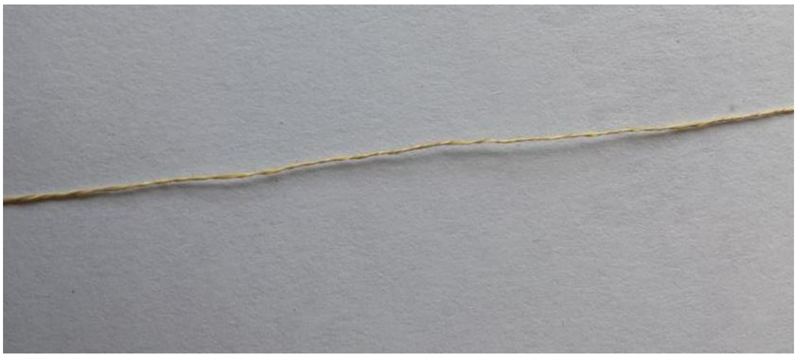


Plate 17: Kigelia pinnata yarn with S twist

4.3.2. Testing of yarn:

After preparation, the yarns were subjected for following tests

- Yarn Twist:

The spiral disposition of the components of a thread which is usually the result of relative relation of the two ends. The average twist per inch of the yarn was 1.57 tpi which falls in the category of low twist. The low twist is due to its low cohesiveness and harsh nature. The results of the yarn twist done on (specification) are given in table 9.

Table 11: Yarn Twist

Yarn	Twist per metre (TPM)	Twist per inch (TPI)	Direction
Kigelia pinnata	62. 32	1.57	S

The fabrics prepared by this type of yarn will result into a less durable, softer fabric with an open weave structure.

- Yarn diameter:

  To determine the fineness of the yarn, diameter needs to be measured. The diameter and fineness of the yarn are inversely proportional to each other. Lesser the diameter finer will be the yarn. The diameter of the yarn was tested by micrometer attached to a compound microscope.

  From the test it was found that the diameter of the yarn was in the range between 13-15 µm and thus average diameter was 14 µm which is slightly coarser. Slubs and unevenness was observed throughout the surface of the fibre.

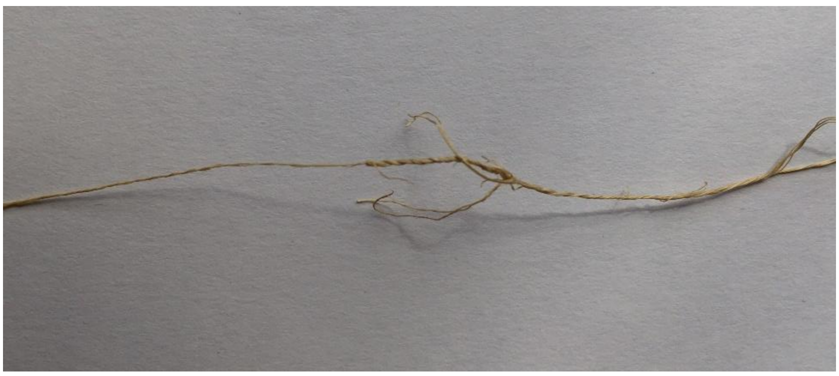


Plate 18: Slub in the yarn

Further improvements can be done by different softening treatments and spinning modifications.

- Fibre fineness:

For fineness in the direct system, denier was obtained and converted into tex. Count was also calculated by indirect system as per cotton count. The values are as follows:

Table 12: Yarn fineness

Denier	Tex	Cotton count (Ne)
643	71	8.26

In direct system of yarn count, lower denier or tex implies finer the fibre, whereas in direct system, lower count means finer fibre. The yarn is coarse in character and can be improved by subjecting it to suitable treatments and exploring different spinning systems.

4.4. Fabric Stage:

Fabric construction refers to the process of converting yarns into a interlaced or interloped structure with specific characteristics determined by the materials and methods used. Exploring the application of a novel fibre in fabric construction widens the scope of utilization of the fibre. The construction can be done by either handloom or power loom. While exploring the fabric construction process for a new fibre from agro- waste source, usually handloom is preferred since it easier to control and modify the process as per the requirements, as the strength of such fibres are usually low.

4.4.1. Construction of the Union Fabric:

Weaving is one of the most basic forms of fabric construction which involves interlacing of yarns. The lengthwise yarn with respect to selvedge are known as warp and cross-wise yarns are known as weft. Fabric construction can be using either same type of yarns in both warp and weft or using different yarns. When warp and weft are different the product is union fabric.

A fabric sample with warp and weft both as cotton was prepared to keep as a control to compare the fabric properties of fabric prepared using Kigelia pinnata fibre. The union fabric sample was constructed on a handloom with a throw shuttle with Kigelia pinnata hand spun yarn used a weft.

For weaving the warp yarn needs to be strong enough to handle the tension and stretch whereas weft can be finer and does not need to to be as strong as the warp, for this reason union fabric was constructed by keeping the warp as cotton and the weft as the 100% Kigelia pinnata hand-spun yarn.

Table 13: Specifications of constructed fabric

Sr. no	Fabric sample	Warp yarn (yarn count)	Weft yarn (yarn count)	Width (in inch)
1.	100% Cotton	70’ s	20’s	14 inches
2.	Cotton: Kigelia pinnata union fabric	70’ s	16’ s	7 inches

Plate 19: Winding of weft yarn on pern

Plate 20: (left) Shuttle with the yarn, (right) Weaving of the union fabric

As the yarns were hand spun where the continuous length was obtained by end-to-end joining, during the construction process the yarn broke several times while weaving because of the inherent harsh property of fibre.

Plate 21: union Fabric

4.4.2. Testing of fabric:

- Fabric count:

  It is the number of warp and weft threads in one inch of a fabric, and is determined by the use of pick glass. It gives the idea about the compactness of weave as well as the cover factor of fabric. The fabric count of the developed sample are as followed:

  Table 14: Fabric Count

Sr. no.	Fabric Sample	EPI (Ends per inch)	PPI (Picks per inch)	Fabric count
1	100% cotton	40	38	40 x 38
2	Cotton: Kigelia pinnata union fabric	40	36	40 x 36

  The fabric count of union fabric was found lesser than 100% cotton due to the coarser nature of Kigelia pinnata yarn.

- Fabric thickness:

  Fabric thickness is not the same as GSM (grams per square meter), which is a measure of fabric weight. The thickness of the fabric depends on the yarn thickness (yarn count) and density of the yarns in the woven fabric. Fabric thickness is measured in millimeters or inches and refers to the distance between the two surfaces of the fabric. Thickness of both the samples is given below:

  Table 15: Fabric thickness of the constructed fabric

Sr. no.	Fabric Sample	Thickness (mm)
1	100% cotton	0.892
2	Cotton: Kigelia pinnata union fabric	1.068

  The thickness of union fabric was found to be slightly higher than the 100% cotton fabric. It may be because of the unevenness in the Kigelia pinnata yarn.

- Fabric GSM:

GSM stands for grams per square meter and is a metric measurement used to describe the weight of a fabric. It is the weight of a square meter of fabric in metric measurements he higher the GSM, the heavier the fabric. Fabric weight per unit area (GSM) of both the samples is mentioned below:

Table 16: GSM of the constructed fabric

Sr. no.	Fabric Sample	GSM (in grams)	GSM (in ounces)
1	100% cotton	76	2.68
2	Warp: cotton, weft: Kigelia pinnata	85	2.99

GSM between 1 – 4 oz falls under the category of lightweight fabric. It was observed that GSM of Kigelia pinnata union fabric was higher than that of 100% cotton fabric due to the harsh and coarse nature of the weft yarn. Fabric structure of the union fabric was compact but certain unevenness was observed. It may be because of the slubs present in the weft yarn.

4.4.3. Uses of Kigelia pinnata fabric

The constructed union fabric obtained had a very unique texture and feel which can be explored in various fields of textile application. In the field of household textiles, the fabric can be used in the construction of blinds and partitions. The fabric can also be used in the making of utility gifting such as file covers, pen stands, diary covers and souvenirs. In the field of technical textiles, the fibre can find its utility in the manufacturing of composites and bio composites, building materials such as bricks, sheets, wall covers. Because of the unique antibacterial nature of the fibre, it can also be utilized in the making masks. The Kigelia pinnata fabric can also be used to for bags, foot mats.

Recommendations:

There were a number of difficulties faced by the researcher during the construction of the union fabric. Major problem was the yarn breakage while weaving. This was due to the reason that even after the softening treatment the fibre were still harsh to handle and lacked sufficient cohesiveness for spinnability.

In spite of some shortcomings in the performance of the fibre, it still possesses a good potential for the application in different technical fields. Because of the porous nature of the bundles of the fibre, its application may also be suggested for sound proofing and thermal purposes.

CHAPTER V

SUMMARY AND CONCLUSION

In the contemporary economy, industry sustainability goes beyond the use of organic materials and efficient processes. This concept of sustainability is widely used in every industrial arena, including the clothing and textile industries.), "A sustainable textile product is one that is created, produced, transported, used, and disposed of with due consideration of environmental impacts, social aspects, and economic implications." For sustainable products, there have been explorations, experiments, and debates.

Since the last decade, there has been an increase in the use of synthetic fibres in the textile industry, including carbon, aramid, nylon, polyester, acrylic, rayon, and others, the life cycle of which causes pollution and has a negative impact on living beings.

Utilising agricultural waste in textiles is a new area of research and development. Agricultural waste refers to agricultural byproducts such as crop residues, husks, stems, leaves, and seeds. These materials can be converted into a wide range of textile products, such as fibres, yarns, fabrics, and nonwovens. The production of sustainable and eco-friendly fibres is one of the most promising uses of agricultural waste in textiles. These fibres are frequently produced using a process known as "regenerated cellulose," which involves breaking down agricultural waste into its constituent fibres and then reforming them into new materials. Aside from that, agricultural waste can be used in textiles in a variety of ways, including fibres, natural dyes, biopolymers, and composites.

India is endowed with an abundance of biodiversity. From the towering Himalayan mountains to the tropical rainforests, India has a diverse range of ecosystems that support a diverse range of flora and fauna. There are numerous vegetations that provide fibres. These sources must be investigated and tested in order to obtain fibres for textile use. The species "Kigelia pinnata," which is common in the Indian states of Kerala, Tamil Nadu, Karnataka, Gujarat, and Maharashtra, is also an unexplored source of fibres. It is a popular ornamental plant that is frequently grown in gardens and parks due to its eye-catching appearance. The Kigelia produces a fruit that can grow up to 2 feet long, weighs about 7 kg, and resembles sausage. It is a tree growing up to 20 m tall. The bark is grey and smooth at first, peeling on older trees. It can be as thick as 6 mm on a 15-cm branch. The tree is evergreen where rainfall occurs throughout the year, but deciduous where there is a long dry season. After the fruit ripens and dries up, the long stalk is of no utility that eventually has to be discarded for new growth.

The aim of this research was to explore and experiment this agro-waste for its utilization in the field of textiles.

5.1. Purpose of the study:

The study aims to utilize agro-waste of Kigelia pinnata stalks by its eco-conscious modification to reduce waste, reduce dependence on non-renewable resources, and promote sustainability by creating a circular economy.

5.2. Objectives:

- To explore Kigelia pinnata stalks and its availability in Vadodara city.
- To extract fibres from Kigelia pinnata stalks and establish the identification features of the novel fibre
- To test the fibre properties based on physical, chemical and biological parameters.
- To find out the best possible use of fibres based upon the results for its application in textiles.

5.3. Materials and Methods

The study undertaken was an exploratory and experimental and in nature. The study was divided into 4 phases:

Phase 1:

The study initiated with the survey and literature study for the availability of Kigelia pinnata trees. The procurement of Kigelia pinnata stalks was done from the MRID campus, The Maharaja Sayajirao University of Baroda. After collecting the stalks, the fibres were extracted.

5.3.1. Phase 2:

In the extraction process, the 3 stalks were first pounded with a hammer to separate the hollow core and fibre containing bark, followed by rubbing the pounded mass from a rough surface to remove the unwanted dried waste. Then the pounded mass was water retted and fibre were extracted after cleaning with a plastic bristled brush. Extracted fibres were subjected to identification test which included physical appearance and burning characteristics also the materials characterization. Then the fibres were tested on three parameters namely physical parameter, that included fibre length, fibre fineness, fibre diameter, length to diameter ratio, single fibre strength, moisture content and regain. Chemical parameter included solubility testing and biological parameter included quantitative antimicrobial test.

5.3.1. Phase 3:

The extracted Kigelia pinnata fibres were hand-spun by end to joining of the fibre bundles to obtain a continuous length. 100% Kigelia pinnata handspun yarn was prepared. The testing of yarn was done at the testing lab of the Department of Clothing and Textile, Faculty of Family and Community Sciences. The testing of yarn was done in standardized laboratory conditions that was 65 $\pm$ 2^{o}C. relative humidity and temperature was 20^{o}C. Before testing the yarns were conditioned for 24 hours in the laboratory conditions. The yarns were tested for twist and diameter. After the spinning, construction of union fabric was done, keeping 100% Kigelia pinnata yarn as weft and 100% cotton yarn as warp, Weaving was done at the Weaver's Service Centre, Ahmedabad. Loom used was a throw shuttle loom with 4 shafts, width of the loom was 14 inches and the reed number was 36. The constructed union fabric was then tested for the physical properties, namely, thickness by thickness tester, GSM, and fabric count that is the Ends per inch (EPI) and Pick per inch (PPI) was done by pick glass.

5.4. Results and Discussions:

5.4.1. Procurement of the stalks:

The procurement of the stalks was done from the MRID campus, The Maharaja Sayajirao University of Baroda.

5.4.2. Extraction process of Kigelia Pinnata fibre:

This process was done keeping 3 stalks together to speed up the process, after which the pounded material was rubbed against a rough surface to remove as much dry waste as possible. The obtained mass to be used as raw material was weighed, The extraction of fibre was done by water retting, followed by the cleaning of the fibres by a plastic bristled brush.

5.4.3. Yield of the fibre:

The yield of the fibre extracted from the pounded mass was 40 %.

5.4.4. Identification tests:

To determine the class of this novel fibre, a number of identification tests were done.

a. Microscopic appearance:

Longitudinal view:

Bundle: straight and regular appearance with striations of the bundle was observed under the 10x and 40x magnification. The longitudinal structure of the fibre was similar to that of hemp as seen in the figure , which also a bast fibre.

Cross-sectional view:

Cross-sectional view was observed by arranging the fibre bundles inside a rubber tube, reinforced with adhesive and later the tube was thinly sliced in circular shape and placed in compound microscope and observations were made.

b. Burning Characteristics

Since the fibre belongs to the class of natural cellulosic, its burning nature is like that of the other fibres such as Jute, Hemp, Banana etc.

5.4.5. Material characterization

The results of the chemical composition showed that maximum content of the fibre comprised of Cellulose which was 65.32%, followed by hemicellulose

10%, lignin 10%, water soluble impurities 8.23 %, pectin 2.5% and fats and waxes 0.3%.

5.4.6. Physical Properties

- Fibre Length:
  Since, there was a lot of variation in the length of the extracted fibre because it is a bundle fibre it was divided into 3 categories, short (7cm), medium (18 cm), and long (45 cm).
- Fibre diameter:
  The diameter of the fibre was observed between the range of 8-10 μm and the average diameter was 8 μm.
- Length to diameter ratio:
  Since there was a lot of variation in the length of the fibre, different the length to diameter ratio was obtained for different category of length. For short fibre the ratio was 8750 :1, for medium length 22500 : 1, and for long fibre 56250 : 1.
- Fibre fineness:
  Fibre fineness was determined by both direct and indirect systems of yarn numbering. The denier obtained was 283 D.
- Single fibre strength:
  Load, extension stress, and % strain values were obtained. The load was 805 gf, followed by extension being 6.545, stress was 2.844 gm/ den, and strain was 13.091 %.
- Fibre Moisture:
  Moisture content of the fibre was 13.1% and regain was 14.5% which is more than cotton and rayon and closer to Jute, Sisal, Hemp and Banana.

- Colour of the fibre:
  Due to the presence of pectin which the organic compound responsible for colour, it was observed that the colour was off white to yellowish-brown.

5.4.7. Chemical properties:

It was observed that the fibre was quite resistant towards the action of alkalis and even acids, only concentrated sulphuric acid on heating because of to the high lignin content in the raw fibres.

5.4.8. Biological Properties:

The fibres were subjected to both gram positive (*Bacillus*) and gram negative (*E. coli*) microphages, and the inferences was made that the fibres were resistant towards the gram positive microbes.

5.4.9. Yarn Stage:

a. Spinning of extracted yarn:

The fibres obtained from Kigelia pinnata could be classified in harsh category. Due the harsh nature of the fibre it was difficult to join them to form a continuous length for spinning so, softening treatment by softening by 5% NaOH treatment keeping the material and liquor ratio as 1: 40 at 80^{o}C for 60 mins was done to improve the fibre handle. To achieve continuous length the 3 fibre bundles were joined end-to-end. While trying to twist the fibres in both S and Z directions, S direction twist was found to be more stable.

b. Testing of yarn:

- Yarn Twist:

The average twist per inch of the yarn was 1.57 TPI which falls in the category of low twist.

- Yarn diameter:

From the test it was found that the diameter of the yarn was in the range between 13-15 µm and thus average diameter was 14 µm which is slightly coarser.

5.4.10. Fabric Stage:

a. Construction of the Union Fabric:

A fabric sample with warp and weft both as cotton was prepared to keep as a control to compare the fabric properties of fabric prepared using Kigelia pinnata fibre. The union fabric sample was constructed on a handloom with a throw shuttle with Kigelia pinnata hand spun yarn used a weft.

b. Testing of fabric:

- Fabric count:
  The count of the union fabric was obtained as 40 x 36.
- Fabric thickness:
  The thickness of the union was fabric was recovered as 1.068 mm which was slightly thicker than 100 % cotton fabric.
- Fabric GSM:
  The GSM recorded for the union fabric was 85 GSM, which comes under the category of light weight fabrics.
- The resulting union fabric had a very distinct texture and feel that can be explored in a variety of textile applications. The fabric can be used to make blinds and partitions in the field of household textiles. The fabric can also be used to make useful gifts like file covers, pen stands, diary covers, and souvenirs. In the field of technical textiles, the fibre can be used to make composites and bio composites, as well as building materials such as bricks, sheets, and wall covers. Because of the fiber's unique antibacterial properties, it can also be used to make masks. Kigelia pinnata fabric is also suitable for making bags and foot mats.

5.5. Conclusion:

The aim of this study was to explore and experiment the Kigelia pinnata stalks which are treated as agro-waste for its potential utilisation as a source of a novel textile fibre. It was concluded from the study that:

- There is an availability of Kigelia pinnata trees in Vadodara.
- The entire process from the procurement of stalks to the extraction of yarns was completely sustainable and eco-friendly.
- The mode of extraction is manual and hence time consuming.
- The fibres had exceptional tensile strength.
- The fibres also possessed unique antibacterial properties.

- After softening treatment, it was possible to spin the fibre and obtain a yarn and construction of union fabric.
- The fabric prepared can be utilized for making household textiles, the fabric can be used in the construction of blinds and partitions. The fabric can also be used in the making of utility gifting such as file covers, pen stands, diary covers and souvenirs. In the field of technical textiles, the fibre can find its utility in the manufacturing of composites and bio composites, building materials such as bricks, sheets, wall covers. Because of the unique antibacterial nature of the fibre, it can also be utilized in the making masks. The Kigelia pinnata fabric can also be used to for bags, foot mats.
- Thus, this study will be useful for people engaged in textile researches, fashion designs, fabric manufacturing, ecology and environment.

Recommendations:

- Since the fibres possessed antibacterial properties, the fibre can find its use in the field of functional medical textiles, which after the COVID period has become a need of the hour.
- Due to the exceptional strength properties of the fibre, it can be utilized as technical textile material and can be explored as composites both bio composites and concrete reinforced ones.
- The harsh nature of the fibre can be resolved by subjecting the fibre to different softening treatments to improve the spinnability and handle.
- Different spinning mechanisms can be explored for getting variety.

BIBLIOGRAPHY

1. Abraham, E., Deepa, B., Pothan, L., Jacob, M., Thomas, S., Cvelbar, U., & Anandjiwala, R. (2011, October). Extraction of nanocellulose fibrils from lignocellulosic fibres: A novel approach. *Carbohydrate Polymers*, *86*(4), 1468–1475. https://doi.org/10.1016/j.carbpol.2011.06.034
2. Agrawal, N. (2018). *An exploratory study on Pineapple fibers for its use in woven textiles (Unpublished Master's Dissertation).* Department of Clothing and Textiles, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat.
3. Basu, G., Mishra, L., Jose, S., & Samanta, A. K. (2015, December). Accelerated retting cum softening of coconut fibre. *Industrial Crops and Products*, *77*, 66–73. https://doi.org/10.1016/j.indcrop.2015.08.012
4. Bhoj. R. (2015). *A comparative study on the effect of chemical and enzyme treatments on the softening of Sisal fibers (Unpublished Master's Dissertation).* Department of Clothing and Textiles, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat.
5. Blackburn, R. (Ed.). (2005, November 30). *Biodegradable and Sustainable Fibres*. Woodhead Publishing Limited.
6. Blackburn, R. (Ed.). (2009, October 19). *Sustainable Textiles: Life Cycle and Environmental Impact*. Woodhead Publishing Limited.
7. Booth, J. E. (1996). Principles of Textile Testing. New Delhi, India: CBS Publishers and distributors Pvt. Ltd.
8. Bora, R., & Padmini, T. (2019). Fiber extraction from Calotropis gigantea stem with different retting methods and its comparision. *International Journal of Conservation Science IJCS*, *7*(3), 144-150.
9. Cesarino, I., Carnietto, M. B., Bronzato, G. R. F., & Leao, A. L. (2020). Fabrication of Pineapple Leaf Fibers Reinforced Composites. *Pineapple Leaf Fibers*, 265–277. https://doi.org/10.1007/978-981-15-1416-6_13
10. Cheng. C., Guo, R., Lan, J., & Jiang, S. (2017). Extraction of lotus fibres from lotus stems under microwave irradiation. Royal Society Open

Science. 4(170747). Retrieved from https://dx.doi.org/10.1098/rsos. 170747

11. Doshi, A (2017). Banana Fiber To Fabric: Process Optimization For Improving Its Spinnability And Hand (PhD Thesis). Department Of Clothing And Textiles. The Maharaja Sayajirao University Of Baroda, Vadodara, Gujarat.

12. Duman, M.N., Kocak, E.D., Merdan, N., and Mistik, I. (2017). Nonwoven production from agriculture okra wastes and investigation of their thermal conductivities. Material science and engineering, 1-7. doi:10.1088/1757-899X/254/19/192007

13. Emmanuel, A., Ezeanyanaso, C., Muniru, O., Nwaeche, C, Tumbi, M., Igwe C, Gloria & Gupta, M. (2019). Extraction and Characterization of Bast Fibres from Roselle (Hibiscus sabdariffa) Stem for Industrial Application. 1-7. 10.9734/JMSRR/2019/45087.

14. Goal 12 Department of Economic and Social Affairs. (2023, September 1). Goal 12 Department of Economic and Social Affairs. Retrieved from https://sdgs.un.org/goals/goal12

15. Haldar, S. (2019). *An Experimental Study on Lotus Petiole (Nelumbo Nucifera Gaertn.) for its Textile Application (Master's Dissertation).* Department Of Clothing And Textiles. The Maharaja Sayajirao University Of Baroda, Vadodara, Gujarat.

16. Hossain. M.B., & Begum, H.R. (2017). The Effect of Chemical Treatment on Tensile Strength and Weight of Banana Stem Fiber after Treating with Various Chemicals. Journal of Dental and Medical Sciences. 16(7). 66-70. doi:10.9790/0853-1607046670

17. Ilangovan, M., Guna, V., Prajwal, B., Jiang, Q., & Reddy, N. (2020). Extraction and characterisation of natural cellulose fibers from Kigelia africana. *Carbohydrate Polymers*, *236*, 115996. https://doi.org/10.1016/j.carbpol.2020.115996

18. Jani, H. (2020). An Experimental Study on OJani, H. (2020). An Experimental Study on Okra Bast Fiber (Abelmoschus Esculentus) for its Textiles Application (Unpublished Master's Dissertation).

Department Of Clothing And Textiles. The Maharaja Sayajirao University Of Baroda, Vadodara, Gujarat.

19. Jewel, R. (2017). Textile Testing, New Delhi, India: A.P.H Corporation.
20. Khan, A.G.M., Yilmaz, N.D., and Yilmaz, K. (2017). Okra fibers: potential material for green bio composites. 261-284. Springer International Publishing.
21. Muthu, S. S. (2017). Sustainable Fibres and Textiles, Britain, United Kingdom: Woodhead Publishing publications
22. Omenna, Adeniyan, Ejigbo, Oduwaye, & Ezaka. (n.d.). Comparative effect of chemical and stream retting on the kenaf fibre quality. *AGRICULTURE AND BIOLOGY JOURNAL OF NORTH AMERICA*, *2151–7525*. https://doi.org/10.5251/abjna.2016.7.5.275.283
23. Patel, B. Y., & Patel, H. K. (2022, September). Retting of banana pseudostem fibre using Bacillus strains to get excellent mechanical properties as biomaterial in textile & fiber industry. *Heliyon*, *8*(9), e10652. https://doi.org/10.1016/j.heliyon.2022.e10652
24. Rambabu, V., Kona, S., Naidu, A.L., and Rao, R. (2018). Mechanical properties of okra and jute fibres filled with groundnut shell ash reinforced composites with epoxy(LY556) and epoxy(XIN 100 IN) resin matrices. Journal of materials and environmental sciences, 9(7), 2169-2173. Retrieved from http://www.jmaterenvironsci.com
25. Reneta Nafu, Y., Foba-Tendo, J., Njeugna, E., Oliver, G., & Omar Cooke, K. (2015, July 9). Extraction and Characterization of Fibres from the Stalk and Spikelets of Empty Fruit Bunch. *Journal of Applied Chemistry*, *2015*, 1–10. https://doi.org/10.1155/2015/750818
26. Saikia, Kalita, & Gogoi. (2020, December). Extraction of bast fibres from odal (Sterculia villosa) and evaluation of Physical characteristics. *International Journal of Home Science*, *7*(2395–7476), 255–260. https://www.homesciencejournal.com/archives/2021/vol7issue1/PartD/7-2-2-927.pdf
27. Saravanakumaar, A., Senthilkumar, A., Saravanakumar, S. S., Sanjay, M. R., & Khan, A. (2018, August 18). Impact of alkali treatment on

physico-chemical, thermal, structural and tensile properties of Carica papaya bark fibers. *International Journal of Polymer Analysis and Characterization*, *23*(6), 529–536. https://doi.org/10.1080/1023666x.2018.1501931

28. Saravanan, N., Sampath, P., & Sukantha, T. (2016, May 1). Extraction and Characterization of New Cellulose Fiber from the Agrowaste of Lagenaria Siceraria (Bottle Guard) Plant. *JOURNAL OF ADVANCES IN CHEMISTRY*, *12*(9), 4382–4388. https://doi.org/10.24297/jac.v12i9.3991
29. Senthamaraikannan, P., Saravanakumar, S. S., Arthanarieswaran, V. P., & Sugumaran, P. (2015, December 17). Physico-chemical properties of new cellulosic fibers from the bark ofAcacia planifrons. *International Journal of Polymer Analysis and Characterization*, *21*(3), 207–213. https://doi.org/10.1080/1023666x.2016.1133138
30. Sheferaw, L., Gideon, R. K., Ejegu, H., & Gatew, Y. (2022, November 25). Extraction and Characterization of Fiber from the Stem of Cyperus Papyrus Plant. *Journal of Natural Fibers*, 1–14. https://doi.org/10.1080/15440478.2022.2149661
31. Singh, J. K., & Rout, A. K. (2022, August 31). Characterization of raw and alkali-treated cellulosic fibers extracted from Borassus flabellifer L. *Biomass Conversion and Biorefinery*. https://doi.org/10.1007/s13399-022-03238-x
32. Singh, R., Das, R., Sangwan, S., Rohatgi, B., Khanam, R., Peera, S. K. P. G., Das, S., Lyngdoh, Y. A., Langyan, S., Shukla, A., Shrivastava, M., & Misra, S. (2021, August 30). Utilisation of agro-industrial waste for sustainable green production: a review. *Environmental Sustainability*, *4*(4), 619–636. https://doi.org/10.1007/s42398-021-00200-x

33. Smole, M. S., Hribernik, S., Kleinschek, K. S., & Kreže, T. (2013, July 31). *Plant Fibres for Textile and Technical Applications*. Plant Fibres for Textile and Technical Applications | IntechOpen. https://doi.org/10.5772/52372

34. Smole, M. S., Hribernik, S., Kleinschek, K. S., & Kreže, T. (2013, July 31). *Plant Fibres for Textile and Technical Applications*. Plant Fibres for Textile and Technical Applications | IntechOpen. https://doi.org/10.5772/52372
35. Sow, S., Ranjan, S., . S., Kumar, A., & Kumar, M. (2021, January 1). Improved retting methods of jute to enhance fibre quality and retting waste management. *Journal of Pharmacognosy and Phytochemistry*, *10*(1), 2614–2618. https://doi.org/10.22271/phyto.2021.v10.i1ak.13754
36. Standard Test Method for Assessing Clean Flax Fiber Fineness. (2021, August 20). Standard Test Method for Assessing Clean Flax Fiber Fineness. Retrieved from https://www.astm.org/d7025-09r21e01.html
37. Standard Test Method for Determining Antimicrobial Activity and Biofilm Resistance Properties of Tube, Yarn, or Fiber Specimens. (2018, May 18). Standard Test Method for Determining Antimicrobial Activity and Biofilm Resistance Properties of Tube, Yarn, or Fiber Specimens. https://www.astm.org/e3151-18.html
38. Standard Test Method for Tensile Properties of Single Textile Fibers. (2020, February 21). Standard Test Method for Tensile Properties of Single Textile Fibers. Retrieved from https://www.astm.org/d3822_d3822m-14r20.html
39. Tobler-Rohr, M. I. (2011, August 28). *Handbook of Sustainable Textile Production*. Woodhead Publishing Limited.
40. Vanishree, S., Mahale, G., Vastrad, J. V., & Babalad, H. B. (2019). Extraction of sunnhemp fibre and its properties.
41. Vinod, A., Sanjay, M., & Siengchin, S. (2023). Recently explored natural cellulosic plant fibers 2018–2022: A potential raw material resource for lightweight composites. *Industrial Crops and Products*, *192*, 116099. https://doi.org/10.1016/j.indcrop.2022.116099
42. Weteka, Githinji, Namago, & Starovoytova. (2016, November). AGRICULTURE AND BIOLOGY JOURNAL OF NORTH AMERICA. *American Journal of Engineering Research (AJER)*, *5*(2320–0847), 339–345.

43. Yusuf, M. (2017). Agro-Industrial Waste Materials and their Recycled Value-Added Applications: Review. *Handbook of Ecomaterials*, 1–11. https://doi.org/10.1007/978-3-319-48281-1_48-1

Webliography:

1. Chanana . (2019). *Water Hyacinth: A Promising Textile Fibre Source*. Retrieved March 2023, from https://www.technicaltextile.net/articles/water-hyacinth-a-promising-textile-fibre-source-7619
2. *Classification of fibers and their general properties*. (2018). https://nptel.ac.in/. Retrieved March 2023, from https://nptel.ac.in/courses/116102026
3. *Difference Between Gram-positive and Gram-negative Bacteria*. (2019). https://byjus.com/. Retrieved March 2023, from https://byjus.com/biology/difference-between-gram-positive-and-gram-negative-bacteria/
4. Hasan. (2015). *Standard Moisture Regain and Moisture Content of Fibers*. https://www.textilecalculations.com/. Retrieved March 2023, from https://www.textilecalculations.com/standard-moisture-regain-and-moisture-content-of-fibers/
5. *Raffia palm*. (2019). https://en.wikipedia.org/. Retrieved February 2023, from https://en.wikipedia.org/wiki/Raffia_palm
6. *Sausage Tree Kigelia Pinnata: An Ethnobotanical and Scientific Review*. (2018). https://www.herbalgram.org/. Retrieved February 15, 2023, from https://www.herbalgram.org/resources/herbalgram/issues/94/table-of-contents/feat_sausagetree/
7. W. (n.d.). *Water Hyacinth - Textile Fibre Source Water Hyacinth*. Water Hyacinth - Textile Fibre Source Water Hyacinth. http://www.technicaltextile.net/articles/water-hyacinth-a-promising-textile-fibre-source-7619

Appendix - I

Consent Form for procurement of raw material and its appropriate utilization

To,

Date:

Respected Sir/ Ma’am,

This is to inform you that I Ms. Shagun Rao am doing M.Sc. from the Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara.

The study is being carried out by a researcher on “Innovative use of Agro Waste (Kigelia pinnata stalks) for Technical Textiles” as partial fulfilment of M.Sc. Dissertation under the guidance of Prof. (Dr.) Madhu Sharan, Department of Clothing and Textiles.

India is primarily an agricultural country. In agriculture, there is always a residue along with the crops. In our country, there is a lot of residual waste which is also called agro waste. At present most of these residues are either left to decay or burned, even though some of them have inherent properties that, when studied scientifically, can be an innovative source of useful products. This type of exploration of agro waste has two benefits: one is that it produces innovative products, and the other is that it reduces the number of landfills that would otherwise occupy the land.

The study presented here will be undertaken to investigate Kigelia pinnata stalks for the extraction of fibres that would otherwise have been discarded as agro-waste.

The properties of the fibres will be tested and explored for the determination of their utilization in the field of technical textiles. For the same, I require consent from you for the procurement of the raw materials which includes the stalks of Kigelia pinnata (sausage tree). The procured raw material will be utilized appropriately for the extraction and testing of the extracted fibres.

We hope that the findings of this study will contribute to the development of newer materials with unique functional properties in the field of sustainable technical textiles. Due acknowledgement will be given to you in the dissertation.

Please sign on the consent letter in the space below that you are willing to accept the due consent for the procurement of the raw material and supply us with the required quantity for the research.

Thanking you,

Yours sincerely,

Investigator
Guide

Shagun Rao Prof. (Dr.) Madhu Sharan

9634455478 9409699948

raoshagun101@gmail.com sharan.madhu-ct@msubaroda.ac.in

I give my due consent for providing the raw material as and when it will be required by the researcher for experimentation of the fibres.

Signature of the Provider.

मूलभूत सामग्री की प्राप्ति और उसके उचित उपयोग के लिए सहमति प्रपत्र

सेवा में, दिनांक:

आदरणीय श्रीमान/ श्रीमती

आपको सूचित किया जाता है कि मैं कुमारी शगुन राव डिपार्टमेंट ऑफ़ क्लोथिंग एंड टेक्सटाइल्स, फैकल्टी ऑफ़ फॅमिली एंड कम्युनिटी साइंसेज, महाराजा सयाजीराव यूनिवर्सिटी ऑफ़ बरोदा, वड़ोदरा से एम.एससी. कर रही हूँ।

मेरे द्वारा एम.एससी की आंशिक पूर्ति के रूप में "इनोवेटिव यूज़ ऑफ़ एग्रो वैस्ट (काइजेलिया पिन्नता स्टॉक्स) फॉर टेक्निकल टेक्सटाइल्स" पर प्रो. (डॉ.) मधु शरण डिपार्टमेंट ऑफ़ क्लोथिंग एंड टेक्सटाइल्स, के मार्गदर्शन में अध्ययन किया जा रहा ह।

भारत मुख्य रूप से एक कृषि प्रधान देश है। कृषि में, फसलों के साथ-साथ हमेशा एक अवशेष होता है। हमारे देश में रेसिडुअल वैस्ट बहुत अधिक मात्रा में होता है जिसे कृषि अपशिष्ट (एग्रो वैस्ट) भी कहा जाता है। वर्तमान में इनमें से अधिकांश अवशेषों को या तो सड़ने के लिए छोड़ दिया जाता है या जला दिया जाता है, हालांकि उनमें से कुछ में निहित गुण होते हैं, जो वैज्ञानिक रूप से अध्ययन किए जाने पर उपयोगी उत्पादों का एक अभिनव स्रोत हो सकते हैं। कृषि अपशिष्ट (एग्रो वैस्ट) के इस प्रकार के अन्वेषण के दो लाभ हैं: एक यह है कि यह नवीन उत्पादों का उत्पादन करता हैं, और दूसरा यह उन लैंडफिल की संख्या को कम करता है जो भूमि पर कब्जा कर लेते।

यह प्रस्तुत अध्ययन फाइबर के निष्कर्षण के लिए काइजेलिया पिन्नाटा के डंठल की जांच करने के लिए किया जाएगा जो की कृषि-अपशिष्ट (एग्रो वैस्ट) के रूप में खारिज कर दिया गया होता।

तकनीकी वस्त्रों (टेक्निकल टेक्सटाइल्स) के क्षेत्र में उनके उपयोग के निर्धारण के लिए तंतुओं के गुणों का परीक्षण और अन्वेषण किया जाएगा। उसी के लिए, मुझे कच्चे माल की प्राप्ति के लिए आपकी सहमति की आवश्यकता है जिसमें काइजेलिया पिन्नाटा (सॉसेज ट्री) के डंठल शामिल हैं। प्राप्त की गयी मूलभूत सामग्री का उपयोग निकाले गए रेशों के निष्कर्षण और परीक्षण के लिए उचित रूप से किया जाएगा।

हमें उम्मीद है कि इस अध्ययन के निष्कर्ष टिकाऊ तकनीकी वस्त्रों (सस्टेनेबल टेक्निकल टेक्सटाइल्स) के क्षेत्र में अद्वितीय कार्यात्मक गुणों वाली नई सामग्रियों के विकास में योगदान देंगे। शोध प्रबंध में आपको उचित स्वीकृति (रेकग्निशन) दी जाएगी।

कृपया नीचे दिए गए स्थान में सहमति पत्र पर हस्ताक्षर करें कि आप कच्चा माल उपलब्ध करने के लिए उचित सहमति स्वीकार करने और अनुसंधान के लिए आवश्यक मात्रा में हमें आपूर्ति करने के लिए तैयार हैं।

धन्यवाद,

सादर ।

अन्वेषक
मार्गदर्शक

शगुन राव | प्रो. (डॉ.) मधु शरण
9634455378 | 9409699948
raoshagun101@gmail.com | sharan.madhu-ct@msubaroda.ac.in

मैं तंतु के प्रयोग के लिए अनुसंधानकर्ता के लिए आवश्यक कच्चा माल उपलब्ध कराने के लिए अपनी उचित सहमति देता हूं।

प्रदाता का हस्ताक्षर
