# CHAPTER IV
# RESULTS AND DISCUSSION

Increasing awareness on a global level on the benefits of using natural fiber has been the lead cause for development of agro based fibers. One of such potential fiber is banana fibers. However due to its inherent drawback of stiffness, softening is required. The present study aims to soften banana fibers using two methods- enzyme and chemical treatment. The untreated and treated fibers were used to spin yarns by two methods- hand spun using phoenix charkha and banana blend on ring spinning system. The spun yarns were used as weft for weaving ten different handloom and powerloom fabrics. The fabrics were finished with silicon finish. Banana fiber, yarn and fabric properties were tested at every stage.

The results have been given and discussed under the following sub section:

4.1 Raw material
4.2 Standardization of softening treatments
4.3 Properties of untreated and treated banana fibers
4.4 Hand spun yarn (process and properties)
4.5 Ring spun banana blended yarns (process and properties)
4.6 Fabric construction and its properties
4.7 KAWABATA analysis
4.8Market potential of constructed banana fabrics
4.9 SWOC analysis
4.10 Chemical treatment costing and its yield

## 4.1 Raw material

4.1.1Selection of raw material
4.1.2Fine structure
4.1.3Physical properties

### 4.1.1Selection of raw material

Three varieties of banana fibers were obtained from three different regions of India; they were Maharashtra, Tamil Nadu and Gujarat. Banana fiber samples received from Navsari Agricultural University, Gujarat had maximum bundle fiber strength of 42 grams/tex. Also the research locale was in Gujarat; hence banana fibers obtained from Navsari Agricultural University were taken for study.

Banana fibers obtained from Navsari Agricultural University were of *G9* variety. *Grand Nain* bananas (also spelled *Grande Naine*) are banana cultivars of Musa acuminate. It is one of the most commonly cultivated bananas and a source of commercial Cavendish bananas.

### 4.1.2Fine structure

The chemical composition of untreated banana fiber obtained by elemental analysis is mentioned in Table 4.1 and Figure4.1.

**Table 4.1:** Chemical composition of raw banana fiber

| Chemical Constituent of banana fiber | Percent value (%) |
|---|---|
| Water soluble | 10 |
| Cellulose | 64 |
| Hemicellulose | 15 |
| Lignin | 9 |
| Pectin | 2 |
| Fats and waxes | 2 |

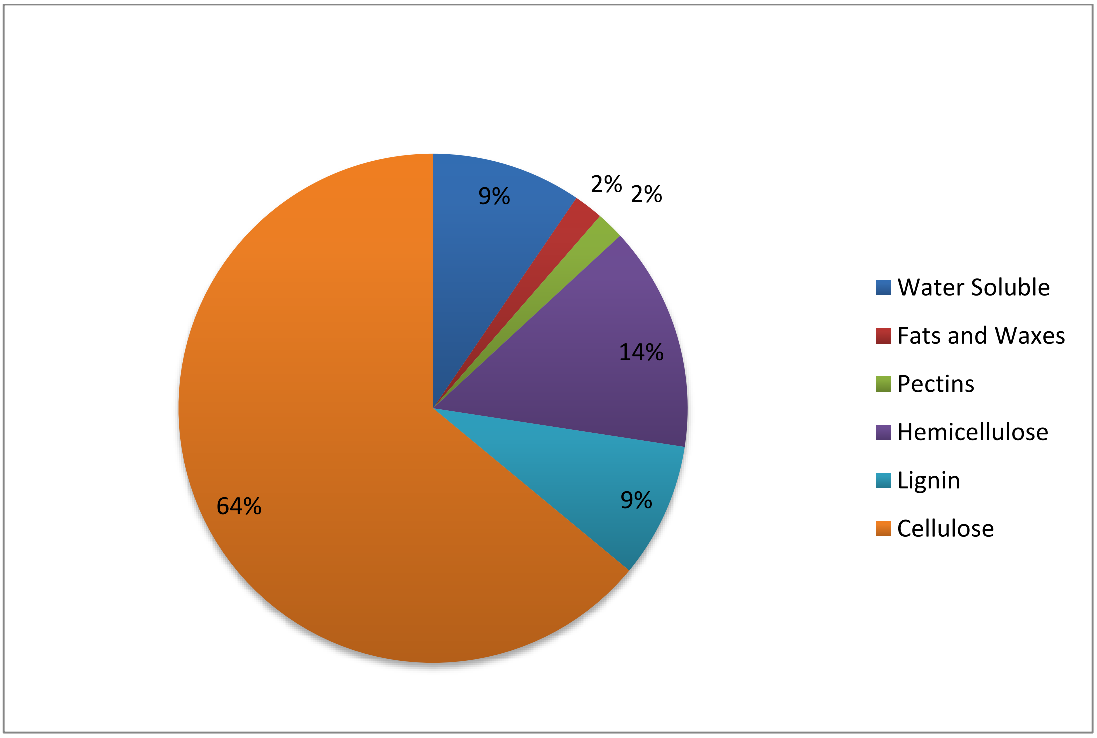



**Figure4.1:** Chemical composition of raw banana fiber

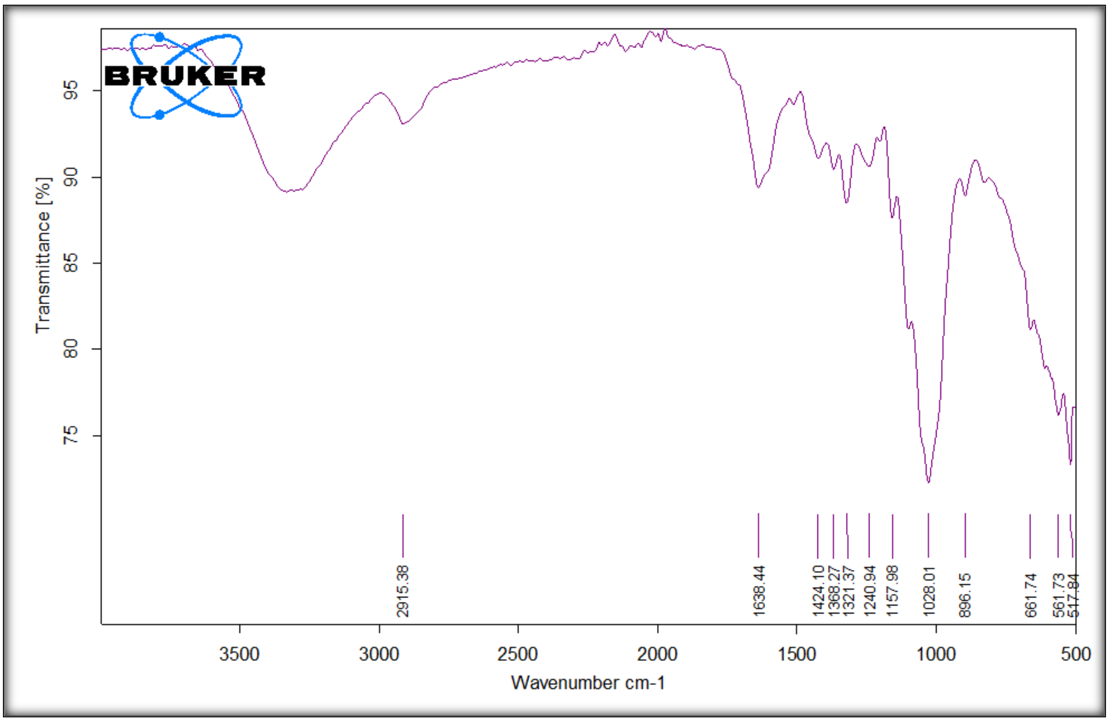
From the chemical composition data, it can be concluded that banana fibers have high content for lignin and hemicellulose. Hence, to use banana fiber for textile application, softening method was required.

**Bonds and linkages in untreated banana fiber (FTIR)**

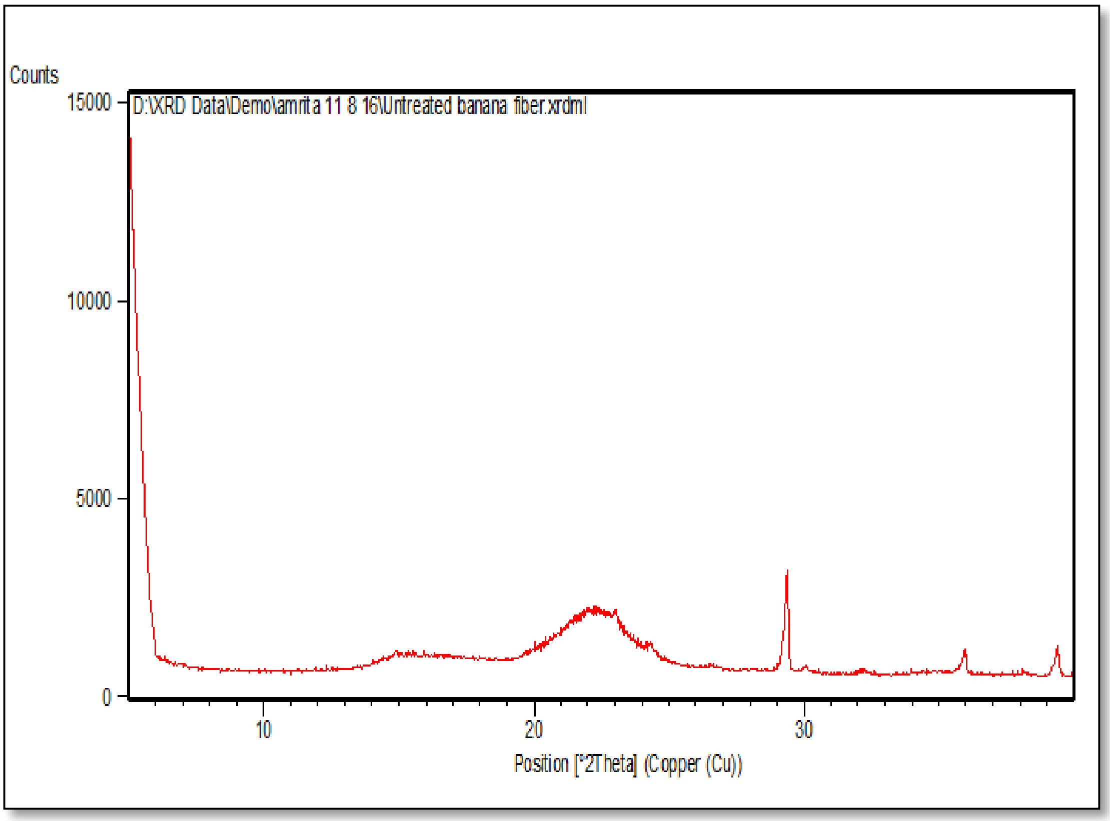
The absorbance peaks have been shown in Graph 4.1. The observed peaks at 1240 $cm^{-1}$ is indicative of ether bond. Ether bonds are found in lignin and hemicelluloses and also as interpolymer linkage between the two. Glycoside ether bond is found between lignin and cellulose. The peak at 1638 $cm^{-1}$ indicates C=C stretching, of alkenes. This indicates the presence of lignin. The stretching between 2915 $cm^{-1}$indicated C-H stretching and O-H stretching. C-H and O-H bonds are found in cellulose and lignin. These bonds are also found as interpolymer linkages between cellulose and hemicellulose, hemicelluloses and lignin and cellulose and lignin.

**Orientation of polymer system studied by X-ray Diffraction (XRD)**

XRD of untreated banana fiber has been given in Graph 2. Two important peaks have been observed 15°, 22° – 23° at 2θ. As it be seen that the peaks are not sharp, thus they account more for amorphous structure of the untreated banana fibers.




**Graph 4.1:** FTIR spectra of untreated banana fiber




**Graph.4.2:** X-ray diffractogram of untreated banana fiber

### 4.1.3Physical properties of banana fiber

Banana fibers are classified as natural, bastfibers obtained from pseudostem of banana plant. Banana fibers are filament fibers of lignocellulosic nature.

#### a) Length and Width of raw banana fiber:

Average length of banana filament fibers was observed between 90 cm to 110 cm. The diameter was 18µm. It was observed that the length to breath ratio was 1:50,000 where as silk is also a natural filament fiber with length to breath ratio 1: 33,000. Fact associated with this aspect ratio is the higher the ratio, the finer the fiber. Hence banana fibers are not very fine fibers naturally.

#### b) Colour and Strength:

Raw banana fibers are coffee creamy to light brown in colour. They posses rough texture, majorly due to the pithy material which remains on the fibers. The fibers still have a natural lustre. Banana fibers have excellent tensile strength, better than cotton. Average bundle strength of raw banana fibers is 42 gms/tex. Where as a single filament fiber strength is 356.51 gf and extension at maximum was 2.16mm. Like any other fiber, banana fibers also have better bundle strength than single filament fiber. Banana fibers are naturally strong fiber, but posse's poor elongation property.

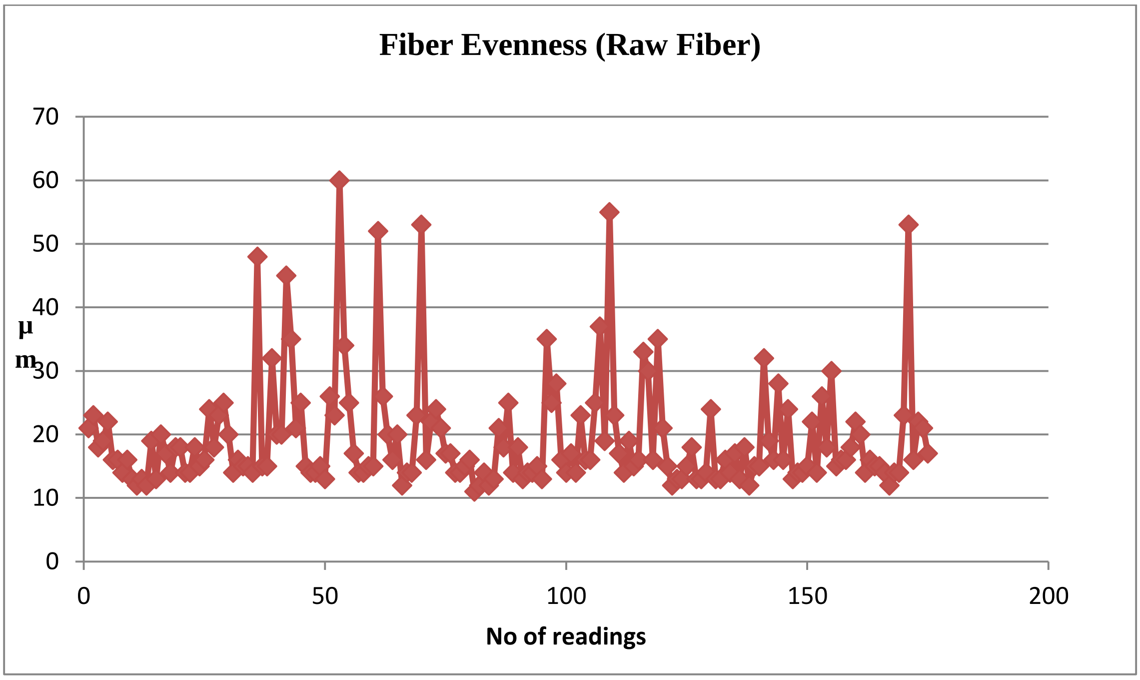
**c) Moisture regain of raw banana fiber:**

Moisture regain of banana fiber was 10.63, which is close to cotton fiber. Moisture affects mechanical properties, including breaking strength, elongation and elastic recovery of fabrics. This degree to which fiber strength is influenced by moisture is closely related to moisture regain. For cellulosic and lignocellulosic fibers the strength increases as the relative humidity increases and moisture regain is directly proportional to relative humidity.

**d) Fineness and Evenness of raw banana fiber**

Linen count of raw banana fiber was 105 Linen. On converted from indirect system to direct system, the value obtained was 157.59 denier / 97's.

The evenness of the filament fiber was evaluated by microscopic observation. Graph obtained by plotting the readings has been given in Graph 4.3.




**Graph 4.3:** Evenness of raw banana fiber

From the above shown graph, wide range of variation in the readings of the diameter was observed. Most of the readings fall in the ranges between 13 μm to 57 μm and there are several points where the diameter is above 40µm. The mean (average) of the fiber diameter was 19.35 µm; however the standard deviation was 8.6. Hence, it can be concluded that raw banana fiber is uneven.

### 4.1.5 Microscopic view

**Microscopic view of banana fiber:**

Under the microscope, the longitudinal section of banana fiber is roughly cylindrical with surface irregularities due to the pithy material attached to it. The fiber has striations, and at some points its splits into two or more sections and furthermore joins back. This observation was made when the fibers were examined from one end to the other. To certain extend, the unevenness of banana fiber can be attributed to this characteristic of being in bundle and separating at random points. However, a single fiber is relatively smooth and straight. The ends of the fibers are slightly tapered and blunt. Pronounced cross marking were seen on the entire length of the fiber. The cross section appears as serrated and polygonal. The cell wall was thin. The lumen was large and distinct, round and uniform in diameter.

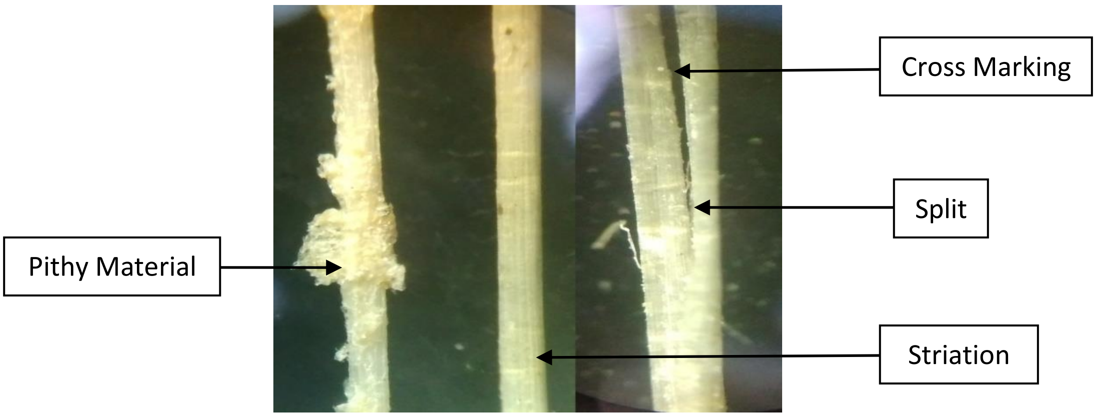



**Figure4.2:** Longitudinal section of raw banana fiber

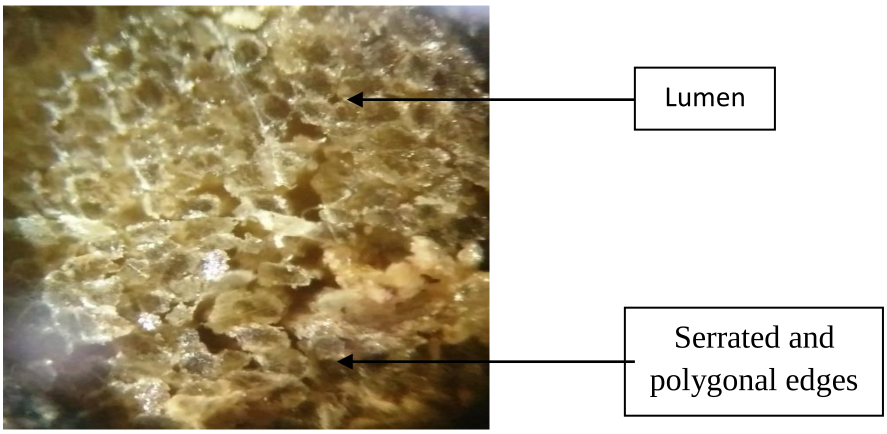



**Figure 4.3:** Cross section of raw banana fiber

## 4.2 Standardization of softening treatment

4.2.1 Chemical treatment

4.2.2 Enzyme treatment

4.2.3 FFT (filament fiber treatment) apparatus

### 4.2.1 Chemical treatment

Chemical treatment included alkalization and bleaching. Alkalization followed by bleaching was not an effective treatment in terms of hand of the fiber and also the strength; hence it was eliminated for further testing. Chemical composition of banana fibers treated by two methods (1) Bleaching (25 min) followed by alkalization (2.5 hours) and (2) Alkalization (90 min) followed by Bleaching (25 min) and Re – alkalization (60 min) is given in Table 4.3.

**Table 4.2:** Chemical constituents of untreated and treated fibers

| **Constituents** | **Untreated banana fiber (%)** | **Chemical treated banana fiber** | |
|---|---|---|---|
| | | **Set I: Bleaching followed by Alkalization (%)** | **Set II: Alkalization followed by bleaching and re-alkalization (%)** |
| Water soluble | 10 | 10 | 8 |
| Fats and Waxes | 1.95 | 3 | 2 |
| Pectins | 1.85 | 1.7 | 1.2 |
| Hemicellulose | 15 | 7.5 | 4.8 |
| Lignin | 9 | 7.4 | 5 |
| Cellulose | 62.2 | 74.45 | 77 |

From Table 4.3, it was observed that re-alkalization was more effective in lignin and hemicellulose removal and even to improve the feel of the fiber. After re-alkalization, 68% of hemicellulose was removed, whereas after bleaching and alkalization 50% of hemicellulose was removed. Percent lignin removal in Set I was 32% and Set II was 44%. Re-alkalization was more effectual to obtain soften fibers. Based on the chemical composition data of the above mentioned fibers, and the feel (hand) of the fibers, chemical treatment recipe was standardised, given in Table 4.4.

**Table 4.3:** Recipe for chemical treatment

| Series of treatment | Parameters |
|---|---|
| Alkalization | 4% NaOH for 90 min at 80˚C to 90˚C |
| Bleaching | Bleach concentration: 0.75%<br>Bleach: $H_2O_2$ : NaOCl: 2:1<br>pH: 9-10<br>Alkali: NaOH<br>Alkali concentration: 4%<br>Time: 30 min<br>Temperature: 80˚C to 90˚C |
| Re-alkalization | 20% NaOH for 60 min at 80˚C to 90˚C |
| Treatment with oil emulsion | Rice bran oil: 5 % w/v<br>Non-ionic emulsifier: 5ml/1000ml of water<br>Water : M:L::1:20 |

The action that takes place during chemical treatment has been explained with the following factors

a) **Effect of alkali treatment**

b) **Use of chlorine bleach**

c) **Effect of sodium hydroxide and chlorine bleach in one bath**

**a) Effect of alkali treatment** - According to Ebisike (2013) alkali treatment of cellulosic fibers, also called mercerization, is the usual method to produce high quality fibers. Alkali treatment improves the fiber-matrix adhesion due to the removal of natural and artificial impurities. Moreover, alkali treatment leads to fibrillation which causes the breaking down of the composite fiber bundle into smaller fibers. In other words, alkali treatment reduces fiber diameter and thereby increases the aspect ratio. Therefore, the development of a rough surface topography and enhancement in aspect ratio offer better fiber-matrix interface adhesion and an increase in mechanical properties. Alkali treatment increases surface roughness resulting in better mechanical interlocking and the amount of cellulose exposed on the fiber surface. This increases the number of possible reaction sites and allows better fiber wetting. The possible reaction of the fiber and NaOH which is represented as

Fiber-OH + NaOH ------- Fiber-O -Na+ + H2O ------------------------- Equation 1

**b) Use of chlorine bleach** - According to Nagarathnamma (1999) conventional pulp bleaching uses a variety of chlorine species as bleaching agents. The advantage of using chlorine is simply that it is cheap and effective. Bleaching with chlorine chemicals usually starts with an acid treatment with elemental chlorine at low temperature, pH, and consistency. During chlorination, wood components—lignin and some carbohydrates—are structurally modified, degraded, and chlorinated. Some of these chlorinated compounds (mostly low-molecular-weight material) are dissolved into the spent chlorination liquor. This stage is followed by an alkaline extraction stage using high temperature, pH, and consistency. In the extraction stage, chlorinated, oxidized lignin, not soluble in the acidic chlorination stage, are solubilised and dissolved into the spent liquor.

Chlorinated organic generated during pulp bleaching not only exert an oxygen demand (biochemical oxygen demand [BOD] and chemical oxygen demand [COD]) but also cause effluent colour and toxicity (acute and chronic). Chlorinated organic in spent bleaching liquor are also responsible for the mutagenicity of the effluent. The low-molecular-weight fraction of the chloro-lignins is the main contributor to the effluent BOD and acute toxicity. The high-molecular-weight chlorinated compounds contribute little to BOD and acute toxicity, due to their inability to pass through cell membranes. They are the major contributor to effluent colour, COD, and chronic toxicity. This leads to chains of adverse effects on the aquatic ecosystem, as the growth of primary consumers as well as secondary and tertiary consumers is adversely affected. Discharge of untreated or partially treated wastewaters from pulp and paper mills results in persistence of colour in the receiving body over a long distance. Under natural conditions, these compounds are slowly degraded to various chlorinated phenolics which may be methylated under aerobic conditions.

**c) Effect of sodium hydroxide and chlorine bleach in one bath** - The chemical constituents of natural fibers can be classified into cellulose and lignin. Lignin plays the role of binding the fibers of cellulose. Alkaline treatment is used for the release of fibers just as it is one of the standard procedures in the pulp and paper industries for lignin removal, lignin can be dissolved in sodium hydroxide (NaOH) solution and the cellulosic fibers can be extracted with relative ease. NaOH causes dissolution of lignin by breaking it into smaller segments whose sodium salts is soluble in the medium.

The mixture of NaOCl and H2O2 in water results in a redox reaction which gives the following equations:

$$NaOCl \rightarrow Na^+ + ClO^- \quad (1)$$

$$Na^+ + ClO^- + H_2O_2 \rightarrow Na^+ + ClO_2^- + H2O \quad (2)$$

Equation 2 shows that when sodium hypochlorite disassociates in presence of hydrogen peroxide, it liberated chlorine dioxide anion ($ClO_2^-$). In aqueous chlorine system, chlorine can exist in three different forms, depending on the pH of the solution. These are molecular chlorine ($Cl_2$), hypochlorous acid (HOCl) and its anion ($OCl^-$).This $ClO_2^-$ de-lignifies and bleaches simultaneously. It oxidizes lignin, but does not add chlorine atoms onto lignin fragments. It also acts on carbon carbon double bonds in the lignin side chains. Hence $ClO_2^-$ acts as a dual agent of removing lignin and bleaching the fibers.

Considering the above mentioned facts and the Figure 4.5 given below, it can be computed that lignin is a highly cross linked molecular complex with amorphous structure and acts as glue between individual cells and between the fibrils forming the cell wall.

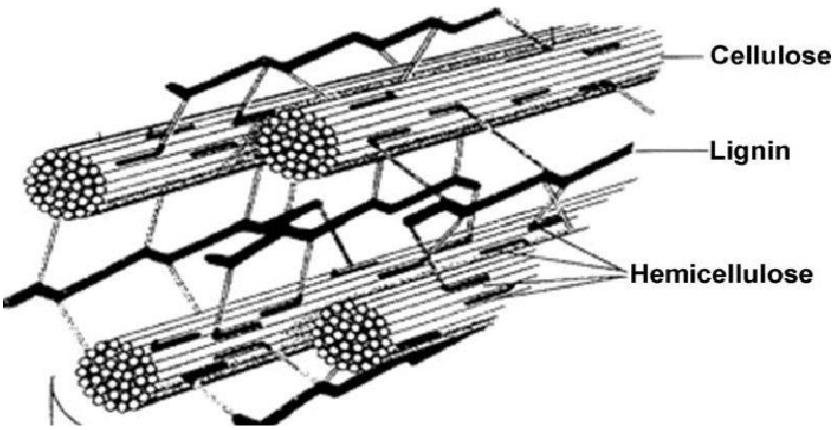



**Figure 4.4:** Lignocellulose Network
**Source:**http://www.intechopen.com/books/ionic-liquids-new-aspects-for-thefuture/applications-of-ionic-liquids-in-lignin-chemistry

When the fibers are treated with sodium hydroxide, NaOH causes dissolution of lignin by breaking it into smaller segments whose sodium salts are soluble in the medium. After this when the fibers are exposed to chlorine bleach, $ClO2^-$ de-lignifies and bleaches simultaneously. It oxidizes lignin, but does not add chlorine atoms onto lignin fragments. It also acts on carbon carbon double bonds in the lignin side chains. Hence $ClO2^-$ acts as a dual agent of removing lignin and bleaching the fibers. The review states that chlorolignin exert the COD and BOD of the effluent generated after the treatment. However in the present study, the amount of chlorine bleach used is very less in quantity and thus the BOD and COD reports shows chlorine in the effluent is into permissible limits. Further when the fibers are re-alkalinized, the composite fiber bundle still breaks down into smaller fibers. The complex lignin is broken into smaller fragments which can be removed during re-alkalization. This helps to reduce the diameter, making the fibers finer, which aids in spinning of finer yarn.

**Chemical Structure of Lignocellulosic fiber**

Banana fibers are lignocellulosic in nature. Lignocellulose is a complex structure made of three basic compounds; cellulose, hemicelluloses and lignin. Figure 4.2 shows the arrangement of lignocellulose in a plant cell. Inside the lignocellulose complex, cellulose retains the crystalline fibrous structure and it appears to be the core of the complex. Hemicellulose is positioned both between the micro- and the macro-fibrils of cellulose. Lignin provides a structural role of the matrix in which cellulose and hemicellulose is embedded.

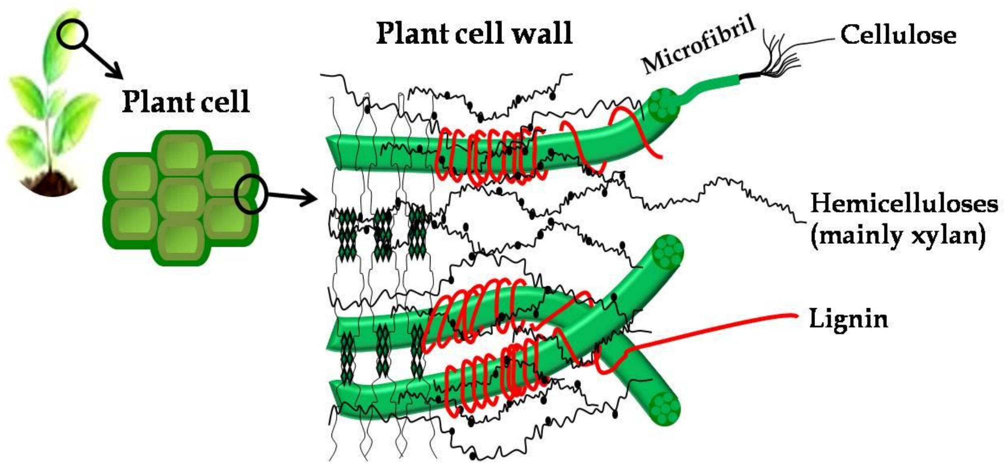



**Figure 4.5:** Positioning of Lignocellulosic Components in a Plant Cell Wall

**Source:** http://www.intechopen.com

**Chemical bonds identified using Fourier Transform Infrared Spectroscopy (FTIR):**

According toHarmsen (2010) there are four main types of bonds identified in the lignocellulose complex. They are ether type of bonds, ester bonds, carbon-to-carbon bonds and hydrogen bonds. These four bonds are the main types of bonds that provide linkages within the individual components of lignocellulose (intrapolymer linkages), and connect the different components to form the complex (interpolymer linkages). The position and bonding function of the latter linkages is summarized in Table 4.2.

**Table 4.4:** Interpolymer and Intrapolymer linkages of lignocellulose

| **Bonds within different components (intrapolymer linkages)** | |
|---|---|
| Ether bond | Lignin, hemicelluloses |
| Carbon to carbon bond | Lignin |
| Hydrogen bond | Cellulose |
| Ester bond | Hemicelluloses |
| **Bonds connecting different components (interpolymer linkages)** | |
| Ether bond | Cellulose –lignin |
| | Hemicelluloses –lignin |
| Ester bond | Hemicelluloses –lignin |
| Hydrogen bond | Cellulose –hemicellulose |
| | Hemicelluloses-lignin |
| | Cellulose – lignin |

### 4.2.2 Enzyme treatment

**Standardised enzyme treatment recipe**

The standardised enzyme treatment parameters are given in Table 4.5. After this experiments were conducted to standardize the order and combination of enzyme treatment.

**Table 4.5:** Optimised conditions for enzymes treatment of banana fiber

| Enzyme | Concentration | Time | Temperature | pH |
|---|---|---|---|---|
| Lacase | 3%owf | 45 min | 55$^o$C | 5-6 |
| Hemicellulase | 1%owf | 60 min | 40$^o$C | 5.5-6 |
| Cellulase | 0.3%owf | 30 min | 55$^o$C | 4.5-5 |
| Pectinase | 0.7%owf | 15 min | 55$^o$C | 5.5 |

The order of enzyme treatment is given below, where in the conditions were kept as mentioned in Table 4.5.

1. Lacase treatment for 45 min
2. Hemicellulase treatment for 60 min
3. Cellulase treatment for 30 min
4. Addition of Pectinase in Cellulase treatment bath after 15 min

Chemical composition, bundle strength and whiteness index of the two sets state that set B, (page 88) gave better results. It can be understood that the fibers reacts in the similar manner as when treated with chemicals. When the fibers are treated with lacase, the lignin complex of banana fiber tends to break down into smaller fragments. Further treatment with hemicellulase, the fiber was still improved as some of the hemicellulose is removed. Whereas when the fiber are treated with all the fibers in one bath, the cementing material of the lignocellulosic fiber i.e. lignin acted equivalently on other components of the fiber. In the earlier case, when lignin fragment was broken the removal of unwanted impurities was easier as compared to the structure where lignin (cementing material) being acted upon at the same time as other components.


**Plate 4.1**: Banana fibers a) Untreated b) enzyme treated c) chemical treated

### 4.2.3 FFT (Fabricated Filament Fiber Treatment) apparatus

The FFT (Filament Fiber Treatment) apparatus worked on simple principle of rotation. The apparatus was made from aluminium vessel. The capacity of the vessel was 12 litres. A disc of 10 cm was attached in the centre of the vessel which was 5 cm above the base and was attached to a motor. The capacity of the motor was 15 rpm.

This disc was an important part of FFT apparatus that actually performs the operation. During the treatment the disc rotates continuously and produces strong rotating currents within the water due to which the fibers also rotate inside the vessel. The rotation of the fibers within water containing the bleach enables the bleaching action evenly. Thus the disc produced most important function of rubbing the fibers with each other as well as with water without any entanglements. After treating the fibers, they were combed and weighted. Combing removed the pithy material from the fiber. Along with the pithy material, filament fibers were also removed due to entanglements. From Table 4.5 it can be observed that less wastage was generated after treating banana fibers in FFT apparatus. Due to fewer entanglements, the waste generated after combing also reduced. The apparatus let the fibers rotate without entangling with each other. This observation was measured by weighing the combed waste. Hence, it can be concluded that any treatment can be made more effective in terms of generating less wastage by utilizing the FFT apparatus. Approximately 33% – 35% of fibers can be saved and utilized for planned end use.

**Table 4.6:** Effective of FFT apparatus on post treatment weight loss

| **Weight of fibers before bleaching** | **Weight of fibers after bleaching and combing** | **Weight of fiber after bleaching in FFT apparatus and combing** |
|---|---|---|
| 200 grams | 60 grams | 80 grams |
| Percent improvement in waste generation | | 33% |

**Plate 4.2:** FFT apparatus for Treatment of Filament fibers

**Plate 4.3:** Banana fiber in FFT apparatus

**Fact Formulated:** in alignocellulosic structure, removal of unwanted material (lignin, hemicellulose, and pectins) is effective when the cementing material i.e. lignin complex is broken first, followed by breakdown and removal of hemicellulose and other components. Breakdown of lignin releases the components of banana fiber, thus providing enough sites for acting of chemicals /enzymes on the components of a lignocellulosic fiber.

## 4.3 Properties of untreated and treated banana fibers



### 4.3.1 Weight loss

The performance of the treated fibers were analysed by weight loss parameter. Weight loss was due to removal of unwanted impurities. Hence it was a positive sign that the treatment was effective. Percent weight loss of enzyme and chemical treatedfibers has been given in Table 4.7.

**Table 4.7:** Percent weight loss of enzyme and chemical treated banana fibers

| Sr.No: | Sample | %Weight loss |
|---|---|---|
| 1 | Raw | |
| 2 | Enzyme Treated | 14 |
| 3 | Chemical Treated | 27 |

Weight loss indicated that impurities were removed after the treatment. Percent weight loss of enzyme treated was 14% and chemical treated was 27%. This indicated that chemical treatment was more effective in removal of unwanted material than the enzyme treatment. Weight loss was majorly due to removal of non-cellulosic material like lignin, hemicellulose and pectins.

### 4.3.2 Tensile strength

**a) Bundle fiber strength test:**

Bundle fiber strength of untreated, enzyme treated and chemical treated banana fibers have been given in Table 4.8. The table also gives percent strength loss of the treated fibers.

**Table 4.8:** Bundle strength of enzyme and chemical treated banana fibers

| S.No | Sample | Bundle Strength (gm/tex) | %Strength loss |
|---|---|---|---|
| 1 | Untreated | 42 | |
| 2 | Enzyme Treated | 37 | 12.5% |
| 3 | Chemical Treated | 40 | 5% |

It was observed that percent strength loss of both the treatments was into acceptable limits. The criteria for considering the limits of strength loss is generally 5-6%, however it also dependent on the industrial requirement. Another factor that was taken into account was during blending, the strength of the treated banana fiber should be comparable to the strength of the fiber that it has to be blended with. Average bundle strength of cotton fiber is 30-35 gms/tex, and raw banana fiber was 38 – 40 gms/tex. Hence, banana fibers are stronger that cotton. Post-treatment strength of banana fiber also was closer to raw cotton fibers. Hence, this percent loss of banana fibers after both the treatment was in acceptable limits.

**b) Single fiber strength and elongation**

Figure 4.6 shows the stress strain curve for some lignocellulosic fibers. Untreated banana fiber also behaves in the similar pattern. In figure 4.6, typical tensile curves of the lignocellulosic fibers present an initial linear behaviour corresponding to the elastic stage. The load drops abruptly at the end of this stage, which corresponds to the fiber maximum strength. This behaviour characterizes a relatively brittle rupture, with negligible plastic strength, in spite of the flexible aspect of most fibers.

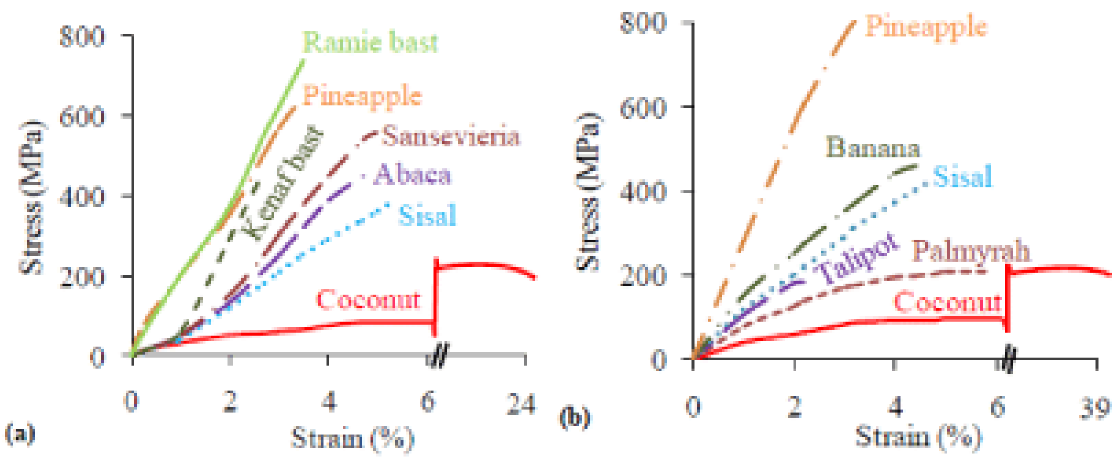


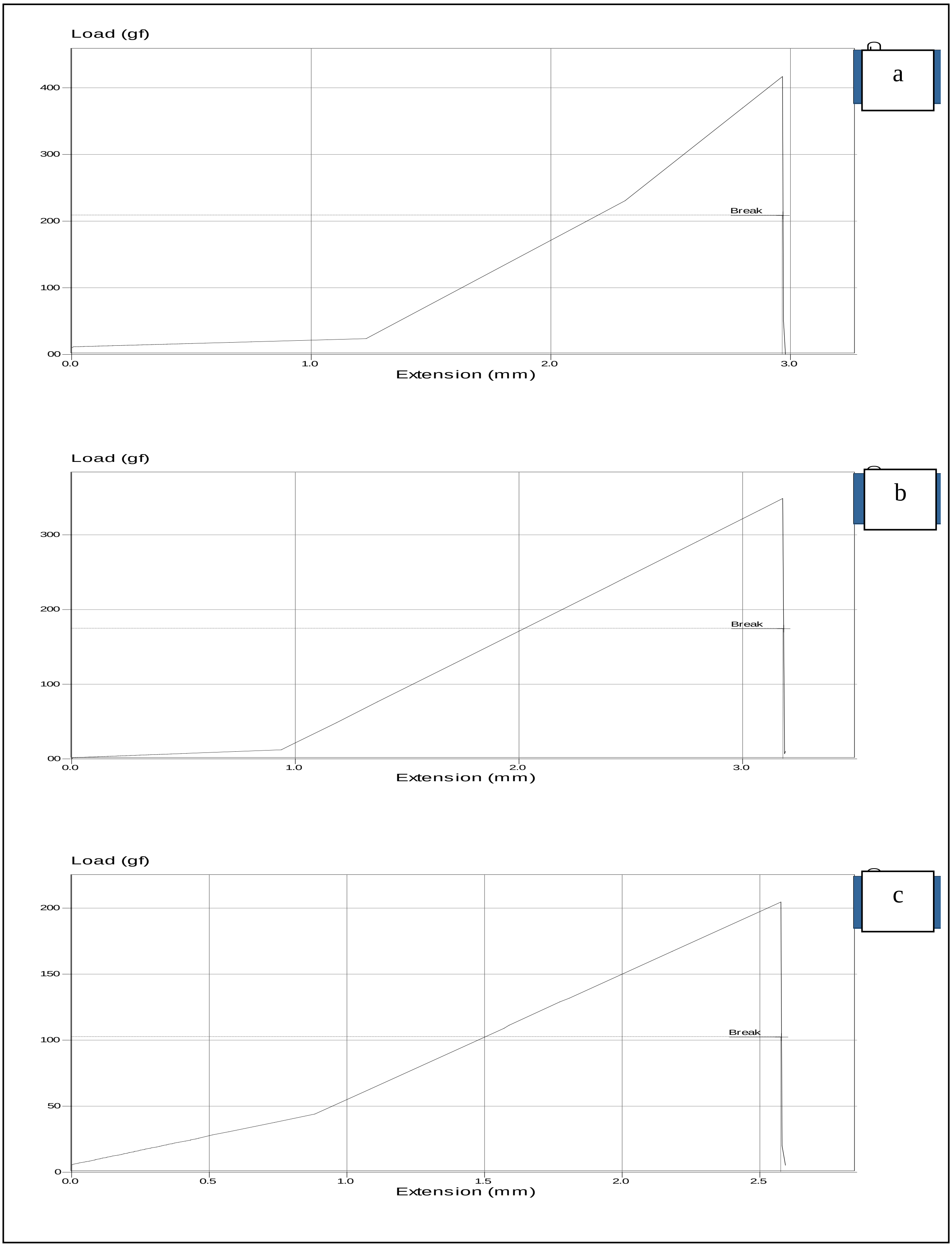

**Figure 4.6:** Stress strain curve of lignocellulosic fibers

**Source**:http://www.esciencecentral.org/ebooks/infrastructure-corrosion durability/images/IFCD_SCS-g004.gif

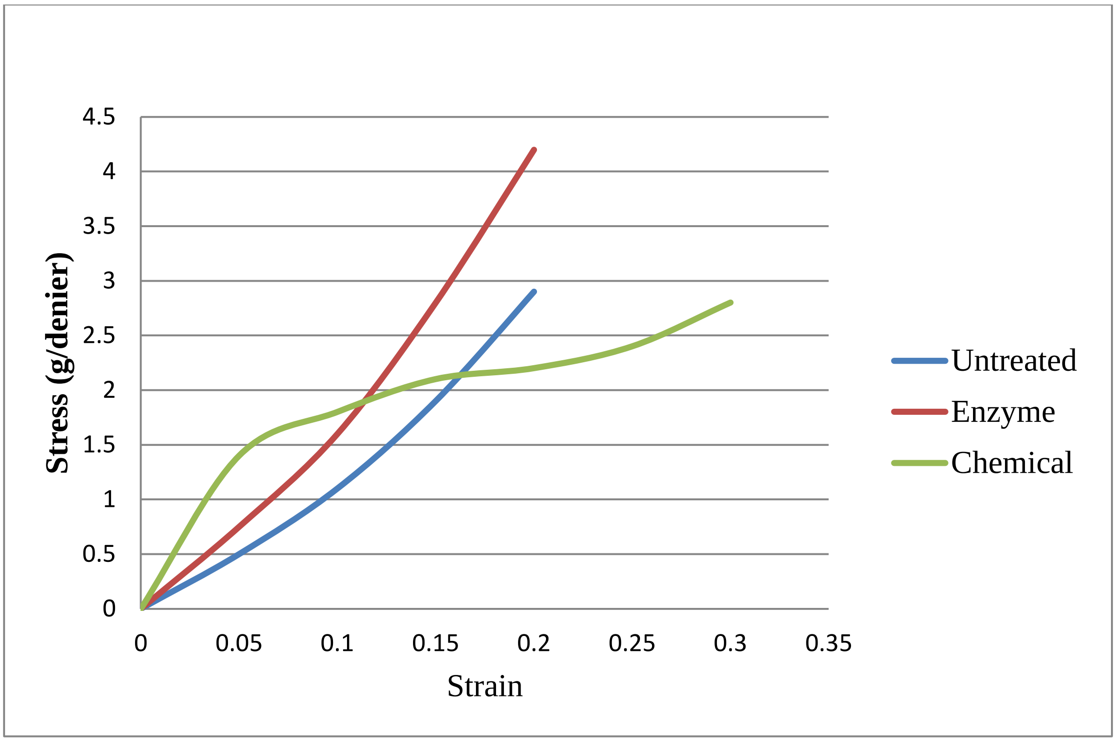
From Table 4.9, it was observed that the Initial young's modulus of chemical treated fiber was lowest followed by untreated and enzyme treated. The lower the value of Initial young's modulus, the greater is the extensibility. Hence, chemical treated fibers had maximum extensibility of all the three fibers, which was an important property required for spinning. The enzyme treated fibers although had high strength but low extensibility, hence difficulty was observed during spinning.

**Table 4.9:** Average load elongation and stress strain values of banana fibers

| Fiber Sample | Maximum Load (gf) | Extension at max. (mm) | Stress (gm/den) | Strain (%) | Initial Youngs modulus |
|---|---|---|---|---|---|
| Untreated | 409.51 | 2.16 | 2.26 | 2.16 | 1.04 |
| Enzyme treated | 364.95 | 2.68 | 3.0 | 2.68 | 1.11 |
| Chemical treated | 220.50 | 2.24 | 2.26 | 2.24 | 1.00 |




**Graph 4.4**: Load elongation curve of banana fibers a) Raw b) Enzyme treated c) Chemical treated




**Graph 4.5**: Stress strain curve of untreated and treated banana fibers

The stress strain curve obtained for untreated and treated banana fibers has been given in Graph 4.5. It was observed that untreated and enzyme treated banana fibers behaves similarly. Whereas, for chemical treated fibers the strength was higher than the untreated fibers till lower strain values. Also elongation of the chemical treated fibers increased. The elongation obtained in the chemical treated fibers aided for spinning.

From Graph 4.5, it can be observed that the first portion of all the three curves were fairly straight, indicating a linear relationship between stress and strain. Value of load was increased in respective order (untreated, enzyme treated and chemical treated) at the same point of extension; the reason for this could be due to increase in crystalinity of the treated fibers.However, all the three samples, the work of rupture, obeying Hooke's law, and work factor was less than 1/2 as all the three curves are concave in nature. Work of rupture is used to measure toughness of the material which indicated the resistance of the material to sudden shock.

### 4.3.3 Fiber fineness

The denier of untreated and treated banana fibers was calculated and the values were obtained in denier and Linen count, which is used for dry spun (hemp, jute and silk). The values obtained are given in Table 4.10.

**Table 4.10 (a):** Fineness of untreated and treated banana fiber

| Fiber | Denier | Cotton Count (‘s) obtained from Tex | Linen count Dry spun Indirect System (‘Linen) |
|---|---|---|---|
| Untreated banana fiber | 157.59 | 97 | 105 |
| Enzyme treated banana fiber | 121.30 | 123 | 130 |
| Chemical treated banana fiber | 87.27 | 170 | 180 |

The denier of untreated banana fiber was 157.59 which were reduced to 121.30 after enzyme treatment and 87.27 after chemical treatment. Fiber diameter decreased due to removal of hemicellulose, pectin and lignin. Chemical treatment was more effective in improving the fineness of banana fibers because alkali treatment separated the fiber bundles into elementary fiber by degrading the cementing material. Count was also calculated by Linen count (Indirect system) and was converted into cotton count (‘s) which was very close to the values obtained by converting Tex and denier to cotton count. (‘s)

### 4.3.4 Fiber evenness

Effect of unevenness in fiber, can lead to unevenness in the yarn. The treatments given on the fiber improves several properties of the fiber, inclusive of fiber evenness. Enhancement in terms of evenness for chemical treated fibers was better as compared to enzyme treated banana fibers, shown in Graph 4.6. 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. The lower the standard deviation, the better is the quality of the yarn in terms of evenness.

### 4.3.5 Whiteness Index

Whiteness index of untreated and treated banana fibers was measured. It was observed that the chemical treated banana fibers obtained more whiteness than the enzyme treated fibers. Not much of marked difference was observed in yellowness of the fiber. This could be due to the use of sodium hydroxide, which imparted yellowness in the chemical treated fibers. The values have been mentioned in Table 4.10 (b).

**Table 4.10 (b):** Whiteness index and yellowness index of untreated and treated banana fiber

| Sr. No. | Sample | Whiteness | Yellowness |
|---|---|---|---|
| 1 | Untreated banana fiber | -84.577 | 47.982 |
| 2 | Enzyme treated banana fiber | -68.711 | 41.722 |
| 3 | Chemical treated banana fiber | -50.350 | 37.300 |

### 4.3.6 Hand Evaluation

The treated banana fibers were evaluated for hand property by a panel of 10 staff members of the department. The fibers that were put for evaluation were:

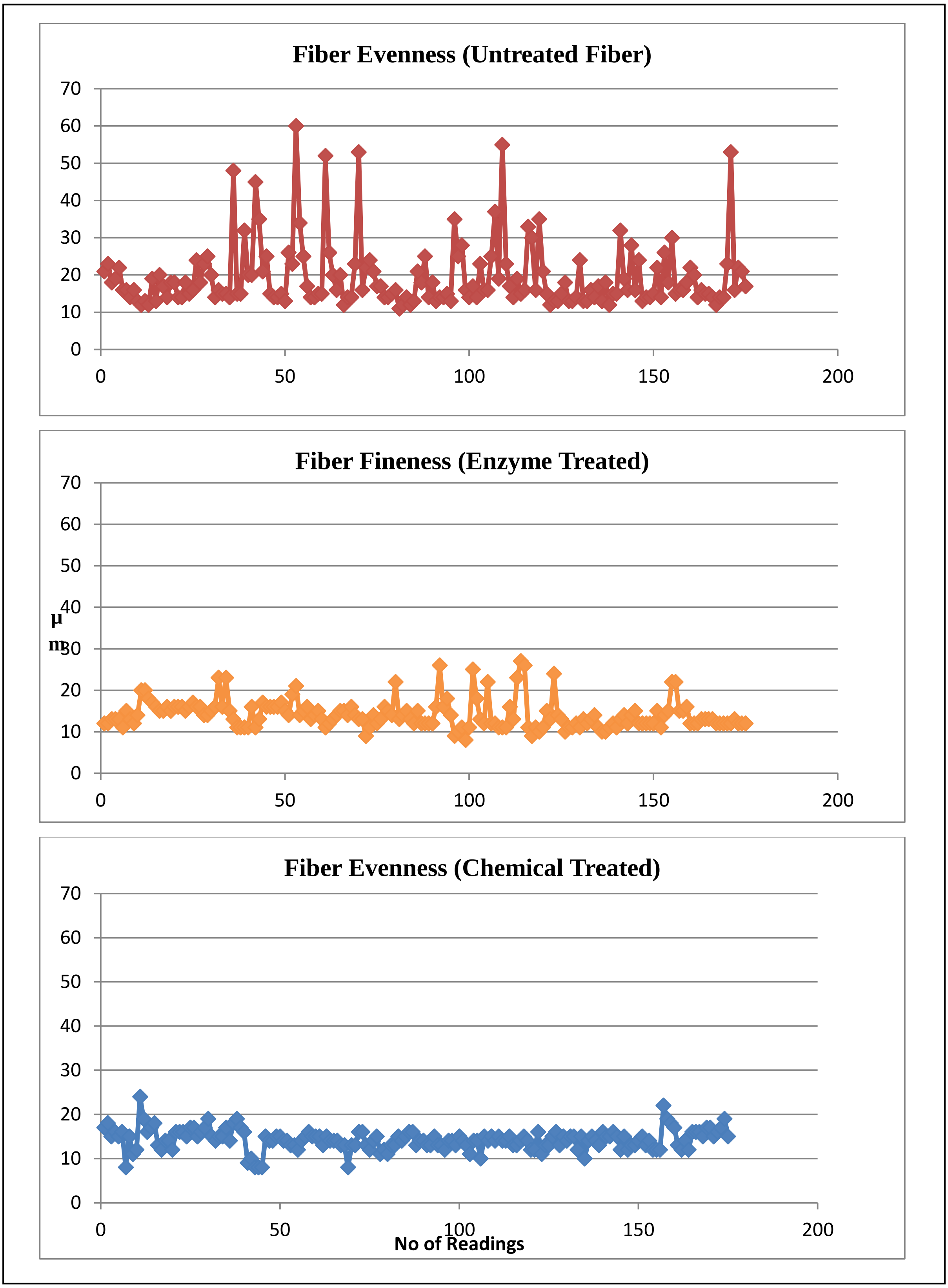
- Untreated fibers
- Enzyme treated
- Chemical treated

All the respondents agreed that the chemical treated was the best to feel followed by enzyme treated and then the untreated fiber

### 4.3.6 Chemical composition

The chemical composition of untreated and treated banana fiber was carried out to analysis the change in the constituents of the treated fibers. The results of chemical composition test have been given in Table 4.11.

The two treatments were effective in lignin and hemicellulose removal, which is depicted by the chemical constituents given in Table 4.11. The percent removal of hemicellulose was 60% in enzyme treatment and 68% hemicellulose was removed by chemical treatment. Lignin removal in both the treatment was also almost similar, 39% lignin was removed by enzyme treatment and 44% was removed by chemical treatment. However, chemical treated fibers had improved softness obtained as compared to enzyme treated fibers




**Graph 4.6**: Fiber Evenness of untreated and treated banana fibers

**Table 4.11**: Chemical composition of Untreated and Treated banana fibers

| Constituents | Untreated banana fiber (%) | Enzyme treated banana fiber (%) | Chemical treated banana fiber (%) |
|---|---|---|---|
| Water soluble | 10 | 11.8 | 8 |
| Fats and Waxes | 1.95 | 2 | 2 |
| Pectins | 1.85 | 1.8 | 1.2 |
| Hemicellulose | 15 | 6 | 4.8 |
| Lignin | 9 | 5.5 | 5 |
| Cellulose | 62.2 | 73.47 | 77 |

### 4.3.7 SEM

Scanning electron microscopic (SEM) provide an excellent technique for the study of surface morphology of raw, enzyme and chemically modified banana fibers. It was observed that surface of raw banana fibers differs in smoothness and roughness than the treated banana fibers. Plate 4.4 shows the difference in their surface morphology.

The SEM showed that the mechanical fibres or filament are organized in bundles. Each of bundle or filament actually consisted of ultimate fibres or fibrils. The fibres are polygonal to round in cross-sectional shape with large lumen. These filaments are as long as the length of the pseudo stem. The ultimate fibres showed nodes at fairly regular intervals which were also seen under the 10X microscope.

The raw fiber (A) surface was smooth in comparison to chemical treated fibers. Abundant amount of pithy material was observed. In case of enzyme treatment, the fibers become smooth, and pithy material was removed. The chemical treated fibers can be seen as rough and flatten, although pithy material was removed.

Treatment with sodium hydroxide reduced the size of the fiber into the smaller bundles. The primary wall of the ultimate fibres ruptured due to tremendous swelling, and they appears like squeezed straws.

### 4.3.8 XRD

Graph 4.7 shows the X-ray diffraction pattern of (a) raw, (b) enzyme treated, (c) chemical treated banana fiber. Natural cellulosic fibers contain both crystalline (ordered) and amorphous region (disordered). Thus, the tendency of dual features in the fiber is consistent with the presence of ordered and disordered region as stated by

Sharma (2013). In the present research, raw, enzyme treated and chemical treated banana fiber exhibited two main peaks at $2\theta = 14^\circ$ and $22^\circ$, which can be assigned to planes of amorphous and crystalline cellulose respectively. 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. According to Zhang (2013), the chemical treatments would remove the amorphous region such as lignin and hemicellulose, thus leading to larger spaces between microfibers, rearrangement of microfibers to more ordered structure and formation of new hydrogen bonds between microfibers. From this it can be concluded that treatments were effective in removal of lignin and hemicellulose which was also observed by FTIR and chemical composition tests of the untreated and treated banana fiber. Although it is important to note that the CI calculated for the three banana samples gives an approximate estimate of the crystallinity and the value calculated does not adheres that this percent amount of the fiber is crystalline. This data gives a comparative analysis for the crystallinity of the fibers.

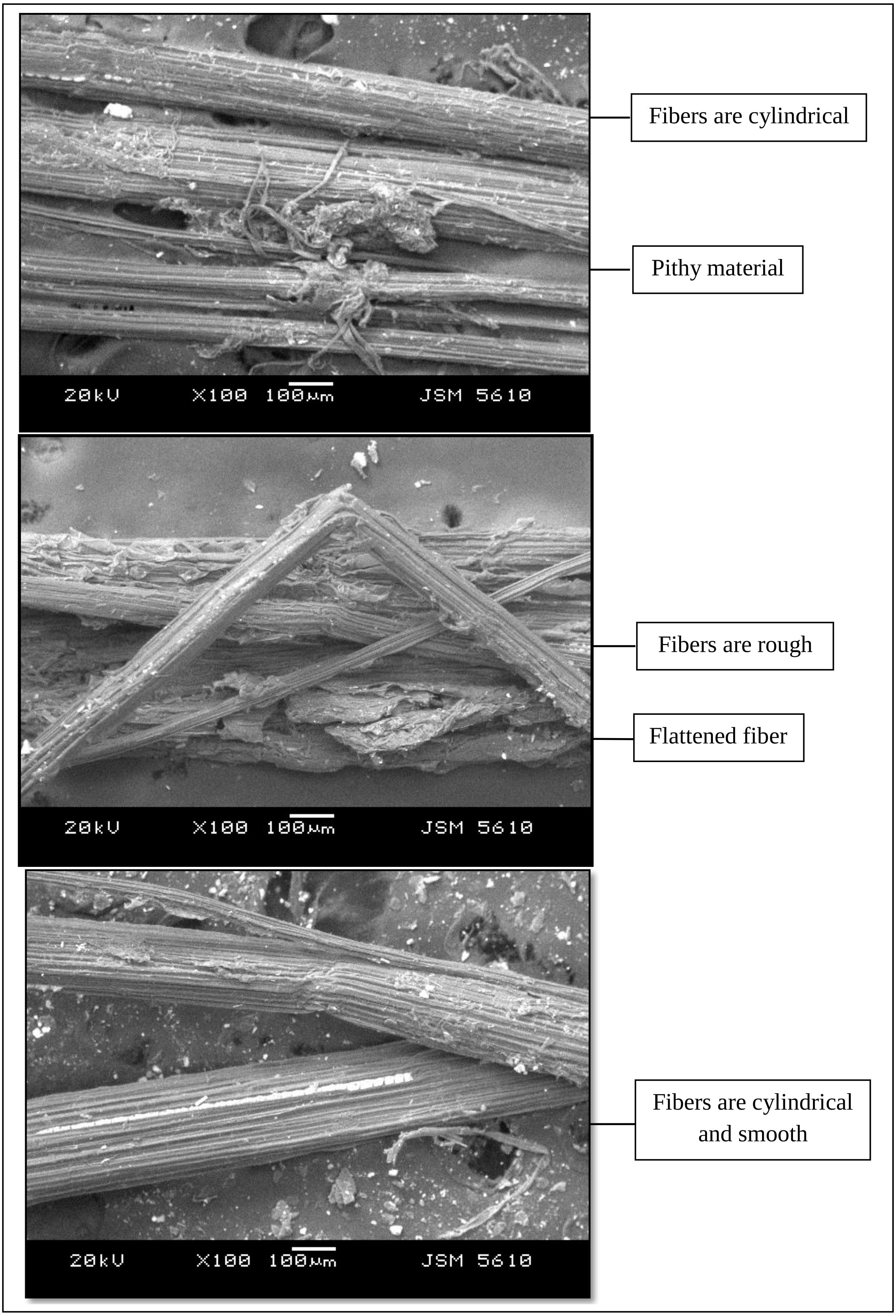



**Plate 4.4**: SEM image of A.) Untreated banana fiber B.) Enzyme treated banana fiberC.) Chemical treated banana fiber

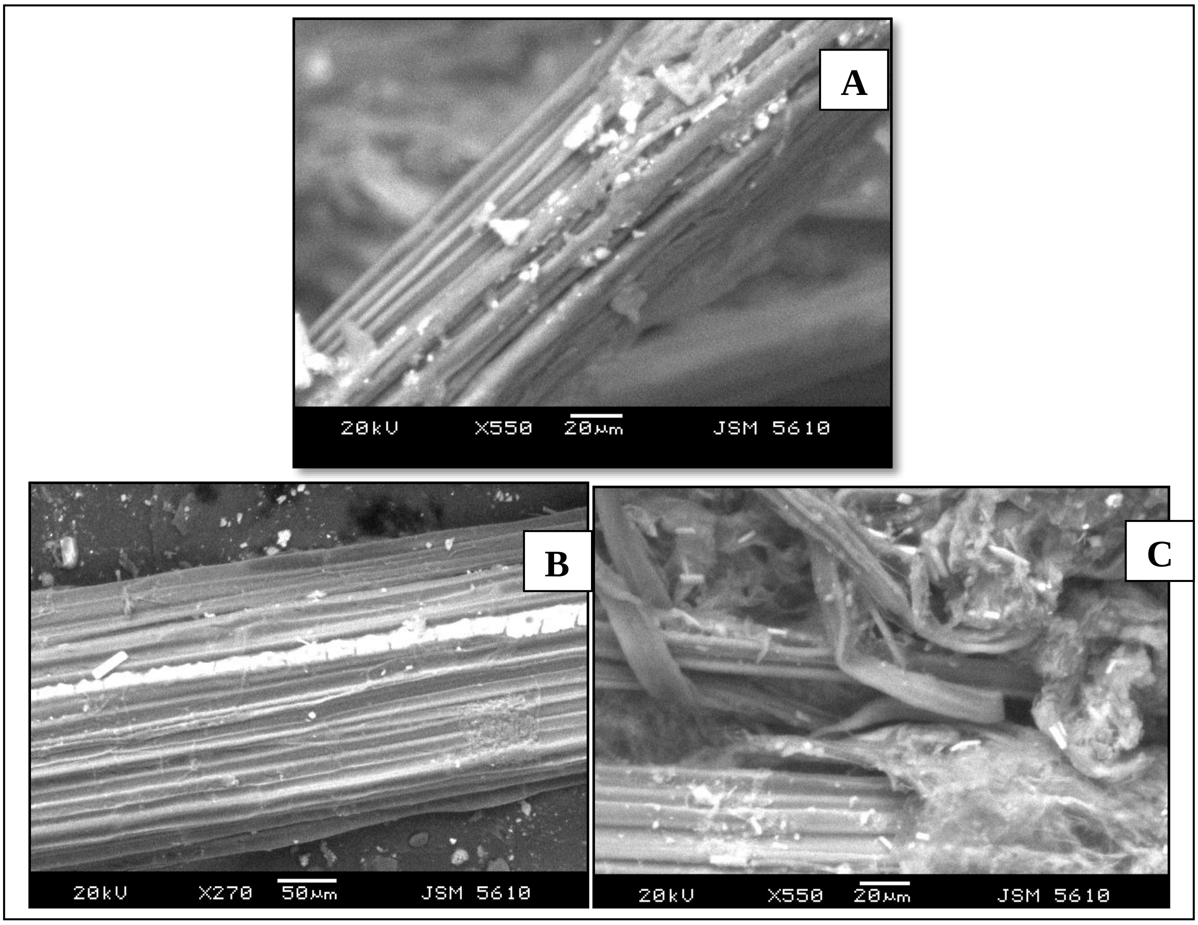



**Plate 4.5**: SEM image of A.) Untreated fiber B.) Enzyme treated C.) Chemical treated

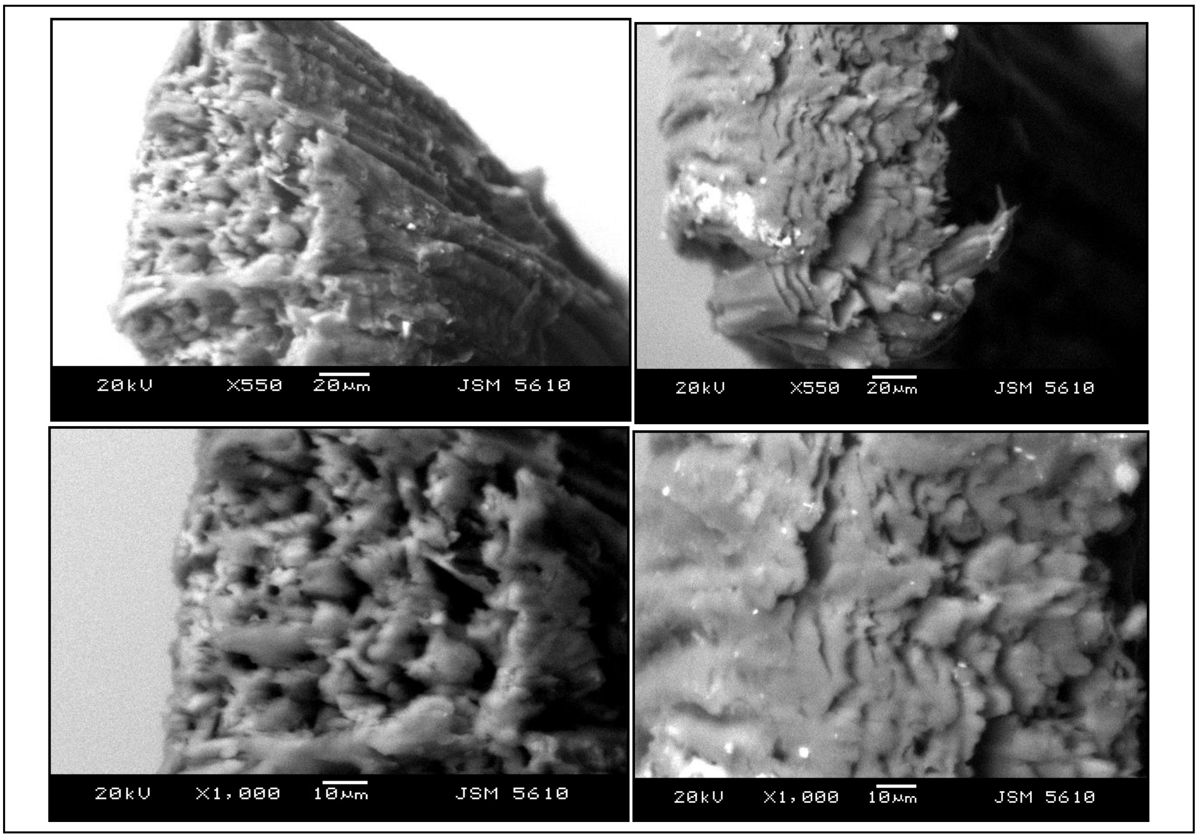



**Plate 4.6:** Cross Section SEM image of A) Untreated fiber B) Chemical treated fiber

Another observation in Graph 4.7 is the peak broadening and the sharpness. The peak broadening is mainly due to the increased amorphous contribution. In crystalline materials atoms are periodically arranged but in amorphous materials atoms are randomly arranged. Thus, x-ray light incident on a crystal plane on atoms then it scattered in a particular direction and gives a high intensity narrow peaks but in the case of amorphous materials, when x-ray light incident on atoms in a plane then it scattered in random directions due to the random orientation of atoms and gives a broad peak or background hump. The broadest peak was observed for the untreated banana fiber which symbolises that the raw fiber was more amorphous than the treated banana fibers. For enzyme treated banana fibers the peak was sharper than the raw banana fiber which means that the crystalline region has increased due to more ordered structure of the banana fibers after treatment. Further the sharpness of the chemical treated fiber was more than the raw and the enzyme treated fibers. This observation indicates that the chemical treated banana fibers should be the most crystalline than the enzyme treated and the raw banana fibers. However the CI of enzyme treated is highest amongst the three fibers. According to Elenga et al (2013) for higher concentration of NaOH treatment for *Raffia textilis*fiber, Na+ ions penetrate and swell crystallites. This swelling may dissolve less ordered crystallites and may explain the decrease of the crystallinity index for higerNaOH treated fibers. This swelling of the crystallites is the beginning of the polymorphic transformation of cellulose I to Cellulose II. Since the chemical treatment includes the treatment with NaOH, hence this fact can be reasoned for lower CI of chemical treated fibers than the enzyme treated fibers.

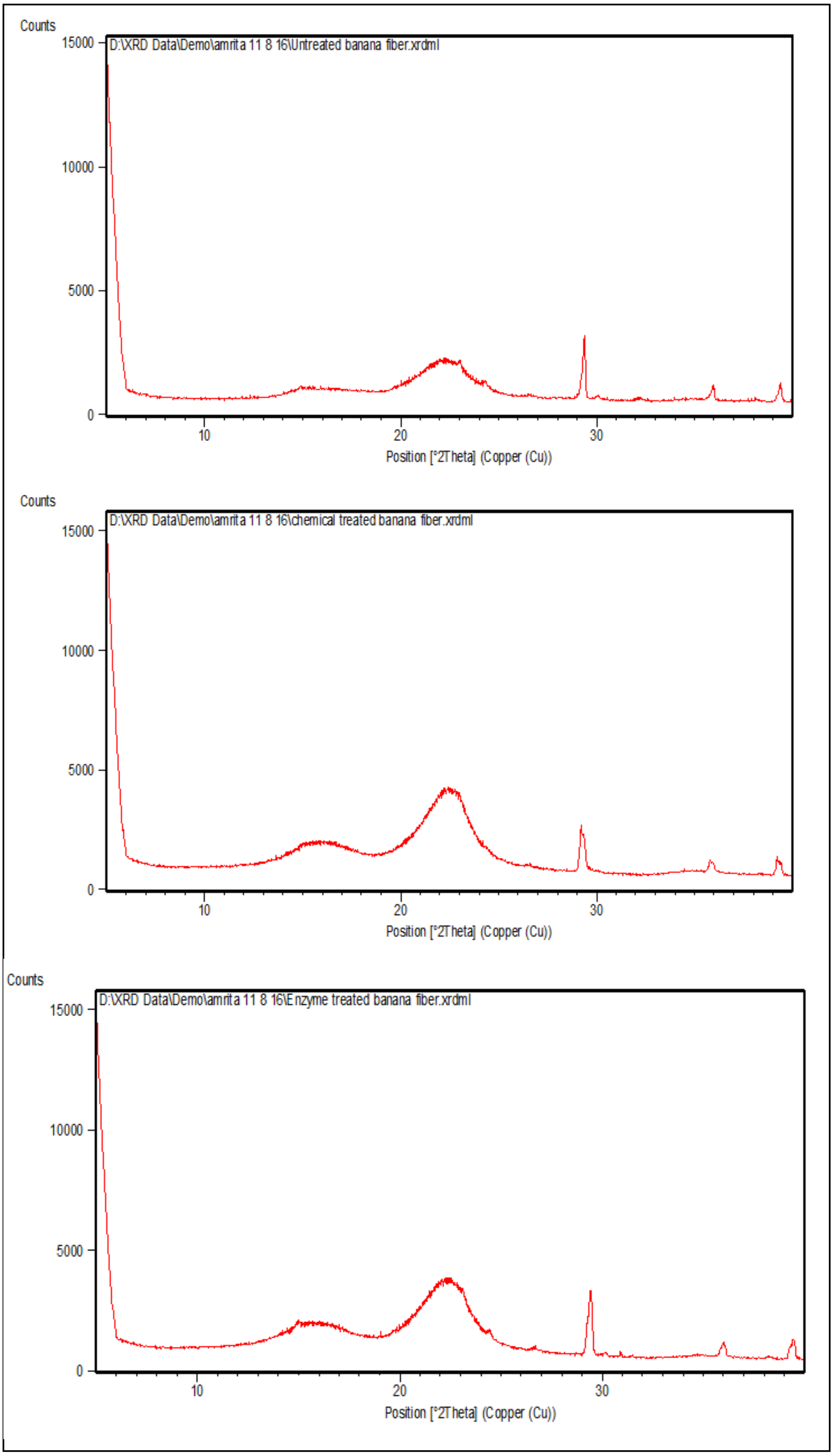
### 4.3.9 FTIR

Graph 4.8 shows the FTIR spectra of banana fiber before and after enzyme and chemical treatment. FTIR absorbance band of lignocellulosic biomass is given in Table 4.12. Graph 4.8 shows a broad peak around 3332 cm -1, which is attributed to the O-H group of the raw banana fiber, which decreases after enzyme and alkali treatment. The almost diminishing of this peak for chemical treated fiber could be due to the addition of chlorine, subjected to chlorine bleach. (Ali 2015)

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. (Temesgen 2014)

**Table 4.12:** FTIR absorbance band in lignocellulosic biomass

| **Wavenumber ($cm^{-1}$)** | **Functional group** | **Polymer** |
|---|---|---|
| 950 | Glycosidic linkages | Cellulose and Hemicellulose |
| 1160 | C-O-C asymmetrical stretching | Cellulose and Hemicellulose |
| 1200 | O-H bending | Cellulose and Hemicellulose |
| 1215 | C-C + C-O stretch | Lignin |
| 1310 | $CH_2$ Wagging | Cellulose and Hemicellulose |
| 1335 | C-H vibration, O-H in –plane bending | Cellulose and Hemicellulose and Lignin |
| 1380 | C-H bending | Cellulose and Hemicellulose and Lignin |
| 1425 | C-H in –plane deformation | Lignin |
| 1595 | Aromatic ring vibration + C=O stretch | Lignin |
| 1730 | Ketone /Aldehyde C=O stretch | Hemicellulose |
| 3421 | O-H stretching | Lignin |

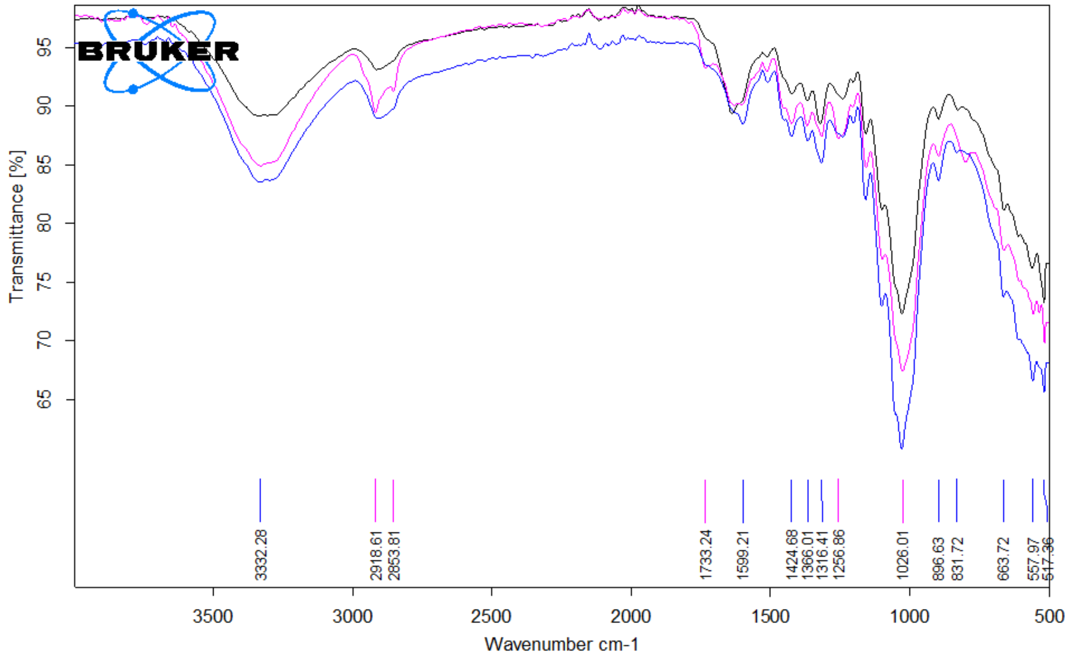



**Graph 4.7:** X-ray diffraction pattern of (a) raw, (b) enzyme treated, (c) chemical treated banana fiber.

Lignin is composed of three basic units, namely p-hydroxyphenyl (H), guaiacyl (G), and syringyl (S). G and S are the main units of lignin but the ratio of S/G varies from one plant to another. It was reported by Mizi (2012) that for hemp fiber on stretching at the band of 1256 cm-1 and 1316 cm-1 G and S ring appears. FTIR for banana fibers were in agreement and the S and G ring stretching appears at 1256 cm -1 and 1366 cm-1for raw fiber which reduced for chemical treated fibers.

The absorbance at peak 1599 cm $^{-1}$ was attributed to lignin. It was observed that the intensity of peak was high for raw fiber, which reduced for enzyme and further for chemical treated banana fibers. The lower absorbance in dislocation means that the lignin was removed from the treated fibers, and such the cellulose content in the treated fiber would be higher than the raw banana fiber.

The slight intensity decrease of the band around 1599 cm$^{-1}$ showed that some lignin was removed, but these compound still remains on fibers after alkalization.




**Graph 4.8:** FTIR spectra of untreated and treated banana fibers

Key
Untreated
Enzyme treated
Chemical treated

The band at 1366 $cm^{-1}$ was attributed to the OH group of cellulose and hemicellulose. Its intensity was observed to be weaker for chemical treated fibers. The decrease could be explained by the following reaction, which was also observed by Elenga (2013) for *raffia textilis*.

Fiber - OH + NaOH $\rightarrow$ Fiber - O - $Na^+$ + H2O

A scrutiny of the IR spectra from 1370 $cm^{-1}$ to 1330 $cm^{-1}$ show that the band at 1366 $cm^{-1}$ almost shifted for chemical treated banana fibers. According to Mizi (2012), this band region is assigned the in-plane CH bending, may be from hemicellulose or cellulose. The near shift in intensity of the peak may be due to the removal of hemicellulose of the chemical treated fiber.

The peak band at 1424 $cm^{-1}$ was assigned to the crystalline structure. The peak was pointed for raw banana fiber which became broader for treated (enzyme and chemical) fibers. This could reflect more disordered structure of the treated fibers. Also a peak was observed at 896 $cm^{-1}$ for raw banana fiber which was flattened. This can be attributed to some deformation or change in the cellulose structure.

### 4.3.10 Waste water analysis

**Wastewater analysis (COD, BOD, TDS, $Cl^-$)**

During the chemical treatment of banana fibers, alkalization and bleaching treatments were carried out. According to Yusuff(2005), the possible effluent composition and its nature from a textile industry have been given in Table 4.13. Hence, effluent composition after the chemical treatment would include Sodium hypochlorite, $Cl_2$, NaOH, $H_2O_2$. Considering this, COD, BOD, TDS and Free chlorine analysis was done of the wastewater generated post chemical treatment of banana fibers. The results obtained have been mentioned in Table 4.14.

**Table 4.13:** Effluent Characteristics from Textile Industry

| Process | Effluent composition | Nature |
|---|---|---|
| Sizing | Starch, waxes, carboxymethyl cellulose (CMC), polyvinyl alcohol (PVA), wetting agents | High in BOD,COD |
| Desizing | Starch, CMC, PVA, fats, waxes, pectins | High in BOD, COD, SS, dissolved solids(DS) |
| Bleaching | Sodium hypochlorite,$Cl_2$, NaOH,$H_2O_2$, acids, sudfacts, NaSiO3, sodium phosphate, short cotton fibre | High alkalinity , high SS |
| Mercerizing | Sodium hydroxide, cotton wax | High PH, low BOD, high DS |
| Dyeing | Dyestuffs urea, reducing agents, oxidizing agents, acetic acid, detergents, wetting agents. | Strongly colored, high BOD, DS, low SS, heavy metals |
| Printing | Pastes, urea, starches, gums, oils, binders, acids, Thickeners, cross-linkers, reducing agents, alkali | Highly colored, high BOD, oily appearance, SS slightly alkaline, low BOD |

Permissible limits given in Table 4.14 have been mentioned according to Gujarat Pollution Control Board, Gujarat, India. According to Patel (2013), if the wastewater pH is highly alkaline, bringing down to neutral is helpful for biological treatment. The BOD, COD, TDS, TSS, NH3-N of the treated effluent reduced significantly. For the present effluent the pH was 10.5 i.e. alkaline. Hence, if the present pH of the effluent is neutralized, it will help to reduce the values of COD and BOD, which are above the permissible limits. NaOCl was not used in higher quantity as it liberates free chlorine in the treatment water. In the present study the use of chlorine bleach was in lesser quantity and hence free chlorine liberated was also very less, under the permissible limits.

**Table 4.14**: Wastewater analysis

| Sr.No. | Test Parameters | Values (mg/lit) | Permissible Limits (mg/lt) |
|---|---|---|---|
| 1 | Chemical Oxygen Demand (COD) | 1088 | 100 |
| 2 | Biochemical Oxygen Demand (BOD @27˚C for 3 days) | 450 | 30 |
| 3 | Total Dissolved Solids | 2094 | 2100 |
| 4 | Free Chlorine (Cl-) | 141.8 | 600 |

## 4.4 Hand spun yarn (process and properties)

4.4.1 Process of yarn spinning on Phoenix charkha

4.4.2 Properties of hand spun yarn

4.4.2.a Yarn fineness

4.4.2.b Yarn evenness

4.4.2.c Yarn strength

4.4.2.d Yarn twist

### 4.4.1 Process of yarn spinning on Phoenix charkha

Banana fibers were spun on Phoenix Charkha (Plate 4.7). It is a double drive charkha. Phoenix Charkha is a pedal driven machine for spinning coarse long-staple fibres like banana pseudostem fibres at the cottage level. Movement of the pedal was manual and this could be one of the uncontrolled factors in the unevenness of the yarn. To avoid this factor, motor was attached to the charkha to put the flywheel in rotation. Due to the motor attached the movement of the pedal and thus the charkha could be kept constant. The only uncontrolledfactor during the spinning of banana yarns was the feeding of the filament fibers. There were two pulleys coaxially coupled to the flywheel and these pulleys drive a bobbin and a flyer simultaneously. The difference in diameter between pulleys created difference in RPM between rotation of the bobbin and rotation of the flyer. The differential in the RPM decides

**Plate 4.7**: Phoenix Charkha

the twist per inch (TPI) imparted to the yarn. When banana fibres fed into the charkha with help of a pair of rollers pressed against each other, the fibres were guided for spinning action with the help of a rotating flyer. It is a simple instrument and can be easily used by farmers and their family members to generate additional income.

The process of spinning on phoenix charkha takes place in the following steps:

1. Banana fibers were loosely tied in a bundle (like hank) of 30 grams, to avoid entanglements. One bundle was opened at a time and fibers were loosened manually so that they can be picked up easily during spinning.

2. Feeding of the filament banana fibers manually. The feeding tray is triangular in shape; top angle is facing towards passing the filament further for spinning. Fibers were fed from two sides (Figure 4.7) of the triangle in alternate pattern. This helps to avoid cluster formation at the joining of the filament fibers.

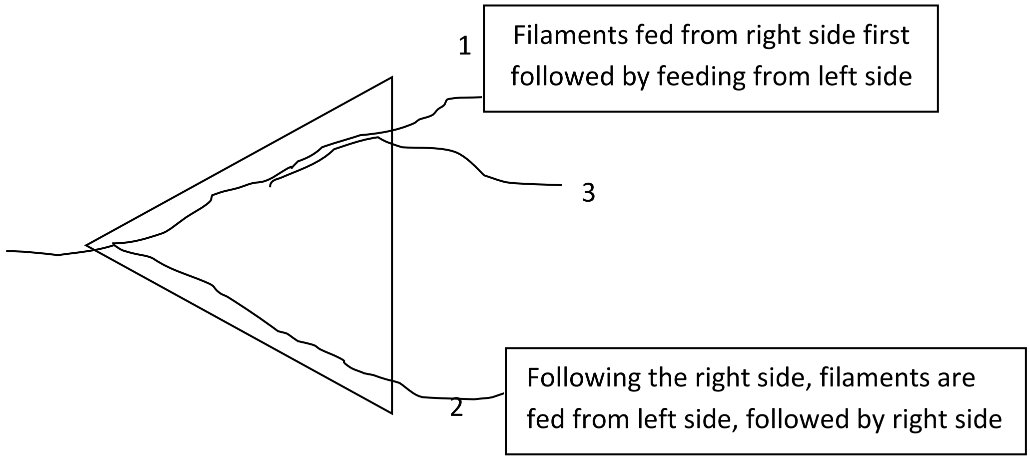



**Figure 4.7:** Feeding mechanism of yarns on phoenix Charkh

3. During the time of feeding the fibers, RBO oil emulsion is sprayed on banana fibers. Oil emulsion improves cohesiveness and reduces friction. Hence a better quality of yarn can be obtained. Filament fibers were further preceded towards the flyer.

4. The flyer inserts twist in the yarn. Each flyer rotation creates one turn in the roving. In the final analysis therefore, since the flyer rotation speed is kept constant, twist per unit length of roving depends upon the delivery speed, and can be influenced accordingly. Formation of twist takes place in the flyer assembly.

5. Yarns were further guided towards the bobbin through the thread guide. The spindle also rotated and thus the yarn is wound on bobbin.

**4.4.2 Properties of hand spun yarn**

**4.4.2. a Yarn fineness**

Fineness of yarn was important to obtain fine fabric. The values have been given in Table 4.15. It was observed that the yarns become finer after treatment. The improvement in fineness of chemical treated yarn was higher, as compared to enzyme treated. Also the spinner found it difficult to handle the enzyme treated fibers for spinning.

**Table 4.15**: Fineness of spun banana yarn

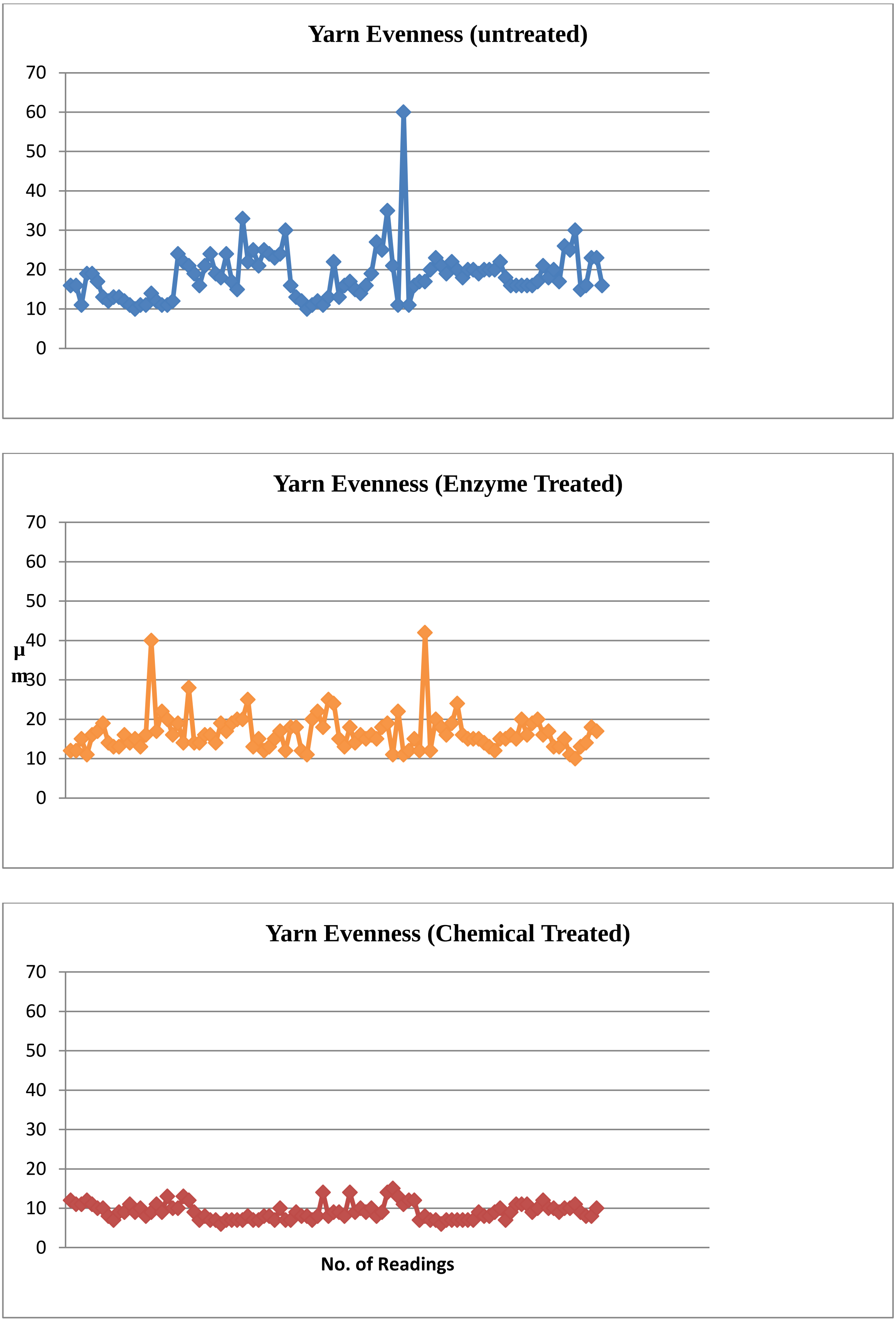
| S.No. | Type of Yarn | Count (Ne) |
|---|---|---|
| 1 | Raw | 3 |
| 2 | Enzyme treated | 3.4 |
| 3 | Chemical Treated | 11 |

### 4.4.2.b Yarn evenness

The yarn evenness has been expressed in graphs 4.9 for untreated, enzyme treated and chemical treated yarns. Effect of unevenness in yarn is also observed as presence of visible faults on the surface of fabrics. If a large amount of irregularity remains present in the yarn, the variation in fineness can easily be detected in the finished cloth, which was observed in raw banana yarn and fabric. Such defects are usually compounded when the fabric is dyed or finished. Hence the softening treatment improved the quality of yarn, even in terms of evenness. The chemical treated yarns were much finer and even than the enzyme treated and the untreated yarn. The improvement in the enzyme treated and chemical treated can be observed in Graph 4.9. The standard deviations on the yarns were 9.7, 4.9 and 2 respectively. The lower values of SD were an indication of improvement in the evenness of the yarn. The lower the standard deviation, the lower were the unevenness of the yarn, hence the chemical treated yarns were the finest and even yarn of all the three types of yarns spun.

### 4.4.2. c Yarn strength

Banana fibbers are extremely strong fibers. It was essential to maintain the strength after treatment. The untreated and treated fibers were spun into yarns on phoenix charkha and their tensile properties were tested on Instron tensile strength tester which is shown in Table 4.16. It was observed that maximum load was taken by untreated banana yarn, which almost reduced to half for enzyme treated and still reduced for chemical treated, however it important to know that the denier of both the treated yarns had also reduced. Hence to compare the strength of all the three yarns nullifying the denier effect, stress strain graph was plotted. The untreated yarn had almost a straight line and little elongation was observed in Graph 4.10. The chemical treated yarns were the strongest.

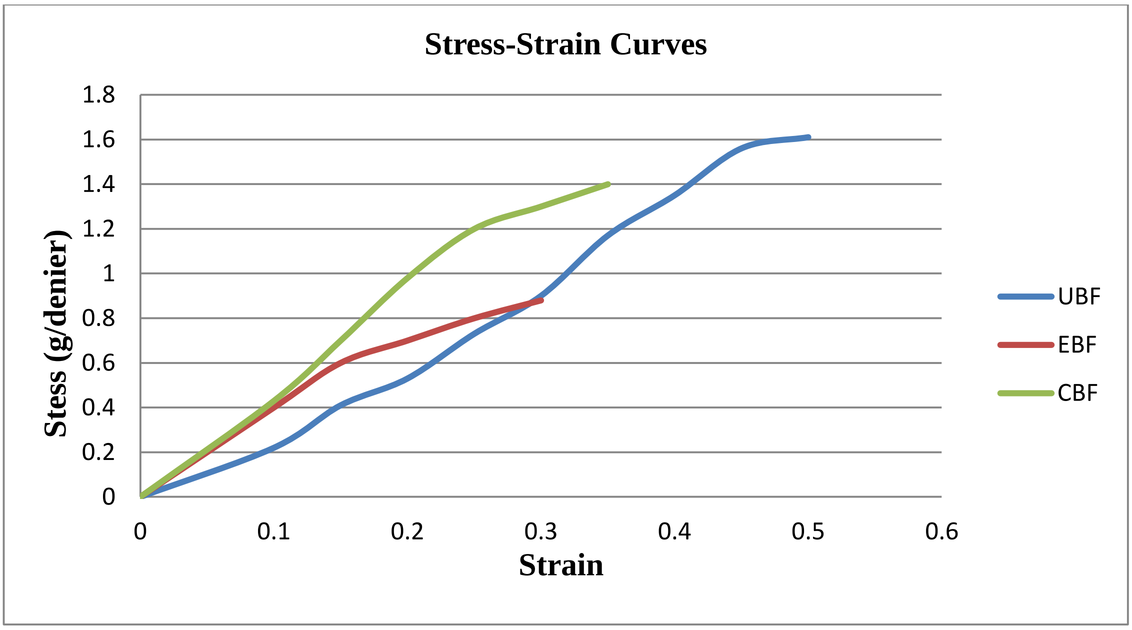



**Graph 4.9:** Yarn Evenness A) Untreated yarn, B) Enzyme treated yarn, C) Chemical treated yarn

**Table 4.16:** Yarn strength and elongation of hand spun yarns

| Yarn Sample | Maximum Load (gf) | Extension at max. (mm) | Stress (gm/den) | Strain (%) | Initial Youngs modulus |
|---|---|---|---|---|---|
| Untreated | 2076 | 4.04 | 1.21 | 4.04 | 0.29 |
| Enzyme treated | 1158.4 | 2.39 | 0.70 | 2.39 | 0.29 |
| Chemical treated | 889.5 | 3.14 | 1.70 | 3.1 | 0.36 |

The enzyme treated yarns show higher strength than the chemical treated yarns but break point is achieved at quite early even than the untreated yarns. From Graph 4.10, at the strain of 0.3% the enzyme treated and the untreated fibers behaves similarly, but the enzyme treated yarns break immediately after this point whereas the untreated yarns can hold 1.6 g/den at 0.5% strain. Hence it can be concluded that the treated yarns possess more strength than the untreated yarns, this may be due to the improvement in the fineness of yarn and more number of twist in the treated finer yarns.




**Graph 4.10**: Stress – strain curves derived from the load –extension curves for untreated, enzyme treated and chemical treated banana fiber

### 4.4.2.d Yarn twist

The twist was described using three parameters: twist direction, twist factor, and twist per inch which have been listed in Table 4.17.

**Table 4.17**: Yarn twist of hand spun banana yarns

| S.No. | Yarn | Twist per Inch | Twist direction | Twist Factor |
|---|---|---|---|---|
| 1 | Untreated | 86 | S | 58 |
| 2 | Enzyme treated | 91 | S | 65 |
| 3 | Chemical treated | 194 | S | 256 |

**Twist Factor:** The chemical treated yarns have highest twist factor, this increases yarn tenacity and elongation. It also improves hairiness and spinning stability. A low twist yarn produces soft hand, but yarns become bulky and more hairy. For the present research work yarn twist factor was not premeditated, it was the resultant and analysed further.

**Twist Direction**: All the three yarns were given "S" twist. The S twist also helps to maintain higher strength, and reduces the chances of hairiness.

**Twist per Inch**: The TPI of the three yarns has been given in Table 4.14. Untreated yarns and enzyme treated yarns have close values for TPI, however the number of twist just doubles for chemical treated yarn. As the number of twist increases the strength also increases and reduces hairiness. With the increased number of twist the yarns become finer, and it was observed that the chemical treated banana yarns were the finest and had higher twist than the enzyme treated and untreated banana yarn.

## 4.5 Ring spun banana blended yarns (process and properties)

4.4.1 Process of blending and spinning of yarns

4.4.2 Properties of machine spun yarn

4.4.2.a Yarn fineness

4.4.2.b Yarn evenness

4.4.2.c Yarn strength

4.4.2.d Yarn twis

### 4.5.1 Process of blending and spinning of yarns

Two sets of fibers were prepared. 1 Kg of enzyme treated banana fibers and 3 kg of chemical treated fibers were prepared following the standardized treatment recipe. The filament length fibers were cut into 34mm staple length fibers. The fibers were then sent to TRADC. Pilot study was done for blending of regenerated fibers and banana fibers. Three regenerated fibers were used namely viscose, modal and excel to blend with chemical treated banana fibers. The blend percent obtained was 88/12 regenerated / banana. 7 fabric samples were prepared – viscose banana, modal banana and excel banana. Three fabrics where the warp and weft both were regenerated / banana 88/12 and the remaining three fabrics were with warp as regenerated fiber (viscose, modal and excel each) and weft was regenerated /banana (viscose banana, modal banana and excel banana). Another fabric was viscose banana with 7's viscose; the details are given in Table 4.18.

**Table 4.18**: Details of pilot fabrics prepared at TRADC

| S.No. | Warp Details | Weft Details | Weave | EPI | PPI | Fabric Blend |
|---|---|---|---|---|---|---|
| 1 | 7s Viscose/Banana 88/12 | 7s Viscose/Banana 88/12 | Plain | 44 | 38 | 88/12 |
| 2 | 7s Modal/Banana 88/12 | 7s Modal/Banana 88/12 | Plain | 44 | 38 | 88/12 |
| 3 | 7s Excel/Banana 88/12 | 7s Excel/Banana 88/12 | Plain | 44 | 38 | 88/12 |
| 4 | 30s Viscose | 7s Viscose/Banana 88/12 | Plain | 48 | 38 | 89/11 |
| 5 | 30s Modal | 7s Modal/Banana 88/12 | Plain | 48 | 38 | 89/11 |
| 6 | 30s Excel | 7s Excel/Banana 88/12 | Plain | 48 | 38 | 89/11 |
| 7 | 7s Viscose | 7s Viscose/Banana 88/12 | Plain | 44 | 38 | 91/9 |

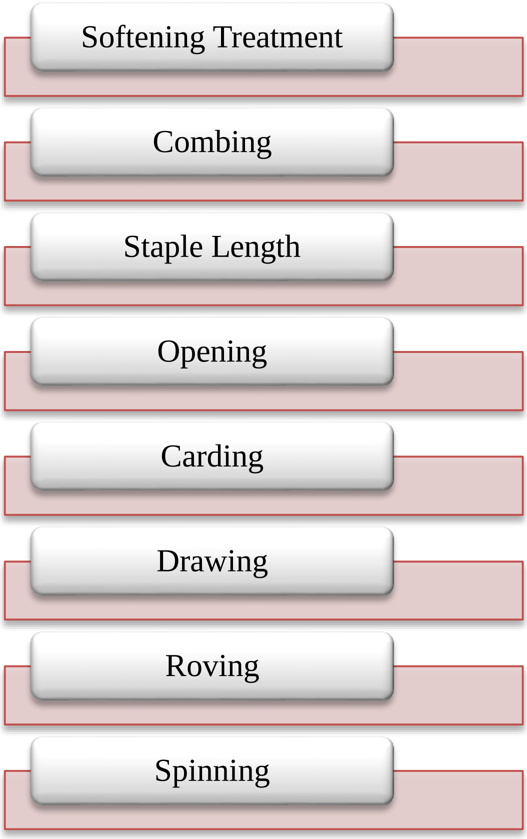



**Figure 4.8**: Process of spinning yarn on ring spinning system

Detailed description of process for spinning of blended banana yarns:

**Softening Treatment**: Two types of softening treatments were given – chemical and enzyme treatment, recipes mentioned earlier during the stage of optimization.

**Staple length**: the treated fibers were combed and dried. After drying banana fibers were cut into staple length of 34mm.

**Opening**: Blowing operation opens and cleans the impurities on the surface by using bale opener machine. Opening of fiber was carried out with the following objectives:

- Opening of fibers
- Cleaning of fiber.
- Blending of fiber.
- Lap formation (fiber mat).

Regenerated fiber (viscose, modal and excel separately) and banana fibers were weighted, where 75% was viscose /modal/excel and 25% was staple length banana fibers. The two fibers were mixed by hand and then send in the blowing machine shown in Plate 4.8. The processed fibers were more open and its processing was further improved in combing.

**Plate 4.8**: Blowroom

**Carding**:In this process the individual fibers opens up. Short fiber or uneven fibers, which may not be suitable for production, were eliminated. Lot of banana fibers were wasted at this stage (Plate 4.9 b). The blow room lap is converted into sliver.

**Plate 4.9:** a) Carding machine b) Fibers adhere to the drum during carding process

**Drawing**: During drawing the sliver is pulled in lengthwise direction over. This causes it to be stronger and thinner in production which is very important in evenness of the yarn. Drawing was carried out with the following objectives:

- To straighten the crimped, curled and hooked fibers.
- To make the fiber parallel to their neighbors.
- To improve uniformity of sliver by drafting and doubling.
- To reduce weight per length unit of sliver.

**Plate 4.10:** Drawing machine

**Roving**: This was the preparatory step for insertion of the twist. Enough twist is given to hold the fibers together but still has no tensile strength. The roving in bobbins is placed in spinning frame where it passes several sets of roller which running at high-speed to convert into yarn forms.

**Spinning**: To produce required count of yarn from the supplied roving by the drafting ring spinning was carried out. This would insert sufficient amount of twist to the yarn and the yarn were wound onto the bobbin. Several yarn breakages were observed at ring frame, due to stiff nature of banana fibers (Plate 4.11).

**Plate 4.11:** a) Ring Frame b) Speed Frame

### 4.5.2 Properties of machine spun yarn

#### 4.5.2.a Yarn fineness

Fineness of yarn is important to obtain fine fabric. The values of yarn blends are given in Table 4.19. It was observed that fine yarns can be obtained when blended with regenerated fibers. It was also observed that ease of spinning was better for chemical treated fibers than the enzyme treated fibers. The maximum blend percentage obtained for all four fibers was 25% banana fibers.

**Table 4.19:** Fineness of spun yarn

| S.No. | Type of Yarn | Count (Ne) |
|---|---|---|
| 1 | VBCT | 5.1 |
| 2 | MBCT | 8.1 |
| 3 | EBCT | 7 |
| 4 | VBET | 7 |

Key: VBCT: Viscose banana chemical treated, MBCT: Modal banana chemical treated, EBCT: Excel banana chemical treated, VBET: Viscose banana enzyme treated.

#### 4.5.2.b Yarn evenness

The yarn evenness has been expressed in graphs 4.11 for viscose banana, modal banana; excel banana using chemical treated banana fibers and viscose banana with enzyme treated banana fibers. Effect of evenness in yarn is also observed as presence of visible faults on the surface of fabrics. If a large amount of irregularity remains present in the yarn, the variation in fineness can easily be detected in the finished cloth. Such defects are usually compounded when the fabric is dyed or finished. For all the yarns, viscose banana, modal banana and excel banana; since banana yarns are cut into filament length, they at time protrude out. Although the yarns appears to be even, but the diameter varies a lot at the points where banana fibers blends. Due to this the evenness of the yarn is decrease, which can be observed by the values of standard deviations of the respective yarns.

The standard deviations for VBCT, MBCT, EBCT and VBET were 4, 5.9, 9.1and 3.9 respectively. The lower values of SD are an indication of improvement in the evenness of the yarn. The lower the standard deviation, the yarn would be more even. Maximum deviation was observed in excel banana because excel was the finest regenerated yarn used and banana was a tough yarn as compared.

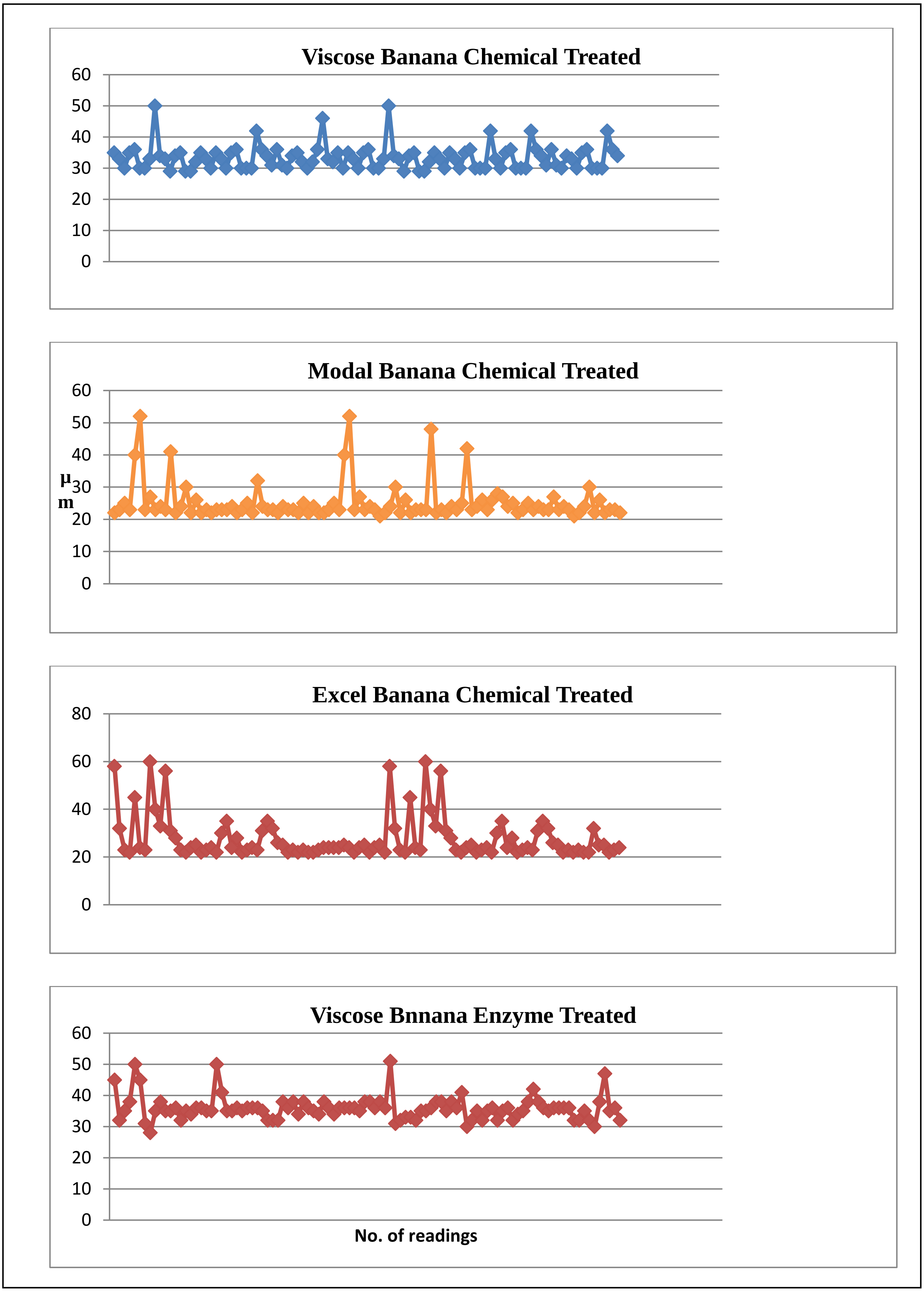
### 4.5.2.c Yarn strength

Yarn strength and elongation are essential property of any yarn to be used for weaving. The maximum load, elongation values are given in Table 4. 20 and stress strain curve is given in Graph 4.8. The initial young's modulus of viscose banana both chemical treated and enzyme treated is similar. The numerical value is low, which indicated great extensibility.

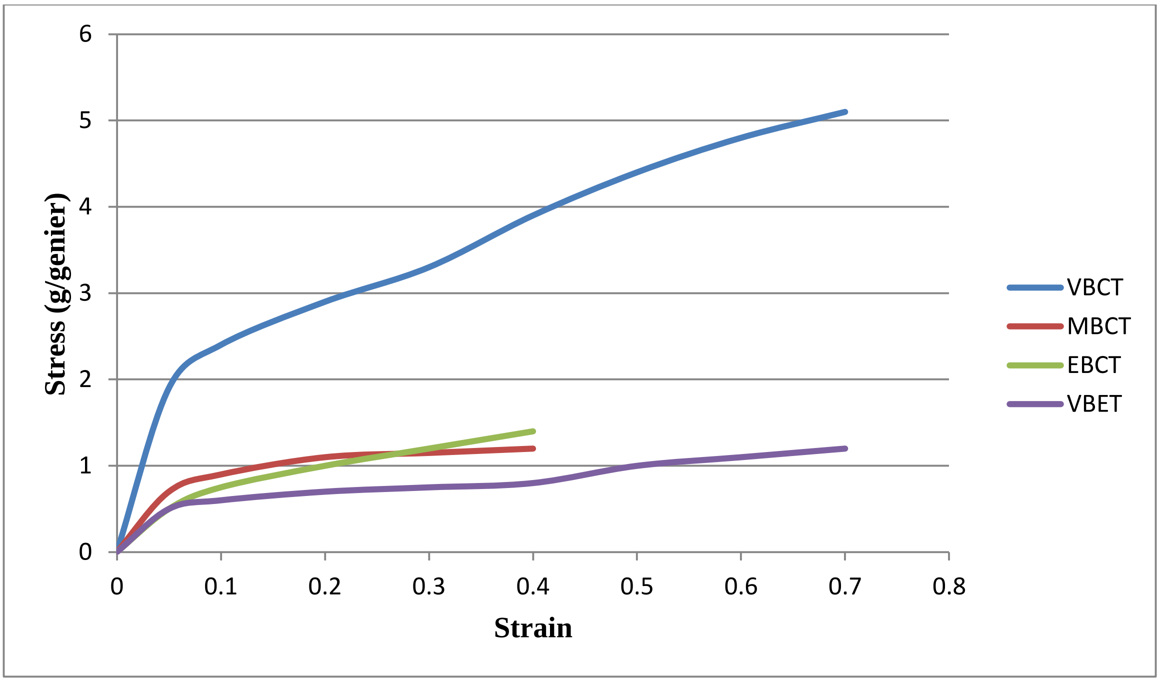
**Table 4.20:** Yarn strength and elongation of banana blends with regenerated fibers

| Yarn Sample | Maximum Load (gf) | Extension at max. (mm) | Stress (gm/den) | Strain (%) | Initial Young's modulus |
|---|---|---|---|---|---|
| VBCT | 1142.10 | 13.6 | 1.09 | 13.6 | 0.08 |
| MBCT | 1224.99 | 9.6 | 1.8 | 9.6 | 0.18 |
| EBCT | 1031.28 | 7.4 | 1.3 | 7.4 | 0.17 |
| VBET | 1062.83 | 14.6 | 1.3 | 14.6 | 0.08 |

Key: VBCT: Viscose banana chemical treated, MBCT: Modal banana chemical treated, EBCT: Excel banana chemical treated, VBET: Viscose banana enzyme treated.




**Graph 4.11**: Yarn Evenness of blends of regenerated fibers and banana fibers




**Graph 4.12:** Stress – strain curves derived from the load –extension curves for regenerated fiber and banana union fabrics

From Graph 4.12, it can be concluded that both the viscose banana yarn (chemical treated and enzyme treated) have almost similar elongation which is high. Since chemical treated viscose banana yarn was coarser (5.1's) than the viscose banana enzyme treated (7's), and the strength of chemical treated banana fibers was more than enzyme treated banana fibers; the superior strength of VBCT is clearly seen in graph 2. Modal and Excel behaves almost similar. There is a slight difference in the count of the two yarns. Hence, modal banana showed a slight higher strength than excel banana. Both the yarns had similar extension values.

### 4.5.2.d Yarn twist

The twist was described using three parameters: twist direction, twist factor, and twist per inch which have been listed in Table 4.21.

**Twist Factor:** The banana regenerated blended yarns have highest twist factor, this increases yarn tenacity and elongation. It also improves hairiness and spinning stability. A low twist yarn produces soft hand, but yarns are bulky and more hairy. For the present research work yarn twist factor was not premeditated, it was the resultant and analysed further.

**Table 4.21**: Yarn twist of regenerated fibers and banana blended yarns

| S.No. | Yarn | Twist per Inch | Twist direction | Twist Factor |
|---|---|---|---|---|
| 1 | VBCT | 160 | S | 352 |
| 2 | MBCT | 175 | S | 490 |
| 3 | EBCT | 185 | S | 481 |
| 4 | VBET | 150 | S | 390 |

Key: VBCT: Viscose banana chemical treated, MBCT: Modal banana chemical treated, EBCT: Excel banana chemical treated, VBET: Viscose banana enzyme treated.

**Twist Direction**: All the three yarns were given "S" twist. The S twist also helps to maintain higher strength, and reduces the chances of hairiness.

**Twist per Inch**: The TPI of the four yarns has been given in Table 4.18. As the number of twist increases the strength also increases and reduces hairiness. For all the four yarns the twist per inch was high indicating strength.

It was also observed that the blended yarns behaved more like the regenerated yarn with which it was blended. For example modal is strongest followed by excel and viscose, the strength was highest for modal, followed by excel and viscose. Modal is known as the fourth generation yarn and was the strongest and softest as compared to the other two, similar observations were made for their blends. When compared with chemical treated and enzyme treated banana fibers, the chemical treated viscose banana yarn was stronger, softer and less hairy than enzyme treated viscose banana.

## 4.6 Fabric Construction and its properties

4.6.1 Fabric shrinkage

4.6.2 Strength and elongation

4.6.3 Fabric stiffness

4.6.4 Cover factor

4.6.5 Drape

4.6.6 KAWABATA evaluation

Woven fabric construction is one of the basic factors that have a direct effect on the properties of fabric for its end use. Woven fabric construction is altered by three primary constructional parameters, namely: yarn fineness, weave type and warp/weft density. Primary parameters of fabric construction are dependent variables, where the choice of one parameter influences the effect of the others. Therefore, yarn fineness influences fabric densities over the weave type. In the present research, yarn fineness of banana yarns was the result of the softness treatment given to the fibers. Thus the development of fabrics was resultant of the yarns spun. The weave type was kept constant for all the fabrics and that was plain weave. The warp and weft density was not predetermined but uttermost care was taken for selection of warp yarn to obtain fine variety of fabrics. Fabric constructed using raw yarn, was opened and the fabric was made again. The fabric constructed for the first time was too limp and was an open weave structure. Table 4.22, the details of the fabrics constructed on handloom and powerloom are mentioned.

**Table 4.22:** Yarn specifications for fabrics constructed

| S.No | Fabric Code | Warp Yarn | | Weft Yarn | |
|---|---|---|---|---|---|
| | | Fiber content | Yarn Count | Fiber content | Yarn Count |
| 1 | UCBF1 | Cotton | 12’s | 100% Banana | 3’s |
| 2 | ECBF1 | Cotton | 12’s | 100% Banana | 3.4’s |
| 3 | CCBF1 | Cotton | 2/60’s | 100% Banana | 11’s |
| 4 | UCBF2 | Cotton | 12’s | 100% Banana | 1.3’s |
| 5 | ECBF2 | Cotton | 12’s | 100% Banana | 1.3’s |
| 6 | CCBF2 | Cotton | 12’s | 100% Banana | 1.3’s |
| 7 | VBCT3 | Viscose | 30’s | 75/25 viscose/banana (CT) | 5.1 |
| 8 | MBCT3 | Modal | 2/40’s | 75/25 modal/banana (CT) | 8.1 |
| 9 | EBCT3 | Excel | 2/30’s | 75/25 excel/banana (CT) | 7 |
| 10 | VBET3 | Viscose | 30’s | 75/25 viscose/banana (ET) | 7 |

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

The preliminary data of the constructed fabrics has been given in Table 4.23, which includes the fabric width after fabric construction, the thickness of the fabric, the weight of the fabric i.e. GSM (grams per square meter), Fabric count and cover factor of the fabric is also mentioned. The visuals of the fabrics are given in Plate 12, 13, 14.

**Table 4.23**: Preliminary data of the fabric constructed

| Sr. No. | Fabric code | Fabric thickness (mm) | Fabric count | GSM |
|---|---|---|---|---|
| 1 | UCBF1 | 0.98 | 12 X16 | 253.2 |
| 2 | ECBF1 | 0.84 | 24 X34 | 240.4 |
| 3 | CCBF1 | 0.51 | 52X50 | 216 |
| 4 | UCBF2 | 1.64 | 12 X16 | 498.8 |
| 5 | ECBF2 | 1.50 | 12 X16 | 446.8 |
| 6 | CCBF2 | 1.24 | 12 X16 | 443.2 |
| 7 | VBCT3 | 0.58 | 64 X48 | 285.2 |
| 8 | MBCT3 | 0.52 | 60 X56 | 228.8 |
| 9 | EBCT3 | 0.50 | 60 X56 | 242 |
| 10 | VBET3 | 0.58 | 44 X54 | 266.8 |

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.

SET 2: 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

### 4.6.1 Fabric shrinkage

According to the AATCC definition, relaxation shrinkage can occur when textiles are immersed in water, but are not agitated. When the fibers absorb water, the filling yarns increase in diameter and the warp yarn is stretched to accommodate them. Because the fabric is no longer under tension, however, the warp yarn is free to moveand crimp more to relieve the stress, shortening the distance between adjacent filling yarns. Because they are under more tension from the weaving process than are filling yarns, warp yarns ordinarily relax more during laundering and exhibit more shrinkage. The relaxation shrinkage of all the constructed banana fabrics has been given in Table 4.24.

**Table 4.24:** Percent shrinkage in Banana Fabrics

| S.No. | Fabric Code | % warp shrinkage | % weft shrinkage |
|---|---|---|---|
| 1 | UCBF1 | 3 | 1 |
| 2 | ECBF1 | 3 | 1 |
| 3 | CCBF1 | 4 | 2 |
| 4 | UCBF2 | 1 | 0 |
| 5 | ECBF2 | 3 | 2 |
| 6 | CCBF2 | 1 | 1 |
| 7 | VBCT3 | 7 | 3 |
| 8 | MBCT3 | 8 | 2 |
| 9 | EBCT3 | 4 | 2 |
| 10 | VBET3 | 5 | 3 |

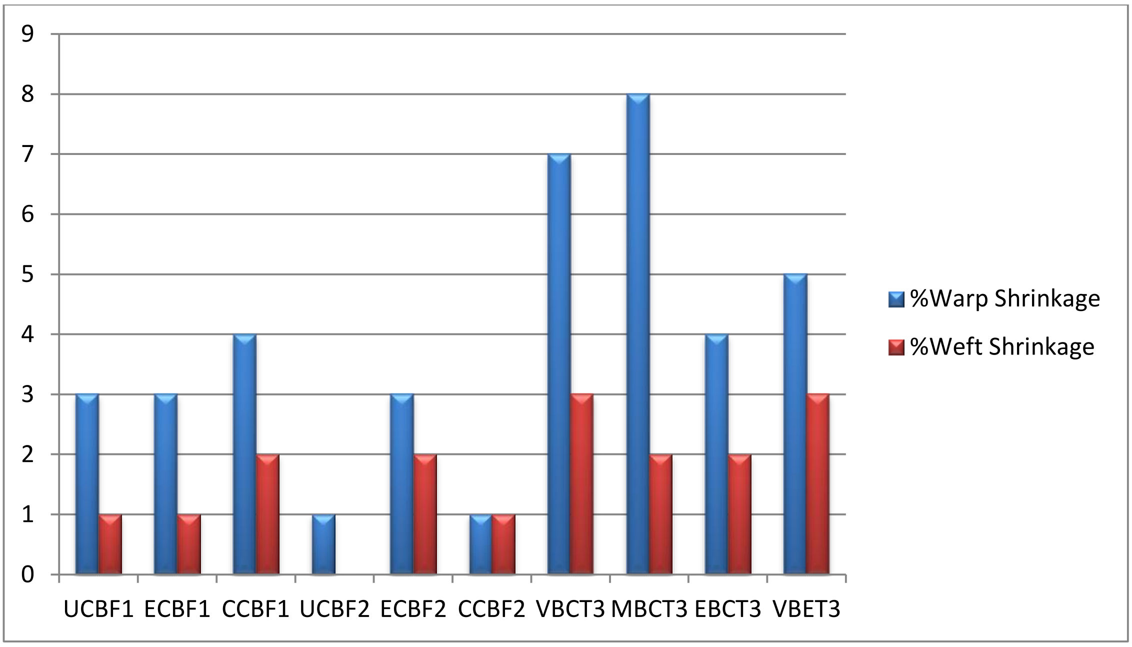
Key

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

It was observed that shrinkage in warp was more than weft for the same reason mentioned above. The handloom fabrics had lower shrinkage in weft as compared to the blends of banana yarns with regenerated fibers, woven on powerloom. It was also be analysed that regenerated fibers viscose, modal and excel had more shrinkage than cotton. This fact is also applicable for weft as the set 3 fabrics has banana blends with regenerated fibers in weft. Hence the percent shrinkage of the set 3 weft yarns was more than the banana yarns of set 1 and 2. Thus it can be concluded that banana shrinks lesser than cotton and regenerated fibers.




**Graph 4.13:** Percent warp and weft shrinkage of untreated and treated banana fabrics

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


**Plate 4.12:**Cotton banana fabrics (Set 1) Left side-normal view, Right side-closer view

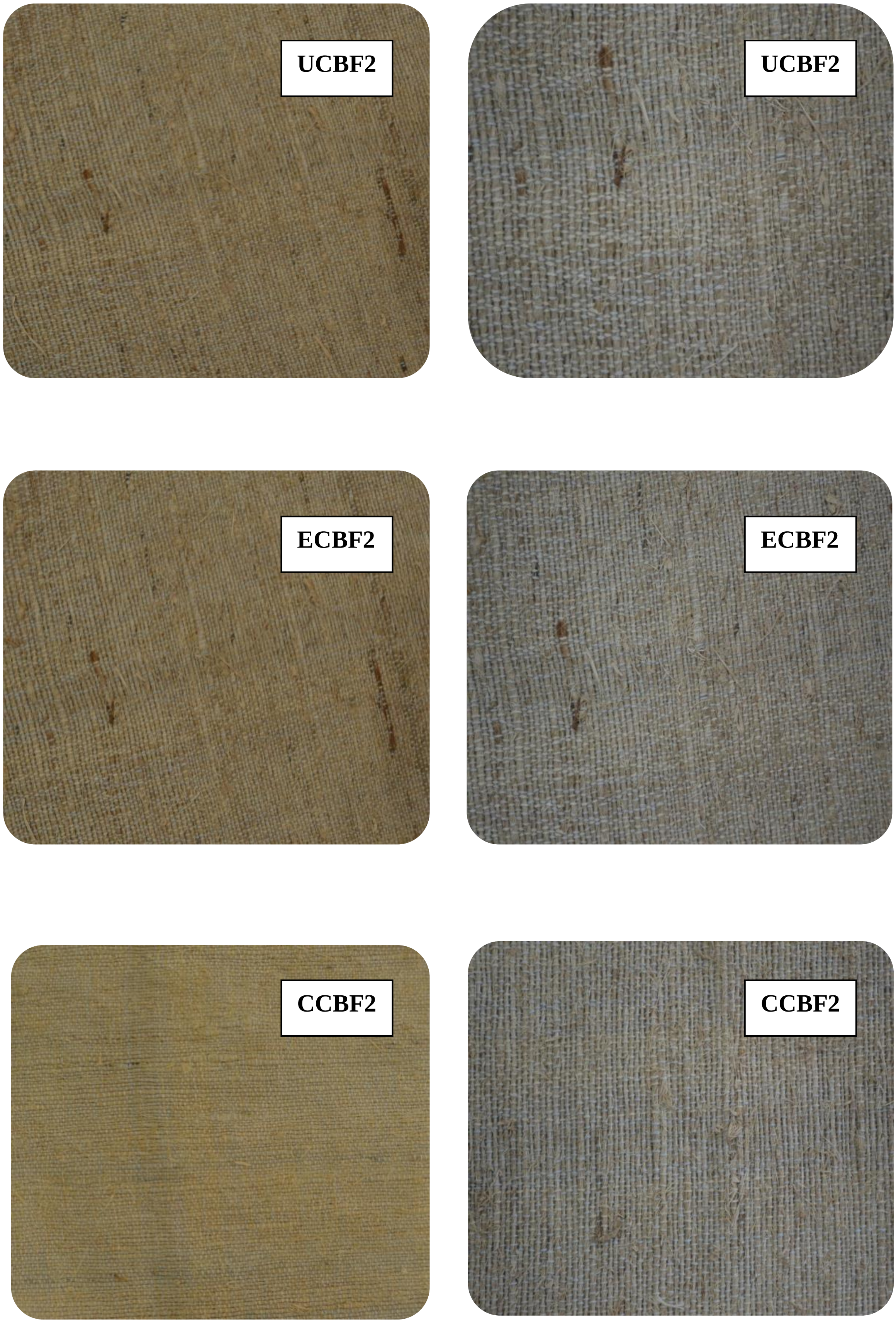



**Plate 4.13:** Cotton banana fabric (Set II) Left side-normal view, Right side-closer view


**Plate 4.14:** Regenerated /banana fabrics (Set III) Left side-normal view, Right side-closer view

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

### 4.6.2 Fabric stiffness

One of the major drawbacks of banana fibers was the stiffness. The stiffness of the constructed banana fabrics was measured by their bending length. The second set of cotton banana fabrics, where the banana yarns were procured directly and the softening treatment was given after the fabric construction. Bending length test was not applicable for this set, as the standard fabric length (15cms) would fall short for them. No readings were obtained in weft direction; hence those fabrics would fall into the set of stiff fabrics. At the same time these fabrics were thicker than the other two categories.

The bending length of the set 2 of cotton banana fabrics has been given in Table 4.25, 4.26, 4.27. It was clearly visible that the stiffness was more in the weft direction than the warp direction. Amongst the three fabrics of this set, the untreated weft yarns had less banding length as compared to enzyme and chemical treated banana fibers. This may be due to the compactness of the enzyme treated and chemical treated fabrics. The untreated fabric was very limp and hence the bending length obtained was lower than the other two.

**Table 4.25:** Bending Length of Untreated Cotton Banana Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | Face to Face | Back to Back | Face to Face | Back to Back |
| 1 | 2.3 | 3 | 9.5 | 11.5 |
| 2 | 2.6 | 3 | 9 | 13.5 |
| 3 | 3 | 2.4 | 7.9 | 13.6 |
| 4 | 3 | 2 | 9.3 | 10.2 |
| 5 | 2.1 | 2.1 | 9.1 | 12.1 |
| Average | 2.6 | 2.5 | 8.9 | 12.1 |

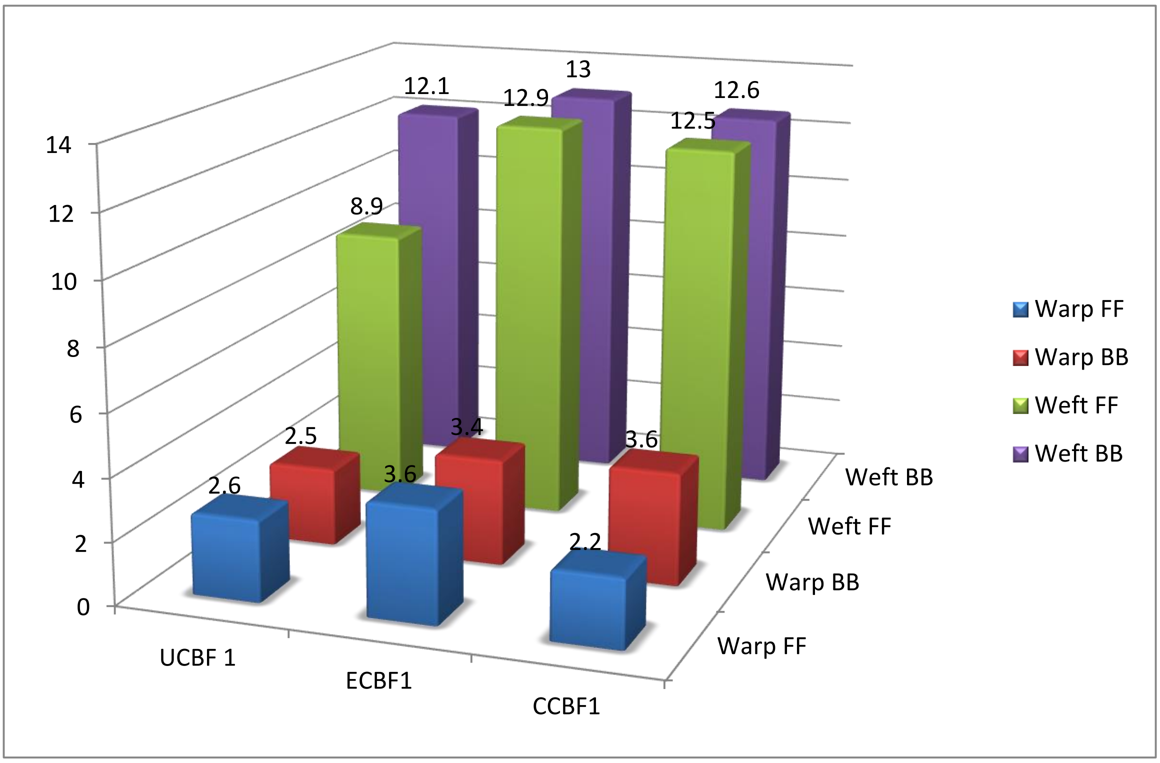
**Table 4.26:** Bending Length of Enzyme treated Cotton Banana Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | Face to Face | Back to Back | Face to Face | Back to Back |
| 1 | 2.7 | 3.2 | 12.8 | 12.5 |
| 2 | 5 | 3.6 | 12.8 | 12.9 |
| 3 | 3.6 | 3.8 | 12.6 | 13.1 |
| 4 | 2.9 | 3 | 13 | 13.5 |
| 5 | 4 | 3.5 | 13.4 | 13 |
| Average | 3.6 | 3.4 | 12.9 | 13 |

**Table 4.27:** Bending Length of Chemical treated Cotton Banana Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | Face to Face | Back to Back | Face to Face | Back to Back |
| 1 | 2.3 | 4 | 13 | 13 |
| 2 | 2.1 | 3.5 | 12 | 12.8 |
| 3 | 2 | 3.8 | 12.4 | 12.5 |
| 4 | 2.5 | 4.1 | 12.6 | 12 |
| 5 | 2.2 | 2.8 | 12.8 | 12.8 |
| Average | 2.2 | 3.6 | 12.5 | 12.6 |

From Table 4.28, 4.29, 4.30, 4.31 and Graph 4.15, it was observed that the bending length of weft yarns increased as compared to the warp yarns. This could be due to the presence of banana fibers in the weft yarns. Maximum difference was observed in Modal followed by excel and viscose. Both the viscose banana (enzyme treated and chemical treated) behaved almost similarly.




**Graph 4.14:**Bending length of cotton banana untreated and treated fabrics of set 1

Key: UCBF1: Untreated cotton banana fabric of set 1, ECBF1: Enzyme treated cotton banana fabric of set 1, CCBF1: Chemical treated cotton banana fabric of set 1.

**Table 4.28:** Bending Length of Viscose Banana Chemical Treated Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | Face to Face | Back to Back | Face to Face | Back to Back |
| 1 | 4 | 4.1 | 6 | 6.3 |
| 2 | 4.2 | 4.1 | 6.1 | 6 |
| 3 | 3.8 | 3.9 | 5.8 | 6.1 |
| 4 | 4 | 3.5 | 5.8 | 5.9 |
| 5 | 3.8 | 4 | 6.2 | 5.6 |
| Average | 3.9 | 3.9 | 5.9 | 5.9 |

**Table 4.29:** Bending Length of Modal Banana Chemical Treated Fabric

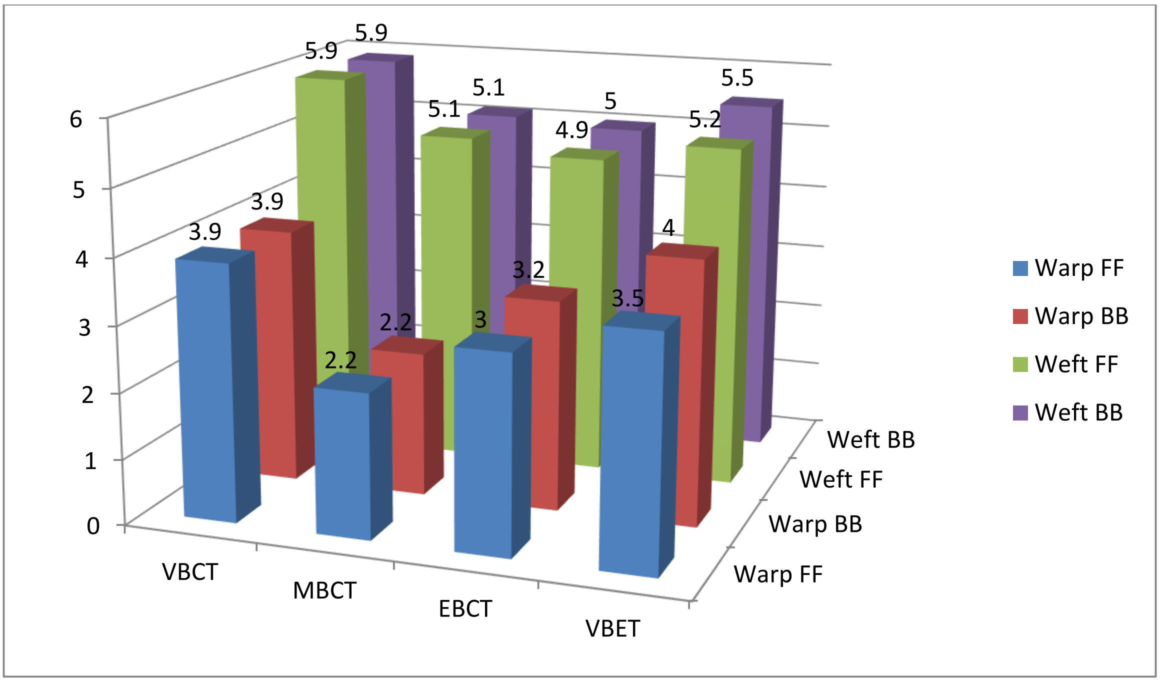
| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | **Face to Face** | **Back to Back** | **Face to Face** | **Back to Back** |
| 1 | 2.3 | 2 | 5.2 | 5.5 |
| 2 | 2.1 | 2.1 | 5 | 5 |
| 3 | 2.5 | 2.5 | 5.4 | 5.2 |
| 4 | 2.3 | 2.4 | 4.8 | 5.1 |
| 5 | 2 | 2.1 | 5.1 | 4.7 |
| Average | 2.2 | 2.2 | 5.1 | 5.1 |

**Table 4.30:** Bending Length of Excel Banana Chemical Treated Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | **Face to Face** | **Back to Back** | **Face to Face** | **Back to Back** |
| 1 | 3.5 | 3.2 | 4.8 | 4.8 |
| 2 | 3.4 | 3 | 4.8 | 4.8 |
| 3 | 3 | 3.6 | 5 | 5.2 |
| 4 | 2.5 | 3.4 | 5.1 | 5 |
| 5 | 2.9 | 3.1 | 4.9 | 5.3 |
| Average | 3 | 3.2 | 4.9 | 5 |

**Table 4.31:** Bending Length of Viscose Banana Enzyme Treated Fabric

| S.No: | Warp | | Weft | |
|---|---|---|---|---|
| | **Face to Face** | **Back to Back** | **Face to Face** | **Back to Back** |
| 1 | 3.6 | 4 | 5.6 | 5.8 |
| 2 | 3.8 | 4.1 | 5.5 | 5 |
| 3 | 4 | 4.2 | 5.2 | 5.5 |
| 4 | 3.1 | 4.1 | 5.1 | 5.8 |
| 5 | 3.1 | 3.8 | 5 | 5.6 |
| Average | 3.5 | 4 | 5.2 | 5.5 |




**Graph 4.15:** Bending length of Regenerated/ banana fabrics of set 3

Key: VBCT: Viscose banana chemical treated, MBCT: Modal banana chemical treated, EBCT: Excel banana chemical treated, VBET: Viscose banana enzyme treated.

### 4.6.3 Cover factor

Cover factor do not necessarily indicate textile merit because differences in count, twist factor, fiber etc., would all play their part. An approximate relationship between the sum of the warp and weft cover factors and the cloth weight per unit area can be given by cover factor. With this an estimate of the closeness of the weave can be made. The cover factor calculated for all the banana fabrics has been given in Table 4.32.

**Table 4.32:** Cover factor of constructed banana fabrics

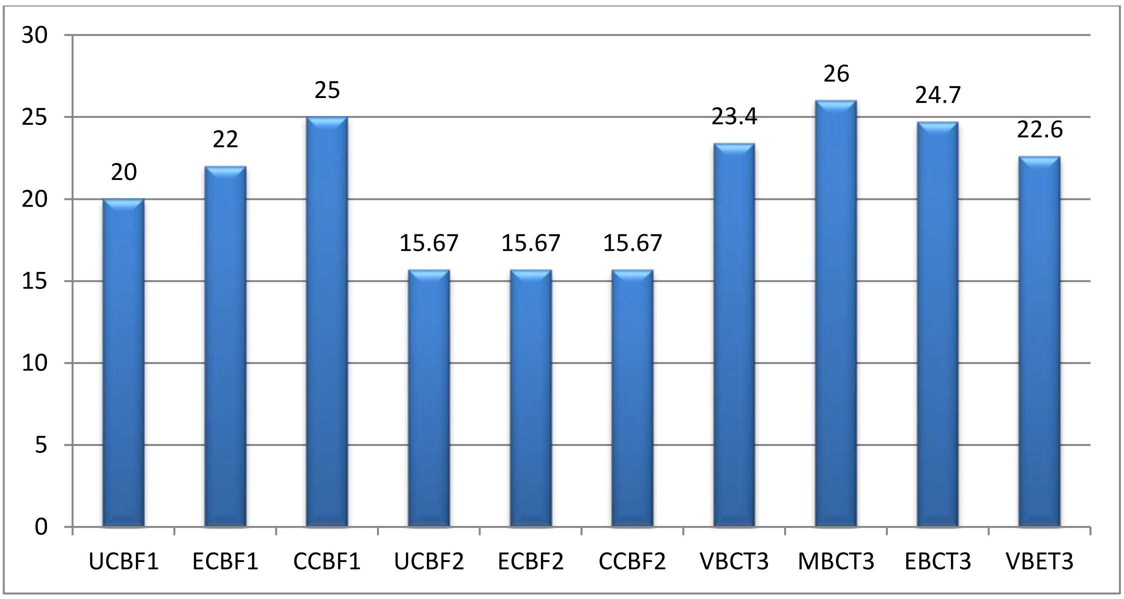
| S.No. | Fabric Code | Cover Factor |
|---|---|---|
| 1 | UCBF1 | 20 |
| 2 | ECBF1 | 22 |
| 3 | CCBF1 | 25 |
| 4 | UCBF2 | 15.67 |
| 5 | ECBF2 | 15.67 |
| 6 | CCBF2 | 15.67 |
| 7 | VBCT3 | 23.4 |
| 8 | MBCT3 | 26 |
| 9 | EBCT3 | 24.7 |
| 10 | VBET3 | 22.9 |

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




**Graph 4.16:** Cover factor of union banana fabrics

### 4.6.4 Drape

According to Collier (1999), a drape coefficient between 25% and 50% would indicate a drapeable fabric. Those with drape coefficient's greater than 75% are stiffer and less drapeable. The drape and the drape coefficient of all the constructed fabrics have been given in Table 4.33. One fact observed during the drape test was that the bending was more in one direction. Such fabrics are more suitable for curtains, drapes and garments like gathered skirts.

**Table 4.33:** Drape Coefficient of constructed banana fabrics

| S.No. | Fabric Code | Drape Coefficient (%) |
|---|---|---|
| 1 | UCBF1 | 58.17 |
| 2 | ECBF1 | 65.84 |
| 3 | CCBF1 | 36.22 |
| 4 | UCBF2 | 65.76 |
| 5 | ECBF2 | 69.55 |
| 6 | CCBF2 | 58 |
| 7 | VBCT3 | 26.11 |
| 8 | MBCT3 | 13.14 |
| 9 | EBCT3 | 10.67 |
| 10 | VBET3 | 23.68 |

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

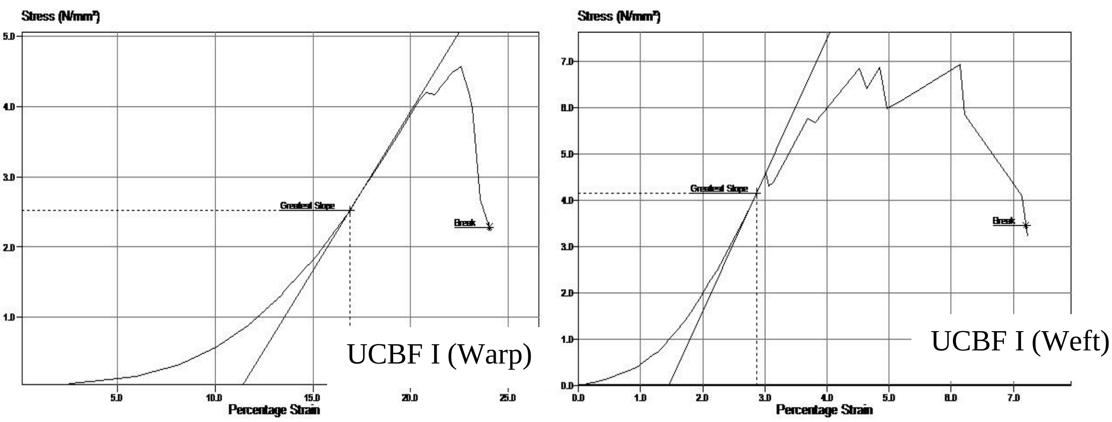
The drape coefficient of cotton banana fabrics of set II, are all above 50% hence, they are stiff fabrics and are less drapeable Even the fabrics from set I had drape coefficient above 50%, except Banana Khadi (CCBF1) with the drape coefficient of 36%. The drape coefficient of both the viscose fabrics was almost similar and the drape coefficient values of modal and excel showed that they can be draped very well. Hence, of all the 10 fabrics constructed, banana khadi and blends of regenerated banana fabrics were drapeable.

### 4.6.5 Strength and elongation

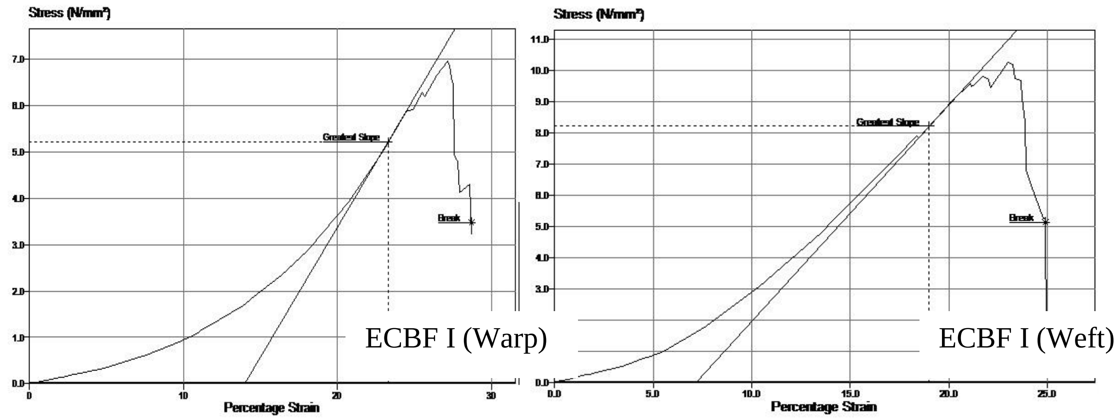
The stress strain or force elongation curve gives a great deal of information about the tensile behaviour of the fiber, yarn or fabric.

Modulus: is the slope of the initial straight line portion of the curve. It denotes the initial resistance of a material to the applied force. In this region the material is elastic i.e. the energy or force absorbed is recovered when the force is removed and thus no permanent damage or deformation results. A slope in the initial region indicates a high modulus and a large resistance to the applied force. A general observation made was that after chemical treatment the elongation is increased in all the fabrics.

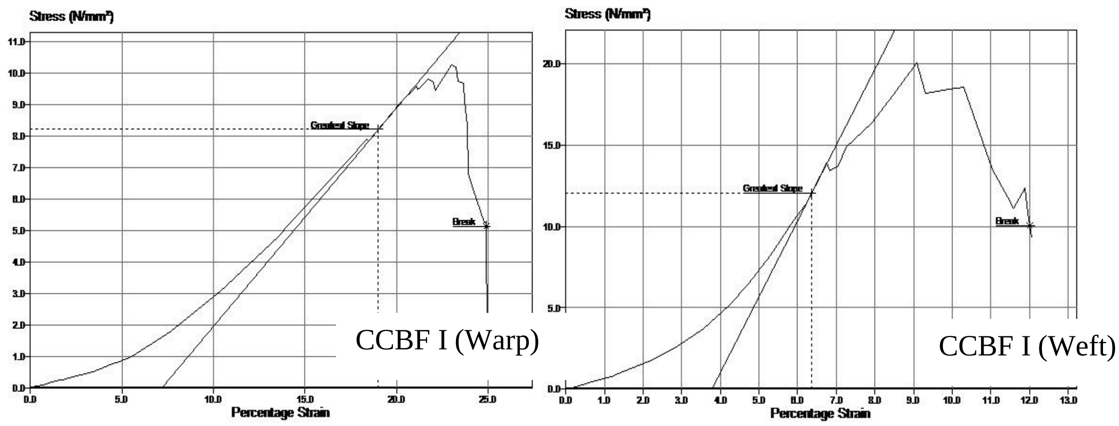
Yield point: is the point on the curve where the slope changes: the point where it deviates from a straight line. It marks the change from the elastic to the inelastic or plastic region that follows. For all the cotton banana fabric the yield point of weft was more than the warp direction, especially after the treatment.



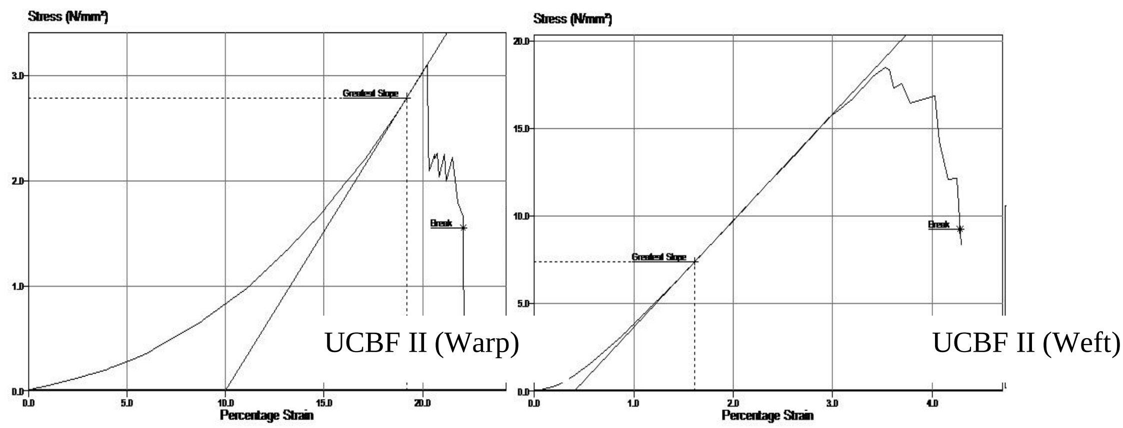

**Graph 4.17:** Stress Strain curve for Untreated Cotton Banana Fabric I



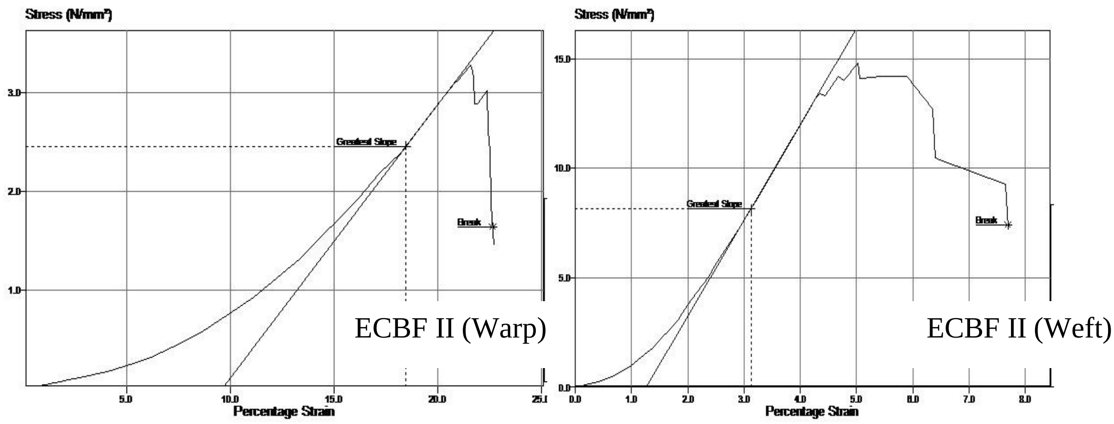

**Graph 4.18:** Stress Strain curve for Enzyme treated Cotton Banana Fabric I



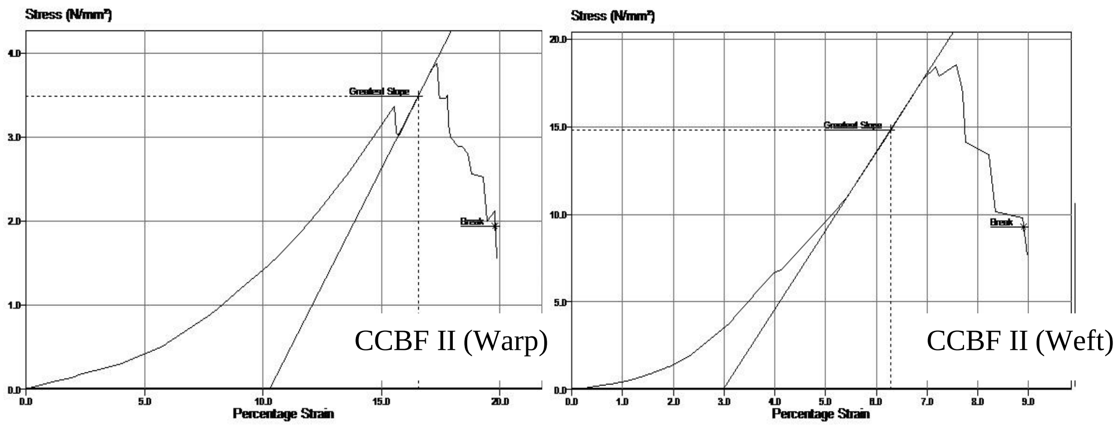

**Graph 4.19:** Stress Strain curve for Chemical treated Cotton Banana Fabric I



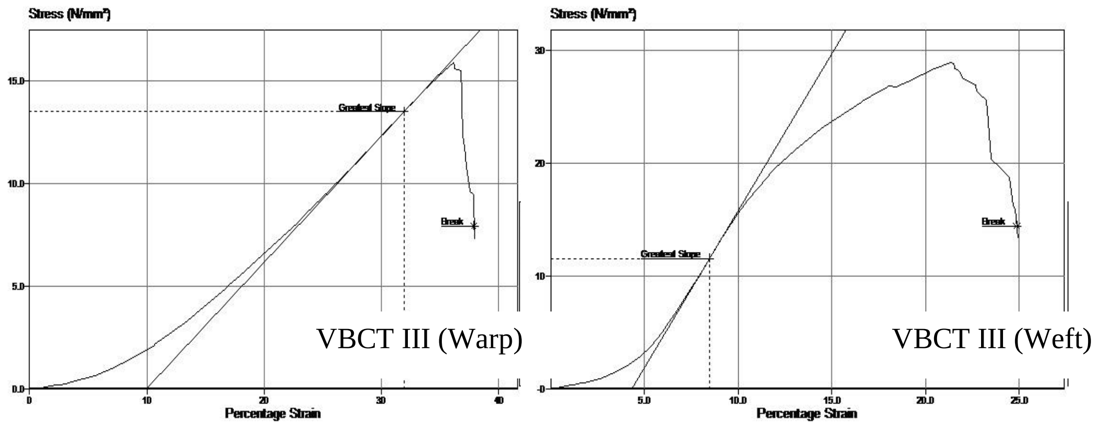

**Graph 4.20:** Stress Strain curve for Untreated Cotton Banana Fabric II



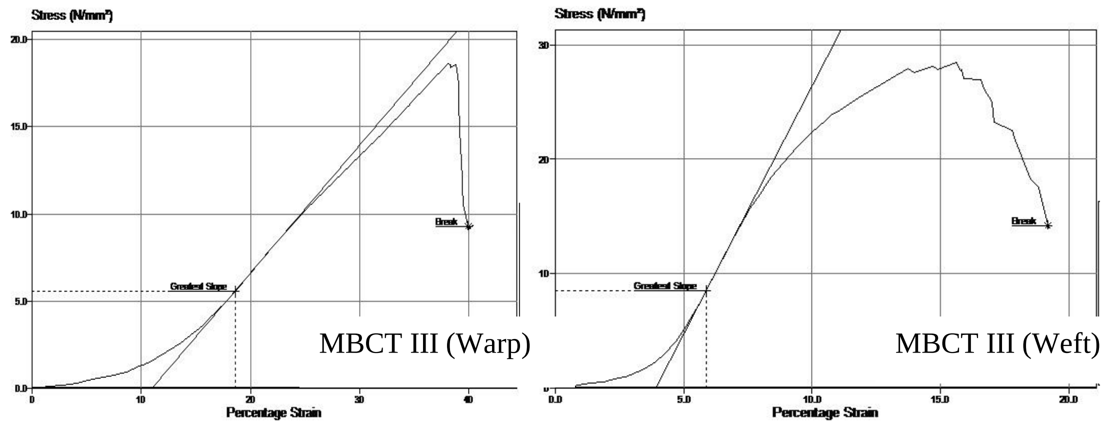

**Graph 4.21:** Stress Strain curve for Enzyme treated Cotton Banana Fabric II



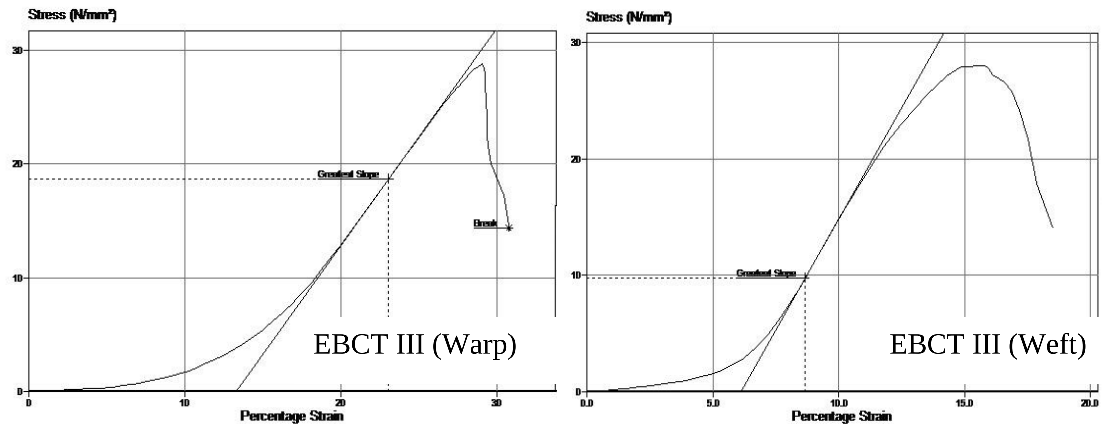

**Graph 4.22:** Stress Strain curve for Chemical treated Cotton Banana Fabric II



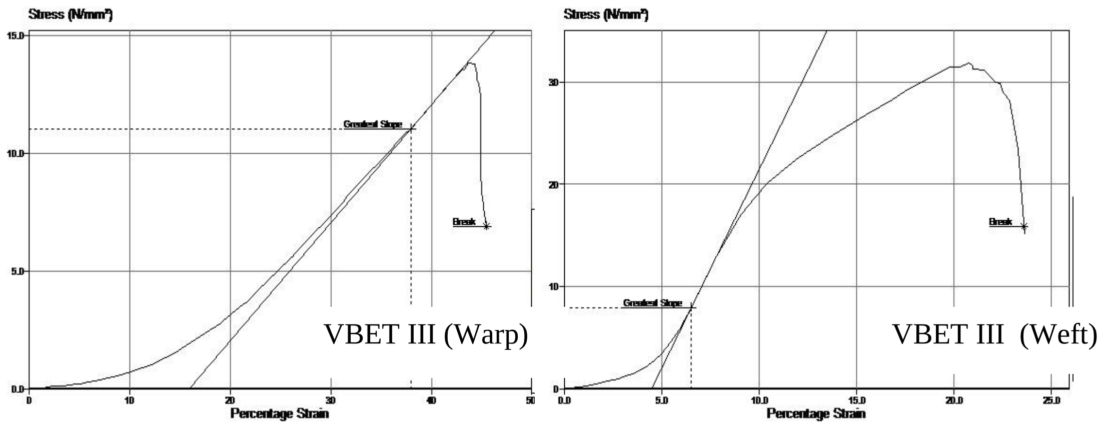

**Graph 4.23:** Stress Strain curve for Viscose Banana chemical treated Fabric III




**Graph 4.24:** Stress Strain curve for Modal Banana chemical treated Fabric III




**Graph 4.25:** Stress Strain curve for Excel Banana chemical treated Fabric III




**Graph 4.26:** Stress Strain curve for Viscose Banana enzyme treated Fabric III

**Table 4.34:** Load elongation values of constructed banana fabrics

| Fabric Code | Sample Reference | Speed (mm/min) | Maximum Load (Kgf) | Percentage Strain at Maximum Load | Young's Modulus |
|---|---|---|---|---|---|
| UCBF I | Warp | 100 | 9.13 | 22.55 | 45.25 |
| UCBF I | Weft | 100 | 13.83 | 6.14 | 294.6 |
| ECBF I | Warp | 100 | 11.91 | 27.16 | 56.16 |
| ECBF I | Weft | 100 | 15.46 | 3.99 | 360.1 |
| CCBF I | Warp | 100 | 10.67 | 23.02 | 69.33 |
| CCBF I | Weft | 100 | 20.85 | 9.08 | 466.7 |
| UCBF II | Warp | 100 | 10.34 | 20.25 | 30.23 |
| UCBF II | Weft | 100 | 61.78 | 3.53 | 609.1 |
| ECBFII | Warp | 100 | 10.02 | 21.57 | 27.79 |
| ECBF II | Weft | 100 | 45.23 | 5.01 | 437.8 |
| CCBF II | Warp | 100 | 9.80 | 17.37 | 55.66 |
| CCBF II | Weft | 100 | 46.82 | 7.58 | 449.2 |
| VBCT III | Warp | 100 | 18.76 | 36.12 | 61.35 |
| VBCT III | Weft | 100 | 34.14 | 21.23 | 278.2 |
| MBCT III | Warp | 100 | 19.70 | 38.10 | 73.21 |
| MBCT III | Weft | 100 | 30.13 | 15.62 | 433.3 |
| EBCT III | Warp | 100 | 29.34 | 29.04 | 191.1 |
| EBCT III | Weft | 100 | 28.49 | 15.83 | 380.7 |
| VBET III | Warp | 100 | 16.35 | 43.47 | 49.94 |
| VBET III | Weft | 100 | 37.61 | 20.77 | 386.6 |

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

From the Table 4.34, it can be concluded that the strength and elongation both improves after the treatment in weft direction and the chemical treatment is more effective to improve the load elongation values than the enzyme treatment. In the set I set where the fibers were treated first and then the yarns were spun and after that fabric construction took place: the load values increased from 13.83 to 15.46 and 20.85 for untreated banana fabric in weft direction followed enzyme and chemical treated fiberswhere as the increase in elongation was observed for chemical treatment from 6.14 to 9.08. In set II the load values decreased after treatment and elongation increased in weft direction. In set III the effect of regenerated fiber was more dominant than the banana fiber for elongation. However, the load values increased in weft direction, this was due the banana fibers which added strength to the weft yarns.

### 4.7 KAWABATA analysis

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.

THV (Total Hand Value) gives a consolidated index reflecting the suitability of the fabric for predetermined applications in a scale of 0 – 5, which was men’s suiting for the present study (Table 4.35). A THV of 5 indicates that the fabric is ideal for the intended use while a THV of 0 suggests its unsuitability. A value of THV between 0-5 would indicate varying levels of suitability of the fabric for the proposed application.

In a fabric the Koshi (stiffness) depends on its bending properties. The Koshi is less for Enzyme treated cotton banana fabric of set 3, fabric since its bending rigidity is less. Numeri means surface smoothness. Numeri values are lower Viscose banana enzyme treated and higher for Enzyme treated cotton banana fabric of set 1.

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 set 1. Although the THV values of all the four fabrics was almostsimilar, however

Fukurami values of Chemical treated cotton banana fabric of set 1 was the highest. Hence the treatment improves the hand of banana fibers and thus the fabric.

**Table 4.35:** Primary and total hand values (Men's Suiting)

| Sr. No. | Fabric Code | Koshi (Stiffness) | Numeri (Smoothness) | Fukurami (Fullness & Softness) | THV KN-101 |
|---|---|---|---|---|---|
| 1 | ECBF1 | 4.26 | 4.30 | 5.14 | 2.83 |
| 2 | CCBF1 | 8.85 | 2.23 | 6.87 | 2.99 |
| 3 | MBCT3 | 4.71 | 4.19 | 5.03 | 2.87 |
| 4 | VBET3 | 6.43 | 1.30 | 3.98 | 2.39 |

ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

The compressional properties of fabrics are measured by placing the sample between two plates and monitoring its thickness with increasing pressure. The linearity of compression (LC) mainly depends on the fabric thickness and compressional characteristics of the yarn. It has been observed from Table 4.36 that LC is higher for Modal banana chemical treated fabric and lower for Chemical treated cotton banana fabric of set 1. Compressional energy (WC) depends upon the LC and the amount of compression. The compressional resilience (RC) mainly depends upon fabric thickness and compressional characteristics of yarn. It has been observed that RC is higher for Chemical treated cotton banana fabric of set 1and lower for Enzyme treated cotton banana fabric of set1.

**Table 4.36:** Compression properties using compression tester

| Sr. No. | Fabric Code | LC | WC g.cm/cm^2 | RC % |
|---|---|---|---|---|
| 1 | ECBF1 | 0.287 | 0.304 | 41.69 |
| 2 | CCBF1 | 0.212 | 0.585 | 50.67 |
| 3 | MBCT3 | 0.300 | 0.290 | 43.02 |
| 4 | VBET3 | 0.238 | 0.246 | 47.20 |

LC: Linearity of compression-thickness curve
WC: Compressional energy
RC: Compressional resilience

ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

Fabric weight and thickness of all the constructed fabrics has been discusses earlier. However, for the fabric sample for which KAWABATA was done, the fabric weight was higher for Viscose banana enzyme treated fabricand lower for Chemical treated cotton banana fabric of set 1and the fabric thickness was higher for Chemical treated cotton banana fabric of set 1and lower for Modal banana chemical treated fabric.

**Table 4.37:** Fabric weight and thickness

| Sr. No. | Fabric Code | Fabric thickness (To mm) | Fabric thickness at max. pressure (Tm mm) | Fabric wt. ($mg/cm^2$) |
|---|---|---|---|---|
| 1 | ECBF1 | 0.972 | 0.538 | 26.13 |
| 2 | CCBF1 | 0.788 | 0.571 | 22.73 |
| 3 | MBCT3 | 0.917 | 0.521 | 26.07 |
| 4 | VBET3 | 0.932 | 0.508 | 28.04 |

To: Thickness at 0.5gf/cm2
Tm: Thickness at 5gf/cm2
ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

Tensile properties of the fabrics are shown in Table 4.38. 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 & lower for Modal banana chemical treated. The tensile energy (WT) values are lower for Chemical treated cotton banana fabric of set 1 and higher for Viscose banana enzyme treated. The tensile Resilience (RT) indicates recovery after tensile deformation. RT is higher for Chemical treated cotton banana fabric of set 1& Modal banana chemical treated fabric and lower for Enzyme treated cotton banana fabric of set1.Tensile resilience values are higher for tighter construction because of crimp removal, which leads to a better recovery in tight fabrics

**Table 4.38:** Tensile properties using tensile tester

| Sr. No. | Fabric Code | | LT | WT gf.cm/cm$^2$ | RT % | EMT % |
|---|---|---|---|---|---|---|
| 1 | ECBF1 | Warp | 0.486 | 23.90 | 42.20 | 19.65 |
| | | Weft | 0.732 | 7.47 | 57.85 | 4.09 |
| | | **Avg** | **0.609** | **15.69** | **50.02** | **11.87** |
| 2 | CCBF1 | Warp | 0.520 | 24.25 | 42.75 | 18.65 |
| | | Weft | 0.724 | 4.18 | 70.50 | 2.30 |
| | | **Avg** | **0.622** | **14.21** | **56.62** | **10.48** |
| 3 | MBCT3 | Warp | 0.496 | 25.15 | 44.51 | 20.25 |
| | | Weft | 0.702 | 6.65 | 69.21 | 3.78 |
| | | **Avg** | **0.599** | **15.90** | **56.86** | **12.02** |
| 4 | VBET3 | Warp | 0.608 | 31.90 | 36.44 | 21.00 |
| | | Weft | 0.760 | 7.63 | 70.20 | 4.02 |
| | | **Avg** | **0.684** | **19.76** | **53.32** | **12.51** |

LT: Linearity of load - extension curve
WT: Tensile energy
RT: Tensile resilience
EMT: Tensile Strain
ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

It has been observed from Table 4.38 that the shear rigidity (G) in higher for Viscose banana enzyme treatedand lower for Enzyme treated cotton banana fabric of set 1. The high value of shear rigidity causes difficulty in tailoring and discomfort during wearing. Shear rigidity of the fabric mainly depends upon the mobility of the warp and weft threads within the fabric. The compact structure of fabric having higher pick density gives higher shear rigidity values and hysteresis of shear.

2HG and 2HG5 indicate the hysteresis of shear force at $0.5^o$ and $5^o$ respectively. It is also observed from Table 4.39 that the hysteresis for shear is higher for Chemical treated cotton banana fabric of set 1and lower for Viscose banana enzyme treated.

Bending rigidity (B) of a fabric depends upon the bending rigidity of the threads and the mobility of warp and weft threads within the fabric. Bending rigidity (B) is high for Chemical treated cotton banana fabric of set 1 & low for Enzyme treated cotton banana fabric of set1. Bending rigidity and hysteresis of bending values are higher for the fabrics with more pick density. 2HB represents the hysteresis of bending moment, which is a measure of recovery from bending deformation. Hysteresis of bending moment (2HB) is high for Chemical treated cotton banana fabric of set 1 & low for Enzyme treated cotton banana fabric of set 1. Bending rigidity is one of the important mechanical properties influencing the tailorability of the fabric. Increase in bending rigidity increases Koshi (Stiffness). Bending rigidity is higher in weft direction than in warp direction.

**Table 4.39:** Shear properties using shear tester

| Sr. No. | Fabric Code | | G gf/cm.deg | 2HG gf/cm | 2HG5 gf/cm |
|---|---|---|---|---|---|
| 1 | ECBF1 | Warp | 0.32 | 0.39 | 0.60 |
| | | Weft | 0.29 | 0.25 | 0.44 |
| | | **Avg** | **0.30** | **0.32** | **0.52** |
| 2 | CCBF1 | Warp | 0.52 | 1.30 | 1.69 |
| | | Weft | 0.54 | 0.96 | 1.39 |
| | | **Avg** | **0.53** | **1.13** | **1.54** |
| 3 | MBCT3 | Warp | 0.31 | 0.38 | 0.55 |
| | | Weft | 0.28 | 0.24 | 0.51 |
| | | **Avg** | **0.29** | **0.31** | **0.53** |
| 4 | VBET31 | Warp | 0.54 | 0.25 | 2.39 |
| | | Weft | 0.72 | 0.28 | 2.75 |
| | | **Avg** | **0.63** | **0.26** | **2.57** |

G: Shear Rigidity;
2HG: Hysteresis of shear force at 0.5o shear angle
2HG5: Hysteresis of shear force at 5o shear angle
ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

**Table 3.40:** Bending properties using pure bending tester

| Sr. No. | Fabric Code | | **B gf.cm$^2$/cm** | **2HB gf.cm/cm** |
|---|---|---|---|---|
| 1 | ECBF1 | Warp | 0.0309 | 0.0188 |
| | | Weft | 0.4145 | 0.3147 |
| | | **Avg** | **0.2227** | **0.1667** |
| 2 | CCBF1 | Warp | 0.0731 | 0.0605 |
| | | Weft | 3.3538 | 4.2188 |
| | | **Avg** | **1.7134** | **2.1396** |
| 3 | MBCT3 | Warp | 0.0372 | 0.0187 |
| | | Weft | 0.4737 | 0.3685 |
| | | **Avg** | **0.2554** | **0.1936** |
| 4 | VBET3 | Warp | 0.1767 | 0.1105 |
| | | Weft | 0.3831 | 0.2837 |
| | | **Avg** | **0.2799** | **0.1971** |

B: Bending Rigidity;
2HB: Bending Hysteresis

The fabric surface properties are shown in Table 3.41. It is observed that the coefficient of friction (MIU) is higher for sample Chemical treated cotton banana fabric of set1 and lower for Viscose banana enzyme treated. The mean deviation of coefficient of friction (MMD) notes the surface smoothness as perceived while moving the fingers on the fabric surface. MMD is higher for Viscose banana enzyme treated and Chemical treated cotton banana fabric of set 1 and lower for Modal banana chemical treated. Also the geometrical roughness (SMD) is higher for Enzyme treated cotton banana fabric of set1 and lower for Viscose banana enzyme treated.Scroopy feel of fabric increases because of increase of twist number of weft yarn. Of all the samples the TPI of Chemical treated cotton banana fabric of set 1 was the highest i.e. 194 and hence aided in improving the surface smoothness.

**Table 3.41:** Surface properties using surface tester (KES-FB4)

| Sr. No. | Fabric Code | | MIU | MMD | SMD µm |
|---|---|---|---|---|---|
| 1 | ECBF1 | Warp | 0.188 | 0.0363 | 15.68 |
| | | Weft | 0.229 | 0.0295 | 9.78 |
| | | **Avg** | **0.209** | **0.0329** | **12.73** |
| 2 | CCBF1 | Warp | 0.209 | 0.0545 | 11.45 |
| | | Weft | 0.220 | 0.0415 | 9.01 |
| | | **Avg** | **0.215** | **0.0480** | **10.23** |
| 3 | MBCT3 | Warp | 0.186 | 0.0329 | 14.27 |
| | | Weft | 0.228 | 0.0299 | 8.36 |
| | | **Avg** | **0.207** | **0.0314** | **11.32** |
| 4 | VBET3 | Warp | 0.173 | 0.0752 | 11.46 |
| | | Weft | 0.138 | 0.0247 | 6.02 |
| | | **Avg** | **0.156** | **0.0500** | **8.74** |

MIU: Coefficient of friction
MMD: Deviation in the coefficient of friction
SMD: Geometrical Roughness
ECBF1: Enzyme treated cotton banana fabric of set1, CCBF1: Chemical treated cotton banana fabric of set 1, MBCT3: Modal banana chemical treated fabric of set 3, VBET3: Viscose banana enzyme treated fabric of set 3.

### 4.8 Market potential of constructed banana fabrics

Market evaluation of the constructed fabric was conducted at an international conference at Bangalore organised by Textile Association of India in January 2016. It was a platform to obtain opinion from the respondents of industry, academic and research institutes, people from textile marketing and students. Data was collected from 200 respondents, using questionnaire and the obtained response has been given below:

The respondents were both male and female, with their educational qualification majorly in the field of textiles. The major respondents were teaching staff from different universities followed by industry associates. The percentage of different respondents have been given in Figure 4.9

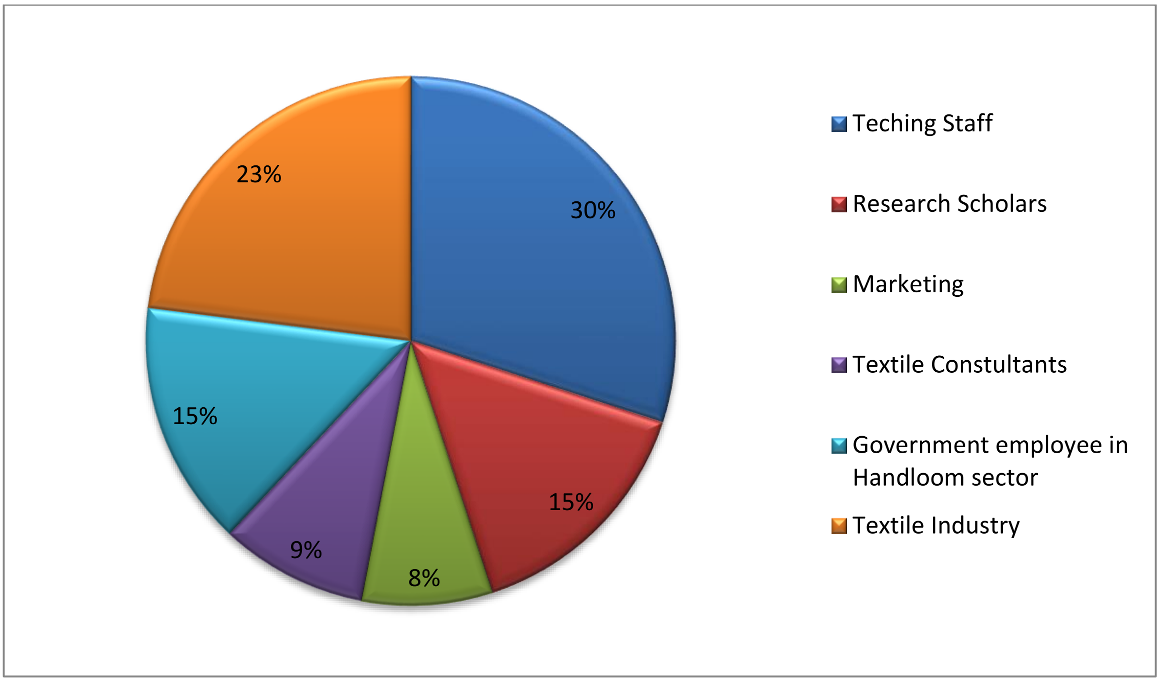



**Figure 4.9:** Percent type of respondents for market evaluation of banana fabrics

It was analysed from the questionnaire that most of the respondents were aware of minor fibers and its use in home furnishing and non woven applications. Only 8% respondents mentioned the use of minor fibers in apparel and that too as a blend with other synthetic fiber or as a regenerated fiber. 90% of the respondents liked the aesthetics of the fabric and more than that agreed that it was a niche market product. A several of respondents mentioned that these fabrics have an excellent export market.

All the respondents approved that the set II fabrics were only suitable for home furnishing whereas the set III and treated fabrics of set I can be used for some apparels and home furnishings. Also they stated that these fabrics were commercially viable.

None of the respondents had seen spun banana yarns of the fineness obtained for the yarns of the present study. However, some reported for coarse hand spun banana yarns.

The respondents agreed that chemical treatment was more effective for banana fibers however, some of them preferred the use of enzymes for environmental concerns.

80% respondents agreed that construction of banana blends could be an interesting project the government scheme of Start up India

The best preferred fabrics for first three ranks were CCBF I (chemical treated cotton banana fabric of set I) followed by EBCT III (excel banana chemical treated) and VBCT III (viscose banana chemical treated both of set III).

**4.9 SWOC analysis**

**Strengths**

- Banana fibers are obtained from the pseudostem of the banana plant after the cultivation of the fruit. Banana plant is not especially grown for textile fibers, these fibers are obtained as a by-product of banana fruit cultivation. Hence, the raw material is cheaply available. It is ecofriendly and biodegradable
- The biggest strength of bast fibers is their tensile strength. Banana fibers also have excellent tensile strength which is higher than cotton too.

**Weaknesses**

- As the fibers are not ready to use for textiles, due to the inherent drawback of its stiffness, hence they need to be treated. Therefore the production cost for the final product become high.
- Not much expertise as yet in India is available for banana fiber extraction.
- Lack of dedicated branding and market expansion drive from entrepreneurs.

**Opportunities**

- Increasing awareness on a global level of the benefits of using natural fiber made products would give banana fibers an excellent market.
- Banana plants are grown for fruits and after the harvesting of fruit, the plant is discarded. The farmers have to pay an additional amount of money to discard

the biomass. Extraction of banana fibers from these pseudostems would provide an additional income to the farmers.

**Challenges**

- Natural fibers have a high level of competition from synthetic fibers.
- Low level of research and development to invent cost effective means of production.

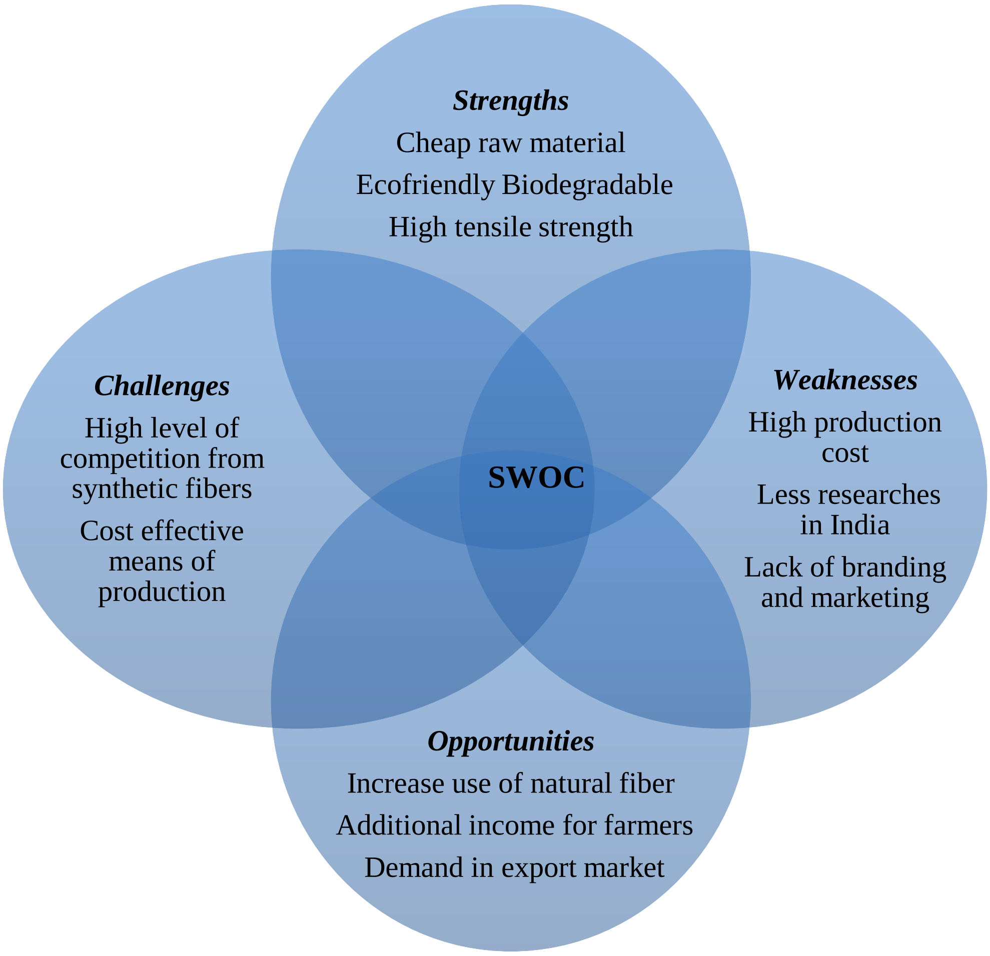



**Figure 4.10:** SWOC analysis of banana fiber

### 4.9 Chemical treatment costing and its yield

Both enzyme and chemical treatment were standardised for banana fiber and their effect on several properties were studied during the study. It was observed that spinning of yarns whether on charkha or on the ring spinning system, the enzyme treated yarns were difficult to work with. The required cohesiveness was missing. The chemical treated fibers were accepted well for spinning of yarn and also had better hand (feel). Hence, calculation for costing and its yield to construct one meter of cotton banana fabric has been given

**Table 4.42:** Chemical treatment costing

| Material Required | Cost of the material | Cost of material used per Kg of banana fiber |
|---|---|---|
| Banana fiber | Rs. 100/- | Rs. 100/- |
| Sodium hydroxide | Rs. 378/- (500gm) | Rs. 45.35/- |
| Hydrogen peroxide | Rs. 493/- (1 lt) | Rs. 395.40/- |
| Sodium hypochlorite | Rs. 236/- (500ml) | Rs. 25.95/- |
| Labolene | Rs. 350 /- (500ml) | Rs. 25/- |
| Rice bran oil | Rs. 120/- (1lt) | Rs. 6/- |
| Gas (for heating) | Rs 720 /- | Rs.13/- |
| Total | | Rs. 510.7/- |

After treating the banana fibers, they are combed and waste is generated. 40% of the treated fiber is waste. Treating 1Kg of banana fiber and combing it, would give 600 gm of finished fiber.

- 1 Kg fibers yields 600 gm treated fiber
- 600 gm of treated fiber yields 450 gm yarn
- 300 gm of 100% banana yarn (weft) is required for 1meter fabric

Hence, 700 gm of untreated fiber is required to obtain 420 gm of treated and combed banana fiber. This 420 gm of fiber was used to spin 300 gm of yarn, which was used as weft for construction of 1 meter of fabric.The GSM of the constructed fabric was 216 with fabric count of 52 X 50.