

AN EXPERIMENTAL STUDY ON EXTRACTION OF FIBERS AND USES OF LOTUS PETIOLE: A HYGROWASTE

Synopsis of proposed Ph.D Thesis

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CHAPTER -1

INTRODUCTION

Textile fiber is an integral part of human civilization. These textile fibers and their use predate the recorded history of textiles. Civilization has taught us to make clothes using common natural fibers such as Cotton, Wool, Silk and Linen (Konwar, M., & Boruah R.R. 2018) From the very beginning of human history, they have served to protect people from the adverse elements of the environment in perfect comfort (Zimniewska, M.et.al. 2002) Natural fibers are a renewable resource, thus providing a better sustainable sourcing solution, as they are low cost, low density, lower processing costs, no health risks and better mechanical properties. The most important properties of natural fibers are their biodegradability and non-carcinogenic properties.

There are global concerns about the use of non-renewable materials in manufacturing and increasing environmental legislation. There is pressure, both from consumers and regulators, for products that are more environmentally friendly and to reduce dependence on fossil fuels. As a result, the use of natural fibers in products will continue to grow as major contributions to the bio-based economy. The transition to a biased economy and sustainable development as a result of the Kyoto protocols on greenhouse gas reduction and CO₂ neutral production offers good prospects for the natural fiber market. A fundamental change in attitude is needed for the development of a sustainable world economy that enables improved purchasing power and living standards without depleting resources for future generations. For ecological reasons, products based on photosynthetic CO₂ fixation should be prioritized. The advantage of these sustainable resources is that they can grow into a foreseeable future without adversely affecting global biodiversity. Therefore, we need to develop competitive products based on renewable raw materials. It is of high quality, has excellent technical performance, and has less environmental impact than current products based on petrochemical materials (<https://www.prnewswire.com/news-releases/global-natural-fibers-market-report-2021-revenues-for-2020-2030-by-fiber-types-industries-and-region-301211682.html>).

Cellulose is one of the major resources available on earth. Minor cellulosic fibers are the fibers which are the agricultural by product (biomass), less explored, seasonal, and suitably grown in some region with the particular soil & climate requirement and needs some additional finishing to be used successfully in textiles. Some of the examples of cellulosic minor fibers are Banana, Sisal, Ramie, Pineapple Abaca, Hemp, Coir, Okra, Nettle, Kenaf, and Roselle which are grown in the terrestrial regions. Apart from the

terrestrial plants a significant number of wetland plants are considered as bio-resources. There are major and minor plant resources harvested from the wetlands of rural India (Mishra, M.K. et.al. 2012)

One such aquatic plant is Lotus (*Nelumbo nucifera*) comes under the family Nelumbonaceae, beautiful flowering aquatic plant has been honored in the history of three countries- China, India and Egypt. (Paudel, K.R, & Panth, N. 2015). In India, it occurs from Kashmir in north to Kanyakumari in South showing huge phenotypic diversity with different shapes, sizes, shades and it is a national flower of India and Vietnam (Sheikh, S.A. 2014). Lotus plants require a humid tropical climate, wetland habitats and floodplains, ponds, lakes, ponds, lagoons, swamps, swamps, and backwaters of reservoirs. The plant grows 1.5 meters high and up to 3 meters horizontally. Its roots stay firmly on the muddy bottom, and leaves up to 60 cm in diameter slide on the surface of the water. Flowers can reach a diameter of 8 inches. The seeds are about 1 cm in diameter and are placed in a wood container like a shower head. Lotus plants grow by spreading rhizomes that creep to the bottom of the body of water over anaerobic sediments. Rhizome carries the node that produces the petioles (Zaidi, A & Srivastava, A.K. 2019).

The entire lotus plant is endowed with numerous medicinal properties. Pharmacological studies of the plant revealed that the whole plant possesses antidiabetic, antipyretic, anti-inflammatory, anticancerous, antimicrobial, antiviral and anti-obesity properties. The cultivated lotus is generally divided into three categories, namely rhizome, seed and flower, according to their usage in reality. The rhizomes and seeds are consumed as vegetables and lotus flower are mainly applied in ornamentation and environmental improvement (Lin, Z. et.al, 2019).

In India, lotus flower has a huge economic importance in the religious functions like Saraswati puja, Bishwakarma puja, Durga puja as well as in daily worshipping. Cultivators of lotus generally cut the flower with little length of petiole (a part between flower and rhizomes) leaving the rest entire as a “waste” and abandoned for a natural decay. Such waste may cause environmental hazards. Petiole can grow up to the height of 6 m, depending upon the depth of the water. The color of the petiole varies from light green to dark green depending upon the water quality and maturation. The stem of a lotus plant has two types of xylem cells, the tracheids and vessels. The tracheids are an elongated tubular cell with a hard, thick, woody wall and a large cell cavity. The vessels have a cylindrical tubular structure with thin lignified wall. These cells help in transportation of water and some nutrients from the roots to the leaves and also provide mechanical support to the plant. Lotus fibres are arranged in these cells in the form of “Helix”.

In India Lotus farming is practiced nearly in all states. It is reported that some wetlands of central Gujarat (like Ahmedabad, Kheda, Anand, Vadodara districts) and South Gujarat (Valsad and Navsari districts) have an impressive growth of lotus plants (<https://www.dnaindia.com/ahmedabad/column-flowers-of-some-wetland-plants-elegance-per>

sonified-2748658) Lotus cultivators used to sell flowers, seeds, fruits, rhizomes. But they are less aware about the petioles which are generally throw away while cutting and bundling the flower and sometimes also left in the pond during picking the flower. Manual extraction process of fibers is practiced only in very few places of world like Myanmar, Cambodia, Vietnam and Manipur in small quantity. The whole process is tedious and time consuming.

Thus, the study aims to fabricate machines for fiber extraction. Evaluation and analysis of extracted fibers from machines for its strength, fineness, twist. Experimenting the manual extraction process by varieting number of petioles and further spinning yarns using Ambar charkha. Assessment of the dyeing properties of yarn and evaluating its color strength and fastness properties. Construction of woven fabrics using different types of developed yarns and testing the fabric properties. Finding the inherent functional properties of fibers for its applications in technical textiles (Hygiene products). Training the group of women for fiber extraction and spinning. Recently in the fashion world there is demand for seamless knitted apparels the attempt was also done to experiment 100 % Lotus yarns for developing circular knitted structure and testing its properties.

RATIONALE OF THE STUDY

The largest portion of the biosphere is the aquatic ecosystem. To fulfill the United Nations Sustainable Development Goals (SDGs) it is very necessary to save the planet's aquatic ecosystems. (Kumar, M., & Padhya, K. 2015). India is a country of wetland eco-systems which is most diverse and productive ecosystems. Wetlands are rich in flora and fauna. The major ecosystem services that wetlands provide include fish, fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and tourism (Millennium Ecosystem Assessment 2005).

Asian lotus (*Nelumbo nucifera* Gaertn.) is one of the most aesthetic ornamental aquatic indigenous species, endowed with unique biological and nutritional traits. While scientific attention on various aspects ranging from basic botany to genome sequencing in lotus is increasing worldwide, India has somewhat lagged behind in taking due scientific, agronomic initiatives. (Goswami et.al 2021). From the biological evidence, Netlak, P., & Imsabaia, W. (2016) it is found that “the bud of the flower fails to open if the cut stems are left in the water”. This bio-waste is composed of fibers that are produced in bulk. Extracted fibers can be explored for diversified uses in textiles.

STATEMENT OF PROBLEM

Cultivators generally pick the flowers with little length of the petiole leaving the rest entire as a waste. This bio-waste is produced in bulk contain the precious fibers which has a potential to be a textile fiber needs to be explored and studied in the scientific manner. Manual extraction of fiber is very time consuming. Moving to the bulk production point of view, machines (with different mechanisms) was fabricated to ease the manual labour. Fibers were explored for its inherent functional properties for the application of hygiene medical textiles. Yarns were developed using different spinning techniques for the application in woven and knitted fabric structure.

BROAD OBJECTIVE

Cultivators generally pick the flowers with little length of the petiole leaving the rest entire as a waste. This bio-waste is produced in bulk which needs to be studied in the scientific manner for its diversified textile applications.

SPECIFIC OBJECTIVES

1. To experiment the extraction process of Lotus fiber :-
 - a). Fiber - By hand – (Number of petioles – one, two and three)
 - b). Web – Non-woven
2. To experiment the spinning of extracted fibers by different techniques and test its properties
3. To design and fabricate the machines (with different mechanisms) for fiber extraction and study the yield with respect to speed and man power involvement.
4. To develop yarns from the fabricated machines and test its properties for denier, strength, twist.
5. To prepare blended yarns (with other natural fibers) and test its properties (both fiber stage & yarn stage).
6. To study the dyeing properties of Lotus yarn and assess its color strength and fastness properties.
7. To prepare woven fabrics – Khadi, Handloom and Powerloom and test its properties.
8. To prepare circular knitted fabrics and test its properties.
9. To study the Lotus fibers for its functional properties:- Absorbency, Antibacterial and Cytotoxicity.
10. To develop non-woven fabric for technical applications – Hygiene medical textiles
11. To train the group of Women for fiber extraction and spinning.

DELIMITATIONS

1. The study is limited to only one species: Lotus (Pink form) *Nelumbo nucifera gaertn.*
2. Waste petioles was collected from near and around Vadodara district of Gujarat

SCOPES OF THE STUDY

1. The main motto of the study was to use this hygrowaste for textile applications. By this approach the aquatic ecosystem is maintained as it cleans of the pond and leads to fastest growth of the plant. It can open new avenues for the Lotus cultivators along with the flowers, fruits and rhizomes they can sell the petioles also.
2. Manual extraction process is very tedious and time-consuming. In the textile sector for fulfilling the demands we require raw material in bulk. Hence the machines with different mechanisms were fabricated. There is a wide scope of job opportunities for rural peoples who are living near the ponds as they can be trained for extracting the fibers and making yarn from fabricated machines.
3. Khadi is the nation's fabric and it is symbol of Indian textile heritage. Handspun lotus yarns will be novel for the entire Khadi sector.
4. World is constantly working towards sustainability. Artisian handloom weavers always urge for new material specifically natural fibers. So this will be a novel fiber for the entire handloom sector.
5. In the minor fibers it is very difficult to use pure form of the particular fiber in powerloom. But the Lotus yarn in this pure form has an ability to withstand the strength of powerloom. So it will be a novel fiber for the industries are specifically manufacturing high end fabrics for niche market.
6. Medical textiles are one of most rapidly expanding sector of the technical textiles. After Co-Vid resistance towards the bacteria is the need of an hour. Due to the numerous functional properties like high water absorbency and inherent antibacterial properties opens wide opportunities for the applications in hygiene products.
7. Minor cellulosic fibers are very difficult to use in knitted structure in its pure form due to the natural characteristics of unevenness and stiffness. But the Lotus fibers can withstand strength on circular knitting machines. Nowadays there is a wider scope of developing seamless knitted fabrics. Hence Lotus knitted material will be an innovative fabric for the knitting secto

CHAPTER – 2

REVIEW OF LITERATURE

A literature review provides a comprehensive overview of the relevant research as it provides clear understanding of the empirical and theoretical contributions made in the field meanwhile highlighting the points that require further exploration, experimentation and investigations. Understanding the nature of the problem of the study, the relevant theoretical literature and researches were studied related to existing machines and techniques for extraction of different cellulosic minor fibers, spinning systems, development of functional nonwoven products & knitted material from minor fibers, dyeing of minor fibers with natural & reactive dyes, training the community for the skill development programmes regarding to fiber extraction, spinning and product development for uplifting the minor fibers.

The literature was collected by the investigator from various libraries like SITRA (South Indian Textile Research Association) Central library of PSG College of Technology, Central library of Avinashillingam Institute for Home Science and Higher Education for Women, Coimbatore, Tamilnadu, Central library of Institute of forestry, Tribhuvan University, Pokhra, Nepal, Smt. Hansa Mehta library, Department of Science library of Faculty of Science, Prof. T.K. Gajjar library of Faculty of Technology and Engineering, Department of Clothing and Textiles library of Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. Other sources were internet and interaction with the researchers involved in similar field.

The review of literature collected was categorized and discussed under the following sub sections:-

2.1. Theoretical Review:

2.1.1. Production of Lotus

2.1.1.1 Global distribution of Lotus (Nelumbo Nucifera Gaertn.)

2.1.1.2. Latest cultivation practices of Lotus plant (Nelumbo Nucifera Gaertn.)

2.1.2. Machinery for extracting minor cellulosic fibers.

2.1.3. Spinning

2.1.3.1 Traditional spinning Techniques

- Drop spindle (Takli)
- Ambar Charkha

- Solarized Ambar charkha
- Phoenix charkha

2.1.4. Spinning systems of plant fibers

- Jute spinning system
- Flax spinning system
- Silk spinning system
- Coir spinning system
- Worsted spinning system
- Semi-worsted spinning system
- Woollen system

2.1.5. Blending

- Major objectives of blending
- Selection of constituents of blending.

2.1.6 Antimicrobial Textiles

- Microbes
- Skin resident microflora
- Microbes in clothing and skin
- Textiles and Infection vectors
- Textiles and skin
- Bacteria and hygiene
- Classification of antimicrobial activity
- Classification based on Mechanism
 - Controlled release mechanism
 - Direct contact mechanism
- Classification based on Substrates
 - Active substances
 - Passive substances

2.1.7. Hygiene medical textiles

2.1.8. Latest studies on Lotus fibers

2.1. Theoretical Review

2.1.1. Production of Lotus

2.1.1.1. Global Distribution of Lotus

According to Nguyen, Q.V., & Hicks, D. (2001), Lotus is widely cultivated in many countries of the world especially India, China, Japan, Korea, South East Asia and Africa.

According to Royal Botanical gardens report, distribution of Lotus in world is mentioned in two classes that is: Native and Introduced.

Native – Lotus is native to Amur, Assam, Bangladesh, Cambodia, China North-Central, China South-Central, China Southeast, East Himalaya, Hainan, India, Iran, Japan, Jawa, Khabarovsk, Korea, Laos, Lesser Sunda Is., Malaya, Manchuria, Myanmar, Nepal, New Guinea, North Caucasus, Northern Territory, Pakistan, Philippines, Primorye, Queensland, South European Russia, Sri Lanka, Thailand, Transcaucasus, Ukraine, Vietnam, West Himalaya, Western Australia.

Introduced - Alabama, Arkansas, Benin, Cook Is., Cuba, Florida, Georgia, Italy, Kentucky, Leeward Is., Louisiana, Maryland, Massachusetts, Mississippi, Missouri, New Jersey, North Carolina, Puerto Rico, Romania, South Carolina, Tennessee, Texas, Trinidad-Tobago, West Virginia, Windward.

Distribution in India.

According to **Barooah, C., Ahmed, I. (2014) Assam Science and Technology council**, In India Lotus is widespread in Himalayan lakes. It is native to Assam, Kashmir, Madhya Pradesh, Manipur, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, Maharashtra, Karnataka, Mysore and Kerala. Endemic distribution of Lotus is throughout the Assam.

2.1.1.2. Latest cultivation practices of Lotus plant (Nelumbo Nucifera Gaertn.)

Huang, J. et.al. (2022) authors mentioned that Lotus cultivation causes considerable amount of waste after harvesting. Different parts of the Lotus: leaf, seed, embryo, root and stamen are used as functional ingredients in the pharmaceutical industry. All these parts has been widely researched for their nutraceutical properties. But the Lotus petiole (Nelumbinis Petiolus) and seed pod (Nelumbinis Receptaculum) are generally thrown as a waste that causes environmental pollution. Pan et al., (2011) reported that lotus petiole consist of natural cellulosic fiber that can be used in textiles.

According to Chen Y., Wu Q., et. al.,(2015) reported that after harvesting Lotus leaf stalks (petioles) are dumped as a waste that may cause environmental hazards.

Pan et al., (2011) reported that Lotus petiole consist of natural cellulosic fiber that can be used in textiles.

Thaun (2020) farmers often toil for hours to clear lotus paddies of rotting stems, which ruin the soil and bring unwanted insects.

2.1.4. Spinning systems of Plant fibers

For the development of yarn from minor cellulosic fiber several trails have to be taken in different spinning systems due to the properties of the fiber.

Fibers like Sunhemp, Mesta and Jute can be processed using Jute Spinning systems due to the similar mechanical properties and fibre structure. As the Jute is coarser in nature as compared to Cotton so the processing machinery for Jute is of heavy duty and robust in nature. Due to the finer nature of Cotton fiber it requires intensive and mild opening as compare to Jute. During the processing of Jute fiber it requires high amount of opening force to de-mesh and split the Jute reeds. The roller settings of yarn processing machinery (drawing to spinning) are much wider for Jute fiber as compare to Cotton spinning machine due to the higher staple length of Jute fiber. Due to the specific nature of Jute fiber, cotton spinning machines cannot be used to develop Jute yarn. Flax and Ramie bast fibers consist a discrete filament structure. Both the fibers are much finer than Jute but they are coarser than Cotton. Thus, both the fibers are processed in the Flax spinning systems. Coir fiber has low length to breadth ratio and consists of high rigidity so it is difficult to spin but coir fibers are pliable into ropes using Coir spinning system. Pineapple fibers are fine in nature. Hence fibers are successfully spun into yarn on Jute, Cotton, Flax and semi-worsted spinning systems. There are specific spinning systems of animal fibers like wool and silk which is not suitable for plant fibers.

2.1.6. Antimicrobial Textiles

Antimicrobial textiles are defined as textiles that act against the bacteria. In recent years, due to the increased public health awareness consumers demand for textiles with antimicrobial property. The importance of reducing or eliminating the growth of microbes on textiles has a high importance due to the susceptibility of textiles to microorganisms such as bacterias and fungi that is based on nutrients, temperature and moisture. Hydrophilic nature of the natural fibers and regenerated cellulosic fibers are more vulnerable to microbial growth. Thus antimicrobial characteristics plays a important role in

diversified uses such as medical, protective, sports, defense, home textiles, water purification systems and apparels. Antimicrobial properties are explored by using synthesized and inherent antimicrobial fibres. In industry, treatment of antimicrobial agents at the fabric stage is widely practiced.

Antimicrobial agents are incorporated in textiles using different methods: Agents are incorporated into the polymers prior to extrusion or by blending it with synthetic fibers at the time of manufacturing and production. This method provides the better durability as the active compounds are embedded in the structure of fiber and they are released slowly during application. Another methods are exhaustion, pad-dry-cure, foaming and spraying on various textiles. The newer method of incorporating antimicrobial agents is through nanotechnology such as carbon nanotubes, nanoclays, natural polymers like Chitosin, metal oxide nanoparticles and nanoencapsulated agents.

The antimicrobial application should fulfill following points mentioned below:

- Any antimicrobial agents should not lead to loss of performance properties and fibre degradation.
- Antimicrobial agents should reduce the formation of odour that later result into the microbial degradation of perspiration.
- Antimicrobial agents should avoid spreading and transferring pathogens.
- It should have a durability to drycleaning, laundering and hot pressing.
- It should not destroy the good bacterias.
- Antimicrobial agents should not generate harmful effects to user, manufacturer and environment.
- Antimicrobial agents should fulfill the requirements of regulatory agencies.
- It must have compatibility with chemical processing.
- The method of the application should be easy.
- The antimicrobial agent should not have a negative effect on the quality of fabric.
- It should have a property of resistance towards the body fluids.
- It should be have a resistance towards disinfection and sterilizations.

Various antibacterial chemicals and fibres available in the international markets are not environment friendly. They majorly consist of synthetic base. Nowadays the consumer preferences are towards the functional fabrics with antimicrobial property. There is a huge requirement to necessitate the production of environmental friendly antimicrobial agents. India has a vast reserve of plants that consist of prominent medicinal values. Extracts from the different parts of the plants like roots, stem,

leaves, flowers, fruits and seeds exhibits the antimicrobial properties. In textile finishing these plant extracts are used in the native form or in the form of microcapsules.

Microbes are the tiny creatures that are not visible by the naked eyes. There are wide variety of microorganisms like fungi, bacteria, algae and virus. Bacteria are unicellular organisms that grow very rapidly under moisture and warmth. The subdivisions of the bacterial family are – Gram positive (*Staphylococcus aureus*), gram negative (*E-coli*), spore bearing or non spore bearing type. Some specific type of bacteria causes cross infection and pathogenic. Molds, mildew and fungi are complex organisms that has a slow growth rate. These organisms are the part of daily lives and they are present everywhere in the environment.

➤ **Skin resident microflora**

Skin flora should be stable. Basically 10^3 – 10^4 microorganisms per cm^2 are found on the skin. Specifically in the wet areas and groins the figures goes upto $10^{6-7/\text{cm}^2}$.

➤ **Microbes in Clothing and skin**

Textiles and skin micro biome is majorly dominated by *Staphylococcus aureus*. and *Micrococcus spp.* It is reported that *Corynebacterium spp.* is an odor causing bacteria. The length of the time the particular clothing is worn also leads to bacterial growth. **Sanders, D. (2021)** reported by showed that there was a growth of *Corynebacterium spp* that was worn for a longer period of time that may be due to the release of apocrine glands to clothing that provide the environment for the growth of *Corynebacterium spp* bacteria. Cotton textiles are majorly affected by *Acinetobacter* that may be originated during fabric processing and manufacturing.

➤ **Textiles and Infection vectors**

Textile materials consists of infectious agents like bacteria, virus and fungi. **Wattiau et al.** in his study mentioned the occurrence of *Bacillus anthracis*. strains isolated in the wool cleaning factory. Spread of infection in the hospitals are majorly through clothing and textiles. **Takahashi et al.** mentioned in the study regarding the presence of *Streptococcus pyogenes strain*. on the vinyl undersheet of 17 patients. In the maternity hospitals strains of *S. pyogenes* is seen in contaminated bras due to the insufficient drying. Employees of the laundering department of the hospitals are infected by *Salmonella*. due to the contaminated sheets. **Barrie et al.** mentioned the occurrence of *Bacillus cereus*. that leads to post

operative meningitis that occur due to contamination in laundry. **Gonzaga et al.** mentioned that newborns in hospitals are infected by *S.Aureas*. when they are handled by the laundry staff.

The risk of contamination is very high in hospitals during bed making. **Perry et al.** mentioned that the strains of *S.Aureas*. can transfer to patient's bed to nurse coats that are highly pathogenic. VRE - *Clostridium difficile*. and vancomycin resistant enterococci are found majorly in white coats in hospitals. Hospital curtains are majorly contaminated by MRSA (*Methicillin-resistant S. aureus*.). Filling of pillows are contaminated by *Acinetobacter*. **Oie et al.** conducted a study on door handles of hospitals. It was observed that contamination is through MSSA (*Methicillin-susceptible S. aureus*) strains. and MRSA (*Methicillin-resistant S. aureus* strains).

➤ **Textiles and skin**

Skin is the habitat and largest organ on the human body. The outer layer of the skin that is stratum corneum is the horny outer layer that interacts with the environment. The acidity of the surface pH 4.5-5 helps in building the favourable climate for the growth conditions of many pathogenic microorganisms. The acidic pH leads to the growth of commensal bacteria such as *Staphylococcus aureus*. and *Corynebacterium*. The primary interaction between clothing and skin is mechanical. In this case ,two major parameters plays a important role – a). Friction & b). Pressure. Friction leads to many skin ailments Keratosis follicularis and Atopic dermatitis. Prolonged pressure leads to superficial abrasions and deformation of tissue. These conditions also leads to favourable environment for microbial growth. Properties like moisture management, air permeability and heat transfer regulation of the specific textile materials are strongly depend on type of fibre and impact on skin microclimate. Skin microbes depends on the microbial composition that varies from person to person depending upon the age, diet , genetic background and many other factors. Textiles material can alter skin and its microclimate , but it also form a microclimate in itself. Fibers leads to formation of microhabitat.

➤ **Bacteria and hygiene**

According **Malheiro, J.N.M & Salvado, L.R.S. (2009)** textile materials are considered as a pointer of vaginal infections. Underwear and feminine panties are in close contact with the areas of vagina that is perineum area, vulvar skin and genital mucosa. The physiology of vaginal skin is very specific in terms of temperature (34°C), pH (less than 4.7) and moisture. Vagina consist of microflora that

leads to protection against the pathogenic bacteria meanwhile balancing the healthy conditions. Proper washing of undergarments also play a key role in bacterial growth. Generally underwears are washed at 40°C because of energy consumption, delicate ness of the fabric and environmental issues but ultimately bacterias are not eliminated and it there are chances of re-infection. Washing at 60°C leads to elimination of bacteria. In vaginal ecosystem two species of bacteria are frequently found that is *Staphylococcus Aureus*. (bacteria coccus shaped, have capsule and produce slime to attach on surfaces) and *E. coli*. (bacteria bacilli shaped and have nano-fimbriae to attach on surfaces).

In case of hygiene, textile material should balance the skin flora. For the prevention of bacterial development, textile material should offer a bacteriostatic activity instead of bactericidal activity which kills the bacteria. Textile material should not lead to destruction of skin flora. The non-specific immune defenses should not decreased by the textile material.

➤ **Mechanism of antimicrobial activity**

The antimicrobial effect is referred as negative effect on the vitality of microorganisms. Two keywords are commonly associated in antimicrobial field termed as “cidal” and “static”. The term cidal (Bacteriocide) defines significant destruction of microbes and static (Bacteriostatic) refers to inhibition of microbial growth without destruction.

Antimicrobial activity is based on two mechanisms:

1. Controlled release mechanism (Conventional leaching type of finish) – In this mechanism, antimicrobial agents are diffuse and poison to kill the microbes. The durability of antimicrobial agents are not strong. Between agent and textile fibers there is no chemical bonding. In this case, the leaching rate of the antimicrobial agent plays a important role affecting the efficiency. This type of mechanism has a poor durability and causes health issues.
2. Direct contact mechanism (Non-leaching or biostatic type of finish) - In this mechanism, antimicrobial agents are strongly attached to the fiber and it acts when it is contact with the microorganisms. Through this mechanism there are minimum hazardous effects of antimicrobial agents. There are more compatible with ecological and toxicological principles. This type of mechanism shows good durability and doesnot have any health issues.

The another classification of antimicrobial textiles are classified into two groups:

1. Active substrates – Active substrates are not released from the surface of the fibre so it is less effective. These substrates act only when they are in contact with microorganism.
2. Passive substrates - Passive substrates donot contain any active substances but there surface consist of negative effects on the living conditions of microorganisms. There is a anti adhesive effect on the structure and surface of the substrate.

2.1.8. Latest studies on Lotus Fibers

The process of extracting fibers manually from lotus petioles is practiced in the few places of the world – Myanmar, Cambodia, China and Manipur.

Bijiyashanti Tongbram

She is the botany honors resides at Thanga Tongbram village near Loktak lake under Bishnupur district in Manipur. She lives close to the Lotus filled Loktak lake . In July, 2018 Bijiyashnti began to collect different varieties of Lotus to establish agrotourism. She learned about the medicinal properties of Lotus during her graduation. But due to lack of machineris she could not able to put her ideas into reality. Bijiyashanti joined entrepreneurships training and programmes on aromatic and medicinal plants organised by Micro Small and Medium Enterprises. She also began her own research work by reading journals and the internet. One of her family friend informed her that there is a possibility of extracting fibers from Lotus stems. In May 2019, she started extracting fibers from Lotus stems and developed clothes from it. She started her own venture – “Sanajing Sana Thambhal”.

She has mentioned in her different articles that :-

1. She mentioned the extraction of the fiber is very tedious and labour intensive process.
2. She is looking for the engineers who can make machine to ease the task of extraction
3. She said that she has not been able to export at present because she still could not produce more products due to lack of manpower.
4. As the lotus thread is delicate, using machines may not be feasible.

Phan Thi Thuan

Phan Thi Thuan, 65 year old women from Vietnam has 40 years of experience in practicing indigenous method for preparing silk from silkworms and weaving it into blankets, scarves and dresses. She born in the family making and selling traditional silk to the French during the colonial time. In 2017, she started to extract fibers from lotus stems . The idea was suggested by Tran Thi Quoc Khanh, a member of the National Assembly of Hanoi. Today she has a group of 20 ladies who snap off the stems from the paddies. She extract fibers by manual spinning process. Thuan also said making lotus silk is a painstaking job. The craftsmen need to be skillful and attend to the smallest details in the whole process.

Samatao lotus textiles in Siem Riep Cambodia

Samatao Lotus textiles is a Cambodian social enterprise. It is a innovative and socially responsible producer of Eco-fabrics – than supports the livelihood of the vulnerable women of Cambodia. The enterprise started in 2003. The founder of the company is Mr. Awen Dheval. They develop eco fabrics made from Banana, Kapok, Silk, Organic cotton and Lotus. Extraction of the lotus fiber is done by the hand. It is mentioned that 1 spinner can produce only 250 m of thread. Major risks are :- low production capacity, long production time that discourage many customers and complexity in the entire process.

2.1. Research Reviews

- 2.2.1. Researches related to machine mechanism for extracting various minor fibers
- 2.2.2. Researches related to spinning process of minor fibers
- 2.2.3. Researches related to dyeing of minor fibers with natural and reactive dyes
- 2.2.4. Researches related to development of knitted fabrics from minor fibers
- 2.2.5. Researches related to specific functional properties of minor fibers and its applications
- 2.2.6. Researches on Lotus fibers.
- 2.2.7. Researches related to training the community for fiber extraction and spinning.

2.2. Research Reviews

- 2.2.1. Researches related to machine mechanism for extracting various minor fibers.

Ahmed ., Tilahum M., et.al., (2019) researchers fabricated plant stem fiber extraction machine with less manufacturing cost and high production in Ethiopia. Ethiopia has a leading agricultural economy, there was a high amount of plant stem which have a fiber dumped as a waste farmers often face the problems for the disposal of stems. There are two methods of fiber extraction: Manual Stripping method which is tedious, time consuming and cannot be recommended for industrial applications. Decorticator is a semi-automatic machine which is expensive and available in Ethiopia. Based on the fiber arrangement in the stem, authors fabricated drum unit. The length of the drum was 75 cm and 65 cm circumference. The drum has two surfaces half of the length of drum has a grooved surface having length of 35 cm and grooved gap of 0.25 inches, each groove has a depth of 0.35 inch whereas another half surface have a length of 35 cm in which nails are welded in the gap of 1.2 cm. Groove surface was used to extract the fibers from the plant stem which has a circular shape like papyrus whereas the nail welded surface is used to extract fiber which have a flat surface like banana and sisal plant. 2 HP machine motor with 900 rpm was used connected with the main shaft by two V- Belts. 0.75 mm thick sheet was used to protect machine from danger. The drum consist of shaft for holding the extraction drum at the two edges of the shaft there are two bearing. Motor under the drum has two pulleys: shaft pulley and motor pulley connected to V-belt. When motor starts rotation, the belt will drive the shaft and start extracting fibers from plant stem. It was concluded the cost of the machine fabricated was found cheap compared to automatic electrical fiber extraction machine and cost of the machine was 650 \$ as compared to 3500 \$ in case of Automatic electrical in the market.

A small-scale portable manually operated sisal decorticator was developed by **Tharun., Shamil K.U., et.al., (2020)**. The main aim of the project was to design sisal fiber extraction machine which can be

operated manually with no electricity using Catia V5 R21 modelling software and later stresses and deformations for the different parts of the machine was analyzed by using ANSYS software. The machine consists of blade which squeezes out the pulp out of the leaf and fiber will be left out. The blade consists of blunt edges and rotates at a certain rpm. Sisal leaf are fed to the blunt edges which scrapes out the pulp from the leaves exposing the fibers. Pedal is connected to the machine which is operated by human. To and Fro motion of the pedal converted to rotary motion by the connecting rod which rotates the driver wheel. Driven wheel is attached to the belt followed by the shaft and then to the blade. Results revealed that quality of the fibers extracted was not similar using electrically motor-powered machine and productivity was also found less but the main advantage was the machine is completely manually operated without using any form of fuel or electricity. So the technology was found cost-efficient for farmers and small scale industries.

Prashant, Y., Gopinath, C., Ravichandran, V. (2014) developed the extraction machine for coconut fibers. The aim of the project was to design and develop a coconut fiber extraction machine for farmers and small-scale coir industries in India to provide an effective solution to the difficulties in existing process, reduce time and labour cost and to develop a compact fiber extraction machine which could be made available to the coir industry directly. The project began with the collection of information and data on user lifestyle and current process by which they perform their job. Interviews were held with the users. Along with this ergonomic simulation was made to understand user difficulty. Five concepts were generated with different functions and operating processes for coconut fiber extraction machine. Five concept was selected by considering the users operating environment and maintenance which could be used in small scale coir industries and farm sector. The machine works with the gear mechanism, in which two barrels rotates in opposite direction to extract fiber from coconut. Cutting pins are inserted in indexed holes to separate fiber and to give linear motion to coconut shell. Validation was carried out with the user's group and feedback was positive. There was a potential market for this product.

2.2.2. Researches related to spinning process of minor fibers

Dhanlaxmi, R.D., & Pujari, K. (2014) explored the possibility of spinning Mesta yarns blended with Organic Cotton in different proportions. Mesta species *Hibiscus sabdariffa* of variety AS73, CP 560 was grown in the Institute of Organic Farming, University of Agricultural Sciences, Dharwad, Karnataka was selected for fiber extraction and spinning. For blending Organic Cotton DHH-11 (Dharwad Hirsutum Hybrid -11) variety was procured. To make the Mesta Fiber pliable and missible with Cotton fibers, it was treated with Jute Batching Oil (JBO). Blending of fiber was done by stack method. Two different blend proportion was prepared that is 60:40 and 80:20 Cotton and Mesta. For comparison 100 % organic yarn

was also prepared. Spinning was done by ring spinning system. Properties such as yarn count (Ne), Lea Strength (lb), Count Strength Product (CSP), Single Yarn Strength (kgf/tex), Yarn elongation (%), Yarn hairiness (number of hairs/Km) was tested. Results revealed that 60:40 Cotton: Mesta blended yarn was finer (13.52 Ne) as compare to 100 % Organic cotton yarn (8.9 Ne). Lea strength of 80: 20 Cotton: Mesta yarn was found higher than 100 % Organic Cotton yarn but the elongation was found lower. It was analyzed that cost of producing 1 kg of 100 % Organic Cotton was Rs.148.52 followed by 80:20 Cotton: Mesta was Rs.134.08 and 60:40 Cotton: Mesta blended yarn was Rs.128.20. It was concluded from the study that blending Mesta Fibers imparted strength to the Cotton yarn suitable for knits, curtains and draperies. Hence value addition to these underutilized minor fibers encourages the farmers for cultivating these crops for the better income and it also helps in conservation and utilization of these natural resources.

Devi, M., & Das, M.J. (2022) develop the yarn from Pine Needle fiber extracted from the dry leaves of Pine trees. For the study, the dry leaves were collected from the hilly areas of Himachal Pradesh. Extraction of the fibers was done mechanically followed by chemical process. The major obstacle of Pine Needle fiber is its outer layer consists of silica and resin which is necessary to remove to further convert into a yarn. For the removal of these components, fibers were treated with Alkali. After extraction of fibers, two blend proportions were tried that is 30 % Pine: 70 % Cotton and 50 % Pine and 50 % Cotton and 50 % Pine. For spinning, initially both the fibers were mixed by hand in the two different proportions and then subjected for carding in the mini carding machine. The carded lap was placed in the prototype draw frame for preparing sliver. After getting the sliver it was plied into 4 plies and again fed into the draw frame for doubling. After doubling the sliver was put in the ring frame for converting into the yarn. Yarn samples developed was subjected for various tests: twist, evenness, imperfections, CSP and lea strength. For the comparison 100 % Cotton yarn of similar count was also tested. It was found that TPI of Pine: Cotton blended yarn was 10.12 slightly lower than TPI of 100 % Cotton yarn that was 11.02. It was observed that Lea strength, CSP, breaking force, elongation and tenacity of 30:70 Pine-Cotton blended yarn was higher than 50:50 Pine-Cotton blended. Higher unevenness was observed in Pine-Cotton blended yarns as compare to 100 % Cotton yarns. Woven fabric sample was developed in CCI Evergreen Rapier machine. In warp direction 100 % Cotton yarn of 2/20 Ne was used 30:70 Pine-Cotton blended yarn of 8 Ne was used in weft direction. The developed fabrics was subject for wet processing operations that is desizing, scouring and bleaching. The fabric produced has a Khadi like appearance. It was concluded from the study that Pine:Cotton blended yarns can be used to prepare heavy weight fabrics . It was further recommended by the researchers that 100 % Pine yarns can be produced by the surface modification of fibers.

Himalayan region of India has an enormous wealth of natural fibers. **Basu, A., et.al (2019)** developed the value added products from Flax and Pine Needle fiber. The most negative point with Pine needle fiber is the Pine Needle fall on the ground every year in huge quantity which later catches fire and become combustible when dried which causes forest fire that leads to huge losses to the people residing in that particular area. Therefore there is a need of the positive utilization of this particular Pine Needle waste in effective manner. For the study Pine needles was procured from the ground of Almora from Uttarakhand. The Pine Needles was brought to NITRA Ghaziabad for extraction of fibers. For the extraction of fibers, several chemical combinations was tried for obtaining best textile grade fiber. Initially the Pine needle fibers were treated with Sodium Hydroxide and in final treatment Aluminum Chloride solution was used. After the number of trial and error the time temperature and concentration of the treatment was optimized. After treatment , fibers were extracted mechanically by rubbing. For the Flax, NITRA procured the seeds from CRIJAF (Central Research Institute for Jute and Allied Fibers) planted in around 7 acres of land. After harvesting fibers were extracted by retting and scutching was done. Testing of Pine needle and Flax fibers was done. It was observed that Pine Needle fibers has low tenacity. Pine needle fiber has a good moisture regain value of 12 %. From the SEM analysis, it was found that the fiber structure was not fully cylindrical and it has a rough surface. From the cross sectional view, it was observed that fiber has a hollow structure which leads to high thermal resistance value and water absorbency. Indian Flax fibers physical properties were compared with the European Flax. Almost all the physical properties were satisfactory and similar to the Imported European Flax but the bundle strength (63.49 g/tex) of the Indian flax was found higher than imported European Flax that is 40.82 g/tex. Spinning trials was done by blending Pine needle fiber with Cotton in different proportions. Spinning was found difficult with increase of Pine Needle in blend proportion. Preferential loss of Pine Needle Fiber was observed during carding. The yarns with 70:30 Cotton: Pine Needle Fiber was successfully spun into yarns. For weaving these 70:30 Cotton: Pine Needle yarns were initially sized and fabrics were developed. The fabric developed has a unique appearance which can be used to prepare jackets, apparels and home textiles. Flax fabric was produced in the small scale as compare to imported Flax fabrics. It was concluded from the study that value added textile products can be developed from Pine Needle fiber which is available in massive amount in Himalayan region. Utilization of this plant waste in textiles will improve the economy of Indian Himalayan region and also it helps us in reduction of forest fires which leads to huge loss to human and animal lives. The usage of imported Flax fiber can replaced by Indian Flax fiber and it will generate income to the people residing in that region.

A study on “Tensile behaviour of Ramie blended yarns” was undertaken by **Sett., S. et.al. (2016)**. In the study, researchers tried to develop the yarn by blending Ramie with Viscose and Pineapple fibers. For blending, all the three fibers were cut in the staple length of 39 mm. Ramie: Viscose and Ramie: Pineapple blended yarns were developed in the proportion of 100:00, 75:25, 50:50, 25:75 and 00:100. Yarns were developed in the cotton spinning machines. Nine different types of yarns were developed: 100 % Ramie, 100 % Viscose, 100 % Pineapple, 75 % Ramie: 25 % Viscose, 50 % Ramie: 50 % Viscose, 25 % Ramie: 75 % Viscose, 75% Ramie: 25 % Pineapple, 50 % Ramie: 50 % Pineapple and 25 % Ramie:75 % Pineapple. All the yarns were tested for different parameters of tensile strength: tenacity, modulus and specific work of rupture. Results revealed that tenacity of 100 % Viscose yarn was higher than 100 % Ramie yarn. As the amount of Viscose yarn increased in the blend proportion the tenacity increased. The value of modulus decreased as the amount of Ramie fiber in the blend proportion reduced but the modulus remains almost same in 50:50 Ramie: Viscose blended yarn. Specific work of rupture increased continuously with the reduction of the amount of Ramie in the blend proportion. Specific work of rupture was higher in 100 % Viscose yarn followed by 25 % Ramie: 75 % Viscose, 25 % Ramie: 75 % Viscose and 75 % Ramie: 25 % Viscose. In the Ramie: Pineapple blended category, the tenacity and breaking extension of 100 % Pineapple yarn was lower as compared to blended Pineapple yarns and 100 % Ramie yarn.

2.2.3. Researchers related to dyeing of minor fibers with natural and reactive dyes

Nakpathom, M., et.al. (2012) carried out an experimental study on natural dyeing of Hemp yarns. In the study three different types of Hemp yarns were explored. Two yarns were of industrial category of 720 and 1908 denier and another one was hilly tribe hemp yarns of 2295 denier. All the three yarns were dyed with four different types of natural dyes: Lac (*Laccifer lacca Kerr.*), Marigold flower (*Tagetes erecta L.*), Garcinia bark (*Garcinia Dulcis (Roxb.)*) and Annatto seed (*Bixa orellana L.*). For the dyeing, Hemp yarns were initially scoured in a solution of 10 g/L Lavenol PA soap and 1.5 g/L Sodium Carbonate and boiled for 1 hour. Extraction of all four natural dyes was done by boiling in water. The weight ratio of yarn to natural dye was 1:3 only in case of marigold dye the ratio was kept as 1: 0.5. For Lac and Annatto seeds dye extraction small amount of tamarind paste and sodium carbonate was added. In Lac and Garcinia bark dyeing, Alum was used as a meta mordant in 5 % owf. In case of Marigold flower dyeing, pre-mordanting was done with Alum. Dyeing was done in the open bath keeping Material to liquor ratio MLR of 1:30. Hemp yarns were placed in the dye bath at room temperature and later the temperature was increased. Dyed yarns were rinsed with water and air dried. All the dyed yarns were subjected for several testing for quality evaluation: color strength test in terms of K/S values, reflectance was measured by

datacolor 650 spectrophotometer and color fastness test for light and washing. Results revealed that highest K/S values were obtained for marigold flower dye . It was observed that K/S values increased with the increase in yarn size. Hill tribe hemp yarns of 2295 denier have highest K/S values as compared to industrial hemp yarns. Light fastness and wash fastness rating of all the dyed yarns were in the range of poor to fair category. Hemp yarns dyed with Mustard flower, Lac and Garcinia bark has low color staining on cotton and silk fabrics with the grey scale rating of 4-5 and in case of annatto seeds the rating was only 1-2. Based on research results on site training of natural dyeing of Hemp yarns was conducted. Hilly tribal peoples were trained in the project. It was recommended by the researcher further study can be done for improvement of light and wash fastness of Hemp yarns dyed with natural sources.

Gahlot, M., Pargai, D & Bhatt, P. (2019) did the study on natural dyeing of Himalayan Nettle fibers using *Kattha* industry waste. Total three mordants were used in the study. One was natural mordant that is Myrobalan and two synthetic mordants that is Alum and Ferrous Sulphate were used in the study. Three types of mordanting methods that is pre-mordanting, post –mordanting and simultaneous mordanting was done. Results revealed that Nettle fiber was dyed successfully in material to liquor ratio (MLR) of 1:40 with 6 % dye concentration for 60 minutes at 90°C. For synthetic mordanted dyed sample, the pre-mordanting method was best suitable whereas for natural mordanted dyed sample, simultaneous mordanting method has a good results. Fastness values of all the dyed samples were satisfactory. K/S value of dyed samples mordanted with Myrobalan was found higher that was 86.366 as compare to un mordanted control sample that is 51.624. Ferrous Sulphate mordanted samples has a higher K/S value of 115.506 as compare Alum mordanted sample that is 112.404. The study will help to increase the market value of Himalayan Nettle fibers.

Amin, A.N.M., et.al. (2021) experimented dyeing of pineapple leaf fiber using different dyeing techniques and also evaluated its washing fastness. For dyeing, Material to liquor ratio was 1:20. Two different types of dyeing process were explored in the study: a). Exhaustion dyeing b). Infrared dyeing technique. Pineapple Fibers were dyed with two reactive dyes – a). MX Basic Red 310N b).11b Procion MX reactive dyes in red color. Concentration of the dyes were kept 1.0 %. For both the dyeing process, temperature was kept 90°C for 60 minutes. It was concluded from the study, that fibers dyed with both the techniques has showed a moderate resistance to color change in washing and good to excellent resistance to staining on both cotton and silk fabric. Hence the infrared red technique leads to reduction in cost, water and electricity consumption.

2.2.4. Researchers related to development of knitted fabrics from minor fibers

Velumani, A., Kandhavadi, P., & Parthiban, M. (2021) investigated the effect of blend proportion on the mechanical properties of banana/cotton blended knit fabric. Mechanically extracted banana fibers were used for the study. For knitting soft pliable yarns are required. Raw banana fibers were initially treated with 8 g/L, 10 g/L, 12 g/L and 16 g/L of NaOH and further softened with 1.5 % of silicon softener. Banana/cotton blended yarns were developed in the Mini TRYTEX spinning frame. Three different blend proportion of banana/cotton yarns was prepared: 10:90, 20:80 and 30:70. The blended yarns were subjected for testing and results were compared with 100 % cotton yarn of the similar counts. From the analysis, it was determined that banana fiber has a low breaking strength as compare to 100% cotton yarn. Hence with the increase of banana fiber ratio during blending lead to the reduction of breaking strength and uniformity of the yarn also decreases. Four different types of single jersey knitted fabrics were prepared that is 100 % cotton, 10:90 Banana/Cotton, 20:80 Banana/Cotton and 30/70 Banana/Cotton. Developed knitted fabrics were subjected for following test: bursting strength, abrasion resistance, pilling and shrinkage. It was found that 30/70 Banana/Cotton knitted fabric has highest abrasion resistance as compare to all other fabric samples. The good abrasion resistance may be due to the low density, bulky structure and lightweight of banana fiber. Bursting strength of 30/70 Banana/Cotton was found lower as compare to all other samples because with the increase of the banana fibers the bursting strength and elongation decreased. The knitted fabric 20:80 Banana/Cotton and 30/70 Banana/Cotton was obtained the pilling grade – 4 (slight pilling) as compare to 10:90 Banana/Cotton and 100 % cotton has obtained pilling grade 3 (moderate pilling) . The good pilling results was obtained with the increase of banana fiber this may be due to the longer fiber length, more bulkiness, rougher surface and hydrophilic nature. Length wise and width wise shrinkage of all four fabrics were tested it was observed that with the increase of banana fiber shrinkage reduces due to the good dimensional stability of banana fiber.

Hemp is the lightweight, durable, inherently antibacterial, UV protective fiber. The plantation of Hemp consumes less water as compare to Cotton. Its growth rate is also higher that Cotton and Flax. **Ramsanthosh, K., & Punitha, V. (2021)** developed knitted fabric from Cotton/Hemp blende yarn and studied its properties. Researchers initially did the retting of hemp fibers with maxtray oil and water mixer. For yarn spinning, three different trials were taken.

In the first trail, Cotton/Hemp 60:40 ratio was decided. In blending, MECH cotton fiber variety was used having the staple length of 28 mm and CSP up to 2000. The hemp used for this blend was higher in denier. During spinning, till carding it worked well and then hemp fiber **losed** the moisture and desired yarn formation was not achieved. In the second trail , researchers tried to reduce the proportion of Hemp fiber

in the blend so the ratio kept was 80/20 Cotton/Hemp and the coarser count of 30's was decided. With this blend ratio spinning process reached till roving operation but difficulties arised in ring frame. Hence the second trial was also failed. In the third trail, researchers analyzed that spinning difficulties may be due to staple length of particular cotton variety and higher denier of hemp fiber. In this trail DCH cotton fiber of 3000 CSP and lesser denier hemp fiber was used. Finally the 80:20 Cotton/Hemp yarn of 20's count was achieved with twist parameter of 3.6. Knitted fabric was developed from 80:20 Cotton/Hemp yarn of 20's count achieved in third trail of spinning. The fabric was subjected for testing its physical and comfort characteristics. It was evaluated that moisture transmission of 100 %cotton fabrics was 16.524 g/hm² whereas Cotton/Hemp blended fabric has a moisture transmission value of 25.234 g/hm². The higher moisture transmission value is due to high moisture regain property of the Hemp fiber. Hence Cotton/Hemp blended fabrics can be used in summer wears.

Velumani, A., Kandhavadiu, P., & Parthiban, M. (2021) investigated the effect of blend proportion on the mechanical properties of banana/cotton blended knit fabric. Mechanically extracted banana fibers were used for the study. For knitting soft pliable yarns are required. Raw banana fibers were initially treated with 8 g/L, 10 g/L, 12 g/L and 16 g/L of NaOH and further softened with 1.5 % of silicon softener. Banana/cotton blended yarns were developed in the Mini TRYTEX spinning frame. Three different blend proportion of banana/cotton yarns was prepared: 10:90, 20:80 and 30:70. The blended yarns were subjected for testing and results were compared with 100 % cotton yarn of the similar counts. From the analysis, it was determined that banana fiber has a low breaking strength as compare to 100% cotton yarn. Hence with the increase of banana fiber ratio during blending lead to the reduction of breaking strength and uniformity of the yarn also decreases. Four different types of single jersey knitted fabrics were prepared that is 100 % cotton, 10:90 Banana/Cotton, 20:80 Banana/Cotton and 30/70 Banana/Cotton. Developed knitted fabrics were subjected for following test: bursting strength, abrasion resistance, pilling and shrinkage. It was found that 30/70 Banana/Cotton knitted fabric has highest abrasion resistance as compare to all other fabric samples. The good abrasion resistance may be due to the low density, bulky structure and lightweight of banana fiber. Bursting strength of 30/70 Banana/Cotton was found lower as compare to all other samples because with the increase of the banana fibers the bursting strength and elongation decreased. The knitted fabric 20:80 Banana/Cotton and 30/70 Banana/Cotton was obtained the pilling grade – 4 (slight pilling) as compare to 10:90 Banana/Cotton and 100 % cotton has obtained pilling grade 3 (moderate pilling) . The good pilling results was obtained with the increase of banana fiber this may be due to the longer fiber length, more bulkiness, rougher surface and hydrophilic nature. Length wise and width wise shrinkage of all four fabrics were tested it was observed that with the increase of banana fiber shrinkage reduces due to the good dimensional stability of banana fiber.

Sanad, S.H. (2011) studied the comfort characteristics of the knitted fabrics made from Flax/Cotton blended yarns. Blended yarns were developed by ring spinning system using different proportion of flax and long staple Egyptian cotton (G80). The main objective of the research was to study the effect of blend proportion and count on the developed knitted fabrics. Three different counts of yarns were developed that is 20's, 30's and 40's. In each count category, four different types of blend proportion was tried that is :- 70 % Flax/30 % cotton, 50 % Flax/ 50% Cotton, 30 % Flax/ 30% Cotton and 100 % Cotton. The similar blend proportions were followed for 30's count and 40's count yarn. All the developed yarns were waxed and knitted in commercial knitted machine. Diameter of the machine cylinder was 8.89 cm (3.5 inch), gauge length was kept 12. Knitted fabrics were prepared at Cairo secondary school of spinning and weaving, Egypt. Knitted fabrics were further evaluated for – bursting strength, air permeability, color efficiency (K/S), ultraviolet protection factor (UPF) and moisture regain. From the testing results it was analyzed that 100 % cotton knitted fabric has a higher bursting strength. With the increase of the percentage of flax in blending the bursting strength reduces. The fabrics made from different counts also lead to the significant impact on the bursting strength. As the count increased the bursting strength decreases. Air permeability is defined as amount of the air passed through a given area of the fabric. This parameter largely influences the thermal comfort properties of fabrics. The results showed that flax blended fabrics has a higher values of air permeability as compare to the cotton knitted fabrics. K/S values of knitted fabrics made from 20 Ne obtained higher K/S values as compare to 30 Ne and 40 Ne. The K/S values of flax knitted fabrics was found higher as compare to cotton knitted fabrics. Ultraviolet protection factor (UPF) values of flax blended fabrics were higher as compare to cotton fabrics. As the count of the yarn increases the UPF factor decreases. Moisture regain values of the flax blended fabrics was found superior as compare to cotton knitted fabrics which may be due to the larger diameter of the flax fibers. Flax blended fabrics made from 20 Ne yarn has a higher moisture regain values as compare to 30 Ne and 40 Ne. Hence the Flax/Cotton blended fabrics found more suitable for dress material especially for summer season.

2.2.5. Researches related to functional properties of cellulosic minor fibers and its applications.

Menstrual hygiene is one of the essential health related aspects in women. Commercially available sanitary napkin can fastly absorb the menstrual fluid but it consists of synthetic fibers, regenerated fibers, dioxin and super absorbent polymers which is harmful for the health and environment. Kumar, R.C., et.al. (2020) conducted an experimental study on moisture behaviour properties of milkweed and

milkweed/cotton blended sanitary napkin. Milkweed is one of the naturally available fibers which has an excellent moisture management properties as compare to cotton fibers because of the low density and hollow structure. In the study, the milkweed fibers was used as absorbent core in sanitary napkins in different blend ratios – 100 % milkweed, 80/20 milkweed/cotton, 60/40 milkweed/cotton, 50/50 milkweed/cotton, 40/60 milkweed/cotton and 20/80 milkweed/cotton. The first layer used was polypropylene spunbond sheet and the bottom layer was polyethylene water resistant sheet. The developed samples were subjected for testing – liquid spreading rate, liquid retention rate, liquid holding capacity under pressure and quantity of the liquid absorbed. Results revealed that sanitary napkins developed from 100 % milkweed core and its blends showed lower liquid spreading rate and this property assist for vertical wicking as compare to horizontal wicking. This property will assist the lower skin contact with the wet area which will leads to higher comfort to the users. The liquid retention, liquid holding and quantity of the liquid absorbed has shown higher in 100 % milkweed core sanitary napkins and its blends as compare to 100 % cotton and its blends due to the unique inherent hollow structure and cellulose content present in the fiber structure.

One of the important substances in the sanitary napkin is frequently available absorbing material. **Sreekumar, S. et.al (2018)** designed and constructed a pulverizing unit for obtaining raw banana fibers with maximum absorptivity for the application as absorbent filler in sanitary napkins. The researchers also worked on optimization of the blades of pulverizing unit to get the most absorbent banana fibers. The main objective of the pulverizing unit is to break the strands of banana fiber into smaller length. The schematic design of pulverizing unit consists of Circular cutter , Shaft and circular chamber with slot on the upper side. Initially the researchers studied many other pulverizing units which are used to grind similar kind of fibers like Banana. Based on literature review the researchers fabricated the pulverizing unit specifically for Banana fibers. After the fabrication of pulverizing unit, experiments were conducted by varying the number of blades and the output size of fiber obtained. The production efficiency was also recorded by measuring the weight of the raw fibers obtained by the variations in blades of pulverizing unit. It was observed that fiber size decreased with the increase in number of blades in pulverizing unit. Maximum production efficiency of 79.5 % was obtained in 6 number of blades. Production efficiency dropped to 58 % when 7 blades were taken because of entanglement of fiber strands due to closer arrangement of blades. The definition of absorptivity is amount of water absorbed by the fiber under the specified test condition which is expressed in percentage. Absorptivity of the different banana fibers obtained by the variation of blades were tested as per ASTM D 570. The test was done by keeping the fiber sample in water for 10 minutes. The percentage was calculated by the weight difference before and after immersion of fibers in the water. It was found that absorptivity of the fiber increased with the

increase in number of blades in pulverizing unit. Absorptivity percentage with seven number of blades (higher number of blades) was 28.7581 % and fiber size obtained was 3.9 mm. It was concluded from the study that raw fibers extracted from this fabricated pulverizing unit with optimized number of blades can be used as an absorbent filler in sanitary napkins.

Devi., M & Karpagavalli.,V.S. (2022) developed the nonwoven fabric from Bagasse fiber for the application in disposable medical textiles. Nonwoven fabric was developed by blending it Cotton and Viscose in different proportions: **a).** 75:25 (Viscose/ Bagasse) **b).**60:40 (Viscose/ Bagasse) **c).** 75:25 (Cotton/ Bagasse) **d).** 60:40 (Cotton/ Bagasse). Nonwoven fabric was prepared by Needle punching method. All the four nonwoven fabrics were subjected for coating using natural herbs: Neem, Turmeric and Lemon. Herbal extracts were coated on the nonwoven fabric depending on heating conditions and further tufting was done with air dry spray method. Coated fabrics were subjected for Antimicrobial evaluation against *E.Coli*. Results revealed that nonwoven fabrics has a antimicrobial property even after three washes. Finally disposable masks and soles were developed from treated nonwoven fabrics.

2.2.6. Researches on Lotus fibers.

Dhama, A., & Singh, S. (2022) conducted the exploratory research on Lotus silk fabric – A luxurious fabric for high Fashion (Indian Silk 30-33). The attempt has been made to study the lotus fiber with following objectives – Foundation, history and manufacturing process of lotus fabric, reason of being a luxurious fabric, sustainability of lotus silk fabric and its life cycle assessment. To fulfill the objectives researchers did the secondary research. The data was collected from various books, periodicals, web pages, internet, fashion companies, exporters. History depicts that Lotus fiber was originally originated from Myanmar and now this fabric making process is practiced by the small cottage industry of Japan, China, Vietnam and India. It is generally practiced by the women due to the expertise and patience. Due to the scare availability and labour intensive process the fabric has remain exclusive. Manufacturing of lotus fiber practiced till now is the exhaustive and labour intensive process. The process starts early morning with the collection of stems from the pond when the flowers are full bloomed to get a good quality fiber. To get a desired length 6-7 stems are taken together they are cut with the knife, snapped and pulled the extracted fiber are wound on the bobbin in a yarn form. Life cycle assessment revealed that lotus fibers has many superior properties and advantages as compare to other conventional textile materials but the only disadvantage is high price due to exhaustive and labour intensive extraction process. It was further suggested in the research paper that there should be a comparative study done on lotus silk fiber with other natural fibers.

Abhijit, A.V., Thayyil, A.D., & Babu, T.N. (2021) developed the epoxy reinforced composites from lotus and E-glass fiber and studied its tensile behavior. In the study, lotus fibers were treated with alkali. About 250 gms of lotus fibers were soaked in 1 L of 0.5 % of NaOH solution for 30 minutes and fibers were allowed to dry for 3 days at 65 % humidity and at normal room temperature. It was expected that after alkalization the mechanical properties of the fibers will improve as the non-cellulosic components will remove. Two different types of composites were developed: Lotus fiber with epoxy resin (without e-glass fiber) and Lotus fiber with epoxy resin (with e-glass fiber).

Lotus fiber composite (without e-glass fibers) was prepared by layering technique which consists of three layers of lotus fibers and four layers of epoxy – hardener in the cavity. Fiber to epoxy volume ratio used in the composite was 60:40. Lotus fiber composite (with e-glass fiber) was prepared in the following composition – 2, 5, 2 layers of lotus fiber, epoxy hardener and e-glass fiber. The fiber to epoxy volume ratio was 45:45. In both the composite, the arrangement of the fibers was done in three different ways:- uniaxially, biaxially and criss-cross manner. Orientation of the fibers in the composites were the prime factor for the achieving the better tensile strength. Tensile strength test of composites were done as per ASTM D638. Results revealed that uniaxially arranged composite (with e-glass fiber) has obtained highest tensile strength of 18.91 MPa whereas criss-cross and biaxial composites showed lower tensile strength of 18.38 MPa and 11.92 MPa. Lotus fiber epoxy composites arranged uniaxially, biaxially and criss –cross directions obtained the tensile strength of 17.15, 13.73 and 9.14 MPa. It was concluded that with the addition of glass fibers the tensile strength of the specimens arranged in uniaxially, biaxially and in criss-cross manner were increased by 10.24 %, 33.82 % and 30.43 %. These composites open up the huge scopes in the medical and textile applications and due to higher tensile strength it can be used for soft carry bags.

Chen Y., Wu Q., et. al., (2015) experimented with lotus leaf stalk (LLS) produced as an abundantly available agro-waste. Nano fibrillated cellulose (NFC) was isolated by using chemical pretreatment combined with the high – intensity ultrasonification. For the study, lotus leaf stalks were collected from the constructed wetland located in Fuzhou, China. Lotus leaf stalks were washed with the de-ionized water and cleaned biomass was dried at 100 °C for 24 h. After drying, the stalks were cut into pieces and grounded to obtain a powdered samples. Initially the chemically purified cellulose was isolated by 3 step. In first step, extraction was done with 2:1 (v/v) of toluene/ethanol extraction method (90° C, 6 h). After this process, the powder was bleached with an acidified NaClO₂ solution (2.1 wt%) at the pH for delignification (75 °C, 1h) the process was repeated five times. The residue obtained was holocellulose which was further treated with 5.0 % KOH at 90°C for 2 h to remove hemicelluloses followed by 1.0 % wt

HCl solution at 80° C for 2 hour to yield the highly purified acid treated lotus leaf stalk (LLS) cellulose fibers. At the end of extraction , bleached cellulose product was obtained referred as bleached lotus leaf stalk (BLLS) which was swelled overnight and the suspension was subjected to a high frequency (20 to 25 kHz ultrasound irradiation treatment and centrifuged to collect nano fibrillated cellulose (NFC) from supernatant fraction. The isolated nanocellulose obtained was tested for its chemical and morphological characteristics. Results revealed that brown color of the original lotus leaf stalk powders was completely changed to snow-white appearance after bleaching indicating highly effective removal of non-cellulose components such as hemicellulose, lignin, wax and other extractives. Bleached lotus leaf stalk sample found enriched with the cellulose content of 91.86 % found highly suitable for the isolation of nanocelluloses. Length and width distribution diagrams of BLLS (bleached lotus leaf stalk) fibers was calculated by Morfi analysis and results indicated that distribution of fiber length was less scattered in comparison of their diameters. Transmission electron microscopical analysis (TEM) of obtained NFC (Nano-fibrillated cellulose) revealed slender wire-like cellulose fibrils with nano-sized widths of 20 ± 5 nm favorable for the antistrophic reinforcing effect and for the network formation at low threshold during nano-composite . FTIR spectra of LLS (Lotus leaf stalk), BLLS (Bleached Lotus Leaf Stalk) and NFC (Nano-Fibrillated Cellulose) samples was carried out. In the increased intensity of 3420 cm^{-1} the absorption peaks of bleached lotus stalk (BLLS) and Nano-fibrillated cellulose) suggests more free hydroxyl groups in comparison to raw LLS (Lotus leaf stalk). Hemicellulose content was found dominant with the absorption band at 1740 cm^{-1} representing the stretching of C= O groups these peaks was almost disappeared in Bleached Lotus Leaf Stalk (BLLS). X- ray diffraction indicates NFC (Nano – Fibrillated Cellulose) has a higher crystallinity index of 70 % compared to the value of 61.25 % for the NFC (Nano-Fibrillated Cellulose) isolated from bamboo fibers. Thermal gravimetric analysis revealed that thermal stability of BLLS (bleached lotus leaf stalk) and NFC (Nano-Fibrillated Cellulose) was found better in comparison to raw lotus fibers. Derivative thermogravimetry analysis (DTG) indicated lower initial decomposing temperature (Ti) of NFC (Nano-fibrillated Cellulose) at 217° C. Finally it was concluded that nano-fibrils obtained from Lotus Leaf stalk have a great potential as a reinforcement agents in composites.

2.2.7. Researchers on training the community for extraction and spinning

Vijayakumar, M., & Manikandan, C. (2020) executed the study on “Role of women employees in Coir making industry”. Coir is the unique natural fibers extracted from the coconut husk and spin into coir yarn. Tamil nadu is the second largest producer of coir fiber in India. Only one shift was running to due to shortage of labour. To overcome the problem of labour shortage, workers from economically backward

North eastern states like Manipur, Assam and Orissa was hired. The objectives of the study were to ascertain the views and perception of the women employees working in the coir industry and to study the present scenario of women employees in coir industry. The study was carried out in Pollachi taluk in Coimbatore district because it has a wide commercial area for agricultural products specially coconuts. For the study 20 respondents were selected as per the convenience and data was collected using questionnaire for basic details. Simple statistical analysis like chi-square, percentage method and ANOVA was used to analyze the data. Results revealed that 100 % of the respondents were working 8 hours per day, 45 % of the respondents belong to the age group of 26 and 30 years, 50 % of the respondents residing in rental house, 45 % of the respondent's daily earnings were Rs.150- Rs 200. It was observed that women employee role was low when compared to men employees the main reason behind this lack of security. It was concluded that most of the women employees have taken the job as a primary and alternative source to meet the domestic expenditure. So it was suggested in the study that role of empowerment of women is more required to lead and upgrade their good health, family and nation.

Pandey, A., et.al. (2020) demonstrated the techniques of low cost fiber extraction and yarn making from nettle plant implemented by G.B Pant National institute of Himalayan Environment (NIHE) in collaboration with its partner organizations in Lingdem and Lingthem Gram Panchayat Units (GPUs) of Dzongu under Khangchendzonga Landscape Conservation and Development Initiative (KLCDI)-India programme. In the study, skill development training programme was organized on nettle fibre based product making and its value addition. Ms.Ongkit Lepcha , local expert was identified to train selected 15 self motivated members of women and self help groups (SHGs) from Lingdem, Laven, Raklu and Kayem villages of Dzongu pilot site. A training programme was organized in two phases. In the first phase, training was organized during December 2018 focusing on extraction of the outer bark, drying, storage methods of raw material and selection and cutting of stem of wild nettle plants. In second phase of training was organized during the month of March 2019. Selected members were trained for yarn making, weaving and various marketable products.

Shahi, V., et.al (2018) did the study on Social and economic empowerment of farm women in banana fibre based entrepreneurship for sustainable income. The paper has listed numerous use of waste pseudo stem like it can be used in making – organic fertilizer, sap-based products, enriched sap, liquid fertilizer, nutrient spray solution (NSS). With the initiative of Krishi Vigyan Kendra, Vaishali district of Bihar which has a large production of banana has started giving training rural farm women on fibre based technology on the wasteful harvested pseudo stem. In the initial training period the fiber

extraction was done by hand but the output was very less nearly 250 gm per day. To solve this problem they started the training for fiber extraction by machine in which 6-8 trainees can extract the fibers simultaneously which cut down the cost and one person can extract 2.5 kg of banana fiber per day. Women were also trained for making value added handicraft products. Later the study was done to analyze change in livelihood pattern of 100 rural farm women engaged in fiber extraction and handicraft making. Most of the women were from backward community. After engaging in the fiber extraction and handicraft making products from banana fiber there living condition improved in all the ways like: financially, self believe, social participation, there physiological status also increased. They gained the confidence towards entrepreneurship and marketing.

CHAPTER – 3

EXPERIMENTAL PROCEDURE

The study is experimental and exploratory in nature. The main aim of the study was to utilize the hygrowaste that is lotus petioles for fiber extraction and its application in the different areas of textiles like woven, knitting and non-woven. The researcher started with the collection of lotus petioles from local cultivator of Vadodara district of Gujarat. In the study researcher developed the hand extracted yarns by varieting the number of petioles and further spinning was carried out in Ambar charkha. The major drawback was time consuming hand extraction and spinning process for that researcher designed and fabricated the apparatus which can automatically extract and spin the fibers. Ply yarn by twisting it with other natural fibers was explored. Open end yarns in different proportions were developed in Avinashillingam Institute of Home Science, Coimbatore. Total 11 different types of yarns were developed. 14 Woven fabrics with different compositions were prepared in handloom and power loom. For the application in woven textiles the dyeability and fastness properties are also important commercially so the researcher experimented dyeing of Lotus fiber with natural and reactive dyes and assessed its fastness properties. The fiber has an inherent softness, elasticity, pliability and functional properties so the machine extracted yarns was also experimented for making a circular knitted structure. Leftover fibers from the petioles after extracting the long length of fibers were explored for developing nonwoven web. The study also intended to test and analyze the properties of all the structures that is woven, knitted and nonwoven. Based on results the applications were found. Group of ladies were trained for extraction and spinning of Lotus fibers. Hence this chapter deals with materials and methods developed and followed for fulfilling the objectives.

The experimental procedure of the study has been further subdivided and discussed under various phases:

3.1. Procurement and analysis of raw material

3.2. Extraction of fiber (by hand)

3.2.1. Extraction of fiber for yarn making (by varieting number of petioles)

3.2.2. Extraction of fiber for making non-woven web (loose fiber extraction from leftover)

3.2.3. Testing of fiber

3.3. Spinning of hand extracted fibers

3.4. Testing of yarn

- Determination of yarn count
- Determination of tensile strength
- Determination of twist

3.5. Development of Machines

3.5.1. Machine – 1:- Development of machine for extraction and spinning (specifically for yarn making)

- Designing of apparatus
- Construction of apparatus
- Working of apparatus for fiber extraction and yarn making
- Yield of machine
- Testing of machine extracted yarn
 - Determination of yarn count
 - Determination of tensile strength
 - Determination of twist

3.5.2. Machine -2:- Development of machine for extracting raw fibers (specifically for nonwoven web preparation and development of rotor yarns)

- Construction of apparatus

3.6. Development of blended yarn and its testing

3.6.1. Blending in fiber stage (Open end spinning/Rotor spinning)

3.6.2. Blending in Yarn stage (Plying mechanism)

3.6.3. Testing of blended yarn

- Determination of yarn count
- Determination of tensile strength
- Determination of twist

3.7. Dyeing of Lotus yarn

- Dyeing of Lotus yarn with natural dyes
- Dyeing of Lotus yarn with reactive dyes

3.7.1. Testing of dyed yarns

- Determination of Color strength
- Determination of Washing fastness
- Determination of Light fastness

3.8. Construction of woven fabrics

- Khadi fabrics
- Handloom fabrics
- Power loom fabrics

3.8.1. Testing of woven fabrics

- Determination of fabric thickness
- Determination of fabric count
- Determination of cover factor
- Determination of weight per unit area of fabric
- Determination of stiffness/bending length
- Determination of drape co-efficient
- Determination of tensile strength
- Determination of abrasion
- Determination of tearing strength
- Determination of pilling
- Determination of shrinkage
- KAWABATA analysis of the fabrics (**Samples send to CIRCOT for testing**)

3.9. Development of Knitted fabrics

3.9.1. Testing of knitted fabrics

- Determination of knitted Fabric count (Assessment of Wales and coarses)
- Determination of bursting strength
- Determination of pilling
- Determination of stretch and recovery properties of knitted fabrics.
- Determination of thickness
- Determination of GSM

3.9.2. Development of knitted product

3.10. Testing of fibers for functional properties

- Absorbency
- pH
- Cytotoxicity.

3.11. Development of nonwoven fabric and its testing

3.12. Development of hygiene products from nonwoven sheet.

3.13. Testing of hygiene product.

3.14. Training group of women for fiber extraction and spinning

- Interaction with NGO
- Locale of the training programme
- Training for fiber extraction and spinning
- Workshop for fiber extraction and spinning.
- Weaving of hand-woven stoles
- Exhibition of the developed fabrics

3.1. Procurement and analysis of raw material

In the study, *Nelumbo nucifera Gaertn.* Species that is a pink lotus was used. It is the national flower of India and Vietnam. The petiole is the part between flower and rhizome (underground stem) of the Lotus plant. After the flower plucking, the petioles are either left in the pond as a waste or if it is taken out with the flower then cultivators only keep small length of petiole with flower the rest long length is throw away as a waste. Waste Lotus petioles were procured from the Lotus flower supplier – Mr. Isabbhai Rathod of the Vadodara district of Gujarat.

The average length of the petiole varies from 50- 115 Cm. The diameter of the petiole varies from 0.5 -2.5 Cm. The length and diameter varies as per the maturity level of the plant and season. The color of the petiole ranges from light green to dark green with the thin spikes in the surface.

3.2. Extraction of fibers (Manual method)

3.2.1. Extraction of fiber for yarn making

For achieving different counts of yarn and checking its feasibility in hand spinning and weaving extraction was done manually by varieting the number of petioles. Three different types of unspun yarns were prepared from one, two and three petiole.

3.2.2. Extraction of fiber for making non-woven web (loose fiber extraction from leftover)

While extracting fibers manually in the unspun yarn form by joining end to end points, there was a small pieces of petioles as a leftover which still contains fibers. These fibers were extracted manually and collected over the woolen felt.

3.2.3. Testing of fiber

All the physical properties like fiber length, fiber diameter, fiber fineness (ASTM D 7025-09), Moisture regain and content and Bundle strength (ASTM D 1445) was tested in Textile testing and Textile chemistry lab of Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda. Fiber strength (ASTM D 3822-07) was tested in Textile testing lab of Department of textile technology, Faculty of Technology, The Maharaja Sayajirao University of Baroda. FTIR, XRD, Whiteness index test was conducted at the laboratory of Bharat Ratna Prof.CNR RAO Research Centre, Avinashillingam Institute of Home Science and Higher Education for Women, Coimbatore, Tamilnadu.

3.3. Spinning and testing of hand extracted yarn

The unspun yarns developed were experimented for twisting on drop spindle, peti charkha and Ambar charkha. The entire hand spinning was done by the researcher with the assistance taken from Mr. Bakul Shah (Expert spinner) at Bhumi Pujan Office, Fatehpura, Vadodara.

3.4. Testing of Yarns

➤ Determination of tensile strength of yarn

Following ASTM 885. Tensile strength of the yarns was determined on Instron Universal tensile tester. The instrument work on constant rate of elongation principle (CRE). For the test the yarn of known denier was clipped between two jaws with the gauge length 500 mm (50 cm) and the pulling speed was 500mm/min. Average of 10 readings was taken.

➤ Determination of Yarn Twist

Following ASTM D 885, The amount of twist was calculated on Alfred suter twist tester. The sample length was 10 inch test length with tension arrangement. An average of 10 readings was taken.

➤ Determination of Yarn Fineness

Following ASTM D 7025 standard, fiber fineness was tested. In the direct system of yarn numbering, Denier was determined by taking the average weight of 20 readings of 80 cm length of the fiber and calculations was done by using the formula:

$$\text{Denier} = \frac{WX}{L}$$

Where, W= Weight of the fiber

L= Length of the sample

l = unit length of the system

The count of the fibers was also determined by indirect system of yarn numbering by using Beesley's yarn balance. The instrument consist 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 fibers based on cotton count system. The fibers were kept on the hook until the pointer reaches the datum line. The count is the number of short length filament fibers used to balance the beam.

3.5. Development of machines

Machine 1: This machine is specifically designed for extracting fiber and simultaneously developing yarn. The main drawback of the Lotus fiber was its time consuming manual extraction process which hinders the mass production. The mechanization of the entire extraction process was also found difficult due to the delicate appearance of the fiber. Researcher in collaboration with the Mechanical Engineer- Mr.Dhaval Raval worked on the entire designing and development of apparatus. Apparatus was designed in such a way that both extraction along with spinning can be done together at the same time. The apparatus has got an Indian patent grant (IN201921032058).

➤ Designing of Apparatus

On the basis of different steps in the manual extraction method :- cutting of petioles, holding of petioles together, twisting of fibers along with stretching and winding on the pern , researcher in collaboration with the mechanical engineer worked on different designs for the apparatus of Lotus fiber extraction and spinning . Later one of the designs was finalized and apparatus was fabricated. The line diagram of the apparatus was prepared in CAD software.

➤ Construction of Apparatus

The apparatus was constructed by engineer Mr.Dhaval Raval in his work shop - The Best Project Maker , 893/3/1, (1st Floor), Makarpura, GIDC Near Krishna Engineers, Purohit Chokdi, Vadodara , Gujarat. The apparatus consist of two sections that is input and output device. The input device comprises of the long PVC pipe in which Lotus petioles are feeded and later with the rotation of PVC pipe, the fibers were extracted and twisted. The output device consists of entire assembly of fixing bobbin in which the twisted yarns are winded. Machine consists of two motors, SMPS connection, speed regulator and sharp knife.

➤ Working of Apparatus

Fresh Lotus petioles are feeded in the PVC pipe. In the opening side of PVC pipe there is a sharp knife attached to slit the petioles. The knife slit the petioles and the extracted fibers are first initially winded in the bobbin. Later with the rotating of the PVC pipe and stretching speed of bobbin winding device the yarns are winded evenly in the pern which can be directly proceeded for weaving. Yarns with different counts were optimized by regulating the speed of both the rollers present in the device. Speed of the machine was analyzed by the Tachometer device.

➤ Yield of machine

The yarns winded on the bobbins were further weighted. Time taken to develop the yarns was noted. Consumption of the petioles were also evaluated.

3.5.2. Machine – 2 :- This machine is specifically designed for extracting raw fibers (specifically for nonwoven web preparation and development of rotor yarns)

The machine 1 is designed in such a way that it can extract and twist fibers and convert into yarn one at a time. These yarns can be used further for developing woven and knitted fabrics. But in the case of nonwoven sheet, rotor and ring yarn preparation there is a requirement of raw fibers. So the researcher in collaboration with Robotic engineer Mr. Shreyash Patel from Vadodara district of Gujarat designed and constructed the machine.

Construction of machine: The machine consist of three sections: First and main section which consist of petiole loader, sorter, two rollers and blades. There are two adjusting knobs to adjust the petioles in the loader. In the front area of machine there are two blades in upper and in lower side. Second section consists of gripper which performs a jaw movement to grip the petiole. Third section consists of comb like device to collect the raw fiber.

3.6. Development of blended yarn and its testing

Lotus is a natural cellulosic fiber comprising all the excellent properties- it is inherently soft, lustrous, moderate strength, good elongation, high moisture absorbency and inherently antibacterial. The entire fiber preparation process doesnot contain any chemical treatments. Focusing on the economic factor researcher tried to blend the Lotus fiber only with other natural fibers – Cotton, Silk and Wool. Blending was done by two methods:

3.6.1. Blending in the fiber stage:-

This is also called as “intimate blending”. It combines two or more fiber substances which is further spun together into a single yarn. The entire blending and spinning process was done at Textile production lab of Avinashillingam Institute for Home Science and Higher Education for Women, Coimbatore Tamilnadu. Spinning of yarns was done by Rotor spinning system/Open end spinning technique.

3.6.2. Blending in the Yarn Stage (Plying Technique)

Ply yarn combines two or more single yarn to increase the diameter, length and strength. The plying was done on 2-spindle Ambar Charkha by the researcher with the assistance taken from Mr. Bakul Shah (Expert spinner) at Bhumi Pujan Office, Fatehpura, Vadodara. Plying of Lotus yarn was done with three different natural fibers – Cotton, Silk and Wool. For plying, Cotton and Wool yarns were procured from Artisan Weaver Pachan Premji from Bhujodi, Kutch, Gujarat. Mulberry Silk yarns were procured from Aliya Silk traders. Count of both the yarns in the ply was taken into the consideration.

3.7. Dyeing of Lotus yarn and its testing

➤ Dyeing of Lotus yarn with natural dyes

Lotus yarn was experimented for dyeing using nine different natural dyes mentioned in Table – Aqueous extraction method was used. Before dyeing, Lotus yarns were pre-mordanted using Alum. Dyeing was done in open bath. Self pH was used. Dyeing was done in 4 % shade.

Table 3.1. Details of dyeing (natural dyes)

	M:L Ratio	Temperature (Celsius)	Time (in minutes)
Extraction of dyes	1:40	60°C	30
Pre-Mordanting	1:30	-	30
Dyeing	1:40	60°C	45

Table 3.2. Sources of Natural dyes

Sr.No	Dye Source	Obtained as
1	Marigold	Flower Petals
2	Madder	Powdered form
3	Lac	Crystal form
4	Sappan Wood	Powdered form
5	Katho	Powdered form

6	Indian Berries	Powdered form
7	Annato	Powdered form
8	Pomegranate rind	Dry form
9	Natural Indigo	Indigo cake

➤ Dyeing of Lotus yarn with Reactive dyes

Cold reactive dyes were used :- Reactofix Blue , Reactofix dark pink , Procion Brilliant orange , Procion Yellow, Procion Brilliant yellow, Procion Orange, Procion Black, Procion Pink and Procion Turquoise. Nine different colors were produced.

Dyeing Procedure

The dye powder was taken in the beaker containing distilled water and dissolved by continuous stirring in the temperature of 60°C for 15 minutes. Then add Sodium Carbonate to dye liquor and dip the yarn sample. After 15 minutes, add common salt in the liquor and allow it to dye for more 15 minutes. After dyeing, yarn sample were washed in the running cold water for 10 minutes. Then wash the dyed yarn with the 2 gpl neutral soap solution and finally wash with the cold water, rinsed and dried.

Table 3.3. Sources of Natural dyes

Percentage shade (%)	2
Material to liquor Ratio	1:30
Sodium Carbonate (Na ₂ CO ₃)	20 gpl
Common Salt (NaCl)	30 gpl
Temperature	60°C
Dyeing time	45 Minutes

3.7.1. Testing of dyed yarns

➤ Determination of Color Strength

Spectrophotometer analysis was done by using Premier Colorscan SS5100A spectrophotometer to measure K/S and C.I.E values of dyed samples. D65 illuminate having a color temperature of 65000k equivalent to average day light and 10° visual angle were selected to obtain the values. The k/s values of the dyed samples were measured at the visual spectrum (360-700nm). The percent transmission curve of control (raw lotus fiber), six samples of natural dyes and nine samples of reactive dyes used in the study

were obtained. Every dye has its own transmission values. The wavelength at which maximum transmission occur indicates the color present in the dye. The L*a*b* values and reflectance curve of control and dyed samples was obtained. The values DE indicate (maximum change in color), k/s indicate the strength of the color, L* indicate the (lightness of color) , a* indicate (redness – greenness of the color), b* indicate (yellowness –blueness of the color). The testing was conducted at Textile Testing Lab of Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda.

➤ Washing Fastness test

Following ISO standard test no. II (IS: 764: 1979), colorfastness to washing was evaluated. In case of yarn, Lotus dyed yarn was braided with the undyed Lotus yarn. The composite specimen was placed in a glass jar containing 5 gpl soap solution and 2 gpl soda ash solution, keeping material to liquor ratio 1:50. Jars were then closed and placed in Launder -O- meter. Machine was then run for 30 minutes at 60 ± 2 C°. After completion of treatment, the samples were removed and washed with water, squeezed and dried in air. By using Grey scale, the change in shade was assessed and graded from 1 to 5 (1 means poor and 5 means excellent fastness to washing). The tests was performed in textile chemistry lab of Department of Textile Chemistry, Faculty of Technology and engineering, The Maharaja Sayajirao University of Baroda.

➤ Light fastness test

Following AATCC test method 16-B- 1977, colorfastness to light was evaluated by exposing the dyed samples to sunlight for 8 hours to see the effect of fading of color due to sunlight. Lotus dyed yarns was wrapped evenly in the black sheet. Light fastness was evaluated by comparison of exposed portion with the unexposed portion of the material. They were graded from 1 to 8 (1 means poor and 8 means excellent fastness to light). The tests was performed in textile chemistry lab of Department of Textile Chemistry, Faculty of Technology and engineering, The Maharaja Sayajirao University of Baroda.

3.8. Construction of woven fabrics

11 different types of yarns was developed and tested. Based on the properties, 14 different types of woven fabrics were prepared. The weaves were kept plain for all the fabrics.

➤ Construction of Khadi fabrics

Two different types of Lotus Khadi fabrics were developed by the researcher on sample loom at Weaver's service center (WSC) Shahibhag Ahmedabad. Fabric was developed by using 100 % Handspun Cotton yarn in warp and 100 % Handspun Lotus yarn in weft.

➤ Construction of handloom fabrics

Four different types of handloom fabrics were developed. Fine Lotus: Silk union fabric was developed by Mr. Vithal bhai Vaghela. He has an expertise in silk weaving and Patola fabrics. The fabric was developed in the workshop of the weaver - Aadesh Patola house at village Somasar, Surendranagar. Another three Ply yarn woven fabrics was developed at Weaver's service center (WSC) Shahibhag Ahmedabad.

➤ Construction of Power loom fabrics

Seven different types of power loom fabrics were developed in various compositions at Coimbatore, Tamilnadu. Five union fabrics in different yarn counts were developed using 100 % Cotton yarn in warp and 100 % Lotus yarn in weft. 100 % Lotus fabric was developed by using 100 % Lotus fine yarn in both warp and weft direction. Two blended fabrics were developed using two different proportions of Lotus: Cotton blended rotor yarn.

3.8.1. Testing of constructed fabrics

➤ Determination of Fabric thickness: Thickness is the distance between the upper and lower surface of the material measured under the specified pressure, expressed in mm. The specimen chosen were free from folds, crushing or distortion and wrinkles. Specimen was tested on Universal thickness tester. The specimens were tested as directed in ASTM D 1777-96.

➤ Determination of Fabric count: Fabric count in woven textile material is the number of ends and picks per unit area. Following ASTM D 3775-98, the number of warp and weft yarns in one square inch of the fabrics is counted with the help of pick glass at five random selected places across the width and along the length of the test specimens. The region near the selvedge should be avoided because the spacing of the thread is often a little different than the body of the cloth.

➤ Determination of Cover Factor: Cover factor is a numerical value indicating the extent to which area of the fabric is covered by the component yarn. Cover factor was calculated with the following formula:

- Determination of Fabric weight (GSM): Cloth weight is expressed as mass per unit area in g/sq.mt. A sample of 5x5 cm was cut and weighted on an electronic weighing balance to determine the weight per sq.m . GSM was calculated using the formula:-

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

- Determination of stiffness (Bending length): Fabric stiffness is the resistance of the fabric to bending. The samples were tested as per ASTM D 1388- 18 using Shirley's stiffness tester. Rectangular strip of fabric, 6 inch x 1 inch was mounted on a horizontal platform in such a way that it hangs as a cantilever and bends downwards. The strip of the fabric was started to droop over the edge of the platform and the movement of the templates and the fabric was continued until the tip of the specimen viewed in the mirror cuts both index lines. Bending length was read off from the scale mark opposite a zero line engraved on the side of the platform.
- Determination of Drape properties of fabric: Cut the fabric as per the large disc of the drape tester. Place ammonia paper below the specimen holder disc in the drape meter cabinet. Mount the test specimen below the small support disc in the drape meter cabinet and close the door. Switch on the lamp for 5 minutes. After 5 minutes, switch off the lamp and remove the ammonia paper from the cabinet. Open the small cabinet and open the lid of the flask containing ammonia solution. Place the ammonia paper in the cabinet for 10 to 15 minutes and let the image develop on the paper. Take out the paper from the cabinet and cut it as per the developed impression. Trace it on a graph paper and measure its area.

Formula for drape co-efficient is mentioned below:

$$\text{Drape Coefficient} = \frac{\text{Area of the draped specimen} - \text{Area of the support disc}}{\text{Area of the specimen} - \text{Area of the support disc}}$$

Determination of Tensile strength:

Tensile strength of the fabrics was tested on Universal tensile tester (UTM) by ravelled strip test method using ASTM D 5035- 95. The instrument works on the principle of constant rate of extension. Specimen size of 150 mm x 25 mm (15 cm x 2.5 cm) was cut. Gauge length was kept 75 mm ± 1 mm (7.5 cm) with the speed of 300mm/min. Average of 10 readings from both warp and weft direction was taken.

Determination of Abrasion

Following ASTM D 3884, Abrasion of the fabrics was tested using TABER Rotary Platform Abraser machine. The machine has a double head tester. Taber tests involve mounting a specimen (typically less

than 12.5 mm thickness) to a round platform that rotates at a fixed speed. Two abrasive wheels, which are applied at a specific pressure, are lowered onto the specimen surface. As the turntable rotates, the wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center while a vacuum system removes loose debris during testing. The sample size was 6 by 6 inches mounted on a round platform.

The evaluation was done by analyzing the number of cycles, weight loss before and after and wear index was also analyzed. The weight of the pressure arms were 1 Kg. There was a sensor connected to the machine which gives the details of number of cycles.

➤ Determination of Tearing strength:

Following (ASTM D 1424-09) tearing strength of the fabrics was tested. The test determines the force required to propagate a single rip tear starting from the cut in a fabric using a falling pendulum type Elmendorf apparatus. The cut size of the sample was 100 mm x 63 mm. Firstly the pendulum was raised to the starting position. The pointer of the pendulum was set against the dial. Then fabric sample was clamped in the jaws. The machine consist of two jaws. Fabric was clamped and both the jaws was tightly closed maintaining same tension. After clamping, a small slit was made in the bottom edge of the fabric using a knife blade and leaving rest of the fabric length of $42 \text{ mm} \pm 0.15 \text{ mm}$ for tearing. Then release the pendulum stop as far as it go. Once the tearing was completed the pendulum was set without disturbing the position of the pointer. Finally reading was taken. Since the scale of pendulum is graduated to determine the percentage of the potential energy of the pendulum required to tear the sample. So the reading observed in the scale was multiplied by the augmenting weight. The augmented weight was 6400 gf.

➤ Determination of Pilling

Pilling was determined based on the standard ISO 12945-1:2020 (E) using ICI pilling box. For the test, three fabric samples each of 125mm X 125mm (12.5 Cm x 12.5 Cm) was cut from the fabric. Each fabric sample was then folded face to face and on the marked line seam is sewn. Then each sample was turned inside out so the face of the fabric form the outer portion of the tube. After the stitching of the fabric tube, 6mm fabric was cut in top and bottom side to remove any sewing distortion. The fabric tubes were mounted on polyurethane tubes. Care was taken that the seamed portion lies as flat as possible. Each of the loose ends of the fabric sample was taped with the PVC tape so that the test specimen is fixed on the

centre of the rubber tube. Fabric specimen of each category was placed in one pilling box. The tumbling of the fabrics samples was done in a cork-lined box. The number of the revolutions taken was 18,000 which taken around 5 hours. After revolutions tubes were taken out from the box. The fabric specimens were removed from the rubber tube and placed under the light for the evaluation of pills. The pilling of the fabric surface was evaluated against standard swatch as per the standard.

➤ Determination of Shrinkage

The sample size of (300 mm × 300 mm) is cut both from warp and weft way. The samples are marked with three sets of mark in each direction. The marks of 250 mm are made apart are made from all the edges. After marking samples are soaked flat in the vessel containing water with the wetting agents for 24 hours. After 24 hours the samples are taken out from the water and placed flat in the tissue without unnecessary handling and allowed to dry flat. (Saville, B.P. 1999) .

Relaxation shrinkage was calculated using the formula : -

$$\frac{(\text{Original measurement} - \text{Final measurement})}{\text{Original Measurement}}$$

3.9. Development of Knitted fabrics

Initially for experimenting the feasibility of Lotus yarn in knitting, the researcher tried to develop knitted structure using 70:30 Lotus:Cotton blended rotor yarn in the knitting lab of South Indian Textile Research Association, Coimbatore ,Tamilnadu. 100 % Lotus yarn was also experimented for knitting at Knitting Lab of Department of Textile Technology, PSG College of technology, Coimbatore. It was observed that there was great possibility of using lotus yarn (both in pure & blended form) in knitted structure.

Further for making final knitted samples researcher contacted and visited Angel Knitting industry at Surat, Gujarat. With the assistance from the industry chairman and knitting technicians, two different types of knitted fabrics were developed in the circular knitting machine.

3.9.1. Testing of Knitted fabrics

The developed fabric was subjected for the testing of fabric count, thickness, bursting strength, air permeability, pilling and stretch and Recovery properties. The tests were performed in textile testing lab of Department of Textile Technology Faculty of Technology and engineering and Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda.

➤ Determination of knitted fabric count (assessment of wales and coarses)

Following ASTM-D 8007-15, fabric count of the knitted fabrics was determined. This test method is only applicable to weft knitted fabrics – circular, flat bed and double knit fabric categories. Fabric count was assessed by calculating number of wales (wpi) and coarses (cpi) per inch. For the test, fabric was first laid in the table. Pick glass, ruler and pick needle was used for the test. Average of 10 readings were taken.

➤ Determination of Bursting strength

Bursting strength of the knitted fabrics was tested as per ASTM D3786M-18. The test was done on hydraulic bursting tester consist of elastic diaphragm. Knitted fabric was clamped by a ring over a very thin rubber diaphragm which itself clamped over a circular hole in the upper face of reservoir. The operating fluid in the reservoir was oil. After clamping the fabric specimen, the hydraulic pressure is increased by the screw driven piston and the diaphragm distends till the fabric bursts. In the break point the strength is measured in kg/cm^2 .

➤ Determination of Pilling

The developed lotus knitted fabric propensity to pilling was determined based on the standard ISO 12945-1:2020 (E) using ICI pilling box. For the test, three fabric samples each of 125mm X 125mm (12.5 Cm x 12.5 Cm) was cut from the fabric. Each fabric sample was then folded face to face and on the marked line seam is sewn. Then each sample was turned inside out so the face of the fabric form the outer portion of the tube. After the stitching of the fabric tube, 6mm fabric was cut in top and bottom side to remove any sewing distortion. The fabric tubes were mounted on polyurethane tubes. Care was taken that the seamed portion lies as flat as possible. Each of the loose ends of the fabric sample was taped with the PVC tape so that the test specimen is fixed on the centre of the rubber tube. Fabric specimen of each category was placed in one pilling box. The tumbling of the fabrics samples was done in a cork-lined box. The number of the revolutions taken was 18,000 which taken around 5 hours. After revolutions tubes were taken out from the box. The fabric specimens were removed from the rubber tube and placed under the light for the evaluation of pills. The pilling of the fabric surface was evaluated against standard swatch as per the standard.

➤ Determination of Stretch and Recovery

Following ASTM D 2594-99a, stretch and recovery property of the developed knitted fabrics were tested. For the test, three fabric sample of each category were cut in both directions that is wale wise

(lengthwise) and coursewise (widthwise). The sample size was 125 ± 3 mm by 500 ± 10 mm. After cutting the fabric specimen, each sample was fold into half in lengthwise direction. The cut edge was sewed so that it forms a loop like structure.

For performing the test, entire hanger assembly was developed. The assembly consists of hangers, hanger stand, tensiometer (weights), ruler, marker and timer. After arranging the hanger assembly, fabric specimens were laid in the flat surface without tension. Bench marks was made in the central area in lengthwise direction in one side of the fabric specimen. After marking, the fabric specimen was placed between the upper hanger and lower hanger. The folded portion (stitched seam) of the fabric specimen was secured in the lower hanger. The upper hanger was attached in the slot of hanger stand and meanwhile weight of 4.54 kgf (0 to 10 lbf) was secured in the lower hanger by the means of chain. Specified weight is for form-fitting (semi-support) apparel fabrics.

Calculation for fabric growth and stretch properties was determined using the equation mentioned below:

$$\text{Fabric Growth}_{60s} = 100 \times (B-A)/A$$

$$\text{Fabric Growth}_{1h} = 100 \times (C-A)/A$$

$$\text{Fabric Stretch, \%} = 100 \times (D-A)/A$$

Where,

A = original distance between bench marks prior to tension force, mm (in.).

B = distance between bench marks, mm (in.) measured after release of the tension, force following 60 s recovery.

C = distance between bench marks, mm (in.) measured after release of the tension, force following 1 h recovery.

D = distance between bench marks, mm (in.) measured while specimen is under tension force.

Averages of five readings were taken for each fabric sample.

➤ Determination of thickness

Thickness is the distance between the upper and lower surface of the material measured under the specified pressure, expressed in mm. The specimen chosen were free from folds, crushing or distortion and wrinkles. Specimen was tested on Universal thickness tester. The specimens were tested as directed in ASTM D 1777-96.

➤ Determination of GSM

Cloth weight is expressed as mass per unit area in g/sq.mt. A sample of 5x5 cm was cut and weighted on an electronic weighing balance to determine the weight per sq.m . GSM was calculated using the formula:-

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

3.9.2. Development of knitted product

Based on the results of knitted fabrics, 100 % Lotus knitted socks were developed at Angel Knitting industry, Surat, Gujarat.

3.10. Testing of fibers for functional properties

➤ Absorbency of Lotus fiber

Three different types of absorbency test was conducted:-

a). Free Swell absorptive capacity

Free Swell absorptive capacity of Lotus fiber was tested as per WSP 240.3-2011 standard. The test was conducted in the CoE medical textiles laboratory of SITRA South Indian Textiles Research Institute, Coimbatore.

b). Absorbency under Load/Pressure (AUL/AUP)

2 gms of raw Lotus fibers were finely chopped and spread evenly on 400 micron mesh of stainless steel that is fixed at the bottom of acrylic cylinder having the diameter of 6.0 Cm. Load of 21 g/Cm² was placed in the acrylic cylinder. A porous ceramic plate of the diameter of 8.5 Cm and thickness of 5 mm was placed on petridish of diameter 9.5 Cm. The test solution of 0.9 % aqueous Sodium Chloride (NaCl) was taken in the petri dish. Filter paper of diameter 7 Cm comprising the pore size of < 25 μm was placed at the top of ceramic plate and allows it to wet with Sodium Chloride solution. The acrylic cylinder was placed in the center of filter paper to allow fibers to absorb the test solution for 60 minutes. For the accuracy of the results, the experiments were repeated five times and average was calculated.

The AUP/AUL was calculated using formula –

$$Q = \frac{W2-W1}{W1} \times 100$$

Here Q is the absorbency percentage.

W2= Wet weight/Final Weight

W1= Dry weight/Initial Weight

(c). Equilibrium Absorbency

A specified weight of 0.168 gm of raw Lotus fibers was placed in the tea bag (lwx). Specified weight of the fibers was taken in 8 individual tea bags. The top of the tea bags were sealed and the paperclip hanger was inserted in each tea bag for hanging in the titration stands. 8 tea bag containing the fibers were soaked in the beaker containing 150 ml of distilled water for the time interval of 24 hours to determine the maximum absorptive capacity of the fibers. After 24 hours, fibers were taken out from the tea bags and squeezed. Equilibrium Absorbency was calculated using the formula :

$$Q' = \frac{W2-W1}{W1} \times 100$$

Here Q' is the percent equilibrium absorbency

W2= Wet weight/ Final weight of the sample after immersion in the solution

W1= Dry weight/Initial Weight of the sample before immersion in the solution

➤ pH of the Lotus Fibers –

The pH value of the Lotus fibers was measured using pH meter apparatus. pH meter was calibrated before measuring the values. 2 gms of Lotus fiber were chopped and immersed in a beaker containing 400 ml of distilled water. The beaker was manually stirred and shaken till the fiber disintegrates completely. Electrode was inserted in the beaker and the measurements was observed and recorded. Average of five readings was taken.

➤ Antibacterial test

100 % Lotus fiber (in the nonwoven web form) without any treatment was subjected for Assessment of the antibacterial activity of textile materials test as per AATCC 147- 2016 Parallel streak method. It is a qualitative antibacterial test. The test was done in Microbiology lab of Bombay Textile Research Association (BITRA) Bombay, India. The test was performed against four organisms:

1. *Staphylococcus Aurea*. (ATCC 6538)
2. *Klebsiella Pneumonia*. (ATCC 6352)
3. *Candida Albicans*.
4. *Pseudomonas aeruginosa*.

Test method: Test specimens (non sterile) were cut into pieces (25mm x 50mm). The sterilization of the fabric specimen was done by steam flow method. Sterile AATCC bacteriostasis agar plates were

prepared. Using sterile 4 mm inoculating loop, one loop full of culture was and transferred to the surface of the agar plate by making five parallel inoculum streaks spaced 10mm covering the central area of the petri dish without refilling the loop. The test specimen was gently pressed transversely, across the five inoculums of streaks to ensure intimate contact with agar surface. The plates were incubated at 37°C for 24 hours. The inoculated plates were examined for the interruption of growth along the streaks of inoculum beneath the fabric and for a clear zone of inhibition beyond the fabric edge.

➤ Cytotoxicity test (Indirect Method)

Following ISO 10993-5: 2009, Biological reactivity of the L929 mouse fibroblast cell culture is quantitatively determined in response to an extract of the test material in triplicate. The cells are allowed to grow to sub-confluency in tissue culture plates. An extract of the test material is prepared in Minimum Essential Media (MEM) which is transferred onto the cell layer in triplicate. The plates are incubated for 48 h at 37 degree Celsius in a 5 % CO₂ incubator, and scored for reactivity at 24 and 48 h on a scale from Grade 0 (no reactivity) to Grade 4 (severe reactivity). The test item is considered non-cytotoxic if none of the cultures exposed to the test item shows greater than mild reactivity (Grade 2).

3.11. Development of nonwoven fabric and its testing

To check the possibility of developing nonwoven sheet from Lotus fibers, lab scale method was developed. This experiment was done in Textile chemistry Lab of Department of Clothing and Textiles, Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara. Later the final nonwoven sheet was developed in machine at Textile production lab of Avinashillingam Institute for Home Science and Higher Education for Women, Coimbatore Tamil nadu. The developed nonwoven sheet was tested for thickness and GSM.

3.12. Development of hygiene products from nonwoven sheet.

The prototypes were developed in the Incubation Lab of SITRA – South Indian Textile Research Association Coimbatore, Tamilnadu. The hygiene products – sanitary napkin, sweat pads and panty liners was developed as per the standard size and template provided by SITRA. First and second layer of all the hygiene products was kept same as used commercially. The stitching of the hygiene products was done in the Ultrasonic machine. The description of the layers of the hygiene products are mentioned below:

- a). The upper layers consist of polypropylene spun lace sheet.
- b). The absorbent core consist of 100 % Lotus nonwoven sheet.

c). The bottom layer consist of water resistant polyethylene sheet.

3.13. Testing of hygiene product

Absorbency under load:- Ability to withstand pressure after absorption was determined as per IS 5405:2019 Annex B. The test was conducted in CoE medical textiles laboratory of SITRA South Indian Textiles Research Institute, Coimbatore, Tamilnadu. For the test, the titration stand was arranged. In the bottom side of titration stand the transparent plastic tray was placed. The auto burette unit was connected in the titration stand. The flow rate of auto burette unit was 5 ml per minute. The height between the point of auto burette unit and sanitary napkin was kept 22 mm. The sanitary napkin was placed over the flat tray. Reason behind using the flat transparent tray was to have the easy visualization of leakage from back and sides of sanitary napkin. For the artificial blood , .02 mol Bromocresol purple was dissolved in 1000 ml of analytical distilled water. Stop watch was used for time evaluation. Once the entire experimental set up was arranged the beaker containing the artificial blood was poured in the auto burette unit which falls in sanitary napkin. 5 ml of artificial blood was poured per 1 minute in the auto burette unit. Total 6 minute was allowed to absorb the entire 30 ml liquid. After 6 minutes, the observation regarding leakages was done.

If no leakage is observed from back and sides of sanitary napkin then further testing was done by putting the standard weight of 1 kg over the same sample of sanitary napkin for 1 min and the observation was done regarding leakages. Evaluation of the wetness was checked by putting the white tissue paper over the same sample of sanitary napkin. If the tissue doesnot get completely wet and no leakages are observed then sanitary napkin is considered satisfactory for the use.

3.14. Training group of women for fiber extraction and spinning

For conducting training programme, researcher searched on internet about different NGOs working in Vadodara District of Gujarat. Researcher purposively selected NGO HAPPY FACES, Vadodara.

➤ Interaction with NGO

HAPPY FACES is the voluntary public welfare organization in Vadodara works for the betterment of the livelihood of rural peoples including health, education for children, nutrition and infra structure. The NGO was started in 10th May, 2015. Researcher conducted the meeting with the founder of NGO Mr. Piyush Khare on 18/06/2021 for the discussion regarding the training programme related to Lotus fiber extraction. The founder of the NGO was very keen and interested to start women empowerment

activities. The NGO was connected with the different rural clusters of Vadodara district. The founder of the NGO suggested to train the ladies of Zadeshwar village at Akshar Chowk, Atladara, Vadodara. So the entire training programme was done in collaboration with NGO HAPPY FACES, VADODARA. The training programme was named as “Project Sulbha”. Initially the women coordinator the NGO conducted the meeting regarding this lotus fiber training programme with the ladies of the Zadeshwar village.

➤ Locale of the training programme

Zadeshwar is the area near Sun Pharma Road, near BAPS Swaminarayan Temple Narayanwadi Atladara, Vadodara. The NGO has developed the street school in the Zadeshwar village. In this school poor children gets the free education in the morning time and in afternoon session parents of these children specially the mothers and young girls (above 18 years of age) were trained for Lotus fiber extraction. The training programme was done in the school of the village so that ladies can save time for transport and meanwhile they can take care of their family members.

➤ Training for fiber extraction and spinning.

The first training session was conducted on 7/7/2021. Researcher, founder and coordinator of NGO went to the center with all the equipments and raw material. The session started with the general introduction about the training programme by the founder of the NGO and researcher. After introduction the researcher demonstrated the entire fiber extraction process and also given the chance to the ladies to practice the extraction process. Training for spinning was also given to ladies. Two week training was given to the ladies. (not paid) The timing of the training programme was for 3 hours that is 3.00 to 6.00 PM.

➤ Selection of ladies for final training programme

After two weeks training the researcher purposively selected 8 ladies as per the quality of fiber extraction, quality spinning, productivity and dedication towards the work. Copy of Aadhar cards of all the 8 ladies was collected by the researcher. It was taken care of that all the 8 ladies selected were above 18 years. Consent of all the ladies were taken.

➤ Development of schedule for the training programme

After development of the cluster for training the entire schedule was prepared for fiber extraction on the basis of duration, time and fund. All the necessary equipments were purchased before starting the project. The entire project was funded by NGO and the researcher got the project from GARGI – “Center for holistic development for women” scholarship by Dr. Babasaheb Ambedkar Open University, Ahmedabad. The researcher, mentor and NGO founder decided to develop handwoven stoles from the yarn developed by the ladies.

➤ Weaving of handwoven stoles

For weaving researcher visited Bhujodi, Kutch. Weaving of the stoles was done by Artisian weaver Mr.Pachan Premji. Stoles was prepared using 100 % Lotus yarn in weft and 100 % cotton yarn in warp on handloom.. Fabric was dyed with natural dyes: sappan wood and indigo.

➤ Exhibition of the developed fabrics

Developed fabrics were exhibited in three different exhibitions. First exhibition was done on International women’s day on 8 March, 2022 at Eva Mall Manjalpur, Vadodara, Gujarat. Second exhibition was at “Agripreneurs conclave – 2022” at GTU campus, Chandkeda, Gujarat. Third exhibition was done at “Weave Knit 2022 (The complete fabric show) 2nd Edition”at Sarsana, Surat.

CHAPTER -4

RESULTS AND DISCUSSIONS

The results were aimed to utilize the byproduct that is Lotus petioles for textile applications. In the present study, fibers were extracted manually by varying number of petioles and further spinning it using Ambar charkha. The major drawback of Lotus fiber is tedious and time consuming extraction process. Hence two machines (with different mechanism) were designed and fabricated. The machine - 1 was specifically designed for extracting and spinning the yarns simultaneously one at a time. Different counts of yarns were obtained from the machine-1. Yarns obtained from the machine were used directly for developing fabrics on Handloom and powerloom. The machine -2 was specifically designed for extracting raw fiber which can further used for developing nonwoven sheet, rotor and ring spun yarns. Total 11 different types of yarns were developed. Based on the results of yarn, 14 different types of woven fabrics were constructed which comprises of 2 khadi fabrics, 5 handloom fabrics and 7 powerloom fabrics. As the Lotus fiber was extremely soft, has a good elongation property, excellent pliability and inherent antibacterial properties so the attempt was made to develop circular knitted structure. Two different varieties of 100 % Lotus circular knitted structure were developed. Based on the testing results of fabric, 100 % Lotus socks were developed. Lotus fibers were tested for its functional properties like absorbency, antibacterial property, Cytotoxicity and pH. Based on the positive testing results further nonwoven fabric was developed and hygiene products :- sanitary napkin, sweat pads and pantyliners were developed and tested. Color is the major concern when selling the fabrics in the market. Hence the 100 % Lotus yarns were dyed with 9 different types of natural and reactive dyes. The dyed yarns were tested for color strength and fastness properties. To take the research from lab to community, researcher conducted the training programme in collaboration with HAPPY FACES NGO, Vadodara. Group of ladies were trained for fiber extraction and spinning. Handwoven stoles were prepared from the developed yarn and exhibited.

The results have been given and discussed under following section:-

- 4.1. Extraction of fibers for yarn making and nonwoven sheet preparation
- 4.2. Testing of fiber

- 4.3. Spinning of hand extracted yarn using Ambar charkha and analysis of its properties
- 4.4. Designing and construction of machines
 - Machine -1
 - Machine -2
- 4.5. Development of yarns from machine- 1 and its Testing
- 4.6. Development of blended yarns and its properties
- 4.7. Analysis of dyed yarns (Color strength and fastness properties)
- 4.8. Construction of woven fabrics and its properties
- 4.9. Construction of knitted fabrics and its properties
- 4.10. Development of knitted product
- 4.11. Functional properties of Lotus fibers
- 4.12. Construction of nonwoven fabric and its properties
- 4.13. Development of hygiene products and its properties
- 4.14. Training the women force for extraction and spinning.
- 4.15. SWOC Analysis

4.1. Extraction of fibers for yarn making and nonwoven sheet preparation

For yarn making, several trails were done by varieting number of petioles. The main reason behind varieting the number of petioles is for obtaining different counts of yarns and checking its feasibility for spinning and weaving. For extraction required petiole was taken and it was slited into 5-7 sections as per the length with a sharp knife. After each slit the petioles were slowly stretched and fibers were laid into the wooden slab. Extracted fibers were directly winded on the pern joining end to end by palm twisting. It was observed that more concentration and skill is required for extracting fiber from one petiole and the extraction from two and three petioles were easy manageable. The output obtained by the manual extraction process was “unspun yarn”.

It was observed that while yarn making there was a small left over pieces of petioles which still contains fibers. The attempt was made to utilize these fibers for developing nonwoven sheet. Felt fabric (53 L × 41W) was laid on the floor. Bunch of four to seven Lotus small leftover pieces were taken together and slited with sharp knife. Extracted fibers were laid horizontally and vertically on the woolen felt. Due to the inherent cohesive nature of the fiber it naturally form a web like structure.

4.2. Properties of fibers.

Length of the fiber was 60-150 Cm. Diameter of the fiber was in the range of 2-5 μm which falls under the category of microfiber. Bundle strength of the fiber was 18.5 g/tex and extension was 4.2 mm. By the visual appearance the color of the fiber varies from off white to light yellowish. The whiteness, brightness and yellowish index of the lotus fiber was 15.028, 41.130 and 38.198 respectively. Single fiber strength was 161.5 g/f with the extension of 1.5589 mm. The moisture regain of the fiber was 11.8 more than Cotton but near to silk and viscose. From the FTIR analysis it was observed that broad characteristic peaks were 3718-3628 Cm^{-1} belong to the stretching of OH-groups of Cellulose – I . In the XRD analysis, a sharp peak was observed at 14° and wide peak was found at 21°. Peaks were not very sharp thus there were more amorphous region in Lotus fibers. Crystallinity index (CI) was 40 %.

4.3. Spinning of hand extracted yarn

In the pilot work the spinning was tried on Takli (Drop spindle) and peti (box) charkha also. But the output of the spun yarn was very less. Hence the Ambar charkha was used for spinning.

Table 4.1. Codes of handspun yarns

Sr.no.	Yarn codes	Description
1	L1A	Lotus yarn , 1 petiole extracted , Ambar charkha spun yarn
2	L2A	Lotus yarn , 2 petiole extracted , Ambar charkha spun yarn
3	L3A	Lotus yarn , 3 petiole extracted , Ambar charkha spun yarn

Analysis of the properties of hand spun yarns.

Three different hand spun yarn was obtained that is L1A , L2A, L3A. It was observed that most finer yarn was L1A having a count of 96's followed by L2A that is 86's and L3A that is 81's. All the yarns consist of S-direction twist. L1A has a highest twist of 130 TPI followed by L2A that is 121 TPI and L3A that is 63 TPI. Strength of L1A yarn was higher with the maximum load of 219.188 gf followed by L3A has a maximum load of 129.763 gf. L2A yarn has a less strength with the maximum load of 115.618 gf. Amongst all the three yarns extension of L2A yarn was higher that is 4 mm.

4.4. Designing , construction and working of machines

➤ Machine – 1

The machine -1 is specifically designed in such a way that it can extract fibers and spin the yarn simultaneously. Machine was fabricated and got the patent grant (IN201921032058). The machine was found successfully for developing Lotus yarn

➤ Machine -2

The machine 2 is designed in such a way that it can extract fiber in the raw form which can be further used for developing nonwoven web, rotor and ring yarns. Fabricated machine has been applied for patent.

4.5. Development of yarns from machine- 1 and its Testing

Four different counts of yarns were achieved from the fabricated machine by optimizing the speed of feeding and winding rollers. It was observed that MYHS1 was more finer with the count of 71's followed by MYHS2 (60's), MYMS (33's) and MYLS (28's). Twist direction of all the yarns were S. MYHS1 and MYHS2 has a higher twist of 100 TPI. MYLS yarns has a higher strength with the maximum load of 223.41 gf followed by MYMS (194.46 gf), MYHS2 (81.454 gf) and MYHS1 (78.028 gf). Amongst all the four yarns, MYHS1 yarn showed highest extension of 6 mm. 600 grams of yarn can be developed from fabricated machine in high speed 1 in 6 hours using 1 man power.

Table 4.2. Codes of machine spun yarns

Sr.no.	Yarn codes	Description
1	MYHS1	Machine yarn high speed 1
2	MYHS2	Machine yarn high speed 2
3	MYMS	Machine yarn moderate speed
4	MYLS	Machine yarn low speed

4.6. Development of blended yarns and its properties

Two different types of blending were done: 1). Fiber blending 2). Yarn blending

Two blend proportion was obtained that is: 50:50 (Lotus: Cotton) and 70:30 (Lotus: Cotton). For fiber blending, long length of fibers were collected manually from the petiole and arranged lengthwise over a felt. These fibers were subjected for developing blended yarns using Rotor spinning technique.

To enhance the inherent superior length quality of Lotus yarn, blending was done in the yarn stage by plying technique. Another reason for developing ply yarn is in handloom 100 % Lotus yarn cannot withstand strength in warp direction due to the lower strength. So plying with the other natural fiber like Cotton, Silk and Wool can help to impart strength in warp and in weft 100 % Lotus yarn was used. With this concept ply yarns were developed. Analysis of the properties of blended yarns

It was observed that Rotor spun yarns were coarser in count. LCRY (50:50) yarn has 5's count finer than LCRY (70:30) yarn that has 3's count which may be due to the more amount of Lotus fiber in LCRY (70:30) yarn composition. Both the yarns have a twist in Z direction. LCRY (50:50) yarn has higher twist of 94 TPI as compare to LCRY (70:30) yarn which has 82 TPI. The strength of LCRY (70:30) yarn was more with the maximum load of 656 gf as compare to LCRY (50:50) yarn which has a maximum load of 528 gf. The extension of LCRY (70:30) yarn was higher that is 32 mm as compare to LCRY (50:50) yarn that is 30.5 mm this may be due to inherent elongation property of Lotus fibers.

In the ply yarn category, Twist direction of all the Ply yarns were Z. Amongst all the ply yarns YLWP showed higher tensile strength with the maximum load of 445.36 gf followed by YLSP (278.056 gf) and YLCP (205.68gf). YLWP showed higher extension values of 22.60 mm this is because of inherent elongation property of Wool fiber. YLSP showed higher twist of 90 TPI followed by YLWP (70 TPI) and YLCP (60 TPI).

Table 4.3. Codes of machine spun yarns

Sr.no.	Yarn codes	Description
1	YLCP	Yarn Lotus Cotton Ply
2	YLSP	Yarn Lotus Silk Ply
3	YLWP	Yarn Lotus Wool Ply
4	LCRY (50:50)	Lotus:Cotton Rotor yarn 50:50
5	LCRY (70:30)	Lotus:Cotton Rotor yarn 70:30

4.7. Analysis of dyed yarns (Color strength and fastness properties)

Fastness properties

Light fastness properties of Lotus yarns dyed with natural dyes excluding yarns dyed with Indigo has an excellent lightness properties ranging from 6-7. Only the Lotus yarns dyed with Indigo has good color fastness properties has showed the value 4 out of 7. Washing fastness properties of Lotus yarns dyed with natural dyes were good to excellent ranging from 3-4 and 4-5.

Light fastness properties of Lotus yarns dyed with reactive dyes was excellent ranging from 6-7. The washing fastness properties of Lotus yarns dyed with reactive dyes were good to excellent ranging from 3-4 and 4-5.

4.8. Construction and properties of woven fabrics

Based on the testing results of yarns, 14 different woven fabrics was developed which consists of 2 Khadi fabrics, 5 handloom fabrics and 7 power loom fabrics. Construction details of all the woven fabrics are given in Table – 4.4.

Table – 4.4. Construction details of woven fabrics

Sr. No	FABRIC CODE	WARP		WEFT				
		FIBER CONTENT	YARN COUNT	FIBER CONTENT	YARN COUNT	NUMBER OF PETIOLES	EXTRACTION METHOD	DESCRIPTION OF YARN MAKING
1	HS Fabric - 1	Fine cotton hand spun yarn	120's	100 % Lotus hand spun yarn	2/ 86's	2 petiole	Manual	Hand spinning by Ambar charkha
2	HS Fabric - 2	Fine cotton hand spun yarn	120's	100 % Lotus hand spun yarn	3/81's	3 petiole		

HANDLOOM FABRICS

Sr.No	FABRIC CODE	WARP			WEFT			
		FIBER CONTENT	YARN COUNT	DESCRIPTION OF YARN MAKING	FIBER CONTENT	YARN COUNT	No.of petioles	DESCRIPTION OF YARN MAKING
3	HL Fabric - 3	Mulberry silk :Lotus ply yarn	100's	Machine spun mulberry silk	100 % Lotus	96's	3	Hand spinning by Ambar Charkha
4	HL Fabric - 4	Lotus:Cotton ply yarn (3 Lotus + 1 Cotton)	4/23's	Twisting by Ambar Charkha	100 % Lotus	3/28's	3	Machine extracted and machine spun from fabricated machine
5	HL Fabric - 5	Lotus:Silk ply yarn (3 Lotus + 1 Silk)	4/40's	Twisting by Ambar Charkha	100 % Lotus			
6	HL Fabric - 6	Lotus:wool ply yarn (3 Lotus + 1 Wool)	4/9's	Twisting by Ambar Charkha	100 % Lotus			
7	HL Fabric - 7	Handspun Cotton	120's	Handspun by Ambar Charkha	100 % Lotus			

POWERLOOM FABRICS

Sr.No.	FABRIC CODE	WARP			WEFT			
		FIBER CONTENT	YARN COUNT	DESCRIPTION OF YARN MAKING	FIBER CONTENT	YARN COUNT	Description of yarn making	Number of petioles
8	PL Fabric - 8	Cotton	80's	Machine spun	100% Lotus	3/71's	Machine extracted and machine spun from fabricated machine	3
9	PL Fabric - 9	Cotton	70's	Machine spun	100% Lotus	3/60's	Machine extracted and machine spun from fabricated machine	3
10	PL Fabric - 10	Cotton	30's	Machine spun	100% Lotus	3/33's	Machine extracted and machine spun from fabricated machine	3
11	PL Fabric - 11	Cotton	20's	Machine spun	100% Lotus	3/28's	Machine extracted and machine spun from fabricated machine	3
12	PL Fabric - 12	100 % Lotus	3/70's	Machine extracted and machine spun from fabricated machine	100% Lotus	3/70's	Machine extracted and machine spun from fabricated machine	3

13	PL Fabric - 13	70:30 Lotus: cotton blended	5's	Rotor yarns spun	70:30 Lotus: cotton blended	5's	Rotor yarns spun	Fiber extracted in the raw form
14	PL Fabric - 14	50:50 Lotus: Cotton blended	3's	Rotor yarns spun	50:50 Lotus cotton blended	3's	Rotor yarns spun	Fiber extracted in the raw form

Evaluation of the properties of the woven fabrics.

➤ Thickness of the fabrics

PL Fabric -14 (fabric woven with 70:30 Lotus Cotton open ended yarns both in warp and weft direction on power loom) has showed higher thickness of 0.52 mm due to the coarser appearance of the rotor yarns. HL Fabric – 1 (fabric woven with mulberry silk warp and Lotus weft woven on handloom) has showed lower thickness of 0.24 mm. This may be due to the finer count and appearance of mulberry silk yarns and finer count of lotus yarn extracted from one petioles.

➤ Fabric count and Cover factor

Powerloom fabrics developed from Rotor yarns has obtained low fabric count and higher cover factor. Union fabrics developed on power loom has obtained higher fabric count and cover factor. Amongst all the fabrics , HL Fabric – 3 (Handloom fabric :Warp - Machine spun Mulberry Silk yarn ; Weft – handspun Lotus yarn – 1 petiole) has showed cover factor of 2.8 means fabric consist of more spaces to pass air and light and the fabric will be more breathable. Thus, this constructed fabric has a sheer net light appearance.

➤ GSM of the fabric

In the Khadi fabric category, HS fabric -1 (Handspun fabric:- Warp – handspun Cotton yarn ; Weft – handspun Lotus yarn – 2 petiole) was lighter in weight of 80 GSM as compare to HS fabric -2 (Handspun fabric :- Warp – handspun Cotton yarn ; Weft – handspun Lotus yarn – 3 petiole).

In the handloom fabric category, HL Fabric – 3 (Handloom fabric: Warp - Machine spun Mulberry Silk yarn ; Weft – handspun Lotus yarn – 1 petiole) has obtained lesser weight of 71 GSM.

In the powerloom fabric category, PL Fabric -13(Powerloom fabric :Warp & Weft – Open end/Rotor yarn – 50:50 Lotus: Cotton) and PL Fabric -14 (Powerloom fabric (Warp & Weft – Open end/Rotor yarn – 70:30 Lotus: Cotton) was very heavier in weight of 323 and 336 GSM respectively. This may be due to the coarser count of yarns.

It was analyzed that all the fabrics excluding the fabrics developed from rotor yarns were lighter in weight ranging from 1-4 oz. So these fabrics can be used in blouses, shirting and light summer dresses. Fabrics developed from rotor yarns were heavier in weight that is more than 9 oz . These fabrics can be used in blankets, heavier coats and denims.

➤ Drape Co-efficient of fabrics

Amongst all the fabrics, the drape co-efficient of HL Fabric – 3 (Handloom fabric :Warp - Machine spun Mulberry Silk yarn ; Weft – handspun Lotus yarn – 1 petiole) was 18 means the fabric has good Drapability. This may be due to the finer and light weight Silk yarns in warp and finer Lotus yarn extracted from one petioles. The drape co-efficient of PL Fabric – 14 (fabric woven with 70:30 Lotus Cotton open ended yarns both in warp and weft direction) was 64. This may due to the coarser appearance of rotor yarns. Hence this fabric can be used in developing jackets, coats and household applications.

➤ Tearing Strength

HL fabric – 7 (Handloom fabric : Warp - handspun Cotton yarn ; Weft – Machine extracted and spun High RPM -1 Lotus yarn – 3 petiole) has showed higher tearing strength in both warp and weft direction. The lowest tearing strength was observed in HL Fabric – 3 (Handloom fabric: Warp - Machine spun Mulberry Silk yarn; Weft – handspun Lotus yarn – 1 petiole) in both warp and weft direction. It may be due to delicate Lotus yarn used in weft direction which is extracted from one petiole.

➤ Pilling

Khadi fabrics has showed no pilling with the rating 5. Amongst the handloom fabric, HL Fabric – (Handloom fabric: Warp – Cotton: Lotus ply yarn; Weft – Machine extracted and spun low rpm Lotus yarn – 3 petiole) and HL Fabric –6 (Handloom fabric: Warp – Lotus: Wool ply yarn ; Weft - Machine extracted and spun low rpm Lotus yarn – 3 petiole) showed slight pilling with the rating 4. Rest all the fabrics in the handloom category has showed no pilling. In the power loom category, fabrics developed from rotor spun yarns has showed slight pilling with the rating 4.

➤ Dimensional stability – Shrinkage test

Amongst all the 14 fabrics, PL fabric – 11 (Powerloom fabric: Warp – machine spun Cotton yarn ; Weft – machine extracted and spun Lotus yarn - Low RPM) has showed 3 % warp shrinkage and 5 % weft shrinkage. Fabrics developed from rotor spun yarns has showed slight shrinkage of 0.3 % in both warp and weft direction.

➤ Tensile strength

Power loom Fabrics developed from rotor yarns has a higher tensile strength and elongation in both warp and weft direction. Khadi fabrics showed lesser tensile strength in weft direction. This may be due to the lesser strength of Lotus handspun yarns used in weft direction. HL Fabric – 3 (Handloom fabric: Warp - Machine spun Mulberry Silk yarn; Weft – handspun Lotus yarn – 1 petiole) has showed less elongation and tensile strength in weft direction. All the union fabrics developed on powerloom and handloom has obtained higher tensile strength in weft direction. This may be due to higher strength of Lotus yarns developed from the fabricated machine.

➤ Stiffness

Amongst all the constructed fabrics it was observed HL Fabric – 3 (Handloom fabric :Warp - Machine spun Mulberry Silk yarn ; Weft – handspun Lotus yarn – 1 petiole) has showed lower bending length in both warp and weft direction. Higher bending length was observed in the fabrics developed in powerloom using 100 % coarser Lotus yarns and blended rotor spun yarns.

➤ Abrasion

Powerloom fabrics developed from rotor yarns has obtained highest cycles of 800-1000. 100 % Lotus powerloom fabric has showed 600 cycles. Handloom fabrics developed from ply yarns has obtained 500-600 cycles. Lesser cycles was observed in the Khadi fabrics that is 200 cycles.

4.9. Development of Knitted fabrics and testing its properties

The Lotus fiber is soft, lustrous, pliable, inherently antibacterial and has a good elasticity due the spiral arrangement of fine microfibers in the bundle. In knitting the yarn has to pass through several needles so the quality of the yarn especially strength, pliability and evenness plays a major role to obtain a good quality fabric. Amongst all the 11 yarns, only two finer yarns (MYHS1 & MYHS2) developed from fabricated machine was found applicable for the development of circular knitted structure. Two different types of 100 % Lotus circular knitted fabrics were developed.

Table 4.5. Construction details of Knitted fabrics

Sr. No	Fabric Type	Description
1	LK1	Lotus knitted (Machine extracted and spinned 3/71's count yarn) with Elastane)
2	LK2	Lotus knitted (Machine extracted and spinned 3/60's count yarn) with Elastane)

Analysis of the properties.

The bursting strength of LK2 fabric was found higher that is 11.08 Kg/Cm² as compare to LK1 fabric that is 7.57 Kg/Cm². It was observed that LK1 fabric has no pilling with the rating 5 and LK2 fabric has slight pilling with the rating 4. Stretch percentage points (recovery percentage) of LK1 was 40 % in the wale direction and 90 % in the coarses direction. Hence this type of structure can be suitable for the application in form-fitting (semi-support apparel). Stretch percentage points (recovery percentage) of LK2 was 20 % in the wale direction and 40 % in the coarses direction. Hence this type of structure can be suitable for the application in Loose Fitting (Comfort Stretch) apparel type. Both the fabrics were lighter in weight having GSM ranging from 1-4 oz.

4.9. Development of knitted product

Socks were developed from 100 % Lotus yarns. Developed socks were soft in feel and comfortable to wear.

4.10. Functional properties of Lotus fibers

Lotus fibers showed positive antibacterial activity against *Staphylococcus aureas*, *Klebsiella Pneumonia*, *Candida Albicians* and *Pseudomonas Aeruginosa*. Lotus fiber has a bacteriostatic antibacterial activity. No growth of bacteria was seen in the fiber. Free swell capacity of the Lotus fiber was 35.17 %. Free absorbency of the Lotus fiber was 50.85 % in 180 minutes, Absorbency under load was 16.01 % in 60 minutes and Equilibrium absorbency was 40 % in 24 hours. pH of the Lotus fiber was 6.9. As per ISO:5405, the sanitary napkins should have a pH value between 6.9 and 8.5 to fulfill the purpose without causing any skin irritation and discomfort. From the Cytotoxicity tests it was found that Lotus fiber is non- cytotoxic with the grade 1.

4.11. Development of Nonwoven fabric and its testing

To check the possibility for making the nonwoven sheet from Lotus fibers, lab scale method was developed. Fibers extracted on the woolen felt horizontally and vertically forms a web like structure due to the natural cohesiveness properties of fiber. To develop more compact structure the web was further taken from woolen felt to A4 size paper. Water was sprinkled on the web. Then the A-4 size sheet comprising of extracted fibers was covered with the polypropylene mess. To get the compact structure sheet was passed through padding mangle in 3 psi pressure. Then sheet was kept to dry in moisture oven for 1 hour at 100° C. After drying the compact nonwoven structure was formed. Finally for the applications in medical textiles, final nonwoven sheet was developed in machine. For that fibers extracted in the raw form was weighted and passed through the carding machine. The carding machine opens up the individual fibers. Finally the 100 % Lotus nonwoven web was developed. It was observed that the web prepared was thin and its GSM was light. The entanglement of fibers was also good. Since the application of the sheet was in absorbent core material of hygiene products so it was not proceeded further for needle punching. Thickness of the nonwoven fabric was 0.47 mm. GSM of the nonwoven fabric was 58.

4.12. Development of hygiene products and its testing

The entire lotus plant is endowed with numerous medicinal properties. It was observed that Lotus fibers has many functional properties like inherent antibacterial properties without any finishing, excellent free swell capacity and absorbency. The main component of hygiene medical textiles is its absorbent core layer. Moving to the sustainability there is a demand of eco-friendly fibers for the application in the core layers. Hence it was decided to implement these fibers in the core layers of hygiene medical textiles.

Initially the layers of sanitary napkin were cut according to the standard template. The size of the Lotus nonwoven sheet was 62L×23W Cm. After cutting, the Lotus nonwoven sheet for absorbent core of sanitary napkin it was observed that there was small leftover pieces. Hence these leftover pieces were implemented in the absorbent core layer of sweat pads and panty liners. First all the layers were cut according to the standard template. All the layers were arranged. The stitching of the hygiene products was done in the Ultrasonic machine. The sanitary napkin was developed in all the sizes – regular, large and extra large.

A women undergoes many physical activities like walking, sitting, driving etc so there is certain pressure which is exerted. The sanitary napkin should be designed in such a way that it should have a capacity to hold the menstrual fluids without any back and side leakages. To test the ability of the absorbent core the sanitary napkin was subjected for the absorbency under load test. It was found that developed sanitary napkin can absorbed 30 ml colored liquid within 6 minutes and there was no leakage observed at bottom and sides of the sanitary napkin.

4.13. Training the women force for extraction and spinning

Group of rural women learned the manual extraction and hand spinning process of Lotus fibers. They were paid for the work. The main purpose of the training programme is to contribute to all the three E's that is: Economy, Environment and Empowerment.

Economy: Ladies worked in the project have a work of selling clothes in the roadside. After the Co-vid pandemic, there source of income decreased. The training provide some work which they can do from their village itself and they can earn economy for their sustenance.

Environment: Lotus is a fastest growing plant. Plucking the waste petiole biological increases the growth of the plant. It cleans the pond and maintains the pond ecosystem.

Empowerment: After learning the process of extracting fibers the trained women mentioned that, they feel very lucky to learn this kind of skill in their life. The training programme is conducted in their village itself so they donot have to move outside for work they can easily manage their households and this fiber extraction work. Old age ladies were also happy to do this work because they have to sit in one place and work.

Hand woven stoles were prepared from the yarn developed by the ladies. In the initial days of the training programme the quality of the yarn was not so uniform later with patience and practice they improved the quality. The 100 % Lotus yarn developed by the ladies was of 20's count. These hand woven stoles were exhibited in three different exhibitions.

For the first exhibition, the founder of the NGO, researcher and mentor planned to exhibit the fabrics on International Women's day – 8 March, 2022. The main reason behind this was to bring all the hardworking ladies in the limelight for learning this skill of fiber extraction and spinning. The exhibition was conducted at Eva mall, Manjalpur Vadodara. The ladies who have done extraction and spinning were also invited and they were appreciated for their hard work in the stage. Exhibition was not for sale it was just to introduce the concept and promote the novel fabric. Approximately 100 peoples visited the stall, they like the texture and feel of the fabric. After the entire programme the feedback was taken from the ladies. Ladies told that we are very lucky to learn such kind of skill in life and it has helped to manage some of their financial crisis. They quoted that earning the money by their own hard work has a different charm and it gives a great satisfaction. They are ready to continue this work in coming future.

For the second exhibition, GTU Innovation and start up center in collaboration with AIC (Atal Incubation center) and ACCWF (Ahmedabad Chamber of Commerce Welfare Foundation) jointly organized Agri based Exhibition named “Agripreneur conclave – 2022” with the soul objective of filling up the gaps, branding and sector specific sustainable growth for Agri based startups. Through social media coverages, the vice chancellor and committee members of the exhibition contacted and approach the researcher to present the Lotus fabrics in the exhibition. The stall name was – “Agrowaste to Ecotextiles – Lotus petiole finds a new place in Fashion industry”. Different start up agencies, people associated with the agriculture and students visited this stall.

Third exhibition was done at Surat, Gujarat. Due to wide media coverage, vice president and members of Southern Gujarat Chamber of Commerce and Industry (SGCCL) contacted and approached the researcher for exhibiting the Lotus fibers, yarns and fabrics in Weave Knit 2022 (The complete fabric show) 2nd Edition, exhibition. The stall, staying and travel expenses were entirely sponsored by the SGCCL. So the researchers presented the developed fabrics in the exhibition. The exhibition was conducted for three days that is – 24-25 July, 2023 at Sarsana, Surat. The name of the stall was “Padmapalash”. Fabric manufacturing industries :- Nilkant fabrics, Vedanta fabrics, Milan textiles, Krishna Textiles, Suril textiles, Yogeshwar Textiles, , Batsons Textiles, Dhanlaxmi Textiles, Knitworld, Jenny Fashion, Shree Hari Tex etc from Surat , Gujarat visited the stall. Peoples from the industry like the feel, drape and texture of the fabrics. Different yarn manufacturers like Shangvi spinners, Agarwal Fabtex private limited, Color Trendz etc visited the stall. They liked the fineness and feel of the yarns. Peoples from CMAI – The Clothing Manufacturers Association of India of

South Gujarat Region also visited the stall and well appreciated the entire concept of making fabrics from Lotus petioles.

The exhibitions has given a wide coverage of the entire work.

4.14. SWOC Analysis

Strengths

1. There are no chemicals used in the entire process.
2. High yield and quality yarn has been achieved from the fabricated machine
3. The fabricated machine has dual mechanism of extracting fiber and twisting into yarn at the same time.
4. There is a wide availability of raw material – Lotus petioles in and around Vadodara district of Gujarat.
5. Lotus fiber has an inherent functional properties – water absorbency and antibacterial properties
6. The fiber can be alternative to Silk.

Weakness

1. After collecting the waste petioles from the pond the extraction of the fibers has to be done within five days to obtain continuous and uniform fibers. After five days the petioles get stiff and dry.
2. During the heavy rain and flood the availability of the waste petioles is very less because it becomes very difficult for the lotus flower pluckers to get in the pond.

Opportunities

1. Additional time for the spinning process can be reduced if we use fabricated machine.
2. Lotus fibers can be dyed with natural dyes as it has achieved a good fastness property also.
3. It is found that 100 % Lotus yarn is been successfully used in developing knitted structure so there is a wide scope of developing innovative knitted seamless garments .
4. There is a wide scope of generating job opportunities for rural peoples and SHG for fiber extraction and spinning.
5. After drawing yarn from the stems, leftover pieces also consist of fibers which can used for developing nonwoven sheet for technical applications.

Challenges

1. Awareness of Lotus fiber fabric in Indian market.

2. Training for extracting fiber and developing yarn from the fabricated machines
3. Handling of the machine
4. Maintaining the quality of the extracted fiber
5. Systematic supply chain and logistics planning is required in the entire process of fiber extraction to end product.

Chapter -5

Conclusion

Moving to the sustainability there is a need of eco-friendly products which doesnot consist any harmful chemicals in the entire process. Lotus, a minor aquatic fiber hidden in the water has numerous properties can be used success fully in the various areas of textiles – woven, nonwoven and knitting. The very basic need in the entire process is the development of machines for extracting fibers and developing yarn. Consequences of the study indicate that:-

- Fabricated machine has a dual mechanism of fiber extraction and spinning one at a time. 600 grams of spun yarn can be developed from the fabricated machines (high speed) in 6 hours using 1 manpower whose role is to feed the stems in the machine and operating the speed regulators. Whereas in the manual extraction and spinning process only 30 grams of yarn (6 hours extraction + 1 hour spinning) can be developed in 6 hours using 1 manpower.
- Twist per inch of all the developed were high due to the inherent property of adhesion and more amount of fats and waxes in fiber composition.
- Using different spinning systems yarn with the count range of 3's to 96's has been achieved.
- Yarns developed from the fabricated machines has opened wide opportunities of using lotus yarn in the knitting machines and in powerloom weaving.
- Color is one the major concern in apparels. Fastness properties of Lotus yarn dyed with natural and reactive dyes was very good to excellent.
- Amongst all the fabric, Lotus: Silk (Fine lotus in weft and mulberry silk in warp) was lighter in weight, less in thickness, cover factor and fabric count. Dimensional stability property like shrinkage and serviceability properties like abrasion and pilling was also good. But the tensile strength and elongation was less as compared to all other fabrics. So its use can be restricted in the garments where the less stress is required.
- Fabrics developed from open end yarns has showed an excellent tensile strength.
- Lotus fiber has showed inherent functional properties – positive antibacterial property against *S.aureas*, *Klebsialla pneumonia*, *Candida Albicians* and *Pseudomonas aeruginosa*, high free swell capacity and non cytotoxic.
- The outcome of the study has visualized a future possibility of channelizing an entire commercial set up of Lotus fiber extraction, spinning, fabric development (woven, nonwoven & Knitting).

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Endorsement from the Supervisor

Ms. Sumi Haldar has researched extensively on the topic **“AN EXPERIMENTAL STUDY ON EXTRACTION OF FIBERS AND USES OF LOTUS PETIOLE: A HYGROWASTE** vide registration No: FOF/212, (Dated : January 16, 2021). She conducted extensive work which has been substantiated its originality. She has presented her progress of work in seminars well attended by teachers and students of department. She has successfully completed her course work.

She has presented thirteen papers at International level : **1).** *“Development of Union fabrics from Lotus petiole waste”* at International Virtual conference on Sustainability in Fashion Design and Manufacturing conducted by Department of Fashion Technology, PSG College of Technology, Coimbatore, India from 11 and 12 June, 2021. **2).** *“Lotus – a gen next Fiber”* at International Conference on sustainable growth in Textiles conducted by Uttar Pradesh Textile Technology Institute, Kanpur from 19-21 August, 2021. **3).** *“Horticulture waste towards Sustainable textiles and fashion”* at International Conference on Fashion, Apparel and Textile organized by Amity School of Fashion technology, Uttar Pradesh on 16 and 17th November, 2021. **4).** *“Innovative Biofibers and Bio fuels from Aquatic waste”* at 3rd International Conference on Global Initiatives in Agricultural, Forestry and Applied Sciences GIAFAS, 2021 Organized by Shri Guru Ram Rai University, Dehradun. Uttarakhand, India. The paper was awarded as a “Best paper presentation”. **5).** *“ Job Opportunities at the different stages of fabric manufacturing from the extraction of Lotus petiole”* at 2nd International Conference on Social work and Law, Building Social Entrepreneurial Ecosystem for a More Sustainable and Resilient Society organized by Gujarat National Law University, Gandhinagar, Gujarat. The paper was awarded as a **“Best paper presentation”**. **6).** *“Design and Fabrication of Apparatus for Lotus fiber extraction – a way to quality and Productivity* at 4th International Conference on Global efforts on Agriculture, Forestry , Environment and Food Security (Theme – Climate Change and its Impact) GAFEF -2022 at Institute of forestry , Tribhuvan University , Pokhara Campus, Pokhara Nepal . Dated on 17-19,2022. The paper was awarded 1st rank for best oral paper presentation. **7).** *“Nonwoven fabric from bio aquatic waste novel material for medical textiles”* at International E- Conference on Textiles for Advanced Technologies Textile Tech – 2022 dated on 11-13 November, 2022. **8).** *“ Fabrication of apparatus for Extracting Lotus Fiber and Study its Mechanical properties”* at 3rd International conference on Functional Textiles & Clothing at Department of Fiber Engineering and Technology, Indian Institute of Technology, Delhi. Dated on 10th -12th February, 2023. **9).** *“Novel Fiber from Lotus Petiole – A Golden Revolution in Sustainable Textiles and Fashion”* World “in 1st Indo- Japanese Textile Research Conference (IJTRC) 2023 at Department of fiber

engineering and technology, Indian Institute of Technology, Delhi. Dated on 27 -28, November, 2023. **10).** “*Lotus Petiole – Novel Biobased Fiber for Fashion Industry*” in 2nd International conference on Sustainability in Fashion Design and Manufacturing conducted by Department of Fashion Technology, PSG College of Technology, Coimbatore, India. Dated on 8-9 December, 2023. **11).** “*Padma Vastra – Innovative Knitted structure*” in International conference on Innovative advances in indigenous Knowledge in Family and Community Sciences (Home Science) , Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. **12).** “*Jalsutra – The innovative knitted fabric*” in 6th International Conference “Cutting-Edge Solutions in Science- Agriculture, Technology, Engineering and Humanities”(CSATEH-2024) Theme 6 : Social science and Humanities , UGC-HRDC, Kumaun University, Nainital, Uttarakhand, India. Dated on August 24-26, 2024. **The paper was awarded first rank for best oral presentation.** **13).** “*Synthesized skin in textiles*” in International conference on Innovative advances in indigenous Knowledge in Family and Community Sciences (Home Science) , Faculty of Family and Community Sciences, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. **12).** “*Jalsutra – The innovative knitted fabric*” in 6th International Conference “Cutting-Edge Solutions in Science- Agriculture, Technology, Engineering and Humanities”(CSATEH-2024) Theme 6 : Social science and Humanities , UGC-HRDC, Kumaun University, Nainital, Uttarakhand, India. Dated on August 24-26, 2024.

She has also presented four papers at national level : **1).** “*Women empowerment through skill development*”: *Post co-vid challenges* at Green Fashion India 2021 conducted by Soft School of Fashion technology , Pune. **2).** “*Preparation of yarns from aquatic waste and testing the properties for its use in textiles*” at 34th Biennial Conference of Home Science Association of India at St.Terasa’s (Autonomous) college Kochi, Kerala. Dated on 15-17th December, 2022 **3).** *Envisaging a path towards Viksit Bharat 2047: Utilization of Lotus petiole waste for developing Sustainable Textiles* at National Conference On Fashion, Textiles and Crafts : A Global Perspective at IIS university, Jaipur, Rajasthan, Dated on 26-27 September, 2024. **4).** “*Technological intervention in Lotus fiber for developing luxurious fashion fabric*” at “UGC Sponsored” National seminar on “Localization of Sustainable Development Goals (LSDGs) organized by The Gandhigram Rural Institute (Deemed to be the university) Department of Home Science, Gandhigram, Tamilnadu

She has published three papers

- 1) Lotus (*Nelumbo Nucifera Gaertn.*) – An Exploration of Hygrowaste for textile applications. *Acta Scientific Agriculture Journal*, Vol. (5) 119-126. ISSN – 2581-365X.
- 2). Horticulture waste towards sustainable textiles and fashion – published in proceedings of International conference on Fashion, Apparel and Textile (2021) organized by Amity School of Fashion Technology.
- 3). Young scientist award paper – “Experimental study on Lotus petioles for its use in Textiles leading to Social Entrepreneurship” published in *Journal of Home Association of India* 2024, Vol. 36 (2). 430-448.

She has published one book chapter

- 1). Development of Union fabrics from Lotus Petiole waste book chapter in *Sustainable Approaches in Textiles and Fashion, Fibres, Raw Materials and product development*. Edited by Subramanian Senthilkumar Muthu, Springer Publication. ISBN – 978-981-19-0877-4. pp- 101-121.

Awards

- 1). “*Best Research Scholar*” award by Agriculture & Environmental Technology Development Society (AEDTS) on the occasion of 3rd Conference on “Global Initiative in Agricultural, Forestry and Applied sciences for food security, Environmental safety and sustainable development (GIAFAS-2021) at Shri Guru Ram Rai University, Dehradun, Uttarakhand, India. Date – 17-18, 2021.
- 2). “*Young Scientist award*” (Appreciation) in 35th Biennial conference of Home Science association (HSAI) at College of Post graduate studies in Agricultural Sciences Central Agricultural University. ICAR Tura , Meghalaya. Title of the paper for the award - “Experimental study on Lotus petioles for its use in textiles leading to social entrepreneurship”.

3). “*Best Women Maker award*” in Maker Fest Innovation contest 2021 organized by Yuvalay Electronics Lab and , Yuvalay Charitable Trust in collaboration with Vadodara Innovation Council. Title of the innovation - Utilization of Aquatic Plant Waste for developing organic fabric. Dated on 6-7th March, 2021. Certificate of achievement with 5000 Rs. cash prize.

4). “*Special Recognition award*” in “Environment Category” in Maker Fest Innovation contest 2022 organized by Yuvalay Electronics Lab and , Yuvalay Charitable Trust in collaboration with Vadodara Innovation Council. Title of the innovation – Economy from Hygrowaste – A way towards women empowerment, Dated on 26-27th February, 2022. Certificate of achievement with 5000 Rs. cash prize.

Projects

1. Project Sulbha – funded by Happy faces, NGO Vadodara Gujarat. Duration :-June- August, 2021.
2. Women empowerment through spinning of Lotus petiole waste – Textile hidden in the water done under Gargi – Center for Holistic development for women research project scholarship by BAOU – Dr. Babasaheb Ambedkar Open University, Chandkheda, Ahmedabad. Duration:- November 2021- May 2022.
3. Project – “Lotus Petiole – Exploration of Hygrowaste for textile applications” granted from Student Start up and innovation Policy (SSIP) -2.0 Gujarat. The duration of the project is 6 months : December 2023 – May 2024.

Patents

An Apparatus for Fiber Extraction from Lotus Petioles (IN201921032058). The patent got grant on 04/08/2022.

Copy Right

Lotus Knitted structure (32493/2023-CO/L) is filled for copy-right process



Synopsis is approved by

Prof. (Dr) Madhu Sharan, Guide
Department of Clothing and Textiles
Faculty of Family and Community Sciences
The Maharaja Sayajirao University of Baroda

