CHAPTER III

MATERIALS & METHODS

The study undertaken was an experimental and exploratory on banana fibers. The main aim of the study was to soften banana fibers and spin banana, and blends of banana yarn. The spun yarns were used for weaving banana union fabrics. Present study also compared two types of softening treatments i.e. enzyme treatment and chemical treatment. Furthermore machine spun and hand spun yarns were compared in terms of ease of spinning and fineness of the yarn. Finally the fabrics were constructed and the best samples were evaluated by Kawabata for their end use.

The present chapter deals with material and methods followed for fulfilling the objective of the study.

3.1 Selection of raw material

3.2 Determination of fine structure of raw banana fibers

- 3.2.1 Determination of the physical properties of the fiber
- 3.2.2 Material characterization of the fiber
- 3.2.3 Determination of microscopic properties of the fiber

3.3 Optimization of softening treatment

- 3.3.1 Standardization of chemical treatment
- 3.3.2 Standardization of enzyme treatment
- 3.3.3 Fabrication of instrument for treating filament fibers

3.4 Testing of untreated and treated banana fibers using relevant standard methods

3.5 Effluent analysis of post treated liquor

3.6 Spinning and testing of yarns

- 3.6.1 Yarns spun on machine (ring spinning system)
- 3.6.2 Yarns spun on handloom (phoenix charkha)
- 3.6.3 Yarns procured from Navsari (spun on jute spinning system)

3.7 Construction of fabrics

- 3.7.1 Banana fabrics in combination with regenerated fibers (Viscose, modal and excel)woven on powerloom
- 3.7.2 Cotton banana fabrics woven on handloom

3.8 Application of silicon finish on the constructed fabrics

3.9 Evaluation of properties of constructed fabrics

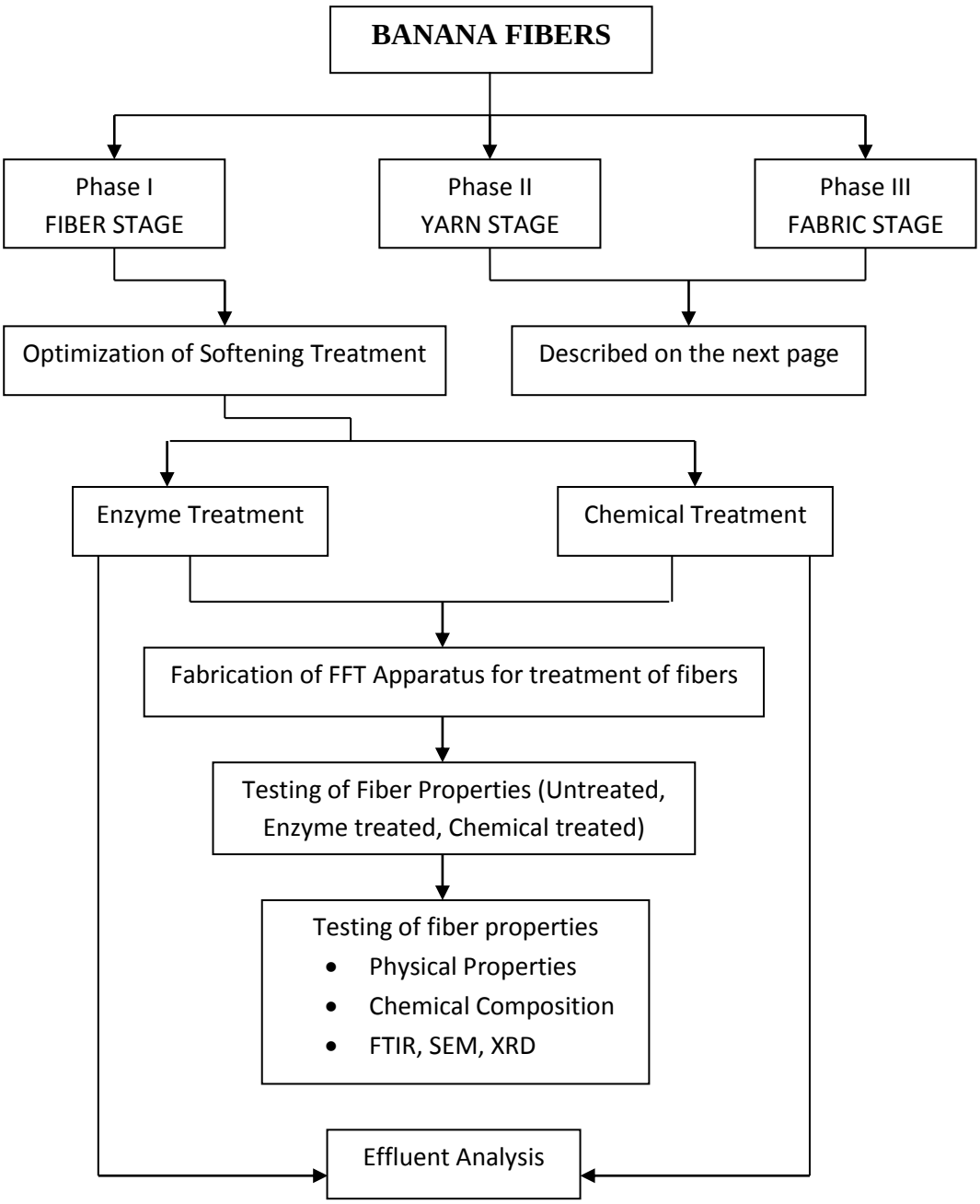
3.10 Kawabata analysis for determination of end use

3.11 Market Evaluation of the constructed fabrics

3.12 SWOC analysis of banana fiber – fabrics

3.13 Costing of the softening treatment standardised

Research Design



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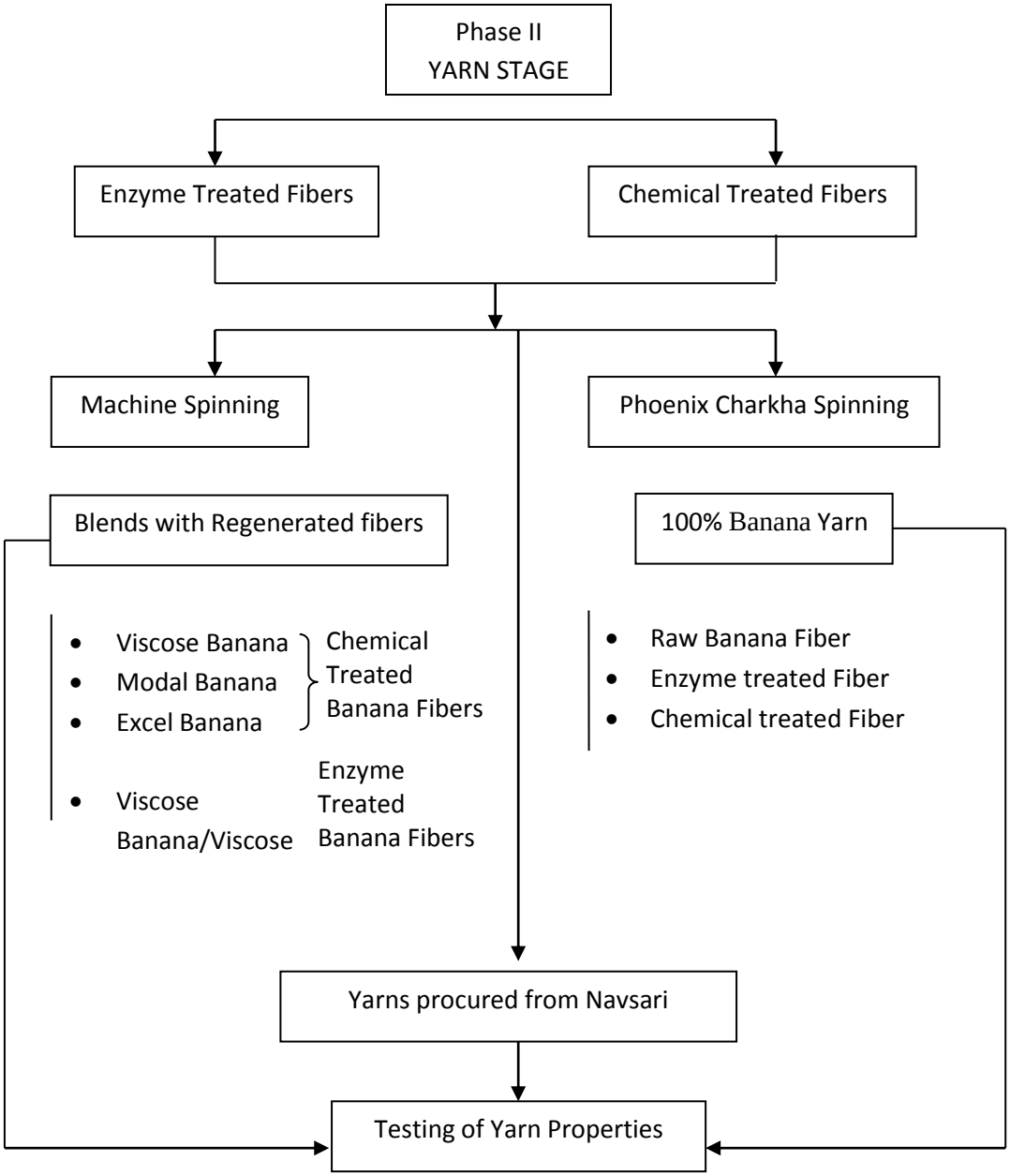

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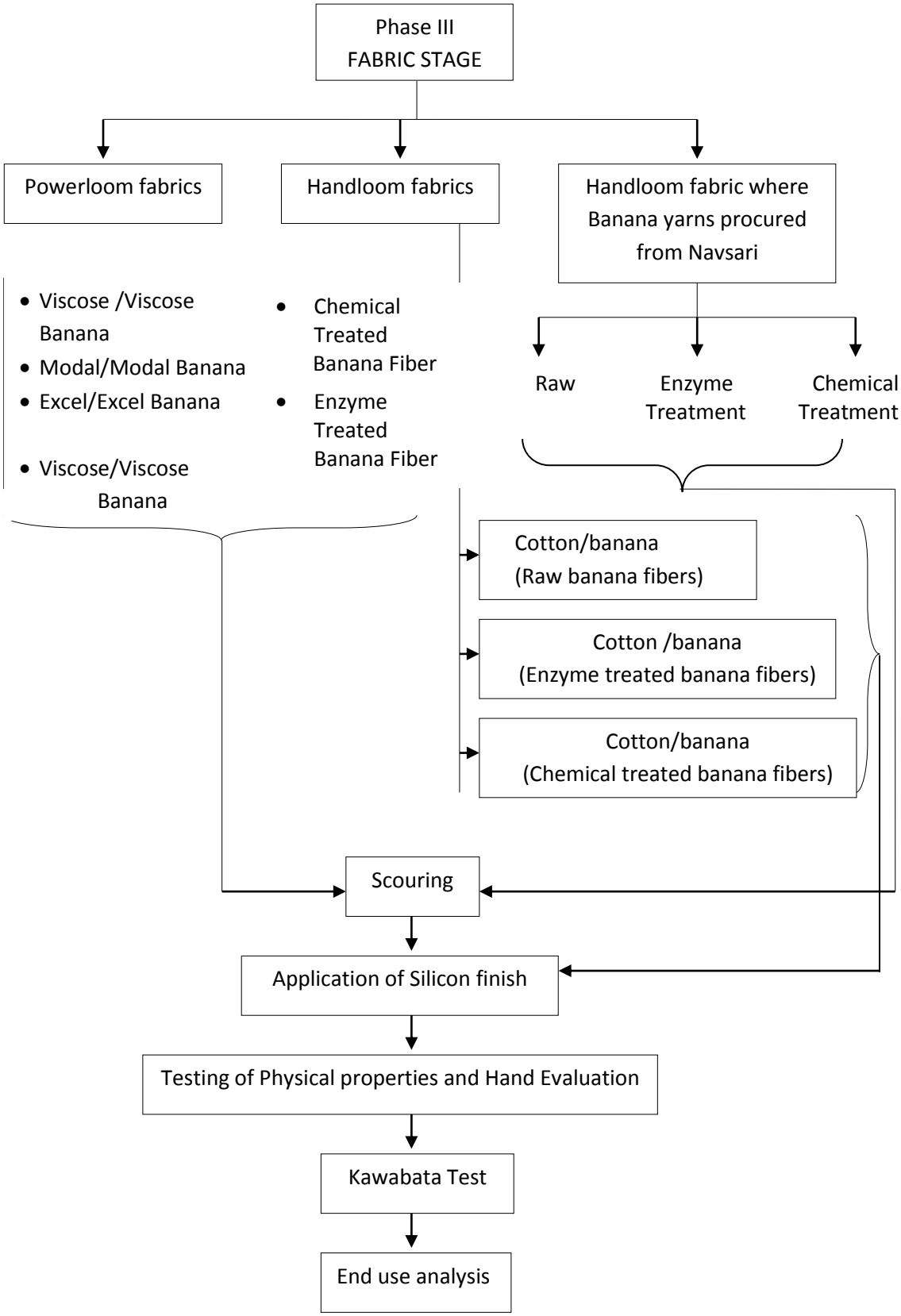
Phase III
FABRIC STAGE
Powerloom fabrics
Handloom fabrics
Handloom fabric where Banana yarns procured from Navsari
Viscose /Viscose Banana
Modal/Modal Banana
Excel/Excel Banana
Viscose/Viscose Banana
Chemical Treated Banana Fiber
Enzyme Treated Banana Fiber
Raw
Enzyme Treatment
Chemical Treatment
Cotton/banana (Raw banana fibers)
Cotton /banana (Enzyme treated banana fibers)
Cotton/banana (Chemical treated banana fibers)
Scouring
Application of Silicon finish
Testing of Physical properties and Hand Evaluation
Kawabata Test
End use analysis

3.1 Selection of raw material

Procurement of banana fibers

Banana fibers samples were procured from three different regions of India, contact details have been mentioned in Table 3.1

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

Sr.No.	Contact Organisation	Postal Address	Contact No./ E-mail address
1	Eco Green Unit	C-5,Agri Business Directorate Tamil Nadu Agricultural University Coimbatore.pin code 641003	Ph.09600876767 www.ecogreenunit.org
2	Jalgaon Banana Fiber Ltd.	Jalgaon - Maharashtra.	Ph. 07588816976
3	Navsari Agricultural University, Navasari	Dandi Rd, Navsari, Gujarat 396445	02637 293 804 chiragdesai@nau.in

3.1.1 Selection of the fibers on the basis of tensile strength and availability

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

The ease of availability of the fibers was also considered at the time of selection of the fibers for study.

3.2 Determination of fine structure of thefiber

The fine structure of banana fiber was determined by the following test:

3.2.1 Determination of the physical properties of banana fiber

3.2.1.1 Determination of fiber length

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

3.2.1.2 Determination of fiber diameter

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

3.2.1.3 Determination of colour and texture of the fiber

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

3.2.1.4 Determination of moisture regain of thefiber

To determine the moisture regain, the fibers of known weight were exposed to 65±2 % RH at 27±2˚C temperature for five days. The samples were weighed in condition state (W_1). The samples were then dried at 110˚C in oven, up to the constant weight (W_2). From these two weight difference, moisture regain was calculated using equation:

$$\text{Moisture regain} = \frac{\text{Weight of moisture } (W_1 - W_2) \text{ X } 100}{\text{Oven dry weight } (W_2)}$$

3.2.1.5 Determination of strength of banana fiber

3.2.1.5 a) Bundle fiber strength test

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

3.2.1.5 b) Single fiber strength test

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

3.2.1.6 Determination of fiber fineness

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

$$\text{Tex} = \frac{W \times l}{L}$$

Where, W = Weight of the fiber

L = Length of the sample

L = the unit length of the sample

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

3.2.1.7 Determination of fiber evenness

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

3.2.2 Material characterization of banana fiber

3.2.2.1 Determination of chemical composition of banana fiber:

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

a) Estimation of water soluble components

A weighed sample of known moisture regain was boiled in distilled water for five hours, using liquor ratio of 1:30. Sample was filtered in a sintered glass crucible of no: 1 porosity, oven dried at 100˚C for 30 minutes, conditioned at 65±2 % RH at 27±2˚ C temperature and weighed on electronic balance. The water soluble

compounds were expressed as percentage of oven dry weight of the original sample and were calculated using the following equation:

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

Where, W_1 is the initial weight of the sample

W_2 is the weight after the procedure (removal of water soluble)

b) Estimation of fats and waxes

After the removal of water soluble from the sample, it was extracted in the soxhlet apparatus with 2:1 alcohol (methanol): benzene for four hours. Sample was then washed with alcohol; oven dried and weighed (w_3 grams). The result was expressed as a percentage of the oven dry weight of the original sample and was calculated using the following equation:

$$\text{Fats and Waxes (\%)} = \frac{W_2 - W_3}{W_1} \times 100$$

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

c) Estimation of pectin content

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

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

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

d) Estimation of Hemicellulose content

After the pectin removal, the fibers were extracted in the soxhlet apparatus with 2% caustic soda solution for one hour and then washed thoroughly with distilled water.

The loss in weight due to removal of hemicellulose is estimated as a percentage of the oven dry weight of the original sample using equation:

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

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

e) Estimation of lignin content

The above treated samples were then treated for two hours under reflux, in a water boiling bath with 50:1 liquor ratio of 0.7% sodium chlorite solution, at 4 pH. The pH was obtained by adding acetic acid in the solution. This treated sample was then filtered in a sintered glass crucible of number 1 porosity. Later the samples were washed with 750 ml of distilled water, then with 250 ml of 2% sodium bisulphite solution, and then finally with 1000 ml of distilled water. Later the samples were dried at 105˚C. The lignin content as a percentage of the oven dry weight of original sample was calculated by:

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

Where, W_6 is the weight after the procedure (removal of lignin content)

3.2.2.2 Identification of chemical bonds suing Fourier Transform Infrared Spectroscopy (FTIR)

Infrared spectroscopy is an important technique to identify the presence of certain functional groups in a molecule. It works on the relationship between *time* and *frequency*. IR spectrum is divided into three sub-regions: the near-IR, approximately 14000 cm^{-1} – 4000 cm^{-1} (0.8 µm – 2.5 µm wavelength), the mid-IR approximately 4000 cm^{-1} – 400 cm^{-1} (2.5 µm – 25 µm wavelength) and the far-IR approximately less than 400 cm^{-1} – 10 cm^{-1} (25 µm –1000 µm wavelength). Majority of analytical FTIR applications used are in mid-IR range, which is approximately around 4000 cm^{-1} – 400 cm^{-1}, and the same range has been used for banana fiber FTIR analysis.

Simple was prepared by freezing the chopped banana fiber in liquid nitrogen and pulverizing it to yield a fine powder capable of being cast into traditional KBr pellets

for IR analysis. The KBr pellets of samples were prepared by mixing 2 mg of fiber sample, finely grounded, with 200 mg KBr (FT-IR grade) in a mortal and pastel. The 13 mm KBr pellets were prepared under vacuum in a standard device under a pressure of 75 kN cm–2 for 3 min. The spectral resolution was 4 cm^{-1} and the scanning range was from 400 to 4000 cm^{-1}.

3.2.2.3 Determination of orientation of polymer system by X-ray Diffraction (XRD)

X-ray diffract grams (scan range 2θ = 10 - 45̊) of the untreated and treated fibers were obtained with X-Ray diffractometer. The test was conducted in the department of Metallurgical and Material Engineering, Faculty of Technology and Engineering, (DST, PURSE, New Delhi), The Maharaja Sayajirao University of Baroda, Vadodara.

3.2.3 Determination of microscopic properties of banana fiber

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

3.3 Optimization of softening treatment

3.3.1 Standardization of chemical treatment for banana fibers

3.3.1.1Optimization of bleaching reagents for banana fibers (Pilot work)

According to the standard recipe for bleaching of cotton fabrics, using hydrogen peroxide, which was taken from several dissertations in the department of Clothing and Textiles, was used as base for treating banana fibers. Further variables were studied for standardization of the bleaching treatment for banana fibers.

Recipe for bleaching with hydrogen peroxide

1% v/v conc. of 100 vol H_2O_2

M:L::	1:40
pH:	9-10
Alkali:	4% owf
Time & Temperature:	80˚C for 1 hour

Cold wash

Neutralised with 1% v/v acetic acid for 5 min

Banana fibers were bleached with hydrogen peroxide, sodium hypochlorite, and peracetic acid. Apart from bleaching sulphonation was also carried out. It is a treatment with sodiumsulphite in presence of ethylenediamine (de-lignifying agent). Weight loss and bundle fiber strength test was carried out for all the treated and untreated samples to monitor the results.

Table 3.2: Variables studied for bleaching banana fibers using hydrogen peroxide to optimize treatment parameters

Fiber Code	**Bleach**	**Bleach Conc.**	**ph**	**Alkali**	**Time**
UN	Untreated				
A1	H_2O_2	**2%**	9	NaOH (4%)	45 min
A2	H_2O_2	**5%**	9	NaOH (4%)	45 min
A3	H_2O_2	**10%**	9	NaOH (4%)	45 min
B1	H_2O_2	5%	8	**NaOH (4%)**	45 min
B2	H_2O_2	5%	10	**NaOH (8%)**	45 min
B3	H_2O_2	5%	10	**NaOH (10%)**	45 min
C1	H_2O_2	5%	8	**Na_2SiO_3 (4%)**	45 min
C2	H_2O_2	5%	9	**Na_2CO_3 (4%)**	45 min
C3	H_2O_2	5%	10	**NaOH (4%)**	45 min
D1	**H_2O_2 : NaOCl ::2:1**	5%	9-10	NaOH (4%)	45 min
D2	**H_2O_2 : NaOCl::5:1**	5%	9-10	NaOH (4%)	45 min
D3	**H_2O_2 : NaOCl :: 2:1**	5%	9-10	NaOH (4%)	**30 min**
D4	**H_2O_2 : NaOCl ::5:1**	5%	9-10	NaOH (4%)	**30 min**
D5	**H_2O_2 : NaOCl :: 2:1**	**2%**	9-10	NaOH (4%)	30 min
D6	**H_2O_2 : NaOCl :: 2:1**	**1%**	9-10	NaOH (4%)	30 min
D7	**H_2O_2 : NaOCl :: 2:1**	**0.75%**	9-10	NaOH (4%)	30 min
E1 **(Sul.)**	**H_2O_2**	5%	9	NaOH (4%)	30 min
E2 **(Sul.)**	**H_2O_2 : NaOCl ::10:1**	0.75%	9-10	NaOH (4%)	30 min
F1	CH_3COOOH	**5%**	7	NaOH (4%)	30 min
F2	CH_3COOOH	**15%**	7	NaOH (4%)	30 min

Peracetic acid had negligible effect on banana fibers. Sulphonation improved the feel (softness) of banana fibers but poorly affected the strength, hence both reagents were eliminated. Sodium hypochlorite was an effective bleach to improve the whiteness and hand of the fibers, but had severely affected the strength. However considering the fact that chlorine bleaches are effective in lignin removal, sodium hypochlorite was combined with hydrogen peroxide, in small portion.

Hydrogen peroxide is universal bleach, and it was also effective for banana fibers. Variables studied to optimize bleaching parameters with hydrogen peroxide have been given in Table 3.2. The treated fibers with these variables were examined by weight loss, bundle fiber strength loss, and whiteness index.

From the above mentioned table, based on the test results, the following conditioned was optimized:

- Bleach: Hydrogen peroxide : Sodium hypochlorite :: 2:1
- Bleach concentration: 0.75%
- pH: 9-10
- Alkali: Sodium hydroxide
- Alkali concentration: 4%
- Time: 30 min
- Temperature: 80˚C to 90˚C

3.3.1.2 Standardization of chemical treatment for banana fibers

i) Alkalization and Bleaching Treatment

To begin the treatment, banana fibers were scoured, which is also termed as alkalization for lignocellulosic fibers. The fibers were treated with 4 % sodium hydroxide at 80˚C to 90˚C for 30 min, 60 min, 1.5 hour, 2 hour, 2.5 hour, 3 hours and bleached with the optimized bleaching recipe. Time of treatment with sodium hydroxide was studied based on bundle fiber strength and the hand of the fiber. Fibers treated for 2.5 hours and 3 hours were almost similar in terms of strength and hand, hence 2.5 hours of NaOH treatment was optimized.

Alkalization for 2.5 hours was accompanied with the combination of bleaches for 25 minutes. Three combinations were studied for alkalization and bleaching, keeping the treatment hours constant.

1. Set I: Alkalization (2.5 hours) followed by bleaching (25 min)
2. Set II: Bleaching (25 min) followed by alkalization (2.5 hours min)
3. Set III: Alkalization (1.5 hours) followed by bleaching (25 min) followed by re-alkalization (1 hour)

The effectiveness of the above treated fibers was studied by calculating the chemical composition of banana fibers.

ii) Treatment with oil emulsion

As jute and banana are similar in composition (lignocellulosic), it was assumed that they would behave similarly. Based on this fact, oil emulsion treatment was carried out as for jute. Three different oil emulsions were studied, Jute batching oil (JBO), Turkey red oil (TRO), Rice bran oil (RBO). Considering the limitations of JBO and TRO, demand has been generated to replace Jute Batching Oil in jute processing by a suitable Eco-fibre lubricant.

According to Chakrabarti (2001), Rice Bran Oil (RBO) is unique in terms of high thermal and oxidation stability and therefore reasonably free from rancidity nature, and also has eco-compatibility. Rice is one of the world's largest crops and thus rice bran oil was adequately available at reasonable price. Considering these factors RBO treatment was finalized for banana fibers.

Working specifications of RBO

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

3.3.2 Standardization of enzymes for treatment for banana fibers

3.3.2.a)Treatment with single enzyme:

Banana fibers were treated with four enzymes – cellulase, hemicellulase, pectinase and lacase, for softening the fibers. The enzymes were procured from Rossari enzymes.

Enzolite A & Bpowder (Lacase)

This enzyme specifically acts on lignin for its breakdown. It is also used as chlorine free bleach system for Indigo dyed denims.

Application Guidelines

Enzolite A Powder: 1 - 3 % o.w.f
Enzolite B Powder: 1 - 3 % o.w.f
pH: 5 – 6 pH
Temperature: 50 – 60^{o}C
Time: 20 – 45 minutes.
Enzolite A Powder and Enzolite B Powder are to be used in the ratio of 1:1

G-zyme Axe liquid (Cellulase)

It is used for bio polishing in several cotton industries. It also acts on cellulose of the fibers.

Application Guidelines

Neutrox HG Conc. Powder: 0.5-1.0 %
pH : 5 -6
Temperature: 40°C
Time: 60-90 min

Neutrox HG conc powder (Hemicellulase)

Neutrox HG conc powder can be used for cold water applicable. It is used in industries to wash down effect on garments. The Constitution is Hemicellulases, and effective for hemicellulose removal.

Application Guidelines

Neutrox HG Conc. Powder: 0.5-1.0 %
pH : 5 -6
Temperature: 40°C
Time: 60-90 min

Scourenz ABE liquid (Pectinase)

Scourenz ABE liquid is a blend of biocatalysts for effective degradation of pectins and glucans

Application Guidelines

Scourenz ABE Liquid: 0.5-1.0 %
pH : 5.5
Temperature: 55°C
Time: 15 min

Following the application guidelines, the fibers were treated with four enzymes individually by varying time and concentrations. For all the treatments the M: L ratio was 1:40. Temperature and pH was kept according to the values mentioned in the technical information provided by the enzyme suppliers. Parameters varied for individual enzymes are given in Table 3.3.

Table 3.3: Variables studied for softening banana fiber using individual enzymes

Enzyme	**Concentration (% owf)**	**Time (minutes)**
Cellulase	0.2	45 and 60
	0.3	45 and 60
	0.5	45 and 60
	0.7	45 and 60
Hemicellulase	0.5	60 and 90
	1	60 and 90
	2	60 and 90
	3	60 and 90
Lacase	2	25 and 45
	3	25 and 45
	4	25 and 45
	5	25 and 45
Pectinase	0.5	15
	0.7	15
	1	15

Weight loss and bundle fiber strength test were studied for analysis of the treatment. After optimisation of time and concentration of individual enzyme, combination treatments were conducted, which are mentioned below. Weight loss, bundle fiber strength test, chemical constituents were tested to monitor the effectiveness of the treatment

3.3.2 b)Treatment with combination of enzymes

Set A: based on time of treatment. All the four enzymes were added in one bath, starting with the maximum time of treatment.

Hemicellulase for 60 min, followed by addition of Lacase for 45 min and cellulase treatment for 30 min, followed by addition of Pectinase treatment for 15 min.

Set B: based on considering the lignocellulosic structure. Targeting to loosening of lignin structure, banana fibers were treated with lacase first followed by hemicellulose and other components.

- Lacase treatment for 45 min
- Hemicellulase treatment for 60 min
- Cellulase treatment for 30 min
- Addition of Pectinase in Cellulase treatment bath after 15 min

3.3.3 Fabrication of instrument for treating banana fibers

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

3.4 Testing of untreated and treated banana fibers using relevant standard methods

Following test were conducted for analysis of the treated fibers.

3.4.1 Weight loss: Weight loss percent was calculated by the given formula [(IW – AW) /IW] x 100.

3.4.2 a) Bundle fiber Strength: The test method and standard have been mentioned on page number 73.

3.4.3 b) Single fiber strength and elongation test: The test method and standard have been mentioned on page 73.

3.4.4 Fiber finesse: The test method and standard have been mentioned on page 74.

3.4.5 Fiber evenness: The test method and standard mentioned on page 74.

3.4.5 Whiteness index: Spectrophotometer was use for testing the whiteness index with CIE standard and Yellowness with ASTM D1925. The test was carried out in the Department of Textile Chemistry, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

3.4.6 Hand evaluation: The softness of the treated fiber were analysed by subjective evaluation. A 10 point scale was used, where 10 was the softest and smoothest to feel. A panel of 20 staff members and Ph.D research scholars of the department were asked to touch and feel the untreated and treated samples, where the samples were anonymously labelled. The eyes of the respondent were covered with a fabric, and before touching any sample, hands of the respondent were washed using finger bowl and wiped with a towel. The respondents were given a questionnaire (Appendix I) and asked to feel the fabric using their index, middle finger and thumb and rank the sample. (Shetti 1998)

3.4.7 Chemical composition: The test method and standard had been mentioned on page number 74.

3.4.8 SEM: The Surface of the control, enzyme and chemical treated samples were analysed using a scanning electron microscope, SEM Joel JSM- 5610V. The test was conducted in the department of Metallurigical and Material Engineering, Faculty of Technology and Engineering, (DST, PURSE, New Delhi), The Maharaja Sayajirao University of Baroda, Vadodara.

3.4.9 XRD: X-ray diffractgrams (scan range 2θ = 10 - 45°) of the untreated and treated fibers were obtained with X-Ray diffractometer. The test was conducted in the department of Metallurigical and Material Engineering, Faculty of Technology and Engineering, (DST, PURSE, New Delhi), The Maharaja Sayajirao University of Baroda, Vadodara.

3.4.10 FTIR: The FTIR analyses of the samples were carried out in Shimadzu IR Prestige 21 analyser over the wavelength of 400 to 4000 cm^{-1}. The test was carried out in National Institute of Research on Jute and Allied Fiber Technology (NIRJAFT)

3.5 Effluent analysis of chemical treated liquor

Effluent analysis of liquor after treatment: analysis was carried out to identify the elements present in the applied softening treatment bath. The test was carried out at ATIRA, Ahmadabad.

3.6 Spinning and testing of yarns

3.6.1 Yarns spun on phoenix charkha (handspun yarns)

For the present study, banana fibers were spun on Phoenix Charkha. This was purchased from Phoenix Products, Belgaum. Three types of yarns were prepared: untreated (made from untreated banana fiber), enzyme treated (made from enzyme treated banana fiber), chemical treated (made from chemical treated banana fiber). Spinning of banana yarns for the research work was outsourced. The researcher trained two people for spinning the yarn. Before the final spinning of the yarns, few days of practice was given to the trained spinners. During these practice days focus was laid on feeding mechanism, as this step was manual and could be responsible for unevenness and also thickness to certain extent, of the yarn. Two men working for two days were able to generate 70 grams of yarn. One person's task was to loosen the fibers and the second person would feed the fibers in the charkha. Two people working on charkha, aids in speeding up the spinning process and also help to obtain finer yarns.

3.6.2 Yarns spun on ring spinning system (machine spun)

Spinning of yarn on the ring spinning system was carried at TRADC Kosamba, Gujarat. A project was undertaken in collaboration with TRADC, titled as "Process

Optimization for softening of Banana Fibre and application development product for Banana and regenerated cellulose to meet aesthetic performance". Banana fibers were softened by two methods, the enzyme and chemical treated, and sent to TRADC for spinning of banana blend with regenerated fibers namely: viscose, modal and excel. Spinning of enzyme treated fibers was carried out with extreme difficulty and only one yarn was spun with viscose.

3.6.3 Yarns procured from Navsari

A project sponsored by central government titled "A value chain utilization of banana pseudostem for fibre and other value added products", National Agricultural Innovation Project had reported several products made from banana pseudostem. One of it was banana yarns, which were used for the present research to have a continuity of the banana fibers and fabrics.

In total eight yarns were analysed by testing their following properties:

3.6.3.1 Determination of yarn fineness:

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

$$\text{Tex} = \frac{W \times l}{L}$$

Where, W = Weight of the fiber

l = Length of the sample

L = the unit length of the sample

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

3.6.3.2 Determination of yarn evenness:

The evenness of the yarn was evaluated by microscopic observation. An average of two hundred readings for yarn diameter was taken at different intervals. 40 slides

were prepared and five readings from each slide were taken, using a micrometer microscope and the obtained values were plotted as graph for evaluation.

3.6.3.3 Determination of yarn strength and elongation:

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

3.6.3.4 Determination of yarn twists (TPI):

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

3.7 Construction of fabrics

Ten fabrics were constructed; using three sets of yarn by hand woven and machine woven technique.

The three sets of yarns prepared were:

- Yarns spun on phoenix charkha – untreated, enzyme treated and chemical treated
- Yarns made by blending with regenerated fibers – viscose banana (CT), modal banana (CT), excel banana (CT) and Viscose banana (VT), where CT is chemical treated banana fibers and ET is enzyme treated banana fibers both cut into staple length.
- Yarns spun on Jute spinning system (procured from Navsari Agricultural University, Navsari)

3.7.1 Banana fabrics in combination with regenerated fibers (viscose, modal and excel) woven on powerloom

The second set of yarns that are the yarns made by blending with regenerated fibers were used as weft and for the warp yarn regenerated yarns were used. Trials were done for spinning of yarns using raw banana fiber, but it was not feasible. Hence no samples were made with untreated fiber, on powerloom. The enzyme treated fibers were used to spun viscose banana (75/25). Using the chemical treated banana fibers three yarns were made with 25% as blend percent of banana fiber – viscose banana, modal banana, excel banana.

3.7.2 Cotton banana fabrics woven on handloom

Using the first set of yarn that is yarns spun on phoenix charkha, which comprises of three types of yarns untreated yarns spun by untreated banana fiber, enzyme treated yarn spun by enzyme treated banana fiber and chemical treated yarn spun by chemical treated banana fiber. These three 100% banana yarns were used for weft. The warp yarn was cotton. Untreated banana yarn fabric was constructed at Shram Ashram, Vadodara, and the treated yarn fabrics were woven at weavers' service centre, Ahmadabad.

Another set of yarn which was used to construct handloom fabric was yarns spun on jute spinning system. These yarns were procured from Navsari Agricultural University, Navsari. These yarns were the outcome of the project titled as" A Value Chain on Utilization of Banana Pseudostem for Fiber and other Value added Products", a National Agricultural Innovation Project, by Indian Council of Agricultural Research. This was their finest variety of yarn spun on jute spinning system. Using these yarns for weft and cotton yarns for warp fabric was constructed. The construction of the fabric was done at Shram Ashram, Sevasi, Vadodara.

Effectiveness of treatment stage (fiber or fabric stage) was also studied. The fabric constructed by using the banana yarns obtained from Navsari, was divided into three equal parts. One part remained as untreated fabric and one part was treated with enzymes and another with chemicals that were standardised for fibers.

Table 3.4: Fabric code and its specifications

S.No	Fabric Code	Fabric specifications
SET 1: Fiber treatment →Yarn spinning →Fabric construction		
1	UCBF1	Cotton banana union fabric made with 100% untreated banana yarn spun on phoenix charkha
2	ECBF1	Cotton banana union fabric made with 100% enzyme treated banana yarn spun on phoenix charkha
3	CCBF1	Cotton banana union fabric made with 100% chemical treated banana yarn spun on phoenix charkha. This fabric was nomenclature as "Banana Khadi"
SET2: Yarn →Fabric construction →Fabric treatment		
4	UCBF2	Cotton banana union fabric made with 100% banana yarn procured from Navsari, spun on Jute spinning system. The fabric was untreated
5	ECBF2	Cotton banana union fabric made with 100% banana yarn procured from Navsari, spun on Jute spinning system. The fabric was treated with enzymes same as fibers
6	CCBF2	Cotton banana union fabric made with 100% banana yarn procured from Navsari, spun on Jute spinning system. The fabric was treated with chemicals same as fibers
SET 3: Fiber treatment →Yarn spinning (Blend) →Fabric construction		
7	VBCT3	Viscose banana fabric made with weft yarn of viscose banana blend, spun on ring spinning system, using chemical treated fibers
8	MBCT3	Modal banana fabric made with weft yarn of modal banana blend spun on ring spinning system, using chemical treated fibers
9	EBCT3	Excel banana fabric made with weft yarn of excel banana blend spun on ring spinning system, using chemical treated fibers
10	VBET3	Excel banana fabric made with weft yarn of viscose banana blend spun on ring spinning system, using chemical treated fibers

3.8 Application of silicon finishes on the constructed fabrics

After the construction of all the fabrics, they were scoured and then finished with commercial silicon softeners. Uniform process was followed for all the fabrics. Silicon softeners were sponsored by Archroma India Pvt. Ltd. A pilot study was conducted to determine optimal concentrations of the two finishes (micro and macro silicon softener) and to obtain add-on between 3% - 4%. To obtain desired add-on the fabrics were treated with different number of dips and nips at different pressure. The number of dips and nips for different fabrics has been given in Table 1. The fabrics were soaked in the prepared solution for 5 minutes after which padding was done on the padding mangle.

Solusoft NMW liq C: Micro amino emulsion silicone for permanent finish. It is colourless to pale yellow liquid, non-ionic, modified polysilioxane in nature.

Application guidelines:

Solusoft NMW liq C 15-25 g/l
$MgCl_2.6H_2O$ 10-25 g/l
Acetic acid to adjust pH 4.5 to 5.5
Pad (pick up 70%) – dry at 100 – 120˚C – cure at 150˚C for 2 to 3 min effective

Solusoft KNT liq.: Amino silicone emulsion for permanent finishing. It is translucent milky liquid, non- ionic, amino modified poly-siloxane in nature.

Application guidelines:

Solusoft KNT liq. 20-25 g/l
$MgCl_2.6H_2O$ 10-25 g/l
Acetic acid to adjust pH 4.5 to 5
Pad (pick up 60%) – dry at 100˚C – cure at 150˚C for 2 to 3 min effective

Recipe for silicon softeners applied on banana fabrics

Solusoft NMW liq C 20 g/l

Solusoft KNT liq. 20 g/l

$MgCl_2.6H_2O$ 10 g/l

Acetic acid to adjust pH 5

Pad (pick up 70%) – dry at 100 – 120˚C – cure at 150˚C for 2 to 3 min effective

Application conditions: Padding conditions of all the fabrics varied according to the GSM of the fabrics. Application conditions for all the fabrics have been given in Table 3.5.

Table 3.5: Application condition for padding

S.No.	Fabric Code	No. of Dip	No. of Nip	Pressure (bar)	Add-on
1	UCBF1	2	3	40	3.8
2	ECBF1	2	3	40	3.9
3	CCBF1	2	2	40	3
4	UCBF2	2	3	60	4.2
5	ECBF2	2	3	60	4.2
6	CCBF2	2	3	60	4.4
7	VBCT3	2	3	40	3.2
8	MBCT3	2	2	40	3
9	EBCT3	2	2	40	2.75
10	VBET3	2	2	40	2.75

Key

SET 1: Fiber treatment → Yarn spinning →Fabric construction. UCBF1: Untreated cotton banana union fabric of set 1, ECBF1: Enzyme treated cotton banana union fabric of set 1, CCBF1: Chemical treated cotton banana union fabric of set 1.

SET2: Yarn → Fabric construction → Fabric treatment. UCBF2: Untreated cotton banana union fabric of set 2, ECBF2: Enzyme treated cotton banana union fabric of set 2, CCBF2: Chemical treated cotton banana union fabric of set 2.

SET 3: Fiber treatment → Yarn spinning (Blend)→ Fabric construction. VBCT3: Viscose banana chemical treated fabric of set 3, MBCT: Modal banana chemical treated fabric of set 3, EBCT3: Excel banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3

3.7 Evaluation of properties of constructed fabrics

3.7.1 Determination of the thread count of woven fabric

Thread count (the number of yarns /cm^2) helped to describe the tightness of the weave. Fabric count was determined according to ASTM D3775-98. The fabric count was determined by counting the number of threads in one square centimetre in the warp and the weft direction.

3.7.2 Determination of Fabric width

The fabric width was measured by steel ruler. Some fabrics were woven on sample loom, some were on broad with loom, and hence width of all the constructed fabrics was measured.

3.7.3 Determination of Fabric thickness

Compressometer was used to determine the thickness of the fabric. Fabric thickness was measured according to the ASTM Test Method D1777-96.

3.7.4 Determination of fabric weight per unit area

The mass unit (g/m^2) i.e. GSM was measure according to ASTM Test Method D3776-96. Using GSM cutter, the samples were cut and weighed.

3.7.5 Determination of Cloth Cover Factor of the fabric

Cloth cover was calculated using thread count and yarn number (cotton count system) using the following equation:

$$\text{Cloth cover} = CF_{warp} + CF_{weft} - [(CF_{warp} \times CF_{weft}) / 28]$$

$$\text{Where Cover factor (CF)} = \text{Threads per inch} / \sqrt{\text{Yarn number}}$$

3.7.6 Determination of tensile strength and elongation of fabrics

The tensile strength and elongation of the fabrics with varying treatments were determined on Instron, Model 1121, 10KN testing instrument using ASTM test method D5035. The instrument was based on the principle of CRE (constant rate of extension). The gauge length was kept 20cm at a speed of 100 meters/minute. The test

was conducted in Department of Textile Engineering, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara.

3.7.7 Determination of drape coefficient

A circular disc of 25 cm, in diameter was supported on a circular disc 12.5 cm in diameter and the unsupported area drapes over the edge. The material would have folded configuration and the shape of the projected area would not be circular but curved and wavy. A value known as drape coefficient F, determined as:

Let AD = area of the specimen

Ad = area of the supported disc

AS = actual projected area of the specimen/ weight of the ammonia paper on which shadow is casted (in gms)

$$F = \frac{AS - Ad}{AD - Ad} \times 100$$

3.7.8 Determination of bending length:

Bending length was calculated using Sherley's bending length tester. 15 cm X 2.5 cm was the sample size. The sample was put on the sliding beam, and was allowed to fall on its own weight. When the sample would hand straight, the readings were noted.

3.8 Kawabata analysis for determination of end use

Handle properties of the selected fabrics were evaluated by measuring the fabric properties such as tactile, shear, bending, compression, surface, roughness and surface friction on KAWABATA evaluation system for fabrics (KES FB). The test was carried out in Central Institute for Research on Cotton Technology, (CIRCOT) Adenwala Road, Matunga, Mumbai

3.9 Market Evaluation of the constructed fabrics

As mentioned earlier, banana fabrics are at exploring stage in India. Banana fabrics were inception concept in the field of textiles for locale as well. Hence a defined group of respondents was selected, who were associated with clothing, textiles,

apparel or designing. The data was collected by displaying the samples at an international conference in Bangalore organised by Textile Association of India in January 2016. This gave a wider platform for generating respondents from different parts of the country, allied to textiles whether an industry or academics. A close ended questionnaire was prepared keeping in mind the newness of the fabrics. The data was collected and evaluated by means of calculating average and mean values.

3.10 SWOC analysis of banana fiber-fabric

SWOCanalysis is an analytical method which is used to identify and categorise significant internal (Strengths and Weaknesses) and external (Opportunities and Challenges) factors faced either in a particular arena, such as an organisation, or a territory, such as a region, nation, or city. As banana fiber and fabric in India is at an inception stage, hence a SWOC analysis of the fiber and fabric would give a perspective sight for further researches.

3.11 Costing of the softening treatment standardised

Both the enzyme and chemical treatment were done on banana fibers and the fabrics were constructed using them. However, it was extremely difficult to spin enzyme treated fibers both on charkha and ring spinning system. Assuming that enzyme treatment does not work for commercialization, costing for chemical treatment was done.