CHAPTER V

SUMMARY AND CONCLUSION

Depleting natural resources, regulations on using synthetic materials, growing environmental awareness and economic considerations are the major driving forces to make the most of annually renewable resources such as biomass for various industrial applications. Agro-based bio-fibers have the composition, properties and structure that make them suitable for uses such as composite, textile, pulp and paper manufacture. Banana is one of the most commonly grown fruit crop of the country. In India, approximately 5 lakhs tones of banana trunk are discarded as waste every year, after harvesting. Instead, banana fibers can be extracted from those trunks. Employment and income to millions of people engaged in its growing and trade can be generated.

India produces about 26.217 Mmt of Banana from an area of 0.709 Mha. Major producing states are Tamil Nadu, Maharashtra, Karnataka, Gujarat, Andhra Pradesh, Assam and Madhya Pradesh. After the consumption of the fruit the plant is cut and thrown on the roadside. This biomass is of great importance, as banana pseudostem is the basic raw material required for extraction of banana fibers and Gujarat (locale of the study) has sufficient availability of the same to cater to the need.

In current world scenario, the banana fiber is being extensively used as a blending material in textile industry; A vast market is in the countries of U.S.A., European Union, Malaysia, and Philippines and in Korea, Japan currency is made out of Banana fiber. Most of the banana fiber that is extracted in India is exported. However, presently in India, a wide range of eco friendly items are being made out of Banana fiber. Products like, doormats, carpets, yarn, rope, geo-textiles, luggage carriers and interior decorative items are made out of these banana fiber. The reason for the underutilization of these fibers is their stiffness and less pliability, which could be due to its lignocellulosic structure.

The chemical composition of banana is inherent according to the particular needs of the plants. Cellulose, hemicellulose and lignin are the three main constituents of any lignocellulosic source, and majorly the proportion of these components in a fiber depends on the age, source of the fiber and the extraction conditions used to obtain the fibers. However, lignin is a highly cross linked molecular complex acting as glue between cellulose and hemicelluloses and the chemical composition of banana fiber is as follows: Cellulose 69.5, Hemicellulose 15, Lignin 6, Pectin 0.5, and Fats 1.5. The higher percentage of lignin contributes to its stiffness and also to the excellent strength. Banana fibers are long filament length lustrous fibers, which needs to be softened for spinning yarns.

The major objective of the present research was to standardize softening treatment/finish for banana fibers. The finishing treatment focuses on banana fibers to improve their handling in the process of spinning and manufacturing. The treated fibers were used to spin banana and banana blends, which were used as weft for fabric construction.

5.1. Objectives of the study

5.1.1 To study the fine structure and physical properties of procured banana fiber.

5.1.2 To optimize chemical and enzyme treatment conditions for softening of banana fiber.

5.1.3 To test the physical properties and chemical composition of untreated and treated banana fibers.

5.1.4 To prepare hand spun yarn using untreated, enzyme treated, and chemically treated banana fibers and test their physical properties.

5.1.5 To obtain maximum blend percentage of chemically treated and enzyme treated banana fiber with regenerated cellulose fiber by machine spinning and test their physical properties.

5.1.6 To develop hand woven and machine woven fabrics using 100% banana yarn and banana and regenerated cellulose fiber blends and banana yarn spun on jute spinning system.

5.1.7 To test and compare the properties of the fabrics prepared and suggest their end use.

5.2. Material and Methods

Methodology: The study undertaken was an experimental and exploratory in nature. The study was divided into three phases: Fiber, yarn and fabric stage.

5.2.1. Phase I: Fiber stage

The study started with selection of raw material. Banana fibers were procured from three different sources and on the basis of their strength and availability, fibers were selected. The raw fibers were studied for its physical properties, microscopic properties and material characterization. The fibers were softened by standardising softening treatment. Two methods were standardised i.e. chemical treatment and enzyme treatment. After the chemical treatment the effluent was also analysed. The untreated and treated banana fibers were tested using relevant testing standards.

5.2.2. Phase II: Yarn stage

Two sets of yarns were prepared using the untreated and treated fibers. Handspun variety of yarns were spun using the untreated and treated yarns on phoenix charkha. Another set of blended yarns was a project with TRADC Kosamba. The treated yarns were cut in staple length of 34mm. The chemical treated fibers were blended with viscose, modal and excel. The enzyme treated staples were blended with viscose.

Another set of yarn was procured from Navsari Agricultural University. The yarn was the resultant of the project undertaken. The yarns were used as weft for constructing cotton banana fabric. The constructed fabric was divided into three. One was kept as untreated and the other two were given enzyme and chemical treatment.

All the yarns were studied for their fineness, evenness, and strength and twist characteristics.

5.2.3. Phase III: Fabric stage

All the yarns were used to construct fabrics. Handspun yarns were used to construct handloom fabric: cotton banana fabrics where untreated and treated handspun banana yarns were used as weft. The blended yarns of regenerated fibers with banana fibers were used to construct fabrics using their regenerated fiber as warp yarn. Hence viscose banana, modal banana and excel banana fabrics were prepared using chemical treated fibers and viscose banana for enzyme treated.

All the fabrics were given silicon finish for improved hand. The fabrics were tested for their wear properties and KAWABATA test. Preference data was also collected for the fabrics, at an International Conference in Bangalore. The data was collected in an international conference to obtain view from the respondents related to textile field, be it from industry or academics.

5.3. Result and Discussion

The present study explored the potential of banana fibers in textile application. For the present study fibers were procured from Navsari Agricultural University. The plant variety used for extraction was *Grand Nine.* Average length of fiber was 80 – 110 cm, with fineness of 157.59 denier, with the bundle strength of 42 gms/tex.

5.3.1. Results of Phase I have been discussed under the following heads:

5.3.1. a Optimization of bleaching and softening treatments
5.3.1.b. Application of FFT apparatus
5.3.1.c. Effect of softening treatments on physical properties of banana fiber
5.3.1.d. Comparison of enzyme treated banana fibers and chemical treated banana fibers

5.3.1.a. Optimization of bleaching and softening treatments: Banana fibers were treated with two types of treatments in order to achieve maximum whiteness and softness. The treatments were done using enzymes and chemicals. Both the treatments consists series of treatments together.

Enzyme Treatment: Based on the composition of banana fibers, four enzymes were selected; cellulase, hemicellulase, pectinase and lacase. Their concentrations and dwell time were optimized. The order of application was also studied and it was concluded that banana fibers should be first treated with lacase, followed by hemicellulase, cellulase and pectinase. From the structure of banana fiber it was observed that lignin acts as glue between cellulose and hemicelluloses. When the fibers are first treated with lacase, it loosens the complex lignin structure. Due to this action other enzymes can penetrate with ease and aids in removal of unwanted impurities.

Chemical Treatment: It was a series of treatments. The fibers were first alkalinized, followed by bleaching. The bleach used was the combination of hydrogen peroxide and sodium hypochlorite. After bleaching the fibers were again alkalinized. This series of treatment reacts similarly as enzymes, by loosening the complex structure and removing the unwanted impurities. This treatment had been applied for patent.

5.3.1.b. Application of FFT (filament fiber treatment) apparatus: After bleaching and softening treatment the fibers were combed. Combing removed the pithy material from the fiber. Along with the pithy material, some filament fibers were also removed due to entanglements. Less wastage was generated after treating banana fibers in filament fiber treatment apparatus. The apparatus let the fibers rotate without entangling with each other. This observation was measured by weighing the combed waste.

5.3.1.c. Effect of softening treatments on physical properties of banana fiber: there was marked difference in the physical properties of untreated and treated fibers. The fineness of untreated banana fibers was 157.59 denier which was reduced to 121.30 denier for enzyme treated and was further reduced to 87.27 denier for chemical treated banana fibers. Any processing on the fibers affects its strength and the same was observed for enzyme treated fibers. However the strength of the chemical treated fiber strength was not much affected because the treatment with alkali behaved as mercerization. The hand of the fiber was improved by both the treatments. The evenness of the untreated and treated fibers was observed by plotting a graph from the readings of its diameter. The standard deviation for untreated fibers was 8.6 SD, which was improved to 3.4 SD and further 2.3SD for chemical treated fibers. Hence the treatment improved the fineness and evenness.

The CI of all the three samples was calculated by XRD peak height method. CI for raw, enzyme treated and chemical treated was 35%, 62% and 46% respectively. The increase in the crystallinity index was attributed to two effects: (a) the removal of some of the amorphous materials and (b) the rearrangement of the crystalline region into a more ordered structure after all treatments.

FTIR results showed vibrations in the region between 3000 and 2850 cm-1 associated with the C-H stretching of lignin, hemicelluloses and cellulose, decrease upon enzyme treatment and further more on alkalization.

The waste water analysis confirmed that the chlorine was in permissible limits, although treatment is required for disposal of waste water as COD, BOD and TDS was high than the permissible limits.

5.3.1.d. Comparison of enzyme treated banana fibers and chemical treated banana fibers: From the results of the enzyme treated and chemical treated banana fibers, it can be said that chemical treatment was more effective for banana fibers. The bundle strength of untreated banana fibers was 42 gms/tex which was reduced to 37 gms/tex after enzyme treatment. Whereas the bundle strength of chemical treated banana fibers was 40gms/tex. This was due to the chemical modification of the fibers. Alkalization acts as mercerization treatment on the fibers. This fact was also supported by the FTIR readings. The XRD results also showed that the chemical treated fibers were more crystalline than the enzyme treated. The lignin content of chemical treated fibers was much reduced as compared to enzyme treated. 100% respondents stated that chemical treatment had better hand (feel) than the enzyme treated.

Hence from all the results of the tests conducted for analysing the properties of untreated and treated fibers, the chemical treatment was more appropriate treatment for banana fibers.

5.3.2 Results of Phase II have been discussed under the following heads:

5.3.2.a. Evaluation of spun yarns

5.3.2.b. Comparison of yarns made by untreated banana fibers, enzyme treated banana fibers and chemical treated banana fibers

5.3.2.c. Comparison of handspun and machine spun yarns

5.3.2.a) Evaluation of spun yarns: Two varieties of yarns were spun for the present study and the third variety was procured from Navsari, which was spun on Jute spinning system (NIRJAFT). The machine spun yarns were a part of project with TRADC and the third set of yarns were spun on phoenix charkha. Yarns procured from Navsari were coarse, uneven and had lot of hairiness. The yarns spun at TRADC were spun on ring spinning system. Four yarns (viscose banana, modal banana, excel banana where banana fibers were chemical treated, and excel banana with enzyme treated banana fibers) were spun. The yarns were fine within the range of 5’s to 8’s count and with the blend percentage of 25/75. The yarns spun of phoenix charkha were 100% banana yarn. This set had three yarns, made from raw banana fiber, enzyme treated and chemical treated. Hairiness was less in this set of yarns as compared with machine spun yarns. Yarn count ranged from 3's, 3.4's and 11's for raw, enzyme treated and chemical treated. However, elongation was less for all the hand spun yarns.

5.3.2.b)Comparison of yarns made by untreated banana fibers, enzyme treated and chemical treated banana fibers: Spinning of yarns using untreated /raw fibers was only possible for hand spinning. The raw fiber did not work on ring spinning system due to their stiffness and bundle behaviour. Yarns made by using enzyme treated fibers gave enhanced hand and were also improved in terms of finenesses. However, the strength of the fibers was affected. Enzyme treated fibers did not blend well with regenerated fibers because after enzyme treatment the fibers lost their crimp. Hence, only one yarn i.e. excel banana was spun. The chemical treated fibers were excellent in terms of increased strength, reduced hairiness. Chemical treated were excellent to be used for machine spinning or hand spinning. These yarns were more even and less hairy. The finest variety of yarns were hand spun, phoenix charkha spun banana yarn.

5.3.2.c)Comparison of handspun and machine spun yarns: Although machine spun yarns and hand spun yarns are two extremely different segments, which need not to be compared. However, for the present study the objective was to spun yarn with best technique that can be used in apparels and home furnishings. It was observed that the yarns spun on machine were more even but were pricking to the skin. Spinning on machine required less time but a lot of wastage was also noted. Hand spun also known as charkha spun yarns were time consuming, but improved hairiness was also observed. Yarn unevenness, and formation of slubs are characteristic feature of hand spun yarns, and that was observed in banana yarns also. 100% banana yarn can only be spun by hand spinning and phoenix charkha with the best results.

5.3.3. Results of Phase III have been discussed under the following heads:

5.3.3. a. Evaluation of fabrics constructed

5.3.3.b. Comparison of handloom and powerloom woven fabrics

5.3.3.c. Comparison of fabrics made from untreated fibers, enzyme treated fibers and chemical treated fibers
5.3.3. d. Comparison of effect of softening treatment pre and post weaving
5.3.3.e. KAWABATA analysis
5.3.3.f. Consumer Response

5.3.3.a) Evaluation of fabrics constructed: The objective of the study was to develop banana fabric and analyze their end use. Largely the construction of the fabric determines the end use and hence care was taken to weave banana union fabrics with possible maximum compactness. Powerloom woven fabrics were excellent with aesthetics with their GSM ranged between 215 to 285. The fabrics had similar appearance to Linen. From the test results of the physical properties of the fabrics, it was concluded that the fabrics are suitable to be used for suiting material, jackets, and other such apparel applications. The fabrics needs a lining material to be used for apparels, they cannot be directly worn next to skin as still had some prickliness. The fabrics woven using procured yarn from Navsari was coarse and heavy with the GSM of 400.This fabric was divided into three parts, one was kept as raw and the other two were treated with enzymes and chemical treatment as optimized for fibers.

Fabrics woven on handloom using phoenix charkha yarn showed wide variation amongst themselves. Fabric made using raw fiber banana yarn was heavy in weight. The fabric was unevenly constructed and was not suitable for apparels. Fabrics with enzyme treated fibers were better than the raw but the tensile strength was low. Fabrics with chemical treated fiber were of the best quality. The fabric was light in weight, soft to feel and had mesmerizing appeal. This fabric was also named as Banana Khadi. Handspun cotton yarns were used for warp and handspun banana yarns were used for weft, the fabric was woven on handloom.

5.3.3.b)Comparison of handloom and powerloom woven banana union fabrics: Powerloom and handloom fabrics are two different strata in the field of textiles. Both have their merits and demerits and do not stand for comparison. But for the present study banana union fabrics are made exclusively and there is a need to understand what method of construction is suitable for banana fabrics. Chemical treated 100% banana hand spun yarns can run on the powerloom but the speed is extremely reduced. Amongst all the handspun yarns only chemical treated phoenix charkha spun yarn could be used on powerloom and the others were thicker and uneven. Besides this the machine spun yarns are a blend, which reduces the percentage of banana fibers in the fabrics, whereas handloom fabrics are attention-grabbing. They range from heavy to fine fabrics. Handloom fabrics are time consuming but 100% banana yarns can be successfully used in weft. Also with handloom compactness of the fabric is less as compared to powerloom fabrics.

5.3.3.c) Comparison of fabrics made from untreated banana fibers, enzyme treated and chemical treated banana fibers: Untreated banana fibers are less pliable, lack smoothness and are attached to each other in bundles. To spin them into a yarn some treatment has to be given, the better the treatment, better is the quality of yarns. Raw fibers were eliminated to be spun on ring spinning system. Hence, only handspun banana yarns were made with low cotton count and the fabric constructed were also heavy to medium in weight. Treating the fibers with enzymes reduces their strength and removes crimp which did not support easy yarn construction both on powerloom and handloom. The chemical treated banana fibers were the best to be used for spinning and thus weaving. Finer varieties of fabrics were constructed using chemical treated fibers and fabrics.

5.3.3.d) Comparison of effect of softening treatment pre and post weaving: To connect the research to the recent developments in the field of banana fiber, this section was undertaken for study. The researcher procured the commercial finest variety of banana yarn made in the recent past research from Navsari. Using these yarns fabrics were constructed and were treated with enzyme and chemical treatment which was applied for banana fibers. At the same time fabrics were made using enzyme treated and chemical treated fibers. It was noticed that chemical treatment reduced the thickness on banana fabric. However, it was also observed that treatment before spinning and weaving gave finer quality of end product as compared to post weaving treatment.

5.3.3.e) KAWABATA evaluation: Handle properties of the fabrics were evaluated 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 & total hand values were calculated from sixteen mechanical properties.

Primary and total hand values of banana fabrics were studied. In a fabric the Koshi (stiffness) depends on its bending properties. The Koshi is less for Enzyme treated Cotton Banana Fabric of category II fabric since its bending rigidity is less. Numeri means surface smoothness. Numeri values are lower Viscose Banana Enzyme treated fabric of category III and higher for enzyme treated Cotton Banana Fabric of category I.

Fukurami (Fullness & Softness) is the bulky, rich and well-formed feeling and it mainly depends on fabric bulk and compression properties. It has been observed that Fukurami values are higher for Chemical treated Cotton Banana Fabric of category 1. Although the THV values of all the four fabrics was almost similar, however Fukurami values of Chemical treated Cotton Banana Fabric of category 1 was the highest. Hence the treatment improves the hand of banana fibers and thus the fabric.

The EMT (Tensile strain) factor affects tailorability and seam slippage. A high value of EMT provides wear comfort but creates problems during stitching and seam pressing. It was observed that EMT for warp was higher for all fabric samples than for weft. The linearity of tensile property (LT) is indicative of wearing comfort. Lower values of LT gives higher fabric extensibility in initial strain range indicating better comfort, but the fabric dimensional stability decreases. It was observed that LT is higher for Viscose Banana Enzyme Treated fabric of category III & lower for Modal Banana Chemical Treated fabric of category III. The tensile energy (WT) values are lower for Chemical treated Cotton Banana Fabric of category 1 and higher for Viscose Banana Enzyme Treated fabric of category III. The tensile Resilience (RT) indicates recovery after tensile deformation. RT is higher for Chemical treated Cotton Banana Fabric of category I & Modal Banana Chemical Treated fabric of category III and lower for Enzyme treated Cotton Banana Fabric of category I. Tensile resilience values are higher for tighter construction because of crimp removal, which leads to a better recovery in tight fabrics

5.3.3.f) Consumer Response: The present study aimed to investigate the consumer acceptance of the constructed union banana fabrics in terms of its newness, its hand (feel of the fabric), aesthetics, perceived value, and its market potential. Hence, the data was collected at international textile conferences. The criterion for collecting data at conferences and selecting the respondents was that they should be from the field of textiles or designing. Consumer's responses were taken by means of a structured questionnaire. Most of the respondents liked the banana union fabrics and Banana Khadi was the most preferred. Most respondents from the industry liked powerloom fabrics and were inquisitive about its further take. It was also analysed that there is a need of supply and consume chain for the raw material i.e. banana fibers. Most of the respondents stated that there could be a good market opportunity, inclusive of export for banana union fabrics, if the production is lined up.

Conclusion

- Banana fibers can be softened by enzymes and chemicals; however chemical treatment is more effective than enzyme treatment. Chemical treatment softens banana fibers, and also improves its spinnability. The treated banana fibers can be used to spin 100 %fine variety of banana yarn.
- Both the treatments standardised during the research, were applied at fiber stage and also at fabric stage. It was observed that treating the fiber had better results (in terms of fabric thickness, evenness) than application of treatment after fabric construction. Treatment at fiber stage improves spinnability of the fibers.
- Treated banana fibers spun on phoenix charkha gives more even yarn than the yarns spun on ring spinning system. Although banana blended yarns can be spun on machines but hand spinning gave finer and even yarns.
- Banana fabrics made from treated banana fibers can be used for home furnishing, and a few can be used for certain apparels. Kawabata test was conducted for Banana Khadi, modal banana, excel banana for its application as men's suiting and the results were given between the ranges from 1 to 5. All the four fabrics fall in the range of 3.
- "Banana Khadi" – is a handloom fabric constructed by hadspun cotton yarn as warp and handspun banana yarn as weft. This can be a prospective contribution to give a new dimension to khadi and village industry.

- All the fabrics constructed during the study are niche marketproduct.

5.5. Recommendations

1. The theory formulated for softening treatment of banana fibers usingchemical treatment can also be applied other lignocellulosic fiber like ramie, sisal, etc.
2. For the fibers which have to be cut into staple length for spinning should be cut first and then be exposed to the treatment. This would soften the cut exposed surface area i.e. the diameter of the fiber. Treating the fibers after cutting can reduce pickiness.
3. Spinning of banana yarns can also be studied on worsted spinning system.