Chapter – 5

SUMMARY AND CONCLUSION

Everyone in the World is constantly working for the fulfillment of sustainability in each and every field. Textile industry is the second largest polluting industry in the world. Textile experts and scientists are constantly working for the search of novel sustainable fiber, process, packaging and finally it should have a less impact to the landfill. Nowadays people have understand the importance of environment so consumers are day by day shifting on eco-friendly products. Cotton fiber alone cannot fulfill demand and it is not considered as 100 % sustainable fiber due to the usage of water and pesticides for farming. Hence there is need to search for alternative sources of the fibers. India is an agricultural country and there is lot of agricultural waste after harvesting the fruits, flowers or crops. Major commodity natural fibers are used but there is many other minor cellulosic fiber – Banana, Sisal, Ramie, Pineapple, Kenaf and Flax etc for which researcher, scientists, research institutes are constantly working to solve the problems that is related to each minor fiber to take and promote these kind of fibers in the global market. All these agro-based fiber plants grow in the terrestrial regions. But there are plants in the wetland ecosystem also which can be used for textile applications.

India is country of wetland eco-system. Lotus (Nelumbo Nucifera Gaertn.) is a national flower of India and Vietnam. Lotus flower has a huge economic importance as offerings for god and goddess. Each part of the Lotus excluding petioles and seed pods is been used for different applications. It is an important cash crop also because the underground stem that is rhizomes are widely eaten by the peoples. The entire plant has medical properties. It was observed and quoted by many authors that after picking the flowers, seedpods and rhizome cultivation the petioles are left as waste. This waste is abandoned as decay. Biological evidences proved that Lotus is the fastest growing plant and bud of the flower fails to open if cut stems are left in the wetland. These petioles contain precious fibers which can be used for textile applications. In few places of the world – Manipur, Myanmar, Cambodia and Vietnam the manual extraction process is practiced near the Lotus ponds. But manual process is time-consuming and tedious to take this

precious fiber for bulk production and there is a systematic scientific study required for the Lotus fiber.

Hence an experimental study was carried out to extract fibers from Lotus petioles for implementing it in different areas of textiles – yarn manufacturing (handspun yarns, ply yarns, machine extracted and spin yarns and rotor spun yarns), weaving (Khadi, handloom and powerloom), nonwoven (hygiene medical textiles) and knitting (Circular knitting). Owing to the issues related to the manual extraction process of fibers, machines with different mechanisms were designed, fabricated and patented. To take the research to the community, the efforts was undertaken to train the group of ladies for extraction and spinning of fibers manually. Group of ladies acquired this entire skill and they are ready to work on this process of fiber extraction and spinning.

To take any new minor cellulosic fiber (especially lignocellulosic fibers) in different products the basic need is the user friendly extraction process. This entire concept of Lotus fiber – manual extraction method for spinning on Ambar charkha, the most important is machine development with different mechanisms , development of woven fabrics, knitted fabrics and nonwovens will open the opportunity to take this precious fiber to national and international level. The entire approach of this work will help to built a commercial set up for the small scale industry with the employment opportunities. Using this hygrowaste will help to clean and maintain the aquatic eco-system. Collecting this hygrowaste will also help in the rapid growth of the plant. The approach of using this hygrowaste in textiles will give advantage to Lotus cultivators as it will open new avenues for selling petioles and meanwhile using these waste petioles will save cultivators time to clean the pond. Finally it will have an positive impact on overall aquatic ecosystem, cultivator's standard of living and textile sector will get a novel fiber which is sustainable in true sense because no a single drop of chemical is used in the entire manufacturing process.

To work on this challenging and intensive experimental process, objectives are framed and are as follows:

5.1. Objectives of the study

5.1.1. To experiment the extraction process of Lotus fiber :-

a). Fiber - By hand – (Number of petioles – one, two and three)

b). Web – Non-woven

5.1.2. To experiment the spinning of extracted fibers by different techniques and test its properties

5.1.3. To design and fabricate the machines (with different mechanisms) for fiber extraction and study the yield with respect to speed and man power involvement.

5.1.4. To develop yarns from the fabricated machines and test its properties for denier, strength, twist.

5.1.5. To prepare blended yarns (with other natural fibers) and test its properties (both fiber stage & yarn stage).

5.1.6. To study the dyeing properties of Lotus yarn and assess its color strength and fastness properties.

5.1.7. To prepare woven fabrics – Khadi, Handloom and Powerloom and test its properties.

5.1.8. To prepare circular knitted fabrics and test its properties.

5.1.9. To study the Lotus fibers for its functional properties:- Absorbency, Antibacterial and Cytotoxicity.

5.1.10. To develop non-woven fabric for technical applications – Hygiene medical textiles

5.1.11. To train the group of Women for fiber extraction and spinning.

5.2. Experimental procedure

For the study, petioles of Lotus (Nelumbo Nucifera Gaertn.) pink variety was used. Petioles were collected from local Lotus flower suppliers and vendors from near and around Vadodara district of Gujarat. Petioles contain precious fibers. Two different types of manual extraction method were developed :**a)**. method for yarn making by varieting the number of petioles which was further spin on Ambar charkha **b)**. extracting fibers randomly on woollen felt for making on nonwoven web and rotor spun yarns. It was observed that manual extraction process was

tedious and time consuming for taking this fiber in mass production. Due to the manual extraction process, this fiber is restrict only to handmade textiles. Due to the delicate nature of thefiber it was difficult to incorporate any mechanical process for extraction of the fibers. Hence the challenging effort was done by designing and fabricated machines with different mechanisms **a).** Machine -1 was for yarn making **b).** Machine-2 was extracting raw fibers which can be used further for nonwoven web and making yarns on rotor spinning systems. Hence the extracted fibers and yarns were experimented and explored in different areas of textiles – woven (khadi, handloom and powerloom), circular knitting and nonwoven. Testing for all the structures - yarn , woven fabric, nonwoven and knitted were done as per standards. To take this work to the community the group of ladies were trained for fiber extraction and spinning. Handloom stoles were developed by the yarns which were prepared by the ladies in the training programme. Handloom stoles were exhibited in the different exhibitions.

The study was divided in five phases:

Phase – 1

Phase – 1 incorporates development of two manual extraction process. One was for yarn making - by varieting number of petioles (1-3) extraction was done. The extracted fibers in the yarn form was termed as “unspun yarns”. To increase the strength, these unspun yarns were spin on 2-spindle *Ambar charkha*. Three developed handspun yarns from 2- spindle*Ambar charkha* : L1A (Lotus yarn , 1 petiole extracted , Ambar charkha spun yarn), L2A (Lotus yarn , 2 petiole extracted , Ambar charkha spun yarn), L3A (Lotus yarn , 3 petiole extracted , Ambar charkha spun yarn)were further tested for fineness, tensile strength and twist as per ASTM test standards. The main motto was to check the feasibility of extracting and spinning the fibers by varieting number of petioles which was successfully achieved.

Another extraction process was focused on extracting raw fibers from the leftover petioles. Extracted fibers were laid on the woollen felt. These raw fibers were

further used for making a 100 % nonwoven sheet and developing the blended rotor spun yarns.

Two different types of nonwoven sheet were developed: One was developed by the lab scale method and another one was prepared on machine. Both the nonwoven sheet was tested for thickness and GSM as per ASTM test standards. The main motto behind developing the nonwoven sheet by the lab scale method is to check the possibility of the fiber for the formation of web.

For the application in technical textiles, these raw fibers were tested for functional properties that is pH, Qualitative antibacterial test (AATCC 147- 2016) against four micro-organisms - *Staphylococcus Aureas, Klebsiella Pneumonia, Candida Albicans and Pseudomonas aeruginosa* ,Absorbency test – free swell absorptive capacity (WSP 240.3-2011), Absorbency under load and pressure(ASTM E691-14) and equilibrium absorbency (ASTM E691-14). It was found satisfactory in functional properties. Hence it was further planned to use the machine developed nonwoven fabric as a core layer of sanitary napkin. The sanitary napkin was developed in the incubation lab of SITRA (South Indian Textile Research Association). To check the efficiency of the core layers, sanitary napkin was tested for absorbency under load test (IS 5405:2019 Annex B).

Raw fibers were also used for developing blended rotor spin yarns with the Cotton fibers in two different proportion that is - LCRY (50:50) – Lotus: Cotton Rotor spun yarn and LCRY (70:30)- Lotus : Cotton Rotor spun yarn. These yarns were subjected for the testing of fineness, tensile strength and twist as per ASTM test standards.

Phase – 2

It was observed that manual extraction process is tedious and time consuming to take this fiber in the mass scale production. Hence two machines with different mechanisms were designed and fabricated. The fabrication of machine was done in collaboration with mechanical and robotic engineers –Er. Dhaval Raval and Er. Shreyash Patel respectively.

Machine -1 was designed and fabricated in such a way that it can extract and spin the fibers one at a same time. For detecting the speed of rollers, Tachometer device was used. Four different categories of speed that is speed of feeding roller and speed of winding roller were optimized. By optimizing the speed of the rollers ,four Lotus yarns with different fineness were achieved that is 1). MYHS1 (Machine yarn high speed 2). MYHS2 (Machine yarn high speed 3). MYHS (Machine yarn moderate speed)and 4). MYLS (Machine yarn moderate speed). The developed machine extracted and spinned yarns were tested for fineness, tensile strength and twist as per ASTM test standards. Amount of the yarn developed in different speed were also assessed. All these yarns were 100 % Lotus yarns. Three petioles were used in the fabricated machines.

Lotus yarns in its 100 % form is unable to take the strength on handloom and focusing on the long length property of the Lotus yarn the approach was made to develop the blending in the yarn stage by plying mechanisms on *Ambar Charkha*. For using any yarn in warp direction, huge amount of yarn is needed. So we cannot use the hand extracted Lotus yarn in the ply structure due to the cost, bulk unavailability of the yarn due to the time consuming extraction process and properties. Hence the yarns extracted and spinned from the fabricated machine were used in the ply structure. Plying was done with the other natural fibers – Cotton, Silk and Wool. For plying, count of the yarn and type of the natural fiber used was taken into the consideration. Three different types of ply yarns was developed that is :YLCP - Yarn Lotus cotton ply, YLSP - Yarn Lotus Silk Ply and YLWP -Yarn Lotus Wool Ply.

Machine -2 was designed and fabricated in such a way that it extract the fibers in the raw form. This machine consists of soft comb like mechanisms which collect the raw fiber from the petioles. Further these fibers can be used for making nonwoven sheet and industrial spinning of yarns.

Phase -3

Phase -3 focused on dyeing properties of Lotus yarn. Coloration is an important part of textiles when working towards woven fabrics especially for the application in

apparels. Hence Lotus yarns were experimented for dyeing with nine different natural dyes such as Madder, Lac, Marigold, Sappan wood, Katho, Indian berries, Annato, Pomegranate rind and Natural Indigo. Aqueous method (M:L ratio of 1:40, Temperature - 60ºC and time -30 minutes) was used for the extraction of dyes. Open bath dyeing (M:L ratio of 1:40, Temperature - 60ºC and time -45 minutes)was used. Before dyeing, yarns were pre - mordanted (M:L ratio of 1:30, room temperature and time -30 minutes) with Alum.

From the industrial perspective, Lotus yarns were also experimented for dyeing with Reactive dyes. For reactive dyeing percentage shade was 2 %, M: L ratio was 1:30 , temperature was 60º C. Dyeing was done for 45 minutes. After dyeing, yarns were washed, rinsed and dried. The dyed Lotus yarns were tested for color strength (K/S), C.I.E lab values using Premier Colorscan SS5100A Spectrophotometer,light fastness (AATCC test method 16-B- 1977) and washing fastness(ISO standard test no. II - IS: 764: 1979) test.

Phase – 4

Phase -4 consists of implementation of Lotus pure and blended yarns that was developed in phase -1 and phase-2 in construction of woven fabrics and circular knit fabrics. Totally twelve yarns were developed. 14 woven fabrics were constructed using different counts of yarns, various compositions of yarn used in warp and weft direction. 14 woven consists of 2 Khadi fabrics, 5 handloom fabrics and 7 powerloom fabrics (four union fabrics, one pure fabric and two blended fabric). Weave was constant for all the fabrics that is plain weave. All the 14 woven fabrics were tested for thickness (ASTM D 1777-96), fabric count (ASTM D 3775-98), cover factor Booth, J.E.(1996), fabric weight , tensile strength (ASTM D 5035- 95), tearing strength (ASTM D 1424-09), bending length/stiffness (ASTM D 1388- 18), drape co-efficient Booth, J.E. (1996) shrinkage(Saville, B.P. 1999), pilling (ISO 12945-1:2020 -E) and abrasion (ASTM D 5035- 95).

From the 14 woven fabrics, two union fabrics were selected for assessing the handle properties by measuring the fabric low-stress mechanical properties on KAWABATA evaluation system for fabrics (KES –FB). The tensile properties and shear properties were studied on KES-FB1 (tensile and shear tester). Bending properties were

measured on KES-FB2 (Pure bending tester). Compressional properties were studied on KES-FB3 (Compression tester). The surface roughness and surface friction were measured on KES-FB4 (Surface tester). The primary and total hand values were calculated from sixteen mechanical properties. One fabric was HS Fabric -2 (Handspun fabric -Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) and another was PL fabric -8 (Powerloom fabric - Warp – Machine spun Cotton yarn – 80's; Weft – machine extracted and spun Lotus yarn: 3 petiole – 3/71's). Both the fabrics were selected on the basis of extraction method, spinning system and type of weaving. First fabric consists of Lotus yarn in which fibers were extracted by hand and spinned on *Ambar Charkha* and weaving was done on handloom. Another fabric consists of Lotus yarn which is developed on the fabricated machine using high speed and weaving was done on powerloom.

Moving to the sustainability and consumer perception towards eco-friendly fabrics, HS Fabric -2 that is Khadi fabric will be a novel fabric in the entire Khadi and Village industry. Looking at the industrial perspective, fashion world and bulk production point of view, PL Fabric -8 will be beneficial.

The Lotus fiber was soft, lustrous, pliable, it has a good elongation and positive antibacterial properties. Focusing on these properties experimentation of Lotus yarn was done for knitting. Initially the blended Lotus: Cotton Rotor yarn (LCRY: 70:30) yarn was tried for making circular knitting structure it was observed that this yarn can withstand strength on circular knitting machine may be due the Cotton fiber in the blend structure. Hence the experimentation was done with 100 % Lotus machine extracted and spinned MYHS1 (Machine yarn high speed 1). It was found that it can withstand strength on circular knitting machine. Both the samples were developed without elastane. This trail was done to check the feasibility of Lotus yarn to withstand strength on circular knitting machine. Final samples with elastane was developed in industrial circular socks knitting machine. Two knitted fabrics was developed: a). LK1 -71 (Lotus yarn (Machine extracted and spinned 3/71's count yarn) and b). LK2- 60 (Lotus yarn (Machine extracted and spinned 3/60's count yarn) The elastane used in both the fabric samples was 60 denier.

Final the two circular knitted fabrics were developed and subjected for the testing of fabric count – assessment of wales and courses (ASTM-D 8007-15), Bursting strength (ASTM D3786M-18), Pilling (ISO 12945-1:2020 -E) , Stretch and Recovery (ASTM D 2594-99a), Thickness (ASTM D 1777-96) and weight. The testing results was found satisfactory in terms of bursting strength, stretch and recovery property and pilling. Hence the utility product –socks was developed. Two different socks were developed with elastane one was by using MYHS1 yarn of 71's (Machine yarn high speed 1) and another was MYHS2 of 60's (Machine yarn high speed 1).

Phase -5

Phase -5 consists of taking one aspect of the entire research to the community. It involves training the group of women for fiber extraction and spinning. For the training programme the researcher initially searched about various NGOs in Vadodara district. Researcher came in contact with Happy Faces, NGO Vadodara. Researcher interacted with the founder of NGO –Mr. Piyush Khare. He was very keen to start and work on women empowerment activities. He liked the concept of the work. He told to train the women of Zadeshwar area, Atladara, Vadodara. The project was named as project "Sulbha" by the founder of NGO. The project duration was for three months. The project was funded by the team members of Happy Faces NGO, Vadodara. The training programme was done in the street school of Zadeshwar area which is run by the NGO itself keeping in the view that it will be easy for the ladies to join the training programme and meanwhile they can take care of their family. Initially 20 women were trained for one week later 8 women was selected for final workshop based on quality of fiber extracted , speed and dedication towards the work. Consent of all the ladies was taken before the training programme. The workshop was done 4 days in the week and timing was 3.00 PM to 6:00 PM. They were paid for this workshop. The duration of this project was for three months that is July- September 2021. In this duration ladies successfully learnt the extraction process. After finishing this project researcher got the another project from GARGI – Center for holistic development for women research scholarship" from Dr. Babasaheb Ambedkar Open University. The duration of this project was six months that is from November 2021-May 2022. In this project same group of ladies who learned the extraction process previously were trained for spinning of Lotus yarns. For spinning training, Mr. Bakul

Shah, expert for hand spinning on different charkhas was invited. The researcher along with the expert trained the group of ladies for spinning. Hand woven stoles were developed from the yarns prepared by the ladies. Hand woven stoles were developed by the Artisian designer Mr. Pachan Premji from Bhujodi. Nine stoles were developed using Lotus yarn in weft and Cotton yarn in warp. These Stoles were exhibited in three different exhibitions : a). Exhibition -1 was conducted by the Happy Faces NGO, Vadodara on International women's day 2022 at Eva Mall ,Manjalpur, Vadodara b). Exhibition -2 - "Agripreneurs Conclave"-2022 held at Gujarat Technological University (GTU) campus, Chandkheda, Gujarat. c). Exhibition -3 - Weave Knit 2022 (The complete fabric show) 2nd Edition"atSarsana, Surat conducted by SGCCL (Southern Gujarat Chamber of Ministry and Chamber of Commerce and Industry).

5.3. Results and Discussions

5.3.1. Manual extraction of fiber

a). Manual extraction of fiber for yarn making

In the manual extraction process, several trails were taken by varieting the number of petioles that is (1-3).

Variation in petioles were done because in few places of the world – Cambodia, Myanmar, Manipur and Vietnam the manual extraction process is practiced were they use 3-8 petioles collectively to form a single strand. They extract the fibers and further impart a palm twisting. But here in the present study, fibers were extracted from the petioles and wound directly on the pern without palm twisting. For extraction, required petioles (1-3) were taken together. Petioles were slit into 5-7 sections as per the length with the sharp knife. After every slit, petioles were stretched and fibers were laid on the wooden slab and winded over the pern. Lotus Fibers are very delicate and cohesive during winding, care was taken that fibers were uniformly winded on the pern otherwise it fastly gets entangled. During extraction it was observed that more focus and skill is required to extract and manage the fiber extracted from single petiole. Extraction from two and three petioles was manageable. The output obtained from this extraction process is termed as "unspun yarn".

b). Manual extraction process for raw fibers

During extracting fibers for yarn making it was observed that small leftover petioles also consist of fibers. The leftover petioles are also in abundant amount after extracting fibers for yarn making. Hence separate extraction process was developed. Concerning the quality of cohesion property of fibers, woollen felt of (53Lx41W) was laid on the floor. Bunch of five to seven leftover petioles were taken together and slit in between and extracted fibers were sticked on the woollen felt. Due to the cohesion property of the fiber and ability of the surface of woollen felt to stuck, raw fibers from the leftover were successfully extracted by this developed method. These fibers were further used for making nonwoven web and subjected for industrial rotor/ open-end spinning by blending it with Cotton fibers.

5.3.2. Spinning of yarns (extracted by the manual process)

To impart strength and twist in the unspun yarn developed by the manual extraction process further spinning was done in the two spindle *Ambar charkha*. Earlier trails were done in *Peti* (box) *charkha* and *Takli* but the quantity of the yarn produced was very less and time consuming. Spinning on *Ambar charkha* is widely used in the Khadi industry. Hence for the faster production, spinning was done on *Ambar charkha.* During spinning of Lotus fiber, the feed roller was removed from the Ambar charkha because the fibers extracted from the petioles itself form a yarn like structure only twisting is required. For the continuous supply of the raw material in *Ambar Charkha* for spinning, creel was developed. For spinning in *Ambar charkha*, strand of unspun yarn was taken from pern and passed through plastic funnel – throw roller pair – traverse ring – spindle. Spinning was done by rotating the hand wheel. Further hanks of 1000 meters were prepared on the winder of *Peti* (box) *charkha*. It was observed that all the three category of the handspun yarns that is L1A (Lotus yarn, 1 petiole extracted ,*Ambar charkha* spun yarn), L2A (Lotus yarn , 2 petiole extracted , *Ambar charkha* spun yarn) and L3A (Lotus yarn , 3 petiole extracted , *Ambar charkha* spun yarn) can withstand in spinning on *Ambar charkha* without any frequent breakages in between.

Analysis of the properties of Lotus hand spun yarns

Yarns were tested for fineness, tensile strength and twist. It was observed that most finer yarn was L1A having a count of 96's (55 Denier) followed by L2A that is 86's (63.09 Denier) and L3A that is 28's (185 denier). Decreasing the number of petiole leads to increase in the count of the yarn.

All the handspun yarns consist of high twist and S-direction twist. L2A that is Lotus yarn developed from two petiole has obtain higher twist of 130 tpi, L1A that is Lotus yarn developed from one petiole has obtain twist of 121 tpi followed by L3A that is Lotus yarn developed from three petiole has obtained twist of 63 tpi. Technically the amount of the twist imparted should be optimum. From the tensile results, it was observed that L2A (Lotus yarn, 2 petiole extracted, *Ambar charkha* spun yarn) yarn having high twist of 130 tpi has obtain lower tenacity that is (1.832 gf/tex) amongst all the handspun yarns. L1A yarn has obtain high tenacity of (36.531 gf/tex) because while stretching and extracting from one petiole it naturally forms an inbound yarn like structure so the strength may be higher for yarn developed from the single petiole. Hence L1A (Lotus yarn, 1 petiole extracted, *Ambar charkha* spun yarn) was planned to use in weft with the fine Mulberry Silk warp to make a finer woven fabric due to the strength and fineness characteristics of the developed yarn. Rest two category of the yarn was planned to use in weft with the handspun Cotton warp to develop Khadi fabrics. The fabrics developed from the Lotus hand extracted and handspun yarns will be a novel material for the Khadi industry, luxury and premium sector.

5.3.3. Development of Machine

It was observed that manual extraction process for yarn making and collecting the raw fiber were tedious and time-consuming. Though the fibers were delicate, soft in nature, arrangement of the fibers in the petiole was not arranged in the single channel it was difficult to implement any mechanical process for extraction. But with the trial and error, two machines with different mechanisms were developed.

a). Machine- 1

It was observed that nature of fiber coming out from the petiole is such a way that yarns can be made along with extraction. Focusing on this point, machine was designed and fabricated in such a way that it can extract and spin the fibers one at a same time. The machine is semi-automatic it consists of two device that is input/feeding device and output/winding device. In the input device, there is a long PVC pipe in which petioles are feeded. In the front section of the pipe, there is junction to hold the entire PVC pipe. In the opening area of the PVC pipe, there is a sharp cutter to slit the petioles. In the output device there is an entire assembly for attaching the pern in which extracted and spinned yarn was collected. Spinning was imparted by the rotation of the PVC pipe and stretching was imparted by the rotating mechanisms of the pern attached in the winding device. By optimizing the speed of both the rollers that is feeding roller and winding roller, four different counts of yarns were achieved. The speed is maintained by the speed regulators and observation of the speed was done by the Tachometer device. Only three petioles were used in the fabricated machine. Machine can withstand the strength of only three petioles. For the extraction process, petioles were feeded in the PVC pipe. Slitting was done by the cutter and stretching was done by the pern attached with the screw gauge mechanism of the winding device. Along with stretching, twisting was done by rotating the PVC pipe. By this machine, all operation that is stretching- spinning and winding can be done one at a time. Yarns developed were uniformly winded on the pern. To operate one machine, only single manpower was required whose task is to feed the petioles in the PVC pipe, managing the speed regulators and changing the pern filled with yarn and attaching the new pern.

Analysis of the properties of yarn developed by the machine -1

In the optimized high speed, finer quality of the Lotus yarn (MYHS-1) was achieved that is of 71’s count. By lowering the speed, a slight decrease in fineness was observed which is categorized as (MYHS2) yarn of 60’s count. In the moderate speed,yarn of 33’s count was achieved. 28’s count yarn was achieved in the low speed. Only three petioles were used in the fabricated machine. In the fabricated machine the variation in fineness was due to amount of fine microfibers stretching out

from the petioles and twisting together to form a yarn in that particular speed. All the yarns consist of S- direction twist. MYHS1 and MYHS2 yarn has achieved twist of 100 tpi. MYMS yarns has achieved 76 tpi and MYLS has obtained 40 tpi. Decreasing the speed of the machine leads to lower count and lower twist of the yarn. MYMS and MYLS yarn has a loose structure with little protruding fibers on the surface. Achieving the maximum tensile strength was most essential factor for extracting such a delicate fibers from the fabricated machine. MYHS1 (Machine yarn high speed 1) has obtained highest maximum load of 883.41 gf/tex having the tenacity of 42.06 gf/tex. With the slight decrease in the speed, the tenacity dropped to 16.77 gf/tex for MYHS2 (Machine yarn high speed 2). The tenacity was found low for MYMS (Machine yarn moderate speed) and MYLS (Machine yarn low speed) yarns that is 9.28 gf/tex and 9.49 gf/tex but the extension was high in both the yarns that is 4.64 mm and 6 mm. It was observed that tensile strength of the machine extracted yarn in high speed (MYHS1) – [Maximum load – 883.41 gf, Tenacity -42.06 gf/tex] was more than the L3A that is (Lotus yarn , 3 petiole extracted , *Ambar charkha* spun yarn) - [Maximum load – 129.763 gf, Tenacity – 18.537 gf/tex]. Hence the machine extracted yarn has higher strength. Hence fabricated machine was helpful in getting finer count of 100 % Lotus yarn with a high twist and tenacity.

b). Machine -2

The machine -2 is semi - automatic works on programming. It is designed in such a way that it can extract raw fibers from the petioles. The machine consists of three sections – a). Feeding device b). Gripping device c). Fiber collection device. For the extraction, five to six petioles were arranged in the feeding device or rectangular slab horizontally. The petioles were set below the rubber roller and horizontal rods. The role of the roller is to slide the petiole forward for extraction. The role of the two horizontal rods is to hold the petiole together in the proper alignment for proper slitting from upper and lower sides. After the arranging the petioles, the blades slits the petiole from both upper and lower side. After slitting operation, the gripper comes forward and carries the slited petiole and arranges the point of fibers over the collecting device that consists of comb. After touching the point of fibers over the collecting device the gripper comes back to its home position. With the rotation of the rod of collecting device the fibers are uniformly winded over the comb consist of

soft teeths to hold the fibers. Once the comb is filled with the fibers. From one side it is slited with the sharp blade and extracted fiber is taken out. The raw fibers obtained by this process are cleaner than the manual extraction process because there is no involvement of human hand while extracting the fibers. For this machine, only single manpower is required for feeding the petioles, managing the speed and taking out the fibers from the comb like device once it is filled and placing the empty combs for next extraction.

5.3.4. Development of Blended yarns

Blending was done in two stages – a). fiber blending by Rotor spinning techniques b). yarn blending by plying mechanisms.

a). Fiber blending

Lotus fiber is extremely soft, lustrous and has a moderate strength. Till date, Lotus fibers are only extracted by manual process which restricts its use only to handmade fabrics. The hand extraction leads to more cost. The approach was made to blend the Lotus fiber with natural cellulosic fiber like Cotton by rotor spinning system. The blended yarn developed by the fiber blending process consists of inherent properties of both the fibers. Hence the blended yarns was developed in two different proportion that is LCRY (50:50) – Lotus :Cotton Rotor spun yarn and LCRY (70:30)- Lotus : Cotton Rotor spun yarn. During spinning process, it was observed that it was successful to achieve the yarn in the proportion of 50:50 (Lotus: Cotton). During processing of LCRY (70:30) –Lotus : Cotton Rotor spun yarn, there were little cracks seen in lap formation which may be due to the increase of Lotus fiber in the blend proportion.

Analysis of the properties of rotor spun yarns

Both the Lotus: Cotton rotor yarns were coarser that is LCRY (50:50) - 5’s count and LCRY (70:30) -3’s count. Fineness, twist and tenacity ofLCRY (50:50) – (Lotus:Cotton Rotor spun yarn) was higher than LCRY (70:30) - (Lotus : Cotton

Rotor spun yarn) which may be due to the equal proportion of Lotus and Cotton used in the blend proportion. But the elongation increased with increasing of Lotus fiber in the blend proportion. 30.5 % for 50:50 (Lotus: Cotton) and 32 % for 70:30 (Lotus: Cotton).

b). Yarn blending

Lotus fiber has a superior quality of long length. Instead of cutting it into a staple length for blending, an approach was made to ply the Lotus yarn with other natural fibers like – Cotton, Silk and Wool. During weaving, 100 % Lotus yarn is unable to withstand strength in warp direction so plying the Lotus yarn with other natural fibers will help to increase the production and weft was 100 % machine extracted Lotus yarn of different counts. Plying was done on Ambar charkha. Ply yarns were durable and it has textured appearance. Three ply yarns were prepared that is YLCP (Yarn Lotus cotton ply), YLSP (Yarn Lotus Silk ply)and YLWP (Yarn Lotus wool ply). During ply yarn preparation count of the yarn was taken into the consideration. Lotus yarn was termed as major yarn in the ply structure and other natural fiber was termed as component yarn in the ply structure. It was observed that Lotus yarn was easily plying with the other natural fibers which is due to the cohesiveness property of the fiber.

Analysis of the properties of the ply yarns

YLSP (Yarn Lotus Silk ply) was finer (23.10's) and consists of high twist (90 tpi) amongst all the ply yarns which may due to fineness of Lotus and Silk yarn used in the ply structure. This plied yarn has lustrous appearance due to Lotus and Silk yarn used in ply structure. All the ply yarns has Z—direction twist. YLCP (Yarn Lotus Cotton ply) has obtained higher tenacity of 13.158 gf/tex amongst all the developed ply yarns.

5.3.5. Analysis of Dyed Lotus yarns

Color strength (K/S) value of Lotus yarn dyed with Indigo dyes (LNI) was higher that is 89.58 amongst all the dyed samples means the absorption of this dye was more. Lotus yarn dyed with Katho (LNK) has obtained lower K/S value of 2.109 from all the natural dyed

samples. The K/S value of the samples dyed with Reactive dye orange bright (LROB) and Reactive dye black (LRBL) was high that is 21.028 and 20.836 respectively means the absorption of these dyes was more. In terms of fastness properties for natural dyes -Lotus yarn dyed with Katho (LNK), Madder (LNM), Marigold (LNMG), Indian berries (LNIB), Sappan Wood (LNS) and Lac (LNL) has obtained very good to excellent light fastness property. Lotus yarns dyed with Indigo dyes (LNI) has obtained fair light fastness property. Lotus yarn dyed with Indigo dyes that is (LNID) and (LNIL) has obtained very good to excellent washing fastness property with the rating 4/5. Lotus yarns dyed with Lac (LNL)-3, Katho (LNK)-4, Sappan Wood (LNS)-3,Maddar (LNM)-3/4, Marigold flower petals (LNMG)-3, Indian Berries (LNIB)-3 has obtained good to very good washing fastness property. In terms of fastness properties for reactive dyes, Lotus yarns dyed with the reactive dyes has obtained very good to excellent Light fastness property with the rating ranging from 6/7 to 7. It was observed that washing fastness property of the Lotus yarn dyed with reactive dyes has obtained very good to excellent washing fastness property with the rating ranging from 3/4 to 4.

5.3.6. Development of woven fabrics

2 Khadi fabrics consists of - HS Fabric - 1 (Handspun fabric - Warp – Handspun Cotton yarn - 120’s ; Weft – Handspun Lotus yarn: 2 petiole - 2/86’s) and HS Fabric -2 (Handspun fabric -Warp – Handspun Cotton yarn - 120’s ; Weft – Handspun Lotus yarn: 3 petiole - 3/28’s) . Here the variation in both the fabric was count of Lotus yarn used in weft and number of petiole used in developing that particular count of Lotus yarn. These Lotus yarns has a natural uneven appearance and shaded color that varies from off white to cream.

The appearance of the Lotus fiber resembles fine silk. India is known for its long Silk route and Lotus is a national flower of country. Fine handspun yarn of 96’s count was developed from one petiole. Due to extreme fineness of Lotus yarn developed from one petiole, fabric was prepared with fine Mulberry Silk. Handloom fabric comprises of HL Fabric – 3 (Handloom fabric - Warp – Machine spun Mulberry Silk yarn - 100’s ; Weft – Handspun Lotus yarn : 1 petiole - 96’s) was developed.

Focusing on the mass production and durability factor ply yarns were used in warp direction. Hence the fabrics -HL Fabric -4 (Handloom fabric -Warp –Lotus: Cotton ply yarn - 19's ; Weft – Machine extracted and spinned Lotus yarn : 3 petiole-3/71's), HL Fabric – 5 (Handloom fabric -Warp – Lotus: Silk ply yarn - 23's ; Weft – Machine extracted and spinned Lotus yarn : 3 petiole -3/60's) , HL Fabric – 6 (Handloom fabric -Warp – Lotus: Wool ply yarn - 14's ; Weft - Machine extracted and spinned Lotus yarn : 3 petiole - 3/28's) was developed .

Concerning the cost factor, HL Fabric – 7(Handloom fabric- Warp - handspun Cotton yarn – 120's ; Weft – Machine extracted and spinned Lotus yarn : 3 petiole- 3/71's) was developed.

Focusing on the fashion world, it changes in minutes and require faster and rapid production of fabric. Seven powerloom fabrics consist of four union fabrics, one pure fabric and 2 blended fabrics was developed. Union fabric includes: PL Fabric -8 (Powerloom fabric - Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's), PL fabric – 9 (Powerloom fabric (Warp – Machine spun Cotton yarn – 70's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/60's) , PL Fabric -10 (Powerloom fabric - Warp – Machine spun Cotton yarn – 40's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/33's), PL Fabric – 11 *(*Powerloom fabric (Warp – Machine spun Cotton yarn – 20's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/28's). Here the variation was in the count of Lotus yarn used in weft direction developed from the fabricated machines in different speed. For the appearance and dominance of Lotus yarn in fabric structure the count of warp yarns was also taken into the consideration. Warp yarn was kept finer than weft yarn in the union fabric category.

Pure fabric was - PL Fabric -12 (Powerloom fabric - Warp and Weft - machine extracted and spun Lotus yarn; 3 petiole – 3/71's).

The rotor yarns were strong, soft, coarser and has a excellent elongation property which was very much suitable for developing sturdy fabrics for jackets, coats and shawls. Hence two blended fabric consists of rotor yarn in both warp and weft directions that is - PL Fabric – 13 (Power loom fabric - Warp and Weft; 50:50 Lotus:

Cotton Rotor yarn 5's) and PL Fabric – 14 (Powerloom fabric - Warp and Weft ; 70:30 Lotus: Cotton Rotor yarn 3's) was developed. Here the variation was in the proportion of Lotus and Cotton fibers in the rotor yarn structure.

Properties of the woven fabrics

The developed fabrics has a different appearance and textures. All the fabrics excluding the fabrics developed from rotor yarns were lighterin weight having the GSM ranging from 64-140 (1-4 oz) which can be used in blouses, shirting and summer dresses. Fabrics developed from Rotor yarns were thicker in appearance, heavier in GSM that is more than 300 GSM (< more than 9 oz) which falls under the category of heavy weight fabrics for the applications in blankets, heavy coats and denims.

In the Khadi fabric category both the fabrics that is HS fabric -1 (Handspun fabric - Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 2 petiole - 2/86's) and HS fabric -2 (Handspun fabric -Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) has a beautiful uneven appearance. The thickness, GSM, bending length, drape co-efficient of HS Fabric -1 was lower than HS Fabric -2 which may be due to the fineness and number of petioles used in developing Lotus weft yarns used in both the fabrics. Decreasing the number of petioles leads to lower thickness, weight, bending length and drape efficient of the fabric. These "Lotus Khadi fabrics" can be a prospective contribution to give a new dimension to the "Khadi and Village industry".

Amongst all the fabrics - HS Fabric -3 (Handloom fabric -Warp – Machine spun Mulberry Silk yarn - 100's ; Weft – Handspun Lotus yarn : 1 petiole - 96's) lower thickness , cover factor and drape coefficient which is due to the finer Lotus yarn developed from one petiole of 96's count used in weft direction and finer mulberry silk used in warp direction. But the durability property – tensile strength and tearing strength was lower in weft direction amongst all the constructed fabrics. So this type of fabrics can use in the garments were less stress is required. Both the warp and weft yarns used in the fabrics were smooth and lustrous so the developed fabric has a beautiful light yellowish shaded appearance. The fabric has an open and sheer

appearance. Hence the yarn developed from the single petiole can be used to develop luxurious fabric with Silk and other extremely fine fibers.

Handloom fabrics developed from the ply yarns were durable. Fabrics made with Lotus: Cotton and Lotus: Silk ply yarn due the durability factor can be used in pants, shirts, tops with interlinings because it has little open structure. Fabric developed with Lotus:Wool ply yarn has a compact and little rough surface due to the Wool . This fabric can be used in jackets and shawls.

All the developed fabrics excluding the fabrics developed from rotor yarns has lower drape co-efficient means the fabric will drape very well which is due to the inherent softness property of the Lotus fiber.Fabrics developed from the Lotus: Cotton blended rotor yarns can be used in developing overcoats and jackets.
Union powerloom fabrics developed from machine extracted and spinned yarns has a smooth and soft texture. These fabrics can be used in developing sarees, stoles, skirts, gowns and the other apparels were more fall and drape is required.

KAWABATA evaluation of the selected woven fabrics

Primary and total hand values of Lotus fabrics were studied. In a fabric, Koshi (stiffness) value depends on bending property. The Koshi was less for PL fabric -8 (Powerloomfabric :Warp – Machine spun Cotton yarn – 80’s ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71’s)as compare to HS fabric -2(Handspun fabric :Warp – Handspun Cotton yarn - 120’s ; Weft – Handspun Lotus yarn: 3 petiole - 3/28’s) . The reason behind this is the finer, stronger, high twist, machine extracted and spinned yarn used for developing fabric on powerloom. HS fabric-2(Handspun fabric :Warp – Handspun Cotton yarn - 120’s ; Weft – Handspun Lotus yarn: 3 petiole - 3/28’s) has high Koshi value because of the coarser, hand extracted and spinned yarn used in the weft for developing fabric on handloom. This fabric has an uneven appearance and few slubswere seen due to the quality of hand extracted and spun yarn.
Fukurami (Fullness & Softness) is the bulky, rich and well-formed feeling and it mainly depends on fabric bulk and compression properties.Fukurami means warm feeling of the fabric. The Fukurami value of PL Fabric -8 (Powerloomfabric :Warp –

Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's)was higher than HS fabric -2(Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) . Hence the fabric developed from the machine extracted and spinned yarn was more softer than hand extracted and spinned yarn.

Numeri (Smoothness) value was higher for PL fabric -8 (Powerloom fabric : Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's)than HS Fabric -2 (Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) due to the finer and stronger Lotus yarn used in PL fabric -8(Powerloom fabric : Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's). It was also observed visually that appearance of the PL Fabric -8 (Powerloomfabric :Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's)was more smooth as compare to HS fabric -8(Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) . Overall the total hand value (THV) of the PL fabric -8 (Powerloom fabric (Warp – Machine spun Cotton yarn – 80's; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's)was more than HS fabric -2(Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) . Hence it can be concluded that yarns developed from the fabricated machine leads to fine fabric with better handle property.

The linearity of the tensile property (LT) is indicative to wearer comfort. Low value of LT leads to high fabric extensibility but the fabric dimensional property decreases. The LT value of HS fabric -2 (Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) was high. The EMT (Tensile strain) factor affects tailorability and seam slippage. A high valueof EMT provides wear comfort but creates problems during stitching and seam pressing. The EMT (Elasticity or stretch) of the PL fabric -8(Powerloomfabric :Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's) was more means it needs more care during the stitching. EMTvalues of both the fabrics in warp direction is higher than weft direction. The WT (tensile energy value) was more in HS Fabric -2 .The tensile Resilience (RT)indicates recovery after tensile deformation. There was very slight difference in RT values of both the fabrics. This may be due to inherent property of elongation and recovery of the Lotus fiber.

Tensile resilience values are higher for tighter construction because of crimp removal, which leads to a better recovery in tight fabrics. Both the fabric has a compact appearance with high fabric count and cover factor. SMD (Geometrical Roughness) property of HS Fabric -2 (Handspun fabric :Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) was more than PL fabric - 8(Powerloom fabric : Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's). This is due the quality of hand extracted and hand spun yarn used in weft direction of the fabric. Hence it can be concluded that fabric developed from machine extracted and spinned yarn was smooth and softer whereas the fabric developed from hand extracted and spinned yarns was more rough. Both the fabrics is attributed to good elongation and recovery property.

5.3.7. Development of Knitted fabrics and analysis of the properties

For the experimentation in Knitting it was observed that two machine extracted and spinned yarns that is – MYHS1 (Machine extracted and spinned yarn high speed 1) and MYHS2 (Machine extracted and spinned yarn high speed 2) was feasible in developing circular knitting structures. Majorly these two yarns can withstand strength on circular knitting machine. Hence two knitted fabrics was developed: a). LK1 -71 (Lotus yarn (Machine extracted and spinned 3/71's count yarn) and b). LK2-60 (Lotus yarn (Machine extracted and spinned 3/60's count yarn) The elastane used in both the fabric samples was 60 denier. It was observed that both the fabrics were soft and stretchable.

Both the fabrics has a good stretch and recovery properties. Stretch percentage points (recovery percentage) of LK1-71 fabric was 40 % in the wale direction and 90 % in the courses direction. Hence this type of structure can be suitable for the application in form-fitting apparels. Stretch percentage points (recovery percentage) of LK2 -60 was 20 % in the wale direction and 40 % in the courses direction. Hence this type of structure can be suitable for the application in loose fitting apparels. The satisfactory stretch and recovery percentage is obtained due to the characteristic of the Lotus yarn (MYHS1 & MYHS2) along with the Lycra yarn used in developing fabrics. LK-1-71 fabric was pilling resistant with no pills seen on the surface. There was slight pilling

observed in LK2 -60 fabric. Bursting strength of LK2-60 fabric was found higher that is 11.08 Kg/Cm^2 as compare to LK1-71 fabric that is 7.57 Kg/Cm^2 . The higher thickness of LK2-60 fabric that is 0.97 mm also leads to higher bursting strength. Due to the satisfactory testing results of both the fabrics in terms of stretch and recovery property, bursting strength and pilling , softness , absorbency, antibacterial property of the Lotus fiber, the utility products socks was developed. Two socks was developed one was made from MYHS -1 (Machine extracted and spinned yarn high speed 1) of 71's count and another was developed from MYHS -2 (Machine extracted and spinned yarn high speed 2). Both the socks were comfortable to wear.

5.3.8. Functional properties of Lotus fiber

Lotus fiber was tested for pH, absorbency, antibacterial and cytotoxicity properties. pH value of the Lotus fiber was 6.9. As per ISO:5405 pH value of the absorbent material used in sanitary napkin should range between 6 to 8.5 to fulfill the purpose without causing any skin irritation and comfort. It was found that Lotus fibers has a positive antibacterial activity with Bacteriostatic effect against four microorganisms - *Staphylococcus aureas, Klebsiella pneumonia*. *Pseudomonas aeruginosa* and *Candida Albicans.* Lotus fiber has a 20 % cytotoxic value and possess slight reactivity against the cell means there are some degenerated or malformed cells observed in the specimen. As per ISO 10993:5:2009, reduction of the cell viability more than 30 % is considered as harmful and cytotoxic. Hence the Lotus fiber is non-cytotoxic means it will not create any toxicity to the cells. Absorbency under load percentage of the Lotus fiber was 16.01 % in 60 minutes. Equilibrium absorbency of the Lotus fibers was 40 % in 24 hours. Lotus fibers possess free swell absorptive capacity of 35. 17 %. Hence Lotus fibers has a functional properties for the applications in the core layers of the hygiene medical textiles.

5.3.9. Development of nonwoven fabrics

Lab scale method was developed to check the possibility for making the nonwoven sheet from Lotus fibers. In this method, fibers were extracted and laid over the woollen felt in horizontal and vertical directions that forms a web like structure due to the natural cohesiveness property of the Lotus fiber. To make the web more compact, it was taken from woolen felt to A4 size paper. Water was sprinkled over the web. Then the A-4 size sheet comprising of extracted fibers was covered with the polypropylene mess which was passed through padding mangle in 3 psi pressure. Then sheet was kept to dry in moisture oven for 1 hour at 100º C. After drying ,the compact nonwoven structure was formed.Finally for application in the hygiene medical textiles, 100 % nonwoven sheet was developed in the machine. The entanglement of the fibers was better in the nonwoven web developed from machine. Thickness of the nonwoven web was 0.47 mm and GSM was 58. Further this nonwoven sheet was used in the core layers of the sanitary napkin.

5.3.10. Development of hygiene product and its testing

Sanitary napkin was developed in three different sizes that is large, medium and small. First layer was polypropylene sheet, core layer was 100 % Lotus and third layer was polyethylene sheet. During the cutting of core layers it was observed that there were leftover pieces from the sides of the nonwoven sheet. Hence these pieces were used in the core layers of other small hygiene products like sweat pads and pantyliners. Sanitary napkin was tested for absorbency under load (AUL) test. It was passed in the test. It was found that developed sanitary napkin can absorb 30 ml colored liquid within 6 minutes and there was no leakage observed at bottom and sides of the sanitary napkin. Hence with these functional properties of high absorbency, positive antibacterial activity and non- Cytotoxicity of Lotus fibers will be a novel material in the area of hygiene medical textiles. The process of fiber extraction and manufacturing into the nonwoven doesnot contain any chemical treatment.

5.3.11. Training group of women for fiber extraction and spinning

Group of ladies were trained for fiber extraction and spinning. Ladies told that we arevery lucky to learn such kind of skill in our life and it has helped to manage some of thefinancial crisis. They quoted that earning the money by their own hard work has a differentcharm and it gives a great satisfaction. They are ready to continue this work in coming future.

Exhibition of the fabrics

Hand woven stoles were developed from the yarns prepared by the ladies in the training programme. The stoles were exhibited in three different exhibitions – a). Exhibition was done in Eva Mall, Vadodara on International Women day -8 March, 2022. Total100 peoples visited the stall, they like the texture and feel of the fabric. b). Fabrics were exhibited in the “Agripreneurs Conclave” at Gujarat Technological University at Chandkheda on 21-22 July, 2022. Different start up agencies, people associated with the agriculture, textiles, fashion and robotics visited this stall. c). Weave Knit 2022 (The complete fabric show) 2nd Edition was conducted on 24-25 July, 2023 at Sarsana, Surat. This exhibition has given the complete shape to the entire work.

Various fabric manufacturers, yarn manufacturers and designers visited the stall. This exhibition has given a future path for the commercialization of the entire work.

Conclusion

India is a country of wetland eco-system. Lotus is widely cultivated across the country. Lotus cultivation generates huge amount of petiole waste. This hygro waste can also be used for textile applications.

In this research, this hygrowaste containing precious fibers was successfully explored and experimented from its baseline problem – that is development of machine (with different mechanisms) for extraction, yarn spinning, fabric weaving, nonwoven fabric preparation for medical textiles, knitting, training the community for women empowerment.

Manual extraction was found feasible with various numbers of petioles (1-3).

For spinning on Ambar charkha, yarns can be made by varieting number of petioles (1-3) which will be used for Khadi industry.

Finer handspun Lotus yarn L1A (Lotus yarn, 1 petiole extracted, *Ambar charkha* spun yarn) of 96's count was achieved from one petiole which was found feasible in handloom weaving especially with fine Silk.

Lotus yarn L1A (Lotus yarn, 1 petiole extracted, *Ambar charkha* spun yarn) of 96's count has achieved high tenacity of 36.531gf/tex amongst the handspun category of yarn.

In manual extraction process, as the number of petiole decreases the fineness of the yarn (count) increases.

The major drawback of Lotus fiber is time-consuming extraction process so fiber is only restricted to handmade textiles. Due to the delicate nature of the fiber and arrangement of the fiber in different xylem cells and side walls of the Lotus petiole, it was challenging to build power operated semi-automatic mechanical device. But it was found feasible to extract fiber from the fabricated machines.

Due to the nature of manual Lotus fiber extraction process, the fibers have to be extracted and simultaneously twisted considering this aspect, Machine-1 was designed and developed successfully for yarn making and it was found feasible to extract, spin and wind the Lotus yarn, all operation one at a time.

Four different counts of 100 % Lotus yarns that is 71's, 60's, 33's and 28's were achieved from Machine-1 by optimizing the speed of feeding and winding rollers of the fabricated machines.

Machine extracted and spinned yarn (MYHS1) developed in high speed using three petiole has obtained higher tensile strength (42.06 gf/tex), twist (100 tpi) and fineness (71's) as compared to hand extracted and spinned yarn (L3A) – tensile strength (18.537), twist (63 tpi) and fineness (28's) using same number of petiole.

In the manual method after extraction, spinning is also required to impart strength and proper twist for using it for handloom weaving whereas the developed machine-1 is designed in such a way that extraction, spinning and winding all the operation are done one at a time which saves time and energy.

All the twelve yarn developed by the different spinning techniques (three) has obtained desired twist range that is due to the inherent cohesiveness, natural crimp and high amount of fats and waxes present in the Lotus fiber which assists in imparting inherent twist during extraction and spinning.

The high cohesiveness property has also lead to take extra care in handling during manufacturing process.

Fiber from the leftover petioles can be used for making web on woollen felt. These fibers can be used in developing rotor spun yarns and nonwoven web.

For bulk production, extraction on woollen felt is not feasible which was taken extra care by machine-2. Machine-2 with specific mechanism was successfully developed and found feasible wherein raw fibers from petioles can be extracted for nonwoven and rotor spinning.

Yarns in two blend proportion can be made that is - 50:50 (Lotus: Cotton) and 70:30 (Lotus: Cotton). These yarns were coarser in fineness but softer in hand due to natural softness of Lotus fiber.

Amongst all the developed yarns, rotor spun yarn has achieved high elongation property in both the blend proportion that is 30.5 % for 50:50 (Lotus : Cotton) and 31.7 % for 70:30 (Lotus: Cotton). There was slight increase in elongation percentage of 70:30 proportions which may be due to the higher proportion of Lotus fiber used in blend.

Lotus fiber extracted for yarn making has a long length which is joined end to end. Keeping two aspects: long length of fiber and un ability to withstand stress in weft direction on loom. Hence the efforts were made to blend in the yarn stage. Due to the cohesive nature of the Lotus fiber it was found feasible to ply the Lotus yarn developed from the fabricated machine with natural fibers (Cotton, silk and Lotus).

It was possible to make ply yarns from Lotus yarn with other natural fibers (Cotton, Silk and Wool).

Developed Lotus Ply yarns has a texturized appearance due to the characteristic of both the fibers used in the ply structure. Amongst the Ply yarns, YLCP that is Lotus: Cotton Ply yarns has achieved high tensile strength that is 13.158 gf/tex. YLSP that is Lotus: Silk Ply yarns has achieved high twist that is 90 tpi because Lotus and silk both has a similar smooth appearance.

Plying was achieved best with the YLSP yarn due to the similar appearance of both the fibers that is Silk and Lotus.

The yarns can be dyed with natural dyes with very good to excellent light and washing fastness property. Similarly with reactive dyes it showed very good to excellent wash and light fastness property.

The color strength K/S value of Lotus yarn dyed with Indigo dyes was high that is 89.58 amongst all the natural dyes means the absorption of the Indigo dyes was more into the Lotus fiber.

LROB (Lotus yarn dyed with reactive dye orange bright) and LRBL (Lotus yarn dyed with black) has obtained high K/S value that is 21.028 and 20.836 respectively amongst all the reactive dyes.

Yarns made from fibers extracted from machine-2 were found suitable to withstand strength on circular knitting machine. The intervention of machine leads to the development of circular knitted structures.

The developed knitted fabric structure are pilling resistant which is attributed to the inherent property of the fiber that is – softness, cohesiveness, water absorbency, the way it is extracted from the petioles and long length.

The knitted fabric thus produced was found suitable for form fitted apparels as well as loose fitting apparels due to the good recovery percentage.

Stretch percentage points (recovery percentage) of LK1-71 fabric were 40 % in the wale direction and 90 % in the courses 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 -60 was 20 % in the wale direction and 40 % in the courses direction. Hence this type of structure can be suitable for the application in Loose Fitting (Comfort Stretch) apparel type.

Development of socks was feasible from two different counts of machine extracted and spinned Lotus yarns along with elastane in industrial circular knitting machine. The socks were soft in feel and comfortable to wear.

LK1 & LK2 knitted fabric was lighter in weight with the GSM value 80 (2.35 oz) and 83 (2.47 oz) respectively.

Lotus fiber (in its natural form without any treatment) has a positive antibacterial activity with the Bacteriostatic effect against four microorganisms: *Staphylococcus aureas,Klebsiella pneumonia*. *Pseudomonas aeruginosa* and *Candida Albicans.* These microorganisms are most prominently found in vaginal ecosystem and also responsible for blood related infections.

Lotus fiber (in its natural form without any treatment) is non cytotoxic in nature with slight reactivity against the cell lines. It has achieved free swell absorptive capacity of 35. 17 % which was suitable for the application in core layers of hygiene products.

Lab scale method is also found suitable for the development of nonwoven web which is due to the inherent property of cohesiveness of the Lotus fiber to form a web structure.

100 % Lotus nonwoven fabric on machine had a better entanglement of fibers and less in weight (58 GSM/1.71 oz). Due to the good entanglement of the fibers in the web structure and further its application restricted to the inner layer. It was not subjected further for needle punching.

The nonwoven sheets were used for developing sanitary napkin with Lotus core was passed successfully in the absorbency under load test. Developed sanitary napkin absorbed 30 ml colored liquid within 6 minutes and there was no leakage observed at bottom and sides of the sanitary napkin. Due to the positive functional properties of the Lotus fibers it can be used as a core and functional layers of the medical hygiene products.

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 25 grams of yarn (6 hours extraction + 1 hour spinning) can be developed in 6 hours using 1 manpower.

All the woven fabrics has different textures and aesthetics. Fabric constructed from yarns developed by different spinning techniques and weaving has its own merits and demerits. But each and every fabric can be used for various applications depending on its properties.

Fabric developed with Silk warp and finer handspun Lotus of 96’s count (HS Fabric -3) has a sheer appearance , light weight, less stiffness, lower drape co-efficient, neglible shrinkage and piling resistant whereas the tensile and tearing strength was lower amongst all the fabrics. This fabric can be used were durability is not a factor.

Amongst the constructed fabrics, PL Fabric-13 and PL Fabric -14 was high in GSM that is (323 GSM/9.52 oz) and (336 GSM/9.90 oz) which falls under the category of heavy weight fabric due to the blended Lotus :Cotton open end yarns of the coarser count used in both warp and weight direction. Both these fabrics are suitable for the applications in denims, blankets and coats. Rest all the fabrics were light in weight in the range of 1-4 oz which is suitable for light weight fabrics.

All the developed woven fabrics has neglible shrinkage excluding PL Fabric – 11 (Powerloom fabric (Warp – Machine spun Cotton yarn – 20's; Weft – machine extracted and spun Lotus yarn: 3 petiole –3/28's). Minor shrinkage was seen in the fabrics developed from open end yarns.

In terms of durability, PL fabric -8 (Powerloom fabric (Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's) and PL fabric -9 (Powerloom fabric (Warp – Machine spun Cotton yarn – 70's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/60's) has obtained high tensile and tearing strength in weft direction which may be due to the higher tenacity of machine extracted and spinned yarn used in weft direction. Hence these fabrics can be used where durability is a factor.

Fabrics developed from the ply yarns has a texturized appearance.

Khadi fabrics (HS Fabric -1 and HS Fabric -2) has lower abrasion resistance property which is due to the hand extracted and spinned yarn used in fabric structure. Hence these fabric cannot be used where more wear and tear is required.

The fabrics developed from rotor spun yarns have obtained higher abrasion resistance property. The fabrics has obtained higher number of cycles amongst all the constructed fabrics.

100 % Lotus fabric that is PL fabric -12 has obtained low tensile strength in both warp and weft direction amongst all the constructed powerloom fabrics. This may be due to the difficulty in maintaining tension during weaving with both Lotus

warp and weft. Hence this fabric cannot be used in the products where strength is a major component.

The fabric containing the yarns developed from fabricated machines has higher tensile strength as compare to the fabrics developed from manual extraction technique. Hence fabricated machine has a huge advantage in terms of yield and properties.

Fabrics developed from open end rotor spun yarns has better elongation property amongst all the constructed fabrics.

Kawabata test revealed that PL fabric -8 (Powerloom fabric - Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's) and HS fabric – 2 (Handspun fabric - Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's) is suitable for **"Women Suiting"**.

Total hand value (THV) of PL fabric -8 (Powerloom fabric - Warp – Machine spun Cotton yarn – 80's ; Weft – machine extracted and spun Lotus yarn : 3 petiole – 3/71's) was higher than HS fabric – 2 (Handspun fabric - Warp – Handspun Cotton yarn - 120's ; Weft – Handspun Lotus yarn: 3 petiole - 3/28's).

Group of women in the training project has learnt the skill of extracting fibers manually and spinning yarns. They are ready to continue this work in future which will be source of income for them. The skill for extraction and spinning can be acquired easily by anyone irrespective of their precious qualifications.

The outcome of the study has visualized a future possibility of channelizing an entire commercial set up of Lotus fiber extraction, spinning, and fabric development (woven, nonwoven & knitting).