

**Development of Blended Woven Fabric using Selected  
Cellulosic Fibres for Bolster**

**GAYATHRI R**

**(20PTF009)**

A Thesis Submitted to the  
**Avinashilingam Institute for Home Science and Higher  
Education for Women  
Coimbatore-641043**

**In partial fulfilment of the requirement for the degree of  
MASTER OF SCIENCE TEXTILES AND FASHION APPAREL**

**May, 2022**

**Development of Blended Woven Fabric using Selected Cellulosic  
Fibres for Bolster**

**GAYATHRI R**

**(20PTF009)**

A Thesis Submitted to the

**Avinashilingam Institute for Home Science and Higher**

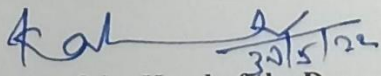
**Education for Women**

**Coimbatore-641043**

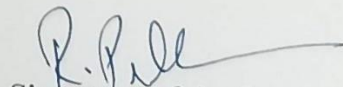
**In partial fulfilment of the requirement for the degree of  
MASTER OF SCIENCE TEXTILES AND FASHION APPAREL**

**May 2022**

**Certified as Bonafide Research work**



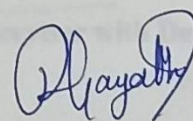
**Signature of the Head of the Department**



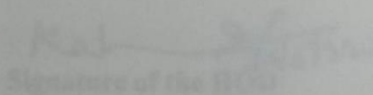
**Signature of the Supervisor**

## DECLARATION

I declare that the dissertation entitled on “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” submitted by me for the degree of Master of science (M.Sc.) is the record of work carried out by me during the period from 2021 to 2022 under the guidance of **Dr. (Tmt.) R.Prabha**, M.Sc., Ph.D., SLET (Avinashilingam), Assistant Professor, Department of Textiles and Clothing, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore-642 043 and has not formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship, Titles in this University or any other similar institution of higher learning.



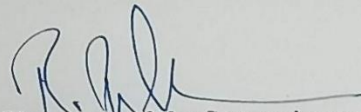
Signature of the Candidate



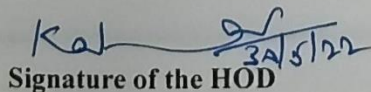
Signature of the Supervisor

## CERTIFICATE FROM THE SUPERVISOR

I certify that dissertation entitled “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” submitted for the degree of Master of science (M.Sc.) Textiles and Fashion Apparel by Gayathri R is the record of project work carried out by her during the academic year 2021 to 2022 under my guidance and supervision and this work has not formed the basis for the award of any Degree, Diploma, Associate ship, Fellowship, Titles in this University or any other similar institution of higher learning.



Signature of the Supervisor with Designation



Signature of the HOD

ACKNOWLEDGEMENT

## ACKNOWLEDGEMENT

First and foremost the investigator places her humble salutations and prayer to the **ALMIGHTY GOD** for his uncountable blessings showered upon her throughout the study.

The investigator owes her respectful gratitude to **Late Dr.(Thiru) T.S. Avinashilingam**, Founder and First chancellor of Avinashilingam Institute for Home Science and Higher Education for Women Coimbatore, for providing this temple of learning to do this research. The investigator regards her reverential gratitude to **Late Hon. Colonel Dr. (Tmt.) RAJAMMAL P. DEVEDAS, M.A., M.Sc., Ph.D (Ohio State), Hon D.Sc.(Madras, Hon D.H.L.(Oregon State), Hon. D.H.L.(Ohio State), D.S.C.(Kanpur), Hon.D.Sc.(Northern Ireland)**, Former Chancellor, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for being a perennial source of inspiration for conducting the study.

The investigator is grateful to **Prof. S.P. THYAGARAJAN D.Sc. Microbiology., Ph.D., M.D.**, Chancellor of Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for providing an opportunity infrastructure and all the amenities to conduct the study in the university.

The investigator owes her special thanks to **Dr. V BARATHI HARISHANKAR Ph.D., FRSA** Vice Chancellor of Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for providing all the amenities required for the conduct of the study.

The investigator records her gratitude to **Dr. (Mrs.) S. KOWSALYA, M.Sc., M.Phil., Ph.D.**, Registrar, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore, for extending all help for the smooth conduct of the study.

The investigator records her respectful gratitude to **Dr. (Tmt) N. VASUGIRAAJA, M.Sc., M.B.A., M.Phil. (Madras), Ph.D. Dean, School of Home Science, Professor and Head of Department of Textiles and Clothing, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore**, for constant encouragement which have helped in the successful completion of this study.

The investigator records her gratitude to **Dr. K. KALAIARASI M.Sc., M.Phil., Ph.D.,SLET** Associate Professor and Head, Department of Textiles and Clothing, Avinashilingam Institute of Home Science and Higher education for Women, Coimbatore, for constant guidance and encouragement which have helped in successful completion of this study.

The investigator feels extremely proud and privileged for having worked under the guidance of her esteemed guide, **Dr. R. PRABHA, M.Sc., Ph.D., SLET** (Avinashilingam), Assistant Professor, Department of Textiles and Clothing, Avinashilingam Institute of Home Science and Higher education for Women, Coimbatore, for her constant motivation, keen interest, untiring patience, innovative ideas, suggestion, constant love and easy approach throughout the study.

She also wishes to thank all the **TEACHING, NON-TEACHING STAFF** and **STUDENTS** of the department of Textiles and Clothing who helped her to carry out the research work. She acknowledges her special thanks to **Avinashilingam Institute of Home Science and Higher Education for Women, BHARATRATNA Prof. CNR RAO Research centre**, library and lab centre facilities.

The investigator gratefully acknowledges the encouragement, timely help and support received from her friends. She expresses her deepest sense of gratitude to her **Beloved Parents, Family Members and Friends** for extending their support without them the study would never have been seen the light of the day.

## LIST OF CONTENTS

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE NO.</b>
	<b>LIST OF TABLES</b>	
	<b>LIST OF FIGURES</b>	
	<b>LIST OF PLATES</b>	
<b>I</b>	<b>INTRODUCTION</b>	<b>1</b>
<b>II</b>	<b>REVIEW OF LITERATURE</b>	<b>5</b>
	<b>2.1 Natural fibres</b>	<b>7</b>
	2.1.1 History	<b>7</b>
	2.1.2 Classification of natural fibres	<b>8</b>
	<b>2.2 Chrysopogon zizanioides</b>	<b>9</b>
	2.2.1 History and Origin	<b>9</b>
	2.2.2 Description and uses	<b>10</b>
	2.2.3 Characteristics of Chrysopogon zizanioides	<b>11</b>
	2.2.4 Chemical composition of vetiver	<b>12</b>
	<b>2.3 Banana fibre</b>	<b>13</b>
	2.3.1 History and Origin	<b>13</b>
	2.3.2 Production of Pseudo-stem fibre	<b>15</b>
	2.3.3 Characteristics of banana fibre	<b>17</b>
	2.3.4 Banana Pseudo-stem fibre properties	<b>18</b>
	2.3.4 Uses and Applications of banana fibre	<b>20</b>
	<b>2.4 Cotton fibre</b>	<b>21</b>
	2.4.1 History and Origin	<b>21</b>
	2.4.2 Structure and Crystallinity	<b>22</b>
	2.4.3 Cultivation	<b>23</b>
	2.4.4 Description and Technical features	<b>24</b>
	2.4.5 Uses	<b>26</b>
	<b>2.5 Blending of Cellulosic fibres</b>	<b>27</b>
	<b>2.6 Yarn and Fabric Production</b>	<b>28</b>

	<b>2.7 Pre-treatments of fabric</b>	<b>30</b>
	2.7.1 Enzymatic treatment of woven fabric	<b>30</b>
	<b>2.8 Natural Dyes</b>	<b>31</b>
	2.8.1 History of natural dyes	<b>32</b>
	2.8.2 Types of natural dyes	<b>32</b>
	2.8.3 Advantages of natural dyes	<b>33</b>
	2.8.4 Disadvantages of natural dyes	<b>33</b>
	<b>2.9 Mordant</b>	<b>33</b>
	2.9.1 Types of mordant	<b>34</b>
	2.9.2 Mordant techniques	<b>34</b>
	<b>2.10 Finishing</b>	<b>35</b>
	2.10.1 Types of finishing	<b>35</b>
	2.10.2 Classification of finish	<b>36</b>
	2.10.3 Functional finishes	<b>36</b>
	<b>2.11 Anti-microbial finish</b>	<b>36</b>
	2.11.1 Fungal Introduction	<b>36</b>
	2.11.2 Bacteria Introduction	<b>37</b>
	<b>2.12 Product development</b>	<b>37</b>

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE NO.</b>
<b>III</b>	<b>EXPERIMENTAL PROCEDURE</b>	
	<b>3.1 Selection of natural fibres</b>	<b>41</b>
	3.1.1 <i>Chrysopogon zizanioides</i>	<b>41</b>
	3.1.2 <i>Banana pseudo-stem fibre</i>	<b>41</b>
	3.1.3 <i>Gossypium</i>	<b>41</b>
	<b>3.2 Extraction of fibre</b>	<b>42</b>
	3.2.1 Fibre extraction of <i>Chrysopogon zizanioides</i>	<b>42</b>
	3.2.2 Fibre extraction of <i>banana pseudo-stem fibre</i> and <i>Gossypium arboreum</i>	<b>43</b>
	<b>3.3 Manufacturing of yarn</b>	<b>43</b>
	3.3.1 Carding	<b>43</b>
	3.3.2 Sliver formation	<b>45</b>
	3.3.3 Rotor spinning	<b>45</b>
	<b>3.4 Manufacturing of fabric</b>	<b>45</b>
	3.4.1 Plain weave	<b>46</b>
	<b>3.5 Pre-treatment of fabric</b>	<b>46</b>
	3.5.1 Bio-enzyme treatment	<b>46</b>
	3.5.2 Papaya peel treatment	<b>47</b>
	3.5.2.1 Tanning method	<b>47</b>
	<b>3.6 Selection of source for natural dyeing</b>	<b>48</b>
	3.6.1 Pilot Study	<b>48</b>
	<b>3.7 Optimization of various parameters for dye extraction</b>	<b>49</b>
	3.7.1 Solvent	<b>49</b>
	3.7.2 Dye concentration	<b>49</b>
	3.7.3 Time	<b>50</b>
	3.7.4 Temperature	<b>50</b>
	<b>3.8 Extraction of natural dye</b>	<b>50</b>
	3.8.1 Aqueous extraction method	<b>50</b>
	<b>3.9 Mordants</b>	<b>50</b>
	3.9.1 Selection of mordants	<b>50</b>

	3.9.2 Selection of mordanting techniques	51
	3.9.3 Dyeing parameters	51
	<b>3.10 Dyeing Method</b>	<b>51</b>
	<b>3.11 Development of product</b>	<b>52</b>
	<b>3.12 Evaluation</b>	<b>52</b>
	<b>3.12.1 Visual inspection</b>	<b>52</b>
	<b>3.12.2 Physical and mechanical evaluation</b>	<b>52</b>
	3.12.2.1 Fabric weight	52
	3.12.2.2 Fabric thickness	53
	3.12.2.3 Tensile strength and Elongation	53
	3.12.2.4 Air-permeability	54
	3.12.2.5 Thermal conductivity	54
	3.12.2.6 Flammability test	55
	<b>3.12.3 Comfort evaluation</b>	<b>55</b>
	3.12.3.1 Fabric stiffness	55
	3.12.3.2 Crease Recovery	55
	<b>3.12.4 Absorbency evaluation</b>	<b>56</b>
	3.12.4.1 Wicking test	56
	3.12.4.2 Sinking test	56
	3.12.4.3 Drop test	56
	<b>3.12.5 Colour fastness test</b>	<b>57</b>
	3.12.5.1 Spectrophotometer Evaluation	57
	<b>3.12.6 Functional evaluation</b>	<b>57</b>
	3.12.6.1 Anti-bacterial activity	57
	3.12.6.2 Anti-fungal activity	58
	<b>3.13 Statistical Analysis</b>	<b>60</b>
	<b>3.14 Nomenclature</b>	<b>56</b>

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE NO.</b>
<b>IV</b>	<b>RESULT AND DISCUSSION</b>	
	<b>4.1 Subjective Evaluation</b>	<b>62</b>
	4.1.1 Visual Inspection	<b>62</b>
	<b>4.2 Objective Evaluation</b>	<b>63</b>
	<b>4.2.1 Physical and Mechanical Evaluation</b>	<b>63</b>
	4.2.1.1 Fabric Weight	<b>63</b>
	4.2.1.2 Fabric Thickness	<b>64</b>
	4.2.1.3 Fabric Strength – Warp	<b>65</b>
	4.2.1.4 Fabric Strength – Weft	<b>66</b>
	4.2.1.5 Fabric Elongation – Warp	<b>67</b>
	4.2.1.6 Fabric Elongation – Weft	<b>68</b>
	4.2.1.7 Air Permeability Test	<b>69</b>
	4.2.1.8 Thermal Conductivity Test	<b>70</b>
	4.2.1.9 Flammability Test – Flame time	<b>71</b>
	4.2.1.10 Flammability Test – Glow time	<b>72</b>
	<b>4.2.2 Absorbency Evaluation</b>	<b>73</b>
	4.2.2.1 Drop Test	<b>73</b>
	4.2.2.2 Sinking Test	<b>74</b>
	4.2.2.3 Wicking Test	<b>75</b>
	<b>4.2.3 Comfort Property</b>	<b>76</b>
	4.2.3.1 Fabric Stiffness – Warp	<b>76</b>
	4.2.3.2 Fabric Stiffness – Weft	<b>77</b>
	4.2.3.3 Crease Recovery Test	<b>78</b>
	<b>4.2.4 Colour Fastness Test</b>	<b>79</b>
	4.2.4.1 Colour fastness to sunlight, crocking and wicking	<b>79</b>
	4.2.4.2 Spectrophotometer Evaluation	<b>80</b>
	<b>4.2.5 Functional Evaluation</b>	<b>82</b>
	4.2.5.1 Anti-bacterial Activity	<b>82</b>
	4.2.5.2 Anti-Fungal Activity	<b>84</b>
<b>V</b>	<b>SUMMARY AND CONCLUSION</b>	<b>87</b>
	<b>BIBLIOGRAPHY</b>	<b>92</b>

## LIST OF TABLES

TABLE NO	TITLE	PAGE NO
1.	Description and uses of vetiver plant	10
2.	Classification and characteristic of vetiver grass	12
3.	Chemical composition of vetiver fibre in various countries	13
4.	Specification of banana fibre	18
5.	Chemical constitution of banana fibre	18
6.	Physical and mechanical properties of banana fibre	19
7.	Composition of cotton fibre	23
8.	Properties of cotton fibre	25
9.	Selected fibres	43
10.	The weight of fibres used for manufacturing of yarn	43
11.	Recipe of papaya peel treatment	47
12.	Pilot study for selection of dyeing parameters	49
13.	Recipe of <i>curcuma</i> dye extraction	50
14.	Parameters for dyeing	51
15.	Nomenclature	60
16.	Visual inspection	62
17.	Fabric weight	63
18.	Fabric thickness	64
19.	Fabric Tensile Strength - Warp	65
20.	Fabric Tensile Strength - Weft	66
21	Fabric Elongation- Warp	67
22	Fabric Elongation- Weft	68
23	Air permeability	69
24	Thermal conductivity	70
25	Flammability – Flame time	71
26	Flammability – Glow time	72

27	Drop test	73
28	Sinking test	74
29	Wicking test	75
30	Fabric Stiffness- Warp	76
31	Fabric Stiffness- Weft	77
32	Crease Recovery	78
33	Color fastness to sunlight, crocking and washing	79
34	Whiteness, yellowness and brightness index of <i>curcuma</i> dyed fabric	80
35	Colour co-ordinates and colour strength of <i>curcuma</i> dyed fabric	80
36	Antibacterial activity	82
37	Antifungal activity	84

## LIST OF FIGURES

<b>FIGURE NO</b>	<b>TITLE</b>	<b>PAGE NO</b>
1	Banana fibre production process	15
2	Cross- sectional and longitudinal view of cotton fibre	22
3	Cotton fibre	24
4	Fabric weight	65
5	Fabric thickness	66
6	Fabric Tensile Strength - Warp	67
7	Fabric Tensile Strength - Weft	68
8	Fabric Elongation- Warp	69
9	Fabric Elongation- Weft	70
10	Air-permeability	71
11	Thermal conductivity	72
12	Flammability – Flame time	73
13	Flammability – Glow time	74
14	Drop test	75
15	Sinking test	76
16	Wicking test	77
17	Fabric Stiffness- Warp	78
18	Fabric Stiffness- Weft	79
19	Crease Recovery	80
20	Colour on screen	81
21	Colour different graph	81
22	Anti-bacterial activity	82
23	Antifungal activity	84

## LIST OF PLATES

PLATES NO	TITLE	PAGE NO
I	Microscopic view of selected fibres	42
II	Fibre extraction of <i>Chrysopogon zizanioides</i>	42
III	Lap formation	44
IV	Preparations of carding process	44
V	Rotor spinning process	45
VI	Blended woven fabric	45
VII	Bio enzyme treated process	47
VIII	Papaya peel treated	48
IX	<i>Curcuma</i> (Turmeric)	48
X	Selection of dyeing parameters	49
XI	Dyed fabric	52
XII	Fabric GSM Cutter	59
XIII	Fabric thickness tester	59
XIV	Fabric Tensile strength tester	59
XV	Fabric stiffness tester	59
XVI	Crease recovery clamp and tester	59
XVII	Sinking tester	59
XVIII	Drop tester	59
XIX	Wicking tester	59
XX	Flammability test	60
XXI	Antibacterial activity	83
XXII	Antifungal activity	85
XXIII	Final product	86

### LIST OF APPENDICES

<b>S.NO</b>	<b>TITLE</b>	<b>PAGE NO.</b>
1	Original Sample	101
2	Enzyme Treated Sample	101
3	Papaya Peel Treated Sample	101
4	Dyed Sample	101



## I. INTRODUCTION

The word 'Textile' comes from an Indian Latin verb 'Texere', meaning to weave. Traditionally textiles are made from yarn, which is developed by processing the fibres although many textiles can be made by the direct conversion of fibres. The term "Textile Fibres" refers to any product which is capable of being made into fabrics. The quality of finished textile is determined by the properties such as length, strength and nature of its constituent fibres. Fibres used for textiles are usually described as being filament or staples. A filament is continuous-length fibre and staple are limited-length fibres requiring twisting together to make them usable (Balan and Vandana, 2013).

Global warming is currently a critical concern that requires the scientific community's complete attention. It is the result of both natural and man-made factors. One of the biggest man-made causes is the use of plastic and composite materials comprised of synthetic fibres. Hence, efforts are being made to replace plastic and synthetic fibres with environmentally friendly alternatives. Synthetic fibres are well known for their great strength and stiffness properties; although, they are being replaced by natural fibres because of advantages such as high specific weight and density, low cost, minimal health risk and most importantly, they are eco-friendly in nature. Several natural fibres like cotton, jute, flax, ramie, hemp, sisal, manila hemp, wool and silk are some of the major fibres, which are widely being used throughout the world. Apart from these, a large number of fibres are grown in much smaller quantities in different parts of the world. However, they have local economic importance and are mostly consumed locally. Some major plus points about the natural fibres are that they are Agro-based, annually renewable and biodegradable (Gautam Basu, 2008).

Natural fibres are distinguished by their inherent physical, mechanical, and surface qualities. As a result, selecting a set of machineries and machine parameters for processing of natural fibre blends to achieve desired yarn quality at the lowest possible cost necessitates a thorough understanding of the properties of fibres as well as a high level of expertise in their processing technologies (Gautam Basu, 2008).

In a future, where textile resources are scarce, natural fibres such as cotton, which is still a resource-intensive material, and petroleum-based fibres such as acrylic, polyester, nylon, and spandex will be in great demand. However, the manufacture of these fibres continues to cause lasting environmental damage, an increasing number of businesses are looking for sustainable alternative fibres and fabrics (Vivian Hendriksz, 2017).

Blended fibres are made by combining two or more fibres to create a new material fibre with specified qualities. The parent fibre can be made of any material. The newly generated variety combines the beneficial qualities inherited from the parent fibres. The variety of natural and man-made fabrics available provides a diverse range of fibres for utilisation. However, no cloth is perfect in every sense. Textiles with distinct qualities are created by combining several natural fibres in a one-of-a-kind handmade production technique. Natural fibres are made from renewable resources and have a low carbon footprint. It is completely biodegradable. Natural materials, as they are popularly known are non-allergenic and lessen the danger of skin rashes and irritation produced by synthetic fabrics. Natural fabrics are helpful to the environment, individuals, and the economy for a variety of reasons (Samatoa, 2021).

Vetiver (*Chrysopogon zizanioides*) is a coarse, evergreen perennial grass that grows in huge, thick clumps up to 1.5 metres tall and sometimes up to 3 metres tall. The plant has a robust, compact, aromatic, branching, sponzy rhizome, and fibrous root system that can develop to a depth of 4 metres. Vetiveria grass is a valuable source of essential oil for which it is frequently farmed commercially. Among its many other purposes it is used to make thatch has numerous medical benefits, and is grown to protect the land from erosion (Ken fern, 2014).

Vetiver, also known as khus grass, is a perennial grass native to India. Vetiver roots yield a pleasant essential oil that can be used as a perfume on its own. This volatile oil is used to make aroma compounds such as Vetiverol, Vetiverone, and Vetiveryl acetate. It is mostly utilised in the perfume, cosmetics, aromatherapy, food, and flavouring sectors in India. Because of its wide finely organised fibrous roots, the plant is beneficial in both soil and water conservation, and it is drought tolerant. The global production of vetiver oil is roughly 300 tonnes per year, with India contributing just about 20-25 tonnes. Haiti, India, Java, and Reunion are the world's leading producers. It is grown in Rajasthan, Uttar Pradesh, Karnataka, Tamil Nadu, Kerala, and Andhra Pradesh, with a yearly production of roughly 20 tonnes of oil. The current usage of vetiver oil in India is approximately 100 tonnes, with export accounting for 80 percent of the domestic demand (Smitha Gingade, 2015).

Banana fibre, also known as musa fibre, is one of the strongest natural fibres on the planet. The natural fibre is biodegradable and manufactured from the stem of the banana tree. It is extremely durable. The fibre is made up of thick-walled cell tissue that is bound together by natural gums and is mostly made up of cellulose, hemicelluloses, and lignin. Banana fibre is similar to natural bamboo fibre, but it is reported to have higher spin ability, fineness, and tensile strength. Banana fibre can be used to manufacture a variety of fabrics with varying

weights and thicknesses, depending on which portion of the banana stem the fibre was harvested from. The outer sheaths of banana trees yield thicker, sturdier fibres, whereas the inner sheaths yield softer fibres (Vivian Hendriksz, 2017).

Banana fibre is not a new invention, despite the fact that few people are aware of its existence or application. Banana stems have been used to make fibre since the early 13th century in Japan. However, when other fibres such as cotton and silk from China and India became more popular, the use of banana plants as a source of fibre for textiles declined. Banana fibre, on the other hand, is making a resurgence in the fashion sector. Banana fibre has recently made a comeback in a variety of industries and is used all over the world for a variety of items ranging from tea bags to automobile tyres to saris and Japanese yen notes (Vivian Hendriksz, 2017).

A typical woven fabric is a textile construction created on a loom by interlacing two sets of threads at right angles. The filling yarns are laid between two warp sheets, normally one pick at a time, at right angles to the warp, and run in a continuous strand from one edge of the cloth to the opposite edge. The core area of the woven fabric is referred to as the body, while the edges are referred to as the selvages. In terms of yarn and fabric manufacturing, the selvages frequently differ from the body of the fabric. The city has grown highly congested, and the only space to rest is at home, which is usually symbolised by flats, thus the importance of the interior of our homes grows geometrically. Fabric influences mood, establishes style, and communicates taste; it is what is visible and is the most malleable of props, readily changed, duplicated, or added. It prevents fading of interior colours and damage of furnishings caused by sunshine. Fabric can improve the liveability or workability of a small room by reducing noise and making music and even voice richer and more resonant. The whole of interior spaces and their furnishings can be defined as the interior environment (Shivendra Parmar, 2007).

Textile finishing process which is carried out after the application of the finish to a textile fabric in which appropriate conditions are used to affect a chemical reaction. The *Chrysopogon zizanioides* and banana fibre blended fabrics will be treated with various enzymes to get a smooth surface. Finishing treatments made the fabric softer, clean, increased pliability and thereby making the fabric more suitable for end-uses. Enzymes function as biological catalysts. A catalyst is any material that accelerates a chemical reaction while remaining unchanged. A catalyst can be reused in a chemical process indefinitely: it does not degrade. Enzymes are essentially similar, with the exception that they can be easily denatured by some techniques. Because enzymes are comprised of protein, they are sensitive to heat, pH

and heavy metal ions. They are particular reaction catalysts, as opposed to regular catalysts. Enzymes must be in the proper form to conduct their work. Enzymes change form when the temperature or pH changes, indicating that they are under the proper circumstances. Enzymes are also easily biodegradable, making them potentially non-harmful and eco-friendly. Enzymes are also readily biodegradable and therefore potentially harmless and environmentally friendly (Chatto Padhyay, 2008).

Considering the above fact, the project is carried on the title of “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” with the following objectives:

- To identify environment-friendly fibres
- To select suitable fabrication method
- To pre-treat the prepared fabric with bio-enzymes
- To dye the enzyme treated fabric with suitable natural source
- To evaluate the finished fabric with suitable testing method
- To develop a product using prepared fabric

## **II. REVIEW OF LITERATURE**

The review of literature pertaining to the study entitled “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” is discussed under the following aspects:

### **2.1 Natural fibres**

2.1.1 History

2.1.2 Classification of natural fibres

### **2.2 Chrysopogon zizanioides**

2.2.1 History and Origin

2.2.2 Extraction of vetiver Fibre

2.2.3 Characteristics of Chrysopogon zizanioides

2.2.4 Properties of vetiver fibre

### **2.3 Banana fibre**

2.3.1 History and Origin

2.3.2 Production of Pseudo-stem fibre

2.3.3 Characteristics of banana fibre

2.3.4 Banana Pseudo-stem fibre properties

2.3.4 Uses and Applications of banana fibre

### **2.4 Cotton fibre**

2.4.1 History and Origin

2.4.2 Structure and Crystallinity

2.4.3 Cultivation

2.4.4 Description and Technical features

2.4.5 Uses

### **2.5 Blending of Cellulosic fibres**

### **2.6 Yarn and Fabric Production**

## **2.7 Pre-treatments of fabric**

2.7.1 Enzymatic treatment of woven fabric

## **2.8 Natural Dyes**

2.8.1 History of natural dyes

2.8.2 Types of natural dyes

2.8.3 Advantages of natural dyes

2.8.4 Disadvantages of natural dyes

## **2.9 Mordant**

2.9.1 Types of mordant

2.9.2 Mordant techniques

## **2.10 Finishing**

2.10.1 Types of finishing

2.10.2 Classification of finish

2.10.3 Functional finishes

## **2.11 Anti-microbial finish**

2.11.1 Bacteria Introduction

2.11.2 Fungal Introduction

## **2.12 Product development**

## **2.1 NATURAL FIBRES**

Natural fibre, any hairlike raw material directly obtainable from an animal, vegetable, or mineral source and convertible into nonwoven fabrics such as felt or paper or after spinning into yarns, into woven cloth. A natural fibre may be further defined as an agglomeration of cells in which the diameter is negligible in comparison with the length. Although nature abounds in fibrous material, especially cellulosic types such as cotton, wood, grains, and straw, only small number can be used for textile products or other industrial purposes. Apart from economic consideration, the usefulness of a fibre for commercial purposes is determined by such properties as length, strength, pliability, elasticity, abrasion resistance, absorbency and various surface properties. Most textile fibres are slender, flexible, and relatively strong. They are elastic in that they stretch when put under tension and then partially or completely return to their original length when the tension is removed (Alicia Zelazko, 2021).

### **2.1.1 History**

The use of natural fibres for textile materials began before recorded history. The oldest indication of fibre use is probably the discovery of flax and wool fabrics at excavation sites of the Swiss lake dwellers (7<sup>th</sup> and 6<sup>th</sup> centuries BCE). Several vegetable fibres were also used by prehistoric peoples. Hemp, presumably the oldest cultivated fibre plant, originated in southeast Asia, then spread to China, where reports of cultivation date to 4500 BCE. The art of weaving and spinning linen was already well developed in Egypt by 3400 BCE, indicating that flax was cultivated sometime before that date. Reports of the spinning of cotton in India date back to 3000 BCE. The manufacture of silk and silk product originated in the highly developed Chinese culture; the invention and development of sericulture (cultivation of silkworms for Raw-Silk production) and of methods to spin silk date from 2640 BCE. With improved transportation and communication, highly localized skills and arts connected with textile manufacture spread to other countries and were adapted to local needs and capabilities. New fibre plants were also discovered and their use explored. In the 18<sup>th</sup> and 19<sup>th</sup> centuries, the industrial revolution encouraged the further invention of machines for use in processing various natural fibres, resulting in a tremendous upsurge in fibre production.

The introduction of regenerated cellulosic fibres (fibres formed of cellulose material that has been dissolved, purified, and extruded), such as rayon, followed by the invention of completely synthetic fibres, such as nylon, challenged the monopoly of natural fibres for textile industry use. A variety of synthetic fibres having specific desirable properties began to

penetrate and dominate markets previously monopolized by natural fibres. Recognition of the competitive threat from synthetic fibres resulted in intensive research directed toward the breeding of new and better strains of natural-fibre source with higher yields, improved production and processing methods, and modification of fibre yarn or fabric properties. The considerable improvements achieved have permitted increased total production, although natural fibres actual share of the market has decreased with the influx of the cheaper, synthetic fibres requiring fewer man-hours for production (Alicia Zelazko, 2021).

### 2.1.2 Classification of Natural Fibres

Natural fibres are those that occur in fibre from in nature. Traditionally, natural fibre sources are broken down into animal, plant or mineral. Fibres from plant or vegetable source are more properly referred to as cellulose-based and can be further classified by plant source. They may be separated from the plant stalk, stem, leaf or seed. Fibres from animal sources are more properly known as protein-based fibres. They are harvested from an animal or removed from a cocoon or web. Mineral fibres are those that are mined from the earth. Except for silk, all-natural cellulose-based and protein-based fibres are obtained in short lengths and are called staple fibres. Silk is a continuous filament fibre (Aravin Periyasamy, 2022).

**The vegetable fibres** can be divided into smaller groups based on their origin within the plant. Cotton, kapok, and coir are examples of fibres originating as hairs borne on the seeds or inner walls of the fruit, where each fibre consist of a single, long, narrow cell. Flax, hemp, jute, and ramie are bast fibres, occurring in the inner bast tissue of certain plant stems and made up of overlapping cells. Abaca, henequen, and sisal are fibres occurring as part of the fibrovascular system of the leaves. Chemically, all vegetable fibres consist mainly of cellulose, although they also contain varying number of substances as hemicellulose, lignin, pectins and waxes that must be removed or reduced by processing. **The animal fibres** consist exclusively of proteins and, with the exception of silk, constitute the fur or hair that serves as the protective epidermal covering of animals. Silk filaments are extruded by the larvae of moths and are used to spin their cocoons. With the exception of **mineral fibres**, all natural fibres have an affinity for water in both liquid and vapour form. This strong affinity produces swelling of the fibres connected with the uptake of water, which facilitates dyeing in watery solutions (Alicia Zelazko, 2021).

## **2.2 CHRYSOPOGON ZIZNIOIDES**

### **2.2.1 History and Origin**

Chrysopogon zizanioides belongs to the species-diversified family poaceae, which consist of 707 genera and 11,337 species. The genus Chrysopogon is natively distributed in tropical and subtropical Asia like India, Cambodia, Pakistan, Sri Lanka, Myanmar, Thailand and Vietnam (Clayton et. al., 2020). In the mid – 1980s, world bank for soil and water conservation first promoted its cultivation in India. After that, to highlight the potential uses of vetiver, world bank also published a handbook on vetiver grass and its role in land and soil conservation in 1989. Since then, nearly 100 countries started their cultivation for steep slope stabilization, wastewater disposal, phytoremediation of contaminated soil, and other environmental issues. Besides this, its essential oil is also the primary reason, whose major producers are Haiti, India, Indonesia, West Java and Reunion (Truong et. al., 2008).

Chrysopogon zizanioides is an evergreen, perennial grass that grows and forms clumps around 1 – 1.5 m tall and sometimes up to 3 m tall. Its roots grow very fast in favourable conditions and can acquire a depth of 3 – 4 m during the first year of cultivation, helping them further to sustain in conditions like drought and floods (De Guzmam, 1999).

Among the whole plant, the root part is of primary interest for oil extraction utilized in food and beverages, spa, home utilities and medicinal aspects. The global market of vetiver oil in 2019 was 408.8 tons which expected to rise by 7.8% from 2020 to 2027. As oil production mainly relies on roots, and to obtain them, the destruction of whole grass is required. The continuous removal of grasses for roots degrades the land quality and makes the area vulnerable to soil erosion and floods, a major concern (Lal et. al., 2020).

Vetiver is a Tamil (India) word, which means the grass that is dug out. Chrysopogon zizanioides Roberty (vetiver), Poaceae family, the vetiver is native to India. Vetiver roots are the main source of vetiver essential oil that has substantial value in pan masala, tobacco, perfumery and essential oil industries. Perhaps no aromatic plants except rose, geranium and sandal have good perfumery utility with comparison to the vetiver. It grows widely in many parts of India. The vetiver essential oil is annually produced in India, which is too low to cover the national and international demand for perfumes, tobacco and essential oil industries. In north India vetiver quality is best in the world (Oyen, 2008).

Vetiver is cultivated in more than a hundred countries to it's to prevent water/ soil erosion, carbon sequestration and water conservation. The vetiver roots are used for making

handicraft, toys, cooling khus-tatties in India. The vetiver essential oil also has many medicinal uses such as stomachic, diaphoretic, tonic, diuretic, etc. the vetiver green leaves are also used as fodder of its high nutritive value (Husain, 1983).

### 2.2.2 Description and Uses

Vetiver commonly known as *resbira* or Sugandbmula, Khas-Khas, Khas, Khus Khus or Khus Grass, vala is a fast-growing perennial grass belonging to family Poaceae. It has thick fibrous adventitious roots which are aromatic and highly valued. This tufted grass grows throughout the plains of India ascending up to an elevation of 1200 m. Though it originated in India, vetiver is widely cultivated in tropical region of the world.

**Table 1**  
**Description and uses of vetiver plant**

<b>Growth from</b>	Perennial grass that forms dense, erect clumps.
<b>Root</b>	Fibrous roots are long and white. When crushed, they emit a somewhat earthy, sandalwood – like fragrance.
<b>Foliage</b>	Narrow, linear leaves (25 – 50 cm long, 1 cm wide) are held erect. The leaves are tightly folded together, forming a V – shape in cross – section. The inner surface of the leaf (when the leaf is opened and flattened) is mostly covered by thin, parallel, white bands and has a green margin. They are held erect, but often bent backwards at a sharp angle near the tip.
<b>Stems</b>	It has an underground, horizontal stem known as a rhizome. The rhizome is composed of small, barrel-shaped segments and resembles a ginger rhizome (commonly called a root).
<b>Flowers</b>	It forms narrow panicles.
<b>Cultivation</b>	This species can tolerate occasional flooding.
<b>Ethnobotanical uses</b>	Medicinal (oil extracted from the roots is used in traditional medicine as an aphrodisiac, antiseptic, or sedative.

<b>Others</b>	It has phytoremediation potential, because it accumulates pollutants such as lead, arsenic, zinc, copper and petroleum hydrocarbons. In tropical climate, it is used for screening and to prevent soil erosion. Oil extracted from the roots is used in 90% of western perfumes including the famous chanel No. 5. the roots are woven together to make mats, baskets and screens which become fragrant when moistened.
---------------	---

### 2.2.2.1 Uses of vetiver

- Vetiver (*Chrysopogon zizanioides*) root is used to make medicine.
- People take vetiver for nerve and circulation problems, and some women take it to start their periods or to cause an abortion.
- Vetiver is sometimes applied directly to the skin for relieving stress, as well as emotional traumas and shock; treating lice; and repelling insects.
- Vetiver is sometimes inhaled as “aromatherapy” for nervousness, trouble sleeping (insomnia), and joint and muscle pain (rheumatism). It is also used for arthritis, stings and burns.
- In manufacturing, vetiver is used as a flavouring in alcoholic beverages (Lal RK et al., 2020).

### 2.2.3 Characteristics of Vetiver

Vetiver is a warm season grass with light green, narrow leaves. It is stiffly erect with good fall colour. V. “Sunshine” is usually what is sold in the states and it is a sterile cultivar. It can be grown as an annual in a container in cooler climate. This is an edible plant and the oil obtain from the root is used as a flavouring in sherbets, syrup, sweet, fruit drinks and can asparagus. These oils may be used in specific medical compounds. It is used world – wide for soil and water conservation and many other environmental protection applications. This is due to its strong and deep root system, a high tolerance to most heavy metals and an ability to remove from soil and water large quantities of exam nitrates, phosphates and farm chemicals (Smitha Gingade, 2015).

**Table. 2**  
**Classification and Characteristics of vetiver grass**

<b>Plant Division</b>	Angiosperms (Flowering seed plants)
<b>Plant growth form</b>	Grass & Grass-like plant
<b>Mode of nutrition</b>	Autotrophic
<b>Plant shape</b>	Grassy
<b>Maximum Height</b>	2.4 m

Vetiver (*Vetiveria zizanioides* (Linn) Nash) or khus of family Poaceae, is a perennial grass which can grow up to 1 to 2 metres high and form wide clumps. The plant stems are erect and stiff and the leaves are 120-150 cm long and 0.8cm wide and rather rigid. The panicles are 15- 30 cm long, brownish -purple in colour and have whorled 2.5-5.0 cm long branches. The spikelets are in pairs, and there are three stamens. The root system of vetiver is finely structured and very strong. It has no stolons or rhizomes. Unlike most grasses, which form horizontally spreading mat-like root system, vetiver's fibrous roots grow downward, 2-4 m in depth and strongly scented. Vetiver is mainly cultivated for the fragrant essential oil distilled from its roots. The main chemical components of the oil are benzoic acid, Vetiverol, furfural, vetivone and vetivene. Due to its excellent fixative properties, it is used widely in perfumes. Dry roots are also used for making mats, fans, screens, pillows, baskets, incense sticks and sachet bags. Since plant has extensive fibrous roots, it is useful in both soil and water conservation. It helps in maintaining soil moisture, absorbs toxic substances in chemical fertilizers and pesticides and improves physical characteristics of soil. The plant is one of the best soil binders and is used through tropics to check soil erosion by planting along contour. Grass is also widely grown as a protective partition in terraced fields and as a border for roads and gardens (Smitha Gingade et al., 2015).

#### **2.2.4 Chemical Composition of Vetiver**

In the year 2011 compared the vetiver oil of nine different countries like Brail, China, Haiti, India, Java, Madagascar, Mexico, Reunion and Salvador by obtaining oil from authentic sources. The quantitative and qualitative analysis reported around 114 compounds containing a mixture of hydrocarbons, alcohols as major fractions and ketones as minor fractions and few

other miscellaneous compounds. These mixture of compounds with varying ratio by hydrocarbons, aldehydes, alcohols, esters, ketones and acids, which vary from country to country (Madhuri Grover et al., 2021).

**Table. 3**  
**Chemical Composition of Vetiver fibre in various countries**

S. No.	Constituent	Composition range (%)		
		Java	India	China
1)	Hydro Carbons	22.7%	21.3%	23%
2)	Aldehydes	6.5%	5.8%	4.2%
3)	Alcohols	47.6%	47%	41%
4)	Esters	0.4%	0.2%	0%
5)	Ketones	11.8%	14.5%	14.3%
6)	Acids	0%	0%	6.4%
<b>Total constituent of oil components</b>		89.4%	89.3%	89.1%

The important compounds that impart the characteristic vetiver odour were: Khusimene,  $\delta$ -Selinene,  $\beta$ -Velivenene, cyclocopacaphan-12-ol, Vetiselinol, Khusimol, Isovalencenol, Khusimone, Eudesmol, Prezizaene, alpha-Vetivone and  $\beta$ -Vetivone. The Sesquiterpenoides  $\alpha$ -Vetivone,  $\beta$ -Vetivone and Khusimol always occurred in the oil up to 35%. In an analysis of Indian vetiver oil, a total of 29 and 33 compounds were identified in south and north Indian vetiver oils, respectively. The major compounds identified included khusimol (16.25%), Khusinol (10.28%), germacrene-D (9.73%), Junipene (5.54%) and  $\gamma$ -Muurolene (4.56%) (North Indian vetiver oil) and Khusimol (15.77%), Bicyclovetvenol (10.76%) and Viridiflorene (4.64%) (South Indian vetiver oil) (Khusminder Kaur Chahal et al., 2015).

## **2.3 BANANA PSEUDO-STEM FIBRE**

### **2.3.1 History and Origin**

Bananas are suspected to be the first fruit in the earth by some horticulturists. The origin of bananas is placed in southeast Asia, in the jungles of Malaysia, Indonesia or Philippines, where so many varieties of wild bananas still grow at present. Bananas have later travelled with

human population. The first Europeans to know about bananas were the armies of Alexander the Great, while they were campaigning in India in 327 BC. The Arabs brought them to Africa. The Portuguese brought them to the Canary Islands. Bananas changed during all these trips, gradually losing its seed, filling out with flesh and diversifying (Balan & Vandana, 2013).

Banana plants, which plant to the family of *Musaceae*, are native to the Malaysia-Indonesian region of South- East Asia. Bananas are widely produced and abundant natural resources in tropical and sub-tropical countries in the world. The banana plants are considered as one of the world's most useful plants. Almost all the parts of this plant, for example, fruit, peel, leaf, pseudo-stem, stalk and inflorescence (flower), can be utilized. They are used in several food and non-food related applications, for example, as thickener, colourant and flavouring, macro and micro-nutrient source, livestock feed, fibres bioactive compound source, and organic fertilizers. The banana pseudo-stem has also been considered for use as pulp and paper raw material, fibre for textiles and filter or structural reinforcement in composites material.

The pseudo-stem of banana plant is the stem of banana plant that provides and transports nutrients from the soil to the fruit. This pseudo-stem will be cut and become waste biomass after the banana fruit is ripe and harvested, because the banana plant is unusable for the next harvest. These wastes are usually disposed of by the farmer into lakes and rivers or simply burned. The banana tree waste if not properly manages can cause problem to the environment, because if they are dumped in wet conditions or burned can produce green house gas, which can cause a problem to the environment. It is believed that this crop waste can be used in a more rational way, namely, as a source of cellulose fibre for further applications (Asmanto Subagyo, 2018).

For centuries, banana fibre textiles were made in Japan and Nepal. In Japan, banana fibres were a prized substitute for silk and were traditionally woven into ceremonial garments for the wealthy. In both Nepal and Japan, the outermost sheaths of banana plant were used for making cloth that was not intended for articles of clothing. Coarser banana cloth was used for place mats, floor mats and sun shader. Today, banana fibre is used all over world for multiply purposes. Commercial value of the fibre has increased over the years. Transforming the waste into the usable fabrics and other products is a great achievement (Avneet Karur, 2015).

### 2.3.2 Production of Pseudo-Stem Fibre

The pseudo-stem fibre of banana plant is like pineapple leaf, sisal and other hard fibres, though the pseudo-stem fibre is a little more elastic (Asmanto Subagyo, 2018).

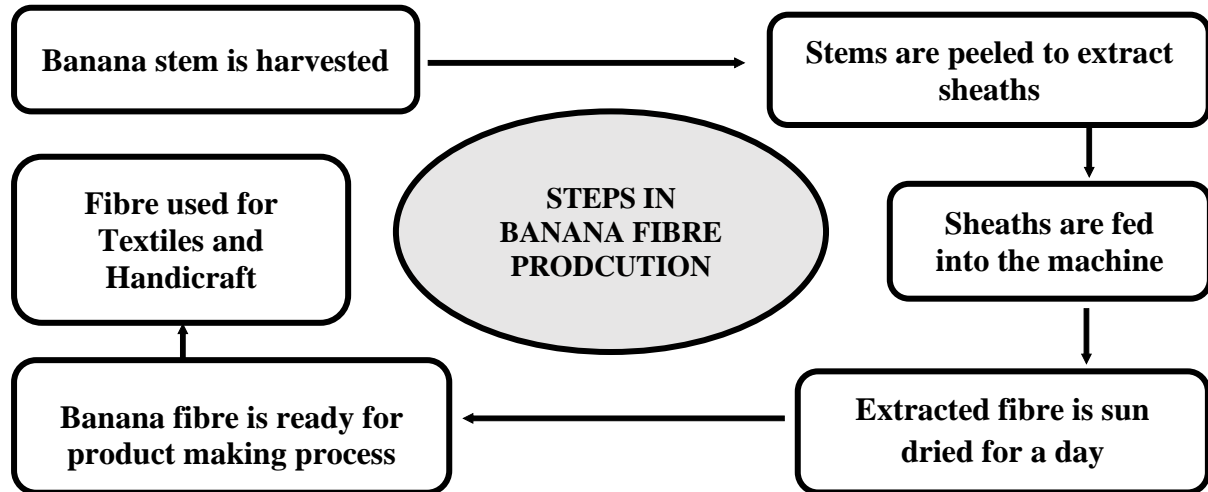


Figure. 1

#### Banana fibre production process

#### 2.3.2.1 Plantation and Harvesting

Bananas are grown in tropical regions where the average temperature is 80° F (27°) and yearly rainfall is 78-98 inches (200-250 cm). they required moist soil with good drainage. In fact, most bananas exported are grown withing 30 degrees either side of the equator (Balan & Vandana, 2013). The banana plant has a shallow rooting system in which the pseudo-stem sprout vertically. As it develops, a single plant may produce about 25 of these pseudo-stems, which mature at different times. When the plants are 18-24 months old, the outer pseudo stems already mature and ready to be harvested. Then, about three or four pseudo-stems are stripped at a period of 6-12 months bared on the rate of growth of the pseudo-stem. When the flower is out, the pseudo-stems are completely ready for harvesting. Furthermore, the shaft is cut off below the in florescence with a knife or sickle attached to a long pole and then the pseudo-stems are cut at their base (Asmanto Subagyo, 2018).

The quality of fibre in each sheath depends upon its width and its location in the stem, as does its quality. In addition to fruit production, huge quantity of biomass (pseudo-stem, leaves, suckers etc.) is generated. Presently, this banana is discarded as waste. In past, some researchers have successfully demonstrated use of banana pseudo-stem and leaves for extraction of fibres on a small scale. In India, the fibres are being used for preparing handicrafts,

ropes etc., which otherwise can be used for making fabrics, home furnishing and good quality papers. The major problem of non-adoption of fibre extraction technology is low recovery of fibres leading to high transport cost (Balan et al., 2013).

### **2.3.2.2 Extraction of Banana Pseudo-stem fibre**

The “pseudo-stem” is a clustered, cylindrical aggregation of leaf stalk bases. Banana fibre at present is a waste product of banana cultivation and either not properly utilized or partially done so. The extraction of fibres from the pseudo stem is a common practice and much of the stem is not used for production of fibres. This is reflected from the relatively expensive price of banana fibres when compared to other natural fibres. There are two ways of extracting the fibre, i.e., Manual extraction and Mechanical extraction.

- **Manual extraction process,**

It involves cutting the trunk in to small pieces and scrapping them with the help of a comb like structure called scrapper.

- **Mechanical process,**

In this process chopped plant is passed through a simple machine called Raspador or Banana Fibre Extractor (Atul Kumar et al., 2013).

The essentially hand driven process of extracting banana fibre is now set to change with the invention of the banana fibre separator machine. An easier and quicker way of extracting fibres is to use a machine extractor, called Raspador, banana fibre is extracted from banana pseudo-stem sheaths. The plants are cut down as soon as the fruit are harvested. The trunk is peeled. Brown-green skin is thrown away retaining the cleaner or white portion which will be processed into knotted fibres. To extract the fibre, the pseudo-stem is cut at the bottom at an angle, and its sheaths are removed, as each series of leaf sheaths produces different grades of fibres. It would be desirable to separate them according to the classification mentioned above prior to the cleaning or stripping that would enable the artisans to market the fibres advantageously.

The fibres are extracted through hand extraction machine composed of either serrated or non-serrated knives. The peel is clamped between the wood plank and knife and hand-pulled through, removing the non-fibrous material. The extracted fibres are sun-dried which whitens the fibres. Once dried, the fibres are ready for knotting. A bunch of fibres are maintained or clamped on a stick to facilitate segregation. Each fibre is separated according to fibre sizes and grouped accordingly. To knot the fibre, each fibre is separated and knotted to the end of another

fibre manually. The separation and knotting are repeated until bunches of unknotted fibres are finished to form a long continuously strand. This fibre can now be used for making various textile products (Balan et al., 2013).

### **2.3.2.3 Advantages of the machine over manual process,**

- Reduces drudgery
- Fifty times increase in fibre production compared to manual process
- User friendly and economic
- Less maintenance cost and safe to operate
- Clean work atmosphere
- 30kg of fibre production per day
- Superior quality fibre in terms of length and softness, strength & colour.

### **2.3.3 Characteristics of Banana Fibre**

Banana fibre is a natural leaf fibre. It has its own physical and chemical characteristics and many other properties that make it a fine quality fibre.

- Appearance of banana fibre is similar to that of bamboo fibre and ramie fibre.
- The chemical composition of banana fibre is cellulose, hemicelluloses and lignin.
- It is a strong fibre.
- It has smaller elongation.
- It has somewhat shiny appearance depending upon the extraction.
- It is light weight.
- It has strong moisture absorption quality. It absorbs as well as releases moisture very fast.
- It is biodegradable and has no negative effect on environment and thus can be categorized as eco-friendly fibre.
- Its average fineness is 4 to 15 tex.

**Table. 4**  
**Specification of banana fibres**

<b>Linear Density (D)</b>	<b>Average Strength (cN/ tex)</b>	<b>Strength unevenness (%)</b>	<b>Average Elongation at break (%)</b>	<b>Elongation Unevenness (%)</b>	<b>Break Strength (cN/ tex)</b>
4.03	39.3	34.3	5.4	19.7	2.3

**Table. 5**  
**Chemical constituents of banana fibres**

<b>Constituents</b>	<b>%</b>
Cellulose	67.4
Lignin	4.8
Ash	1.0
Moisture	7.5
Cold water-soluble compounds	1.9
1% NaOH soluble compounds	28.5

There are characteristics with high strength, small elongation, good lustre, light weight, strong moisture absorption, fast moisture absorption and release, easy degradation as well as environmental production etc., banana fibre can be made into garment, curtain, towel, bedsheet etc., due to its characteristics with good lustre and moisture absorption. Banana fibre can be spun into yarns, whose solidity is suitable for packing textures. The solidity is sufficient and is better than comparable jute textures, when their readiness to not be concerned, textures of banana fibres, as the earth-rotting test are to be declared good (Balan et al., 2013).

#### **2.3.4 Banana Pseudo -Stem Properties**

##### **2.3.4.1 Physical and Mechanical Properties**

Banana pseudo-stem fibres have physical and chemical characteristics and other properties that make them good quality fibre. In terms of physical properties, it has been reported in the literature that the banana pseudo-stem fibre has good modulus of elasticity,

tensile strength and stiffness which makes it a promising fibre material. The appearance of banana pseudo-stem fibre is quite like ramie and bamboo fibre, but its spinnability and fineness are much better than that of ramie and bamboo. It has average fineness of 2400 Nm. It is a strong fibre and has lower strain at break. Its appearance is quite shiny, which depends on the extraction and spinning process. It has low density and strong moisture absorption quality. Its absorbance and release of moisture are quite fast. The acid and alkali-treated banana pseudo-stem fibres showed greater amorphous region than the untreated fibre.

**Table. 6**  
**Physical & Mechanical properties of *banana pseudo-stem* fibre**

<b>Fibres</b>	<b>Width or diameter (µm)</b>	<b>Density (kg/m<sup>3</sup>)</b>	<b>Cell L/D ratio</b>	<b>Microfibrillar angle (degree)</b>	<b>Initial modulus (GPa)</b>	<b>Tensile strength (MPa)</b>	<b>Elongation (%)</b>
Banana pseudo-stem	80-250	1350	150	10±1	7.7-20.0	54-754	10.35

#### 2.3.4.2 Thermal Properties

Thermogravimetric analysis (TGA) is carried out to analyse the heat stability or thermal degradation of banana pseudo-stem fibre. The thermal degradation of the fibre started at a temperature of 25-700° C in N<sub>2</sub> environment at a constant heating rate of 10° C/ min. Thermal degradation of the banana pseudo-stem fibre occurred in three stages. The first stage of degradation was evaporation of moisture at a temperature range of 30-144° C. As the fibre was continuously heated, the weight of the fibre decreased by releasing moisture and some volatile extractives. This is a common phenomenon that occurs in plant fibres, which makes the fibres become more flexible and collapse easily and increases heat transfer. Nevertheless, the moisture contained in the fibre cannot be completely removed due to structural resistance from the fibre and the hydrophilic nature of the fibre. In this, first stage, the weight loss of the fibre was in the range of 5-10 wt %.

The second stage was the degradation of hemicellulose. From banana pseudo-stem fibre, the hemicellulose started to decompose at a temperature of approximately 178° C. The lower stability of the hemicellulose is likely due to presence of acetyl groups, which make the hemicellulose degrade much more quickly than the other components, for example, lignin and

cellulose. The third stage was the degradation of cellulose, which occurred at a temperature of approximately 296° C. the last stage is the decomposition of lignin. Lignin is more difficult to decompose compared to another component. Generally, for any plant fibre, decomposition of lignin occurred slowly all the range of temperature up to 700° C. the range of temperature is in agreement with the TGA results, in which the first stage of degradation was evaporation of moisture at a temperature range of 30-144° C. Additionally, thermal conductivity of *banana pseudo-stem* fibre is found to be quite low at 0.0253 W/m<sup>2</sup> K, which suggests that these fibres could be used as good thermal insulations (Asmanto Subagyo, 2018).

#### **2.3.4.3 Chemical Properties**

- Fat and waxes, which are mostly found on the surface of the plants and can be extracted using benzene.
- Pectin, which exists in water-soluble form as calcium and magnesium from galacturonic acid. These substances are converted into butyric and acetic acids during biological retting.
- Hemicellulose, which are amorphous short-chain polysaccharides and polyuronides. The polysaccharide hemicelluloses are chemically partly linked or intermingled with cellulose molecules.
- Cellulose, which is the major constituent of the fibres.
- Lignin, which is a short-chain isotropic and non-crystalline polymer made up of units derived from phenyl propane.
- Aqueous extract, which is extracted by boiling the dewaxed fibres in water.
- Cellulose fibre can be considered as the most available natural, biodegradable and renewable polymer that can be used in many applications (Asmanto Subagyo, 2018).

#### **2.3.4.4 Uses and Application**

In recent years, more and more plant fibre was considered to be “Environmentally friendly” fibre sources, and many countries are emphasizing the utilizing of these fibres. The best thing about their fabric is that they are biodegradable. Finally broken down into water and carbon dioxide by micro-organism in the soil (Balan et al., 2013).

### **Use in accessories,**

When it comes to accessories, expect to see banana fibre used more frequently to make scarves, hats and gloves as sustainable, organic products become increasingly popular.

### **Use in Industry and Décor,**

Traditionally, a lack of technological sophistication limited banana fibre uses to rough applications like doormats, wall weaves, and ropes. In some indigenous communities, banana fibre is still used for this ancestral purpose, but applications of this fibre outside the realm of wearable products are usually limited to tropical-themed décor item.

The sea water resistance of the pseudo-stem fibre and its natural buoyancy characteristic have made a market for this fibre in the shipping cable manufacture. This fibre is also used to produce fishing nets, other types of cordage, mats, packaging, sheets etc. Additionally, in the Edo period of Japan (1600-1868), banana pseudo-stem fibre was used to make traditional dresses such as kimono and kamishimo. This fibre is usually used due to its light weight and comfort. Furthermore, banana pseudo-stem fibre is utilized to produce cushion cover, bag, table cloth, curtain and others. Additionally, there are some potential uses of banana fibres, such as: to be used as natural absorbent, for production of mushroom, arts or handicraft, string thread, paper cardboard, tea bag and high-quality textiles or fabric materials, currency note paper and many other products. The use of banana fibre as natural absorbent also has promising potential to absorb oil spilling in oil refinery. It also can be used as absorbent in coloured water from the dyes of textile industry. Banana pseudo-stem contain pathogenesis proteins, which possess antimicrobial properties. The pseudo-stem can also be converted into bio-fertilizer. It also contains high amount of cellulose and starch, and thus it can be utilized as feed for cattle.

## **2.4 COTTON**

### **2.4.1 History and Origin**

The cotton plant has always thrived in the wild. By contrast, the historical origin of its commercial exploitation, particularly with regard to textile uses, is fuzzier. Relevant literary references point to two distinct geographical origins of cultivated cotton, namely, Asia and pre-Columbian America. The first cotton fabric would date back to approximately as early as 3,200 BC, as revealed by fragments of cloth found at the Mohenjo-Daro archaeological site on the banks of the river Indus. From India, cotton textile probably passed to Mesopotamia, where the

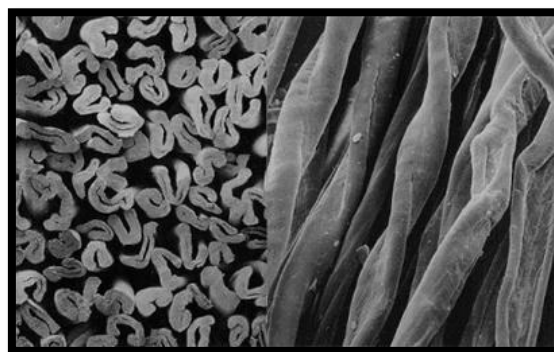
trade started around 600 years BC. There is evidence to suggest that trade in cotton started around Rome at the time of Alexander the Great, in the 4<sup>th</sup> century BC.

**Cotton**, seed-hair fibre of several species of plants of the genus *Gossypium*, belonging to the hibiscus, or mallow, family (Malvaceae). Cotton, one of the world's leading agricultural crops, is plentiful and economically produced, making cotton products relatively inexpensive. The fibres can be made into a wide variety of fabrics ranging from lightweight voiles and laces to heavy sailcloth and thick-piled velveteen, suitable for a great variety of wearing apparel, home furnishings, and industrial uses. Cotton fabrics can be extremely durable and resistant to abrasion.

Cotton accepts many dyes, is usually washable, and can be ironed at relatively high temperatures. It is comfortable to wear because it absorbs and releases moisture quickly. When warmth is desired, it can be napped, a process giving the fabric a downy surface. Various finishing processes have been developed to make cotton resistant to stains, water and mildew; to increase resistance to wrinkling, thus reducing or eliminating the need for ironing; and to reduce shrinkage in laundering to not more than one percentage (Hans-Dietrich H. Weigmann, 2022).

#### **2.4.2 Structure and Crystallinity**

Cotton is the generic name of a fibre that grows from the seed of the cotton plant as seed hair. When cotton is blended with other fibres; the cotton look is maintained because consumer likes the clean, fresh, somewhat dull appearance of cotton fabrics. Cotton has been of service to mankind for so long that its versatility is most unlimited and new uses are constantly being discovered. Cotton is the most abundant and technically most important natural textile fibre (Balan, 2013).



**Figure. 2**  
**Cross-sectional and Longitudinal view of Cotton fibre**

As seen in Fig.1, under a microscope, the longitudinal view of the cotton fibre appears as a very fine, regular fibre, looking like a twisted ribbon or a collapsed and twisted tube. These twists are called convolutions. In the cross-sectional view the fibre appears as bean shaped with a central hollow canal called as lumen. The many varieties of cotton are broadly classified into four groups viz. Sea Island Cotton, Egyptian Cotton, American Pima Cotton and Asiatic cotton.

After removal of the unwanted natural impurities in cotton, it becomes almost fully cellulose. Cellulose is a water insoluble polysaccharide with an empirical formula  $(C_6H_{10}O_5)_n$ . Cellulose is a homopolymer that has been polymerized by condensation, with a molecule of water (HOH) split off where two units join. In case of cotton, the molecular chain involves perhaps 10,000 glucose units. Cellulose is essentially a poly (1, 4)  $\beta$ - D glucopyranose (Balan, 2013).

**Table. 7**  
**Composition of cotton fibres**

<b>S. No.</b>	<b>CONSTITUENT</b>	<b>COMPOSITION RANGE (%)</b>
1.	Cellulose	88.0 – 96.0
2.	Protein	1.1 – 1.9
3.	Pectic substances	0.7 – 1.2
4.	Ash	0.7 – 1.6
5.	Wax	0.4 – 1.0
6.	Total sugar	0.1 – 1.0
7.	Organic acids	0.5 – 1.0
8.	Others	0.5 – 4.3

### **2.4.3 Cultivation**

The various species of cotton grown as agricultural crops are native to most subtropical parts of the world and were domesticated independently multiple times. Cotton can be found as perennial treelike plants in tropical climates but is normally cultivated as a shrubby annual in temperate climates. Whereas it grows up to 6 meters (20 feet) high in the tropics, it

characteristically ranges from 1 to 2 metres (3 to 6.5 feet) in height under cultivation. Within 80-100 days after planting, the plant develops white blossoms, which change to a reddish colour. The fertilized blossoms fall off after a few days and are replaced by small green triangular pods, called bolls, that mature after a period of 55-80 days. During this period the seeds and their attached hairs develop within the boll, which increase considerably in size.



**Figure. 3 Cotton Fibre**

The seed hair, or cotton fibre, reaching a maximum length of about 6 cm (2.5 inches) in long-fibre varieties, is known as lint. Linters, fibres considerably shorter than the seed hair and more closely connected to the seed, come from a second growth beginning about 10 days after the first seed hairs begin to develop. When ripe, the boll bursts into a white, fluffy ball containing three to five cells, each having 7 to 10 seeds embedded in a mass of seed fibres. Two-thirds of the weight of the seed cotton (i.e., the seed with the adhering seed hair) consists of the seeds. The fibres are composed of about 87 to 90 percent cellulose (a carbohydrate plant substance), 5 to 8 percent water, and 4 to 6 percent natural impurities (Hans-Dietrich H. Weigmann, 2022).

#### **2.4.4 Description and Technical Properties of Cotton Fibre**

Cotton is a natural fibre of vegetable origin, like linen, jute or hemp. Mostly composed of cellulose and formed by twisted, ribbon-like fibres. Cotton is the fruit of a shrubby plant commonly referred to as the “cotton plant”. The cotton plant, a variety of plants of the genus *Gossypium*, belongs to the Malvaceae family, which comprises approximately 1,500 species, also including the baobab tree, the bombax or the mallow. The plant, growing up to 10 meters under commercial cultivation in order to facilitate picking. Either herbaceous or ligneous, it thrives in dry tropical and subtropical areas. Whereas by nature the plant is a perennial tree, under extensive cultivation it is mostly grown as an annual shrub.

The cotton flower has five large petals, which soon fall off, leaving capsule, or “cotton bolls”, having a thick and rigid external layer. The capsule burst open upon maturity, revealing the seeds and masses of white/creamy and downy fibres. Cotton fibres of the *Gossypium hirsutum* species range from about 2 to 3 centimetres in length, whereas *Gossypium barbadense* cotton produces long-staple fibres up to 5 centimetres length. Their surface is finely indented, and they become kinked together and interlocked.

The cotton plant is almost exclusively cultivated for its oleaginous seeds and for the seminal fibres growing from them. In ordinary usage, the term “Cotton” also makes reference to fibres that are made into fabric wires suitable for use in the textile industry (Balan, 2013). The classification of cotton is done on the bases of fineness, staple length, maturity, degree of contamination, and strength. The fineness of fibre is denoted in dtex, i.e., number of grams per 100 meters. The fineness of cotton fibre is most commonly expresses in terms of micronaire value, i.e., number of micrograms per inch.

**Table 8**  
**Properties of cotton fibre**

S. No.	PARAMETER	VALUE
1.	Fineness	1-4 dtex /2.3-6.9 micronaire
2.	Fibre length	10-60 mm
3.	Density	1.5 – 1.54 g/cm <sup>3</sup>
4.	Moisture regain	8.5%
5.	Breaking strength	25- 50 cN /tex
6.	Elongation	5-10%
7.	Colour	Creamy yellow

#### **2.4.4.1 Fineness of Cotton fibre:**

Fineness is one of the most important parameters determining the yarn quality characteristics. Fibre fineness influences the number of fibres in the cross section of yarn. Thirty fibres are needed at the minimum in the yarn cross section but there are usually over 100. One hundred is approximately the lower limit for almost all new spinning process. This indicates that fineness will become more important (Mazharul Islam Kiron, 2015).

#### **2.4.4.2 Fibre Length:**

The average length of spinnable fibres is called staple length. Staple length is one of the most important fibre characteristics. The quality, count, strength etc. depend on the staple length of fibre. It is the most important properties of cotton fibre. Fibre length influence: Spinning limit, Yarn strength, Yarn evenness, Handle of the product, Lustre of the product, Yarn hairiness, Productivity (Abdullah Nur Uddin Rony, 2022).

#### **2.4.4.3 Maturity**

The maturity of cotton is defined in terms of the development of cell wall. A fluffy mature fibre has a well-developed thick cell wall. On the other hand, an immature fibre has a very thin cell. The fibre is to be considered as mature fibre when the cell wall of the moisture-swollen fibre represents 50-80% of the round cross section, as immature when it represents 30-45% and as dead when it represents less than 25% (Mazharul Islam Kiron, 2015).

#### **2.4.4.4 Fibre Strength**

Toughness of fibre has a direct effect on yarn & fabric strength. Very weak cottons tend to rupture during processing both in blow room & carding, creating short fibres & consequently deteriorate yarn strength & uniformity (Abdullah Nur Uddin Rony, 2022).

#### **2.4.4.5 Colour**

Colour is partially important as a measure on how well a yarn or fabric will dye or bleach. Instrumental techniques for determining the colour of the sample have only now reached the industry, HVI measurement of colour provides reasonably accurate results of average reflectance & yellowness in a sample (Mazharul Islam Kiron, 2015).

#### **2.4.5 Uses**

Cotton is used to make a number of textile products. These include terrycloth, used to make highly absorbent bath towels and robes; denim, used to make blue jeans; chambray, popularly used in the manufacture of blue work shirts; and corduroy, seersucker, and cotton twill. Socks, underwear, and most T-shirt are made from cotton. Bed sheets often made from cotton. Cotton is also used to make yarn used in crochet and knitting. Fabric also can be made from completely of cotton, some other fibres are blended with cotton, including rayon and synthetic fibres such as polyester. It can either be used in knitted or woven fabrics, as it can be blended with elastine to make a stretchier thread for knitted fabrics, and things such as stretch jeans. In addition to the textile industry, cotton is in fishnets, coffee filters, tents, gunpowder.

Cotton paper and in bookbinding. The first Chinese paper was made of cotton fibre. Fire hoses were once made of cotton.

Cotton linters are fine, silky fibres which adhere to the seeds of the cotton plant after ginning. These curly fibres typically are less than 1/8 inch (3 mm) long. The term also may apply to the longer textile fibre staple lint as well as the shorter fuzzy fibres from some upland species. Linters are traditionally used in the manufacture of paper and as a raw material of viscose. In the UK, linters are referred to as “Cotton wool”. This can also be a refined product which has medical, cosmetic and many other practical uses (Balan et al., 2013).

## **2.5 BLENDING OF CELLULOSIC FIBRES**

The major goal of fibre blending is to produce a homogeneous single yarn composed of an intimate mixture of two or more similar or dissimilar fibre types for overcoming the drawbacks of the used fibre components along with providing a rich diversity to our day-to-day lives which is partially unachievable using the individual components. The extent of improvement in blended yarn properties is governed by type of fibre, blending ratio, and mode of blending, i.e., as different filaments or staple fibres in the same yarn, as different yarns, warp and weft, assembled in the same fabric or as core spun yarns (El-Mogahzy, 2004).

Blending of textile fibres is carried out to attain aesthetic colour effects, to minimise the total production cost, as well as to improve the performance properties of the obtained textile products. Factors affecting the choice of proper dyestuffs as well as dyeing conditions for obtaining high-quality blend dyeing's include: behaviour of blend components and their proportions towards different dyes and dyeing conditions, compatibility of dyebath ingredients, availability of proper dyeing equipment, the increased demand for novel effects achieved by blending, subsequent finishing treatments, as well as economic realities and ecological concerns (Ibrahim N A, 2011).

### **2.5.1 Advantages of Blending**

- The increasing demand for fibre blending can be discussed in terms of its positive impacts on:
- Achieving economic advantages via blending of expensive fibres with cheaper ones.
- Enhancing the performance and quality properties via combination of desirable properties of both fibre components.
- Developing novel textile products to meet the demand.

- Prolonging the durability of textile product via incorporation of a more durable fibre component (Choudhury, 2006).

## **2.6 YARN AND FABRIC PRODUCTION**

Textile has evolved and grown from cottage to complex interrelated industries. Now a standard textile product is produced by undergoing a series of value-added activities and processes. These activities and processes start from cultivation or sourcing of fibre or filament, spinning it into thin yarn, weaving or knitting it into fabric, converting it into life comfort household and industrial articles of furnishing and apparel after bleaching and dyeing, and finally selling it to the consumers by involving distributors and retailers.

### **2.6.1 Yarn Manufacturing Process**

Industrial revolution supplied developments to production units making their process easy in controlling the process by spinning machinery. In this machine process various levels are added to convert fibre (cotton/wool) into yarn to process it further for textile products. This transformation goes through various levels such as:

- ❖ **Blow room**
- ❖ **Carding**
- ❖ **Combining**
- ❖ **Drawing**
- ❖ **Roving**
- ❖ **Winding**

#### **2.6.1.1 Blow Room**

Blow room is the initial stage in spinning process. The name blow room is given because of the air flow and all process is done in blow room because of air flow. Blow room is consisting of different machines to carry out the objectives of blow room. In blow room the tuft size of cotton becomes smaller and smaller. Mixing of cotton is done separately as well as in blow room. Compressed layer of bale is also open in blow room with the help of machine. In blow room cotton bales are opened and cotton is transfer from different number of machines with the help of air flow (Neha Gupta, 2013).

#### **2.6.1.2 Carding**

The second step in the yarn manufacturing process is the carding. The blow room transfers the open cotton to this section through a pipe line for further process. Carding is the

heart of spinning mill and in this section maximum cleaning of cotton is done. In this stage the fibre is more opened and separates individually. In this section the material is collecting in a can in the form of rope (the technical word is silver). This section also describes the technical point, critical success factor, preventive action and also describes the defects rate which affects the yarn quality (Neha Gupta et al., 2013).

### **2.6.1.3 Combining**

As yarn is arranged in parallel manner, it is straightened again in stage of combining. On the other hand, the left short fibre will be subtracted completely from longer staple fibre. This will result in stronger and smoother staple fabric having higher demand in market.

### **2.6.1.4 Drawing**

This is a device in which drafting and drawing are carried out. Doubling is the application of feeding several intermediate strands into a single strand. Drafting is carried out to lessen fibre laps to slivers. The carded silver is drafted between roller to produce drawn silver

### **2.6.1.5 Roving**

The yarn produced is processed into a speed frame to attain roving yarn. This is the initial step where twist is inserted for giving hold to the fibers in a spinning mill. The roving yarn is of little larger diameter as compared to the final yarn. Similarly ring frames are used to produce finished yarns from obtained roving yarns. yarn is resulted having good amount of strength through these ring frames.

### **2.6.1.6 Winding**

The cop who is prepared in the ring frame is not suitable for further process. So the yarn is converted into the shape of cone which is prepared in the winding. Practical experience shows that winding process alters the yarn structure. The factors which affect the yarn structure during winding are bobbin geometry, bobbin unwinding behaviour, binding speed. This phenomenon does not affect the evenness of the yarn but it affects the properties of the yarn such as thick places, thin places, neps, and hairiness (Neha Gupta, 2013).

## **2.6.2 Fabric manufacturing process**

Textile fabric is at least a two-dimensional structure produced by fibre or yarn interlacing. The interlaced fibrous structure mainly used is woven, nonwoven, and knitted. Traditionally, the weaving technology was the principal source for fabric production. The

important types of woven fabric produced are the basic weaves, such as plain or tabby, twill, and satin, and the fancy weaves, including pile, jacquard, dobby, and gauze. Knitted fabric is the second major type of fabric used following the woven. It has a characteristic of accommodating the body contour and provided the ease of movement. It is particularly a comfortable form of fabric structure for sports, casual wear, and undergarment. Knitted fabrics include weft types and the warp types, raschel, and tricot. Net, lace, and braid are other useful interlaced fabric structures. Nonwoven fabrics are rapidly increasing in market consumption. These fabrics are finding interesting uses in industrial and home applications. Nonwoven fabrics include materials produced by felting and bonding (Alkaya et al., 2014).

## **2.7 PRE-TREATMENT OF FABRIC**

Pre-treatment is the processes that are used to remove impurities from fibres or fabric to make it dyeable or printable. Natural fibres and synthetic fibres contain primary impurities that are contained naturally and secondary impurities that are added during spinning, knitting and weaving processes. Textile pre-treatment is a series of cleaning operations. All impurities, which causes adverse effect during dyeing and printing, are removed in the pre-treatment process (Shahriar Shovon, 2020).

### **2.7.1 Enzymatic Treatment of woven fabric**

The processing of cellulosic fibres is generally performed at alkaline conditions. This is mainly due to the free hydroxyl groups of 1-4, b-d glycosodic units that only become ionized at pH values. In general, all treatments done at high pH's need further neutralization washing steps consequently and large amount of water consumption. The reactive dyeing of cellulosic fibres is a well-known example of this type of treatments. The application of biotechnology to process cellulosic fibres could provide an alternative option for its modifications at milder conditions. The use of enzymes in textile processing has been applied since middle of 19th century when malt extract was used to remove amylaceous sizes before dyeing and printing.

Enzymatic processes have been developed for wet processing of textile goods in wide ranging operations from cleaning preparations to finishing processes. The possibility of replacing alkaline scouring with the enzymatic decomposition of non-cellulosic impurities and increasing the wettability of the textile material in using various types of enzyme-cellulase, pectinase, lipases and proteases under different applications have been studied widely. Enzymes have their optimum condition of temperature and pH. Therefore, the enzymatic

treatment temperature and pH control is important from the point of view of getting the maximum activity from enzymes (Kim et al., 2007).

The enzymatic desizing in textile processing is preferable as enzymes are environment-friendly, non-toxic and the wastewater from enzymatic treatment is biodegradable. They also require mild temperature and pH for their activity, and have the potential of replacing harsh chemicals such as acids and alkalis (Farhan Khan, 2006). Enzymes are used in bio-softening process for improving the low-stress mechanical properties such as tensile linearity (LT), shear stiffness, bending rigidity, and compression energy of finished cotton fabric. Enzymes are protein molecules, which are capable of catalyzing chemical reactions of biological processes and can be recovered at the end of the reaction. Enzymes are also used in textile processes such as pre-treatment, dyeing, and finishing by replacing harmful chemicals.

Cellulase enzymes, which consist of a mixture of endo-glucanase, exo-glucanase and  $\beta$ -glucosidases, are employed to remove the protruding fibers from the fabric surface, and also to improve the texture of the fabric. The Kawabata Evaluation System (KES) or FAST (Fabric Assurance by Simple Testing) equipment are used to test the low-stress mechanical properties of the unfinished and finished fabric. The values for bending rigidity and shear stiffness are lower for the enzyme-treated fabric, and thus show the improvement in softness and drapability of the fabric. Thus, the bio-softening process helps in improving softness, drapability, and smoothness of the cotton fabric (Thilagavathi et. al., 2005).

## **2.8 NATURAL DYES**

Natural dyes are eco-friendly; bio-degradable, non-toxic, non-allergic in comparison to synthetic dyes has not only affected the flora and fauna but also caused threat to human safety. Tus eco-friendly natural dyes are gaining importance not only for the safety of health and environment but also for the lustrous and production of varied colours (Prusti *et al.*, 2010).

In many of the world's developing countries, however, natural dyes can offer not only a rich and varied source of dye stuff, but also the possibilities of an income through sustainable harvest and sale of these dye plants. Using natural dyes contributes to the added value to the textiles and also response to the increase demand of compatibility with the environment. Recently there has been growing interest in the use of natural dyes in textile applications (Choudhury, 2006).

Natural dyes are obtained from natural sources such as vegetable, fruits, minerals and insects. These dyes find use in the coloration of textiles, foods, drugs and cosmetics. Small

quantities of dyes are also used in coloration of paper, leather, shoe polish, wood, cane, candles and such other products requiring coloration (Gulrajani, 2001).

### **2.8.1 History of natural dyes**

Colour has always fascinated man. For centuries man used colour derived from nature, for tinting his skin and later for the colouration of natural fabric which he made from cloth, silk and wool. In every civilisation, from the remote ages to the present day, colour has played an important part in adding beauty to the world. It is difficult to tell when exactly people started making colours, but it must have been pretty early since their evolution (Horrocks et al., 2000).

Coloured fragments of madder dyed cloth have been found in the ruins of the Indus valley civilization of Mohen-jo-daro and Harappa (3500 B. C.). Madder dye has been mentioned as “Majistha” in the Vedas. Quick reference of dyed cloth “pitambar” indicate that the process of dyeing is thousands of years old. India has a very rich tradition of using natural dyes. The introduction of synthetic dyes has, however adversely affected the tradition. Still the art and craft of preparing natural dyes is being practised in many villages in India. The evidence of use of natural dyes during pre-Moghul and Moghul period of Indian history is much preserved in the form of paintings and manuscripts etc. the coloured exquisite silk and muslin fabrics of India had acquired fame throughout the world during the 16<sup>th</sup> and 17<sup>th</sup> centuries (Bhat, 2000).

Dyeing, printing and painting were not the only uses of natural dyes in India. Natural dyes were also and being used till today in food and confectioner examples, saffron, turmeric, Kashmir chilli etc. Natural dyes succumbed to synthetic because of inadequate fastness, time consuming process of preparation and lack of uniformity of colour shades (Gulrajani et al., 2001). Like most Indian crafts, the knowledge and expertise of natural dyes was traditionally passed down from the master craftsmen to his disciple. Consequently, documentation on the source of such dye or colourants, the technique of extraction and application is meagre (Bhat, 2012)

### **2.8.2 Types of natural dyes**

#### **2.8.2.1 Vegetable dyes**

Those derived from roots, bark, wood, leaves, flowers and fruits of the plants.

#### **2.8.2.2 Mineral dyes**

Those derived from minerals and found in nature.

### **2.8.2.3 Natural dyes from Animal origin**

Such as dyes derived from lac, cow urines etc.

### **2.8.3 Advantages of natural dyes**

- They are obtained from renewable resources.
- No health hazards, sometimes they act as health cure.
- Practically no or mild chemical reactions are involved in their preparation
- No disposal problems.
- They are unsophisticated and harmonized with nature.
- Lot of creativity is required to use these dyes judiciously (Gulrajani and Gupta 2001).

### **2.8.4 Disadvantages of natural dyes**

- Limit number of suitable dyes.
- Allow only wool, natural silk, linen and cotton to be dyed.
- Great difficult in blending dyes.
- Non-standardized.
- Inadequate degree of fixation.
- Inadequate fastness properties.
- Water pollution by heavy metals and large number of organic substances.

## **2.9 MORDANT**

A chemical substance, usually containing a metallic ion, used to facilitate the fixing of a dye to a fibre. From the earliest days of dyeing, it was observed that for many natural dyes the colour imparted to a fabric was enhanced and the fastness (resistance to fading or running) improved if the fabric was first treated with a solution containing a soluble metallic salt of chromium, aluminium or copper. In this simplest process model, metal ions are incorporated on the surface and within the fibres of the fabric and upon exposure to dye molecules at the appropriate pH and temperature form coloured metal-dye complexes. The metal ion is called a mordant. The complex formation process is called chelation and can result in a fast and deeply coloured fabric. One of the oldest mordant dyes is alizarin, derived from the root of the madder plant (Johnston, 2020).

### 2.9.1 Types of mordant

Generally, three types of mordant used for dyeing purpose.

- **Metallic mordants:** Salts of aluminium, chromium, iron, copper, tin, zinc, cobalt and rare earth metals are used as metallic mordants (Ammayappan *et al.*, 2013).
- **Tannin:** the name “tannin” is derived from the French “tannin” and is used for a range of natural polyphenols. Tannin is an astringent vegetable product found in a wide variety of plants. Plant parts include bark, wood, fruit, fruit pods, leaves, roots and plant galls. Tannins are high molecular weight water soluble polyphenolic compounds. Myrobalan and sumach are the commonly used mordants in the dyeing of textile fibres. Natural mordants exist in bark of the tree and give dark shades i.e., brown and grey shades. It might resist bacterial growth on fibre (Jun *et al.*, 2008).
- **Oil mordants:** oil mordants which forms complex with main metal mordant. These mordants are used mainly in the dyeing of deep red colour from madder (Chakraborty, 2014).

### 2.9.2 Mordanting Techniques

Mordanting is the treatment of textile fabric with metallic salts or other complex forming agents which bind the natural mordant able dyes onto the textile fibres (Samanta and Agarwal, 2009). Mordanting can be achieved by either pre-mordanting, simultaneously mordanting or post-mordanting. Different types and selective mordants or their combination can be applied on the textile fabrics to obtain varying colour or shade, to increase the dye uptake and improve the colour fastness behaviour of any natural dye (Kalpana *et al.*, 2009).

- **Pre-mordanting**

In this method, samples were pre-treated with the solution of different chemical and natural mordants and then dyed with dye extract.

- **Post-mordanting**

In this method, dyed cotton samples were treated with solution of different chemical and natural mordants (Mehta, 2014).

- **Simultaneous mordanting**

In this method, the cotton samples were dyed with dye extract as well as different chemical and natural mordants.

## 2.10 FINISHING

The word “finish” means all the different treatment applied to a fabric to change one or more of the following:

- Appearance
- Feel or hand
- Wearability or care requirements

Finishing is not only what catches the eye, but the feel and touch that the treated materials impacts. Buyers always expect a high degree of wearing comfort and finishing plays, an important role in achieving. The dyed and printed fabric is applied with different finishing chemicals to impart comfort feel, as well as desired functional effects like wrinkle free, easy care, water-oil stain repellency, moisture management flame 35 hermos 35cy, UV production, antimicrobial insect repellent sensory perception odor absorbent properties of various 35hermos chemical application methods like, padding, coating, spraying (Ashok, 2013). After bleaching, dyeing and printing the textile material is expected to acquire aesthetic value, serviceability and comfort, so that is can attract the buyers. The textile Finishing aims at the improvement in appearance, handle, dimensional stability and serviceability render the textile material fit for their end users (Vijay N Patil et al., 2011).

### 2.10.1 Types of finishing

The term finishing means completing the manufacture of cloth by surface treatment. It abroad sense, it covers all the treatment it undergoes after leaving the loom or the knitting machine till it enters the market and includes processes like bleaching mercerizing, dyeing and printing.

Types of textile finishes can be divided into functional finishes and aesthetic finishes.

- **Functional finishes**, which improve the performance properties of the fabric such as durability, strength etc. Property-changing functional finishes provide the added qualities desired for a particular fabric or they may be used to change an undesirable property to a more desirable one (ex) Aesthetic finishes. Functional finishes are used to alter fibre or fabric performance, maintenance, durability, safety and environmental resistance.
  - ◆ Calendaring
  - ◆ Mercerization

- ◆ Napping and seeding
- ◆ Shearing (Anand, 2000).
- **Aesthetic finishes**, which modify the appearance and/or hand or drape of the fabrics.

Finishing that are applied specifically to alter properties related to care, comfort and durability are generally considered functional finishes. Most functional fabric properties are imported using chemical, wet processing methods (Gray Kavin Hyde, 2007).

### **2.10.2 Classification of finish**

In the technological literature, finishes (and finishing treatment) are divided into groups. Mechanical and chemical finishes. Mechanical finishes can be achieved without the addition of compounds, for example calendaring involving heat, moisture and pressure. Chemical finishing involves the application of compounds as finishing agents, which may not include chemical reactions (Dinah Eastop, 2012). Permanent finish, durable finish, semi durable finish, temporary finish on the basis of degree of performance, generally it is classified as basic finishes and special or functional finishes (Mullik, 2006).

### **2.10.3 Functional finishes**

Functional finishes affect a fabrics performance more than is appearance or hand. These finishes include water repellents, flame-retardants, antistatic, bacteriostats and moth proofing. This finish also affects the care of the fabrics and include soil and stain resistants or minimum care finishes (Jill Condra, 2003).

## **2.11 ANTI-MICROBIAL FINISH**

Antimicrobial finishes, particularly important for industrial fabrics that are exposed to cold weather condition. Fabrics used for wings, windscreen, tents, tarpaulins, ropes, frost protection from rotting and mildew. Home furnishing textiles such as carpets, shower curtains, bath mats, floor mats, mattress ticking and upholstery also require antimicrobial finishes. Fabrics and clothing used in places where there might be danger of infection from pathogens can benefit from antimicrobial finishing (Senthil Kumar, 2013).

### **2.11.1 Fungal Introduction**

Antifungal textiles have been mainly developed for the production of textile itself and a better preservation of the characteristics of the fibre. Dampness favors the development of microscopic fungi, which can damage the textile and cause permanent colouring (Harbhajan Singh, 2006). Fungi are thallopytic that have no green plant pigment. Spores generally

reproduce fungi. The fungi derive organic substances from the bodies of the other organisms, living or dead. The fungal body, which is generally called thallus, is either a single cell or a thread structure. That is called hyphae. In the most fungi, spore-producing cells, form a part of special structure made up of hyphal tissue and called the fruit body. The simplest part of fungi possesses a unicellular, filamentous, branching thallus, whose cytoplasm contains, a great number of partitions to divide them (Mishra, 2005).

### **2.11.2 Bacteria Introduction**

*E. coli* can carry genes that allow the bacteria to colonize the small intestine, where bacterial numbers are usually very low. This allows the bacteria to have earlier access to the nutrients passing down the gastrointestinal tract, removing the need to complete the bacteria of the large intestine (Amyes, 2013). Bacteria produce many enzymes that digest or change complex food materials into simpler compounds into larger compounds. Certain bacteria are able to synthesize all compounds necessary for growth from sugars and essential elements. Others must obtain certain growth factors, vitamins and/or amino acids from the environment. Bacteria occur everywhere in soil, water, air, food, dust, the oceans and are found on and in plants and animals.

## **2.12 PRODUCT DEVELOPMENT**

The urban life has become very congested and the only place of rest is home which is normally indicated by the flats and hence importance of the interior of our homes increases geometrically. Fabric affords sun and light control. It protects interior colour from fading, and furnishings from deterioration through sunlight. Fabrics can increase liveability or workability of a small space, reduce noise, and make music and even speech richer and more resonant. Most importantly, furnishings must make neutral, impersonal spaces particular and personal (Shivendra Parmar et al., 2007).

**Bolster**, is a long thick pillow that is put across the top of the bed under other pillows. Over time, sleeping with a bolster pillow works to counteract poor posture, which also relieves and can eventually reverse pain experienced in the neck, back, and throughout the body.

### III. METHODOLOGY

The methodology of pertaining to the study entitled “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” is discussed under the following side heading

#### **3.1 Selection of natural fibres**

3.1.1) *Chrysopogon zizanioides*

3.1.2) *Banana pseudo-stem fibre*

3.1.3) *Gossypium*

#### **3.2 Extraction of fibre**

3.2.1) Fibre extraction of *Chrysopogon zizanioides*

3.2.2) Fibre extraction of *banana pseudo-stem fibre* and *Gossypium arboreum*

#### **3.3 Manufacturing of yarn**

3.3.1) Carding

3.3.2) Sliver formation

3.3.3) Rotor spinning

#### **3.4 Manufacturing of fabric**

3.4.1) Plain weave

#### **3.5 Pre-treatment of fabric**

3.5.1) Bio-enzyme treatment

3.5.2) Papaya peel treatment

3.5.2.1) Tanning method

#### **3.6 Selection of source for natural dyeing**

3.6.1) Pilot Study

#### **3.7 Extraction of natural dye**

3.7.1) Aqueous extraction method

#### **3.8 Optimization of various parameters for dye extraction**

3.8.1) Solvent

3.8.2) Dye concentration

3.8.3) Time

3.8.4) Temperature

### **3.9 Mordants**

3.9.1) Selection of mordants

3.9.2) Selection of mordanting techniques

3.9.3) Dyeing parameters

### **3.10 Dyeing Method**

### **3.11 Development of product**

### **3.12 Evaluation**

#### **3.12.1 Visual inspection**

#### **3.12.2 Physical and mechanical evaluation**

3.12.2.1 Fabric weight

3.12.2.2 Fabric thickness

3.12.2.3 Tensile strength and Elongation

3.12.2.4 Air-permeability

3.12.2.5 Thermal conductivity

3.12.2.6 Flammability test

#### **3.12.3 Comfort evaluation**

3.12.3.1 Fabric stiffness

3.12.3.2 Crease Recovery

#### **3.12.4 Absorbency evaluation**

3.12.4.1 Wicking test

3.12.4.2 Sinking test

3.12.4.3 Drop test

#### **3.12.5 Colour fastness test**

3.12.5.1 Spectrophotometer Evaluation

#### **3.12.6 Functional evaluation**

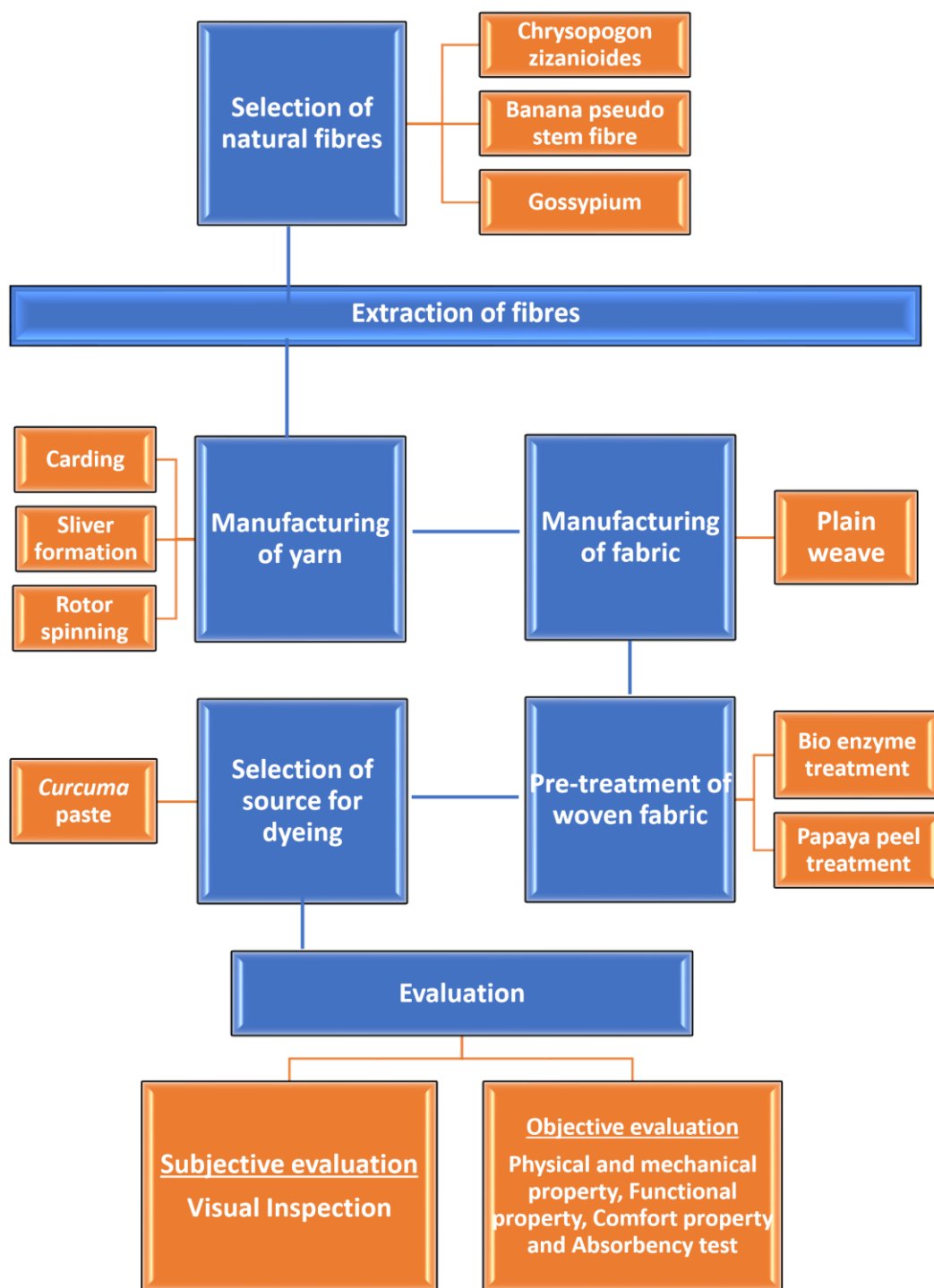
3.12.6.1 Anti-bacterial activity

3.12.6.2 Anti-fungal activity

### **3.13 Statistical Analysis**

### **3.14 Nomenclature**

## METHODOLOGY



## FLOW CHART OF EXPERIMENTAL PROCEDURE

### **3.1 Selection of Natural Fibres**

#### **3.1.1 Chrysopogon zizanioides**

Vetiver (*Chrysopogon zizanioides*) is characterized by its extensive root system that tends to grow deep up to 4 m or more. Because of such characteristic, it is commonly planted to prevent soil erosion in sloping areas. The root yields high quality, woody, and heavy-scented essential oil which is used as a flavouring in canned asparagus and peas, fruit drinks, syrup sweets, etc.

The roots are used to make baskets, fans, mats, and cooling screens. Powdered roots show insecticidal properties. Stems and old leaves, on the other hand, are used either as thatch or process into a coarse paper-pulp (Roberty, 2021). The microscopic view of vetiver root fibre is given in Plate I.

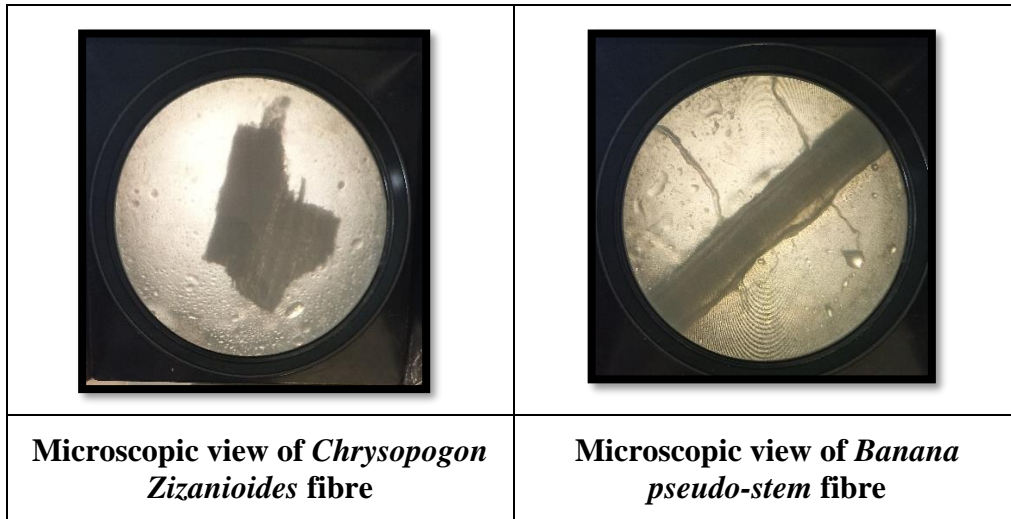
#### **3.1.2 Banana pseudo-stem fibre**

Natural fibres have under intensive study worldwide due to their continuous supply, safe handling biodegradability and nontoxicity. They are usually low-cost fibres with low density with high specific properties (Santhosha et al., 2018). Banana pseudo-stem fibres is characterised as bast fibres and is re-owned as good source of fibre in India, Philippines, Nepal and Japan (Ramdhonee et al., 2017). Almost each and every part of banana plant gives fibres of various strength, colour and long staple length. There is 14 to 18 sheath layers available in the stem, the outermost for 4-6 sheaths yield courser fibres, while the next 6-8 sheaths are soft and lustrous fibres, and the rest middle sheaths excluding the innermost 4-6 sheaths are very soft fibres (Vigneshwaran et al., 2015). The banana pseudo-stem is also used as pulp and paper, fibre for textile products and filler for structural reinforcement in composites material (Salleh et al., 2015). The microscopic view of banana fibre is given in Plate I.

#### **3.1.3 Gossypium**

It is wonderfully versatile and globally important fibre due to its excellent properties like absorbency, biodegradable, breathable, drape, easily sterilized, high weight strength, insulation properties, non-allergenic, renewable resource, softness and water retaining capacity. Cotton continues to dominate the natural fibres and can be formed into woven, braided, non-woven or knitted fabric (Cothorn, 2005). Cotton is the most important natural and cellulosic textile fibre in the world, to produce apparel, home furnishings, and industrial products. Out of total fibre consumption, cotton fibre was consumed worldwide about 40% in

2004. Cotton is a natural fibre that is grown in countries around the world. It is a crop that requires adequate moisture and heat to mature and produce quality fibers. Cotton growing tends to be in warmer climates. Cotton is a true commodity in the world markets and supply and demands truly affect the prices of raw cotton (Aryan Rathore, 2022).

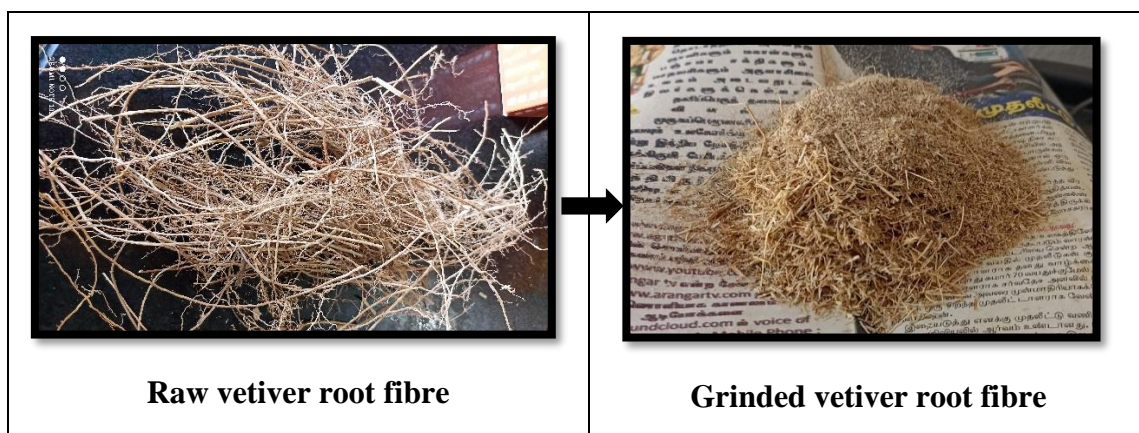


**Plate I**  
Microscopic view of selected fibres

### 3.2 Extraction of fibre

#### 3.2.1 *Chrysopogon zizanioides*

Vetiver is used as a raw material, which has been cleaned and separated into small particles and grinded as a mixture to make the vetiver in rough powder form. The vetiver powder is used as a fibre to make blended woven fabric (Plate II).



**Plate II**  
Fibre extraction of *Chrysopogon zizanioides*

### 3.2.2 *Banana pseudo-stem and Gossypium arboreum fibre*

*Banana pseudo-stem* and *Gossypium arboreum* fibres were purchased from market.

**Table. 9**  
**Selected Fibres**

<b>Fibre</b>	<b>Weight in grams</b>
<i>Chrysopogon zizanioides</i>	500 gm
<i>Banana pseudo-stem fibre</i>	500 gm
<i>Gossypium arboreum</i>	1000 gm

### 3.3 Manufacturing of yarn

The blended yarn was produced by series of carding, sliver formation and rotor spinning. A fibre blend of *Chrysopogon zizanioides*, *Banana pseudo-stem fibre* and *Gossypium arboreum* at ratio of 1:1:2 yielded 375 grams of yarn.

**Table. 10**  
**The weight of fibres used for manufacturing of yarn**

<b>Fibres</b>	<b>Fibre weight in %</b>
<i>Chrysopogon zizanioides</i> (Vetiver root fibre)	<b>12.5</b>
<i>Banana pseudo-stem fibre</i> (Raw banana fibre)	<b>12.5</b>
<i>Gossypium arboreum</i> (Cotton)	<b>25</b>

#### 3.3.1 Carding

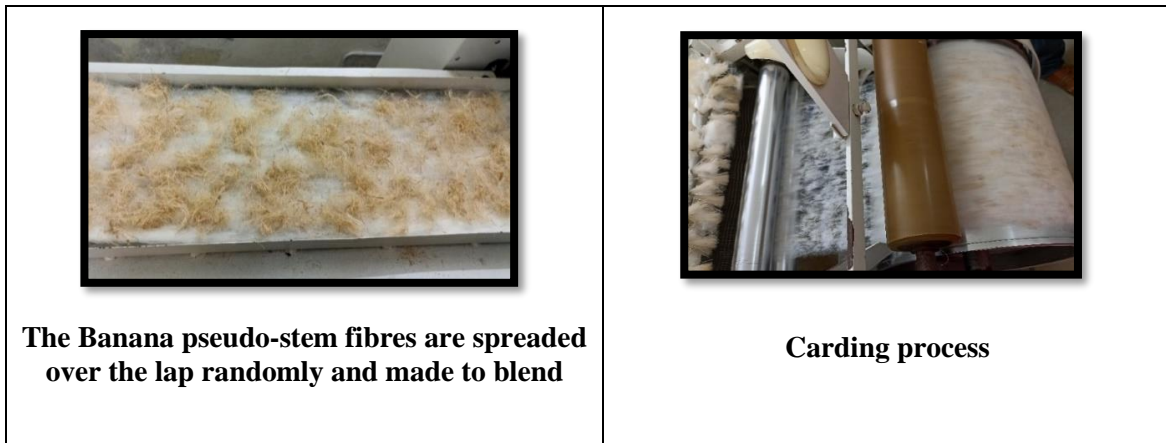
In textile production, carding is a process of separating individual fibres, using a series of dividing and redividing steps, that causes many of the fibres to lie parallel to one another while also removing most of the remaining impurities.

**Step 1:** On the carding machine, the cotton fibres were evenly spread and passed through the feeder, cylinder and doffer. The comb-like structure of the large cylinder, opened the fibres, and then the lap formed as output.

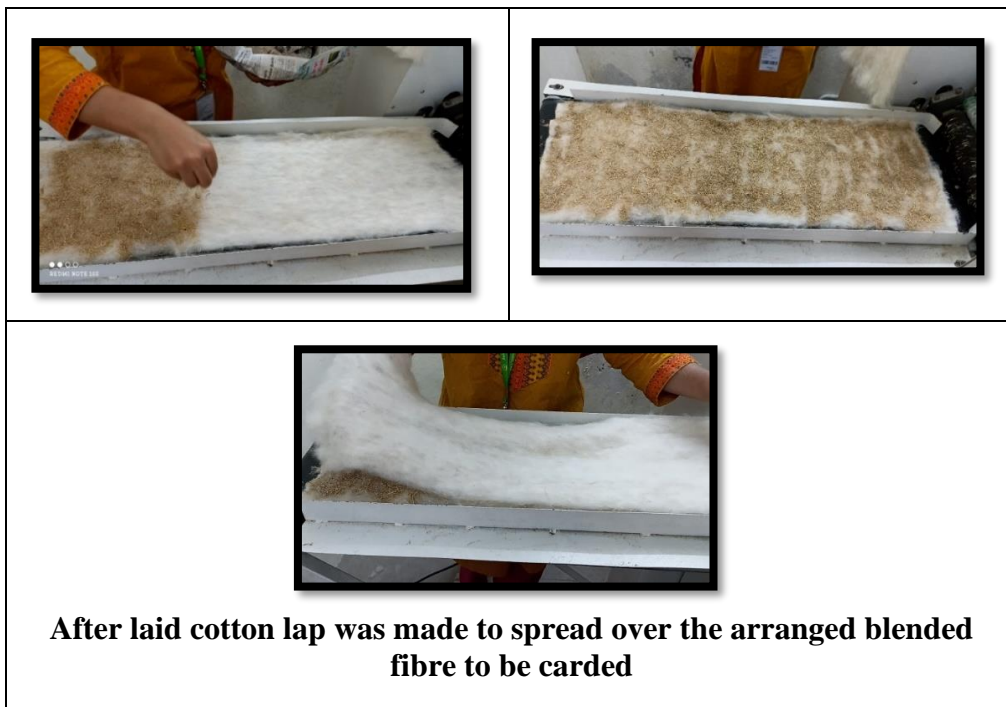
**Step 2:** The lap has eight layers of cotton web, which are parallelly opened as two parts. Then banana fibre was evenly distributed. Afterwards, close the top portion of lap and then the

carding procedure was done. By the following procedures, the cotton and banana fibre blended lap was produced (Plate III).

**Step 3:** Similarly, these procedures were used to create a final lap with the *Chrysopogon Zizanioides* (Vetiver root fibre). At last, Cotton, banana and vetiver root fibre lap were blended together (Plate IV).



**Plate III  
Lap formation**



**Plate IV  
Preparations of carding process**

### 3.3.2 Sliver formation

A sliver is a long bundle of fibre, which is used to make yarn. A sliver is made by carding or combing the fibre, then drawing it into long strips with parallel fibres. During roving, sliver was drawn further with a slight twist.

### 3.3.3 Rotor spinning

Rotor spinning is similar to ring-spun yarns and usually made from short staple fibres. They produce a more regular and smoother, though weaker yarn than ring spinning (Alagirusamy Ramasamy, 2015) (Plate V).



**Plate V**  
**Rotor spinning process**

### 3.4 Manufacturing of fabric

The weight of 500 gm of *chrysopogon zizanioides*, 500 gm of *Banana pseudo-stem fibre* and 1000 gm of *gossypium arboreum* fibres were used to construct the fabric. In that, ratio of 1:1:2 yielded fabric with 5 meters length and 15-inch width.



**Plate VI**  
**Blended woven Fabric**

### **3.4.1 Plain weave (2x2)**

A weave, which has 2 ends and 2 picks in a repeat is called a plain weave. It is the simplest of all weaves and variously known as “calico” or “tabby” weave.

- It has the maximum number of binding points.
- It has the smallest repeat 2 x 2.
- Both sides of the weave are identical.
- Minimum 2 heald frames are required to form the weave (Sohanur Rahman Sobuj, 2015).

Plain weave is the simplest of all woven fabric structures, interlacing in a one under one over formation. This gives the fabric balance with equal amounts of warp and weft threads. It is completely reversible and has a very sound structure. Although the simplest of weaves it is known as the hardest to perfect, as threads are interacting with one another at once giving more room for error (Jenny Newman, 2015) (Plate VI).

### **3.5 Pre-treatment of fabric**

Pre-treatment is the processes that are used to remove impurities from fabric to make it dyeable or printable. Natural fibres and synthetic fibres contain primary impurities that are contained naturally and secondary impurities that are added during spinning, knitting and weaving processes. All impurities, which causes adverse effect during dyeing and printing, are removed in the pre-treatment process (Shahriar Shovon, 2020).

#### **3.5.1 Bio-enzyme treatment**

In order to remove the added impurities in the fabrics, all the fabrics were subjected to pre washing cum relaxation process using 2 gpl of non-ionic detergent, with a MLR of 1:20 at 70°C for a period of 20 min and dried at room temperature. The fabrics were applied with the recipe of solution concentration: 10% (v/v) of bio enzyme solution and 1% of Wetting agent. Glucose was used as wetting agent in the treatment process. The wet pick-up or absorbency of the fabric was 100% for the given fabric material. Entire treatment process was done for 90min. The fabric was removed from the mixture and washed with distilled water. Similar process was done for three cycles till fabric gets softened and decolorized. After three cycles of treatment, the fabrics were then dried in a drying chamber for 10min at 80°C and then cured for another 4 min at 120°C in a curing chamber (Plate VII).



**Plate VII**  
**Bio-enzymatic treatment process**

### 3.5.2 Papaya peel treatment

Enzymes are produced mainly by plants, some filamentous fungi, yeast and many other microorganisms which finds applications in food industries, confectionaries, pharmaceuticals, etc., Papaya fruit peel was treated with water for four days, and the extracted water is used as enzyme solution in tanning method (Chelliappan, 2021) (Plate VIII).




#### 3.5.2.1 Tanning method

In order to add softness to the fabric, all the fabrics were subjected to pre-washing cum relaxation process using 2 gpl of non-ionic detergent, with MLR of 1:20 at 70°C for a period of 20 minutes and dried at room temperature.

**Table. 11**  
**Recipe of Papaya peel treatment**

Papaya fruit peel	2Kg
H <sub>2</sub> O (water)	2 litres
Temperature	Room temperature
Time	45 minutes
Cycles	3 Cycles

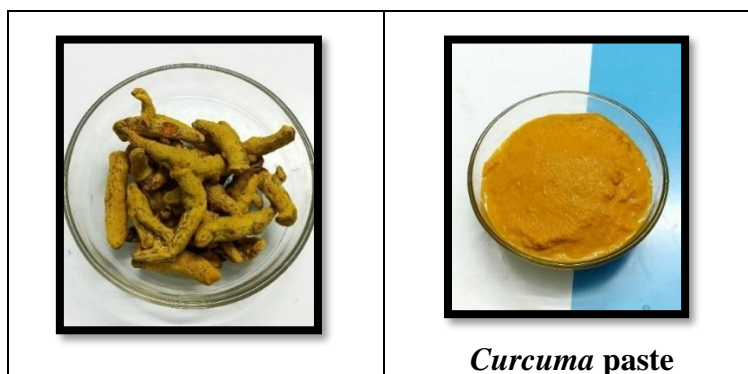
The wet pick-up of the fabric was 100% for the given fabric material. Entire treatment process was done for 45 minutes. The fabric was removed from the mixture and washed with distilled water. Similar process was done for three cycles of treatment, the fabrics were then dried in a drying chamber for 10 minutes at room temperature.

		
Papaya fruit peel	Tanning of papaya fruit peel for 4 days	Soaking the fabric

**Plate VIII**  
**Papaya peel treatment**

### 3.6 Selection of Source for Natural Dyeing

Natural dyes are colourants extracted from vegetable matter, minerals or insects. These dyes are considered as eco-friendly dyes or mordant dyes as they require the inclusion of one or more metallic salts (Huger, 2007). The natural dye namely *Curcuma* (Turmeric) can be used as a brighter shade of natural dye on textiles especially blended fabric. It is non-carcinogenic in nature and so does not affect human body or environment. Hence, the research selects the *curcuma* for this study (Plate VII).



**Plate IX**  
***Curcuma* (Turmeric)**

#### 3.6.1 Pilot Study

The shade of dyeing is expressed as a percentage of dye and fabric. The material to liquor ratio is also a unique quantity. This represents the percentage of dye stuff and the material to liquor ratio which reflects the concentration of the dye bath (Song, 2011) (Plate X).

**Table. 12**

**Pilot study for selection of dyeing parameters**

<b>Samples</b>	<b><i>Curcuma</i> paste (gm)</b>	<b>Fabric weight</b>	<b>Time</b>	<b>Temperature</b>
Sample 1	5 gm	5 gm	45 min	100° C
Sample 2	10 gm			
Sample 3	15 gm			
Sample 4	20 gm			



**Plate X**  
**Selection of Dyeing parameters**

### **3.7 Optimization of various parameters for dye extraction**

#### **3.7.1 Solvent**

To determine the suitable solvent for dye extraction, 20g of *curcuma* paste were mixed with water. The water ratio is 200ml for 20g of *curcuma* paste. The solvent which showed higher absorbance was selected as the suitable solvent and used for further studies extraction (Ammayappan et al., 2013).

#### **3.7.2 Dye concentration**

To determine the optimum concentration of the dye *curcuma*, paste at various concentration such as 5g, 10, 15g and 20g were taken individually and placed in conventional dye bath for 45 minutes. The final quantity of *curcuma* pastes and water ratio is 20g and 200ml. The optical density of the dye solution was determined. The concentration at which the absorbance was maximum was fixed for the subsequent study.

### 3.8.3 Time

To determine the optimum incubation time, the dye extraction was carried out at different time intervals such as 30 – 150 minutes. The time at which the absorbance was maximum are selected as optimum time.

### 3.7.4 Temperature

To determine the optimum temperature, the dye extraction was carried out at different temperature such as 60-100° C. The temperature which the absorbance was maximum was selected as optimum temperature for dye extraction.

## 3.8 Extraction of *Curcuma* dye

### 3.8.1 Aqueous extraction method

In this method, the dye containing material are broken into small pieces and then soaked in water overnight. It is boiled and filtered to remove fine impurities.

*Curcuma* (Turmeric) was grinded into a smooth paste and 20 g of dye paste which was taken in a beaker containing 200 ml of water and allowed to boil for 45 minutes at 100° C. The resulting dye extract was filtered and used as dye solution (Bhattacharyya, 2010).

**Table. 13**  
**Recipe of *curcuma* dye extraction**

Materials	Selected parameters
<i>Curcuma</i> paste	20 g
Water	200 ml
Temperature	100° C
Time	45 minutes

## 3.9 Mordant

### 3.9.1 Selection of mordants

The mordant is a substance used to set dyes on fabrics or tissue sections by forming a co-ordinating complex with the dye which then attaches to the fabric or tissue. The selected natural mordants for this study are pomegranate rind and myrobolan. Pilot study was carried out by conventional method. Among these naturals mordant, myrobolan gave better colour when simultaneous mordanting technique was followed, so myrobolan was selected for this study.

### 3.9.2 Selection of mordanting techniques

Mordanting is a process of impregnating textiles with a mordant usually salt or acid to faster the dye stuff, which is applied before or after the dye stuff. The three ways of mordanting are pre-mordanting. Post-mordanting and simultaneous mordanting. In this pre-mordanting technique the sample is mordanted and then dyed. In post-mordanting technique the sample is first dyed and then mordanted. Simultaneous mordanting is which mordanting and dyeing are carried out at the same time (Herbst and Hunger, 2006). Among these three mordanting technique, the **simultaneous technique** which gave better results when treated with myrobolan, which is a natural mordant was selected for this study.

### 3.9.3 Dyeing parameters

Dyeing parameters namely dye concentration, dyeing time, mordant concentration and mordanting time were selected and followed for the study. The parameter for dyeing the selected cotton fabric as follows:

**Table. 14**  
**Parameters for dyeing**

Material liquor ratio	1:40
Dye soaking time	45 minutes
Dyeing temperature	100° C
Mordant soaking time	45 minutes
Mordanting temperature	100° C

### 3.10 Dyeing Method

Aqueous extract of fresh grind *curcuma* was chosen as colouring material for dyeing blended woven fabric. Dyeing was performed at 100° C for 45 minutes using fixed amount (M:L - 1:40, 1g of blended woven fabric, 40 ml of extracted was taken) of extract in dyeing glass.

**Simultaneous mordant technique:** The mordant is added with natural dye in the same dye bath; dyeing and mordanting take place simultaneously. The application of natural dyes on blended woven material was done by the dipped method.

Dyed sample were extensively washed with cold and hot water to remove any unfixed dyed material and finally dried at room temperature.



**Plate XI**  
**Dyed fabric**

### **3.11 Development of Product**

The dyed fabric was used to make a bolster. It is a long thick pillow that is put across the top of the bed under other pillows or it can be used as decorative product in cushion set. The measurement of bolster is, 25-inch length and 22-inch circumference. The cutting and stitching procedure was followed to make a bolster cover.

### **3.12 Evaluation of finished fabric**

To evaluate the impact of the treated and untreated fabric samples. The samples were evaluated subjectively and objectively.

#### **3.12.1 Subjective Evaluation - Visual inspection**

The fabric samples dyed with *curcuma* (Turmeric) was evaluated visually by the panel members comprising of 25 Post Graduate students specializing in the field of textiles and clothing, evaluated the fabric for general appearance, brilliancy of shade and evenness of dyeing.

#### **3.12.2 Objective Evaluation - Physical and mechanical property**

Physical properties include those that characterized the physical structure of the fabrics and test that measure these properties are sometimes called characterization tests. Physical properties include width, weight and the number of fabric weight, and fabric thickness.

##### **3.12.2.1 Fabric weight (ASTM 3776)**

Fabric weight is determined by weighting the complete piece roll, cut or bolt, or by selecting and weighting the a full with sample, ¼ yard in length there from the weight per

square yard, weight per square yard, weight per linear yard, per pound maybe calculated as follows yards.

$$\text{Fabric weight} = \frac{\text{Fabric weight in lb} \times 6 \times 36}{\text{Fabric length in yards}} \times \text{width in inches}$$

The O was cut with GSM (Grams per square meter) die cutter which is 100 cm<sup>2</sup> (Plate XII). The sample was weighed in an electronic balance. The weight of the sample was measured in grams and multiplied with 100 to get GSM value. Ten samples were tested and the average was calculated. The same procedure was followed for all OF, ETF, PPTF, DF samples.

### **3.12.2.2 Fabric thickness (ASTM 1777)**

Fabric thickness is an important property that adds to the insulating effect. Two thin layers of fabric are more effect. Two thin layers of fabric are more effective than one thick layer because there is extra dead air space between the two layers. Fine fibres fill up spaces in fabric layers and increase its insulating effect. Thickness gauge is the instrument used for measuring fabric thickness (Arrora, 2010). In order to determine the thickness of a compressible material such as textile fabric, the precise measurement of the distance between two parallel plates should be measured with the cloth separates them. A known arbitrary pressure between the plats should be applied and maintained. It is useful to measure fabric thickness is also useful to measure fabric thickness in order to check the material against the specification. Fabric thickness is also useful in studying fabric properties such as thermal insulation, resilience, dimensional stability, fabric stiffness, abrasion and total handle value (Kothari, 2012) (Plate XIII)

### **3.12.2.3 Tensile strength and Elongation (ASTM 848)**

Tensile strength is the most important property of a fabric. In almost every fabric development and manufacturing, tensile properties are reported. Modules, breaking strength and elongation at break are widely used for quality control. This method of tensile testing was commonly used in textile industries such as cotton, wool and flax, but is increasingly being replaced by the single and strength test method. Another important quality of practical interest is the breaking length of the yarn, expressed in kilometres. The breaking length of the specimen breaking under its own weight when suspended vertically, this quantity is usually calculated from the tensile strength (Hall, 2001).

Each sample was clamped between the jaws. It is necessary to see whether the sample was perpendicular to the load. The load was applied and the readings were noted in kilograms and the elongation in inches as well as centimetres was noted as soon as the sample was broken. Ten samples were taken and the mean strength and elongation was found out to the strength loss or gain in the fabric before and after finishing. Similarly OF, ETF, PPTF, DF also tested using same procedure (Plate XIV)

#### **3.12.2.4 Air-permeability (ASTM D 737-96)**

Air permeability is determined by measuring the rate of airflow through a known area of material. This is achieved by applying a known pressure differential across a set area of material. Both these factors can be selected for the particular type of material being tested.

Air permeability of a fabric is the volume of air measured in cubic cm passed per second through 1 sq. cm for the fabric at a pressure of one cm. head of water. Air permeability can be measured using an instrument called Shirley Air Permeability Tester. Air permeability was determined in accordance with Test Method ASTM D-737-96. The conditioned specimens in the standard atmosphere for testing textiles,  $21 \pm 1^\circ\text{C}$  and  $65 \pm 2\%$  relative humidity was tested unless otherwise specified in a material specification or contract order. The test specimens (enzyme treated and untreated swatches) were carefully handled to avoid altering the natural state of the material. Placed each test specimen onto the test head of the test instrument, and performed the test as specified in the manufacturer's operating instructions. Read and recorded the individual test results in SI units as  $\text{cm}^3/\text{s}/\text{cm}^2$ .

#### **3.12.2.5 Thermal conductivity (ISO 11092)**

Thermal conductivity testing is the ability of a material to transmit heat and it is measured in watts per meter- kelvin of surface area for a temperature gradient of 1K per unit thickness of 1m. It is denoted by  $k$ ,  $\lambda$ , or  $\kappa$ . Heat transfer is comparatively slower across materials with low thermal conductivity whereas higher in materials with high thermal conductivity. Hence, the application of this material varies with its conductivity; for example, materials with high conductivity are preferably used as a heat sink and for thermal insulation, a material with low thermal conductivity testing is considered.

The thermal comfort properties (Thermal conductivity) of the enzyme treated, untreated, papaya peel treated and dyed fabric were evaluated. The Alambeta instrument was used to measure thermal conductivity. In this instrument the fabric is kept between the hot and

cold plates according to ISO 11092 method. The detailed protocol was presented in (Prakash et al., 2012).

### **3.12.2.6 Flammability test (ASTM D6413)**

Flammability test methods measure how easily materials ignite, how quickly they burn and how they react when burned. The materials are placed over a Bunsen burner either vertically or horizontally, depending on the specification. During a vertical flammability test, a material is observed for the length of time it burns after the igniting flame is removed, how much of the specimen burns and whether or not it drips flaming particles. In contrast, horizontal flammability tests observe if the material continues to burn after the test flame is removed, and then calculate the rate at which the specimen burns (Plate XX).

### **3.12.3 Comfort property**

#### **3.12.3.1 Fabric stiffness (ASTM 1388)**

The main purpose of the stiffness function is to provide a means to automate the calculation of the stiffness matrix of arbitrary finite elements and thereby increasing the flexibility of the meshing process. The facility with which the material stiffness matrix can be calculated is not only important in terms of under spinning mesh refinement and adaptive meshing, but more importantly, to conduct a more correct and precise, i.e., material adaptive stress analysis (Weissenbach, 2004).

A 5x1 rectangular strip of fabric is mounted on a horizontal platform in such a way that it overhangs, like a cantilever and bends downwards. From the length and angle, a number of values are determined. Each specimen is tested four times, at each end and again with the strip turned over. Mean value for the bending length in warp and weft direction can be calculated and if required, values for flexural rigidity and bending modules can also be included (Plate XV).

#### **3.12.3.2 Crease Recovery (ISO 2313)**

The crease recovery of the fabric sample is checked to remove crease load present in the fabric. The Eureka Crease Recovery tester has gripping spring wale underneath the knot attached to a dial plate engraved with clamp which holds the fabric.

The original fabric, bio-enzyme treated fabric, papaya peel treated and dyed fabric is cut using the template of one inch wide and two inch long. It is carefully folded and kept properly at the centre of creased thickness tester under the 2kg load. After two – five minutes

the fabric is taken out and placed onto the clamp of crease recovery tester and then dial was rotated for two minutes and degree of the sample is noted from the engraved scale.

### **3.12.4 Absorbency property**

The absorbency test includes drop test, sinking test and wicking test.

#### **3.12.4.1 Wicking test (AATCC 197)**

Wetting and wicking in textile fabric are complex processes. The liquid comes into direct contact with fibres, forming a solid-liquid (wetting) and is then transported in the capillaries between the fibres must first wetted, so wetting is an essential procure or to wicking characteristics of fabric depend on the chemical nature of both the liquid and the fibre and on the fabric structure itself (Ward man et al., 2011). This test method measures the distance water will wick up a cut edge of fabric (Wasif, 2013). A strip of fabric was suspended vertically with its lower edge in reservoir of distilled water. The rate of rise of the leading edge of water was then noted. To detect the position of water line a dye was added to the water after 5 minutes and the rise in the water line was noted. The measured height of rise in 5 minutes was taken as a direct indication of the test fabric and recorded in centimetres (Plate XIX).

#### **3.12.4.2 Sinking test (AATCC 79)**

Sinking time test can also be carried out on the fabric cutting it in to a specific small size and dropping the same on the surface of water loosely without putting any thrust (Choudhry, 2006). Fibres of known density are placed in the column and allowed to reach their staple position in the liquid i.e., where the density of the fibre matches that of the liquid. The test fibre is introduced into the system and the point at which the sample stops sinking is taken as the point of equivalent density (Houck, 2009). Ten samples were cut into the size of 5x5cm square from the untreated and treated samples. A 1000 ml beaker was filled with water. The sample was dropped into the surface of the water from a standard height. The stopwatch was started when the fabric struck the surface and the time required for the sample to sink was noted. The same procedure was repeated for five samples. The mean value was calculated for the above samples. Similarly, the mean values of the untreated and treated samples were calculated and the sinking time of each material was recorded separately (Plate XVII).

#### **3.12.4.3 Drop test (AATCC 79)**

It was noted earlier that in the initial stages of wetting the drops of wetter pearl off the fabric but in time pearling ceases, the fabric become wet. The drop test is a count of number of

drops required to penetrate through to the underside of the fabric when all the drops fall on the same spot, (Raul, 2005).

A burette filled with distilled water was clamped in a stand. The stand was mounted in an embroidery frame and was placed at the base of the stand. The distance between the sample and the burette nozzle was kept constant. The nozzle of the burette was opened just to allow a drop of water to fall on the sample. The stopwatch was started simultaneously and it was stopped when the drop of water fully sank into the material. The time taken for this was noted. The same procedure was carried out for the untreated and treated sample and the mean value was calculated and recorded (Plate XVIII).

### **3.12.5 Colour fastness test**

#### **3.12.5.1 Spectrophotometer Test (ASTM D1925)**

The spectrophotometer is a physical apparatus which is famously fit to gauge the main variable of all, the shade and strength of the actual dyestuffs, whether they be in solution or on the fibre (Simon, 1949). Spectrophotometer test is done in dyed cotton fabric to capture appearance and colour of the fabric. Both colour and appearance on a physical sample has greatly improved quality, consistency, and speed to market. To make colour approvals on-screen, the digital colour file has also been colour-accurate.

Spectrophotometers are the most popular and widely recognized tools, providing colour data in the  $L^*$   $a^*$   $b^*$  colour space defined by the CIE (Commission Internationale de l'éclairage). This is the most popular standardized colour space, being a mathematical transformation of the CIE XYZ colour space. The following colour coordinates can be determined by means of a spectrophotometer:  $L^*$  – lightness,  $a^*$  - green/red,  $b^*$  - blue/yellow,  $C^*$  - chroma- an attribute of colour used to indicate the degree of departure of the colour from a grey of the same lightness.,  $h$  – hue angle- an attribute of visual perception according to which an area appears to be similar to one of the colours: red, green, yellow and blue, or to a combination of adjacent pairs of these colours arranged in a circle.

### **3.12.6 Functional property**

#### **3.12.6.1 Anti-bacterial activity (EN ISO 20645)**

Antibacterial as well as antiviral activity of a molecule is completely associated with the compounds that provincially kill bacteria and virus or slow down their rate of growth, without being extensively toxic to nearby tissues. Most recently discovered antimicrobial

agents are modified natural compounds and this modification is done through chemical mode, for example, b-lactams (penicillins), carbapenems, or cephalosporin. Pure natural products, such as aminoglycosides, and other entirely synthetic antibiotics, for example, sulfonamides, are also frequently used (Kushagri Singh and Kavita Singh, 2019).

The test specimens [Enzyme treated and Untreated fabrics] were cut into pieces (20mm in diameter). Sterile Mueller-Hinton Agar (MHA) plates (Composition g/L: Acid hydrolysate of Casein: 17.5g; Starch: 1.5g, Sodium chloride: 5.0g, Agar 17.0 g; Final pH (7.0 ± 0.2) were prepared. Using sterile 4mm inoculating loop or cotton swabs, test culture (*Escherichia coli*, *Staphylococcus aureus*) was transferred by swabbing all around the surface and central part of the MHA plates. For each test organism, separate Mueller-Hinton agar (MHA) plates were used in a sterile zone. All the inoculated plates were incubated at 37°C for 24 hours. The test plates were examined for the clear zone of inhibition around the Treated fabrics. The average width of the zone of inhibition around each type of fabric specimen was calculated. The zone of inhibition was measured in millimetre (mm).

#### **3.12.6.2 Anti-fungal activity (ISO 13629)**

The antifungal activity exerted by citral against molds and yeasts has already been demonstrated in varied conditions. Recently, it was demonstrated that citral has the ability to destroy the integrity of the cell membrane, releasing the cellular components of *Geotrichum citri-aurantii* and dramatically inhibiting the mycelial growth of *Penicillium italicum* through a mechanism of cell membrane damage, compromising its integrity and permeability have demonstrated that citral exhibits significant in vitro activity against *C. glabrata*, *C. krusei*, *C. parapsilosis*, and *C. tropicalis*, and especially against species of *C. albicans*. demonstrated the anti-Candida activity of six terpenoids; all showed excellent activity against *C. albicans* isolates, being the most effective linalool and citral, (Maria Clerya Alvino Leite et al., 2014).

The test specimens [Enzyme treated and Untreated fabrics] were cut into pieces (20mm in diameter). Sterile Mueller-Hinton Agar (MHA) plates (Composition g/L: Acid hydrolysate of Casein: 17.5g; Starch: 1.5g, Sodium chloride: 5.0g, Agar 17.0 g; Final pH (7.0 ± 0.2) were prepared. Using sterile 4mm inoculating loop or cotton swabs, test culture (*Candida albicans* and *Candida tropicalis*) was transferred by swabbing all around the surface and central part of the MHA plates. For each test organism, separate Mueller-Hinton agar (MHA) plates were used in a sterile zone. All the inoculated plates were incubated at 37°C for 24 hours. The test plates were examined for the clear zone of inhibition around the Treated fabrics. The average

width of the zone of inhibition around each type of fabric specimen was calculated. The zone of inhibition was measured in millimetre (mm).



**Plate XII**  
**Fabric GSM cutter**



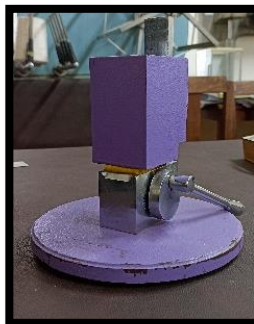
**Plate XIII**  
**Fabric Thickness**



**Plate XIV**  
**Tensile strength tester**



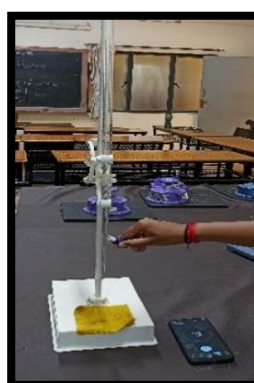
**Plate XV**  
**Fabric Stiffness tester**



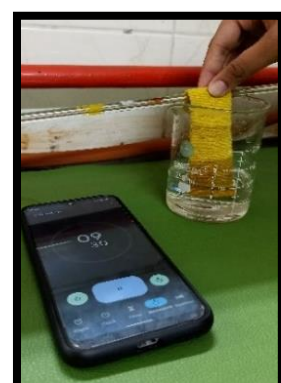
**Plate XVI**  
**Crease recovery tester**



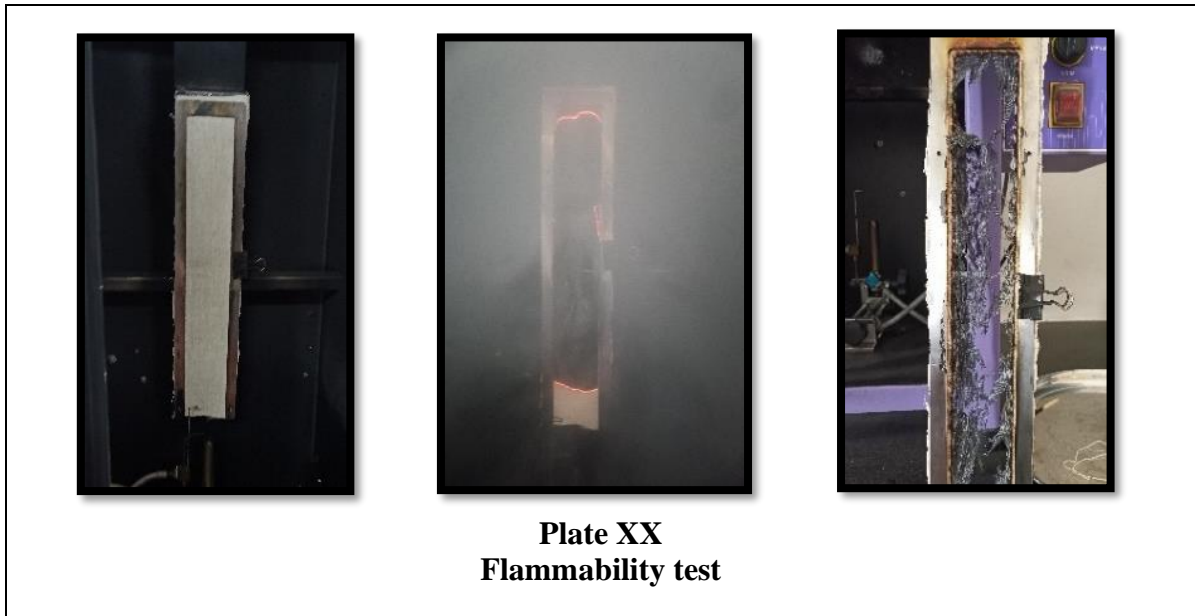
**Plate XVII**  
**Sinking test**



**Plate XVIII**  
**Drop test**



**Plate XIX**  
**Wicking test**



### 3.13 Statistical Analysis

Statistical is used in getting more accurate values. Here information, that are found is tend to be more reliable compared to the ones made by the assumption values. So, by using this statistical analysis it reduces making wrong values. ANOVA method is used to compare the pre-treated and dyed values of the samples to predict the mean value and many other independent groups. This method was mainly carried out to find whether the experiment results are significant.

### 3.14 Nomenclature

**Table. 15**  
**Nomenclature of the samples**

S. No.	Code	Samples
1	OS	Original Sample
2	ETS	Enzyme Treated Sample
3	PPTS	Papaya Peel Treated Sample
4	DS	Dyed Sample

## **IV. RESULT AND DISCUSSION**

The results of the study on “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**”, presented in results and discussion are as follows.

### **4.1 Subjective Evaluation**

4.1.1 Visual Inspection

### **4.2 Objective Evaluation**

#### **4.2.1 Physical and Mechanical Evaluation**

- 4.2.1.1) Fabric Weight
- 4.2.1.2) Fabric Thickness
- 4.2.1.3) Fabric Strength – Warp
- 4.2.1.4) Fabric Strength – Weft
- 4.2.1.5) Fabric Elongation – Warp
- 4.2.1.6) Fabric Elongation – Weft
- 4.2.1.7) Air Permeability Test
- 4.2.1.8) Thermal Conductivity Test
- 4.2.1.9) Flammability Test – Flame time
- 4.2.1.10) Flammability Test – Glow time

#### **4.2.2 Absorbency Evaluation**

- 4.2.2.1) Drop Test
- 4.2.2.2) Wicking Test
- 4.2.2.3) Sinking Test

#### **4.2.3 Comfort Property**

- 4.2.3.1) Fabric Stiffness – Warp
- 4.2.3.2) Fabric Stiffness – Weft
- 4.2.3.3) Crease Recovery Test

#### **4.2.4 Colour Fastness Test**

- 4.2.4.1) Colour fastness to sunlight, crocking and wicking
- 4.2.4.2) Spectrophotometer Evaluation

#### **4.2.5 Functional Evaluation**

- 4.2.5.1) Anti-bacterial Activity
- 4.2.5.2) Anti-Fungal Activity

## 4.1 Subjective Evaluation

### 4.1.1 Visual Inspection

The 25 post graduate students from textiles and clothing department were selected for evaluating the dyed fabric as given in table 16.

**Table. 16**  
**Visual Inspection**

S.no	Sample	Rating in percentage							
		Texture			Appearance			Evenness in dyeing	
		Good	Fair	Poor	Good	Fair	Poor	Even	Uneven
1.	DS	87	13	-	91	9	-	97	3

DS- Dyed Sample

From Table 1, it is evident that the general appearance of the dyed cotton fabric was rated as good as expressed by 91%. The evenness and texture of dyed fabric is rated as 97% and 87% because of the fabric appearance and its evenness in dyeing.

## 4.2.1 Physical and Mechanical Evaluation

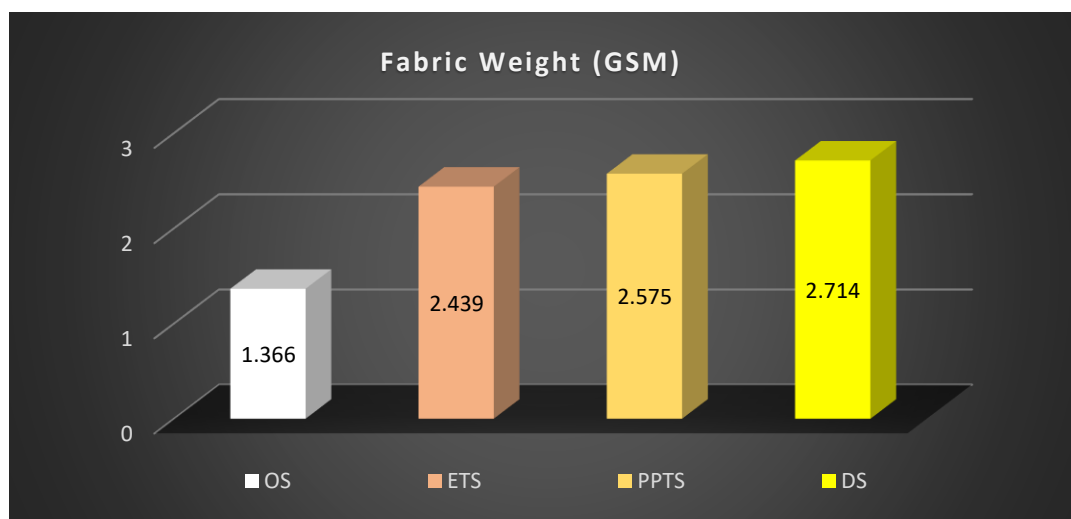
### 4.2.1.1 Fabric Weight

The fabric weight and analysis of variance of the sample OS, ETS, PPTS and DS were shown in Table.17 and Figure 4.

**Table 17**  
**Fabric weight (GSM)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test value	P value
OS	1.366	0.0773	-	-	1972.83	0.001**
ETS	2.439	0.0314	(+) 1.073	78.55		
PPTS	2.575	0.0143	(+) 1.209	88.50		
DS	2.714	0.0222	(+) 1.348	98.68		

\*\*-Significant at 1% level



**Figure.4**  
**Fabric weight (GSM)**

From Table 17 and Figure 4, it is clear that the mean weight of the samples OS, ETS, PPTS and DS are 1.366, 2.439, 2.575 and 2.714 respectively. The fabric weight increased by 78.55 percent in ETS, 88.50 percent in PPTS and 98.68 percent in DS. The weight of the sample ETS, PPTS and DS increased when compared to original sample. The increase in weight is due to enzyme treated fabric absorb more dyeing when compare with untreated fabric. Statistical analysis also proved that there is a significant difference at 1% level between all samples with a F value of **1972.83**.

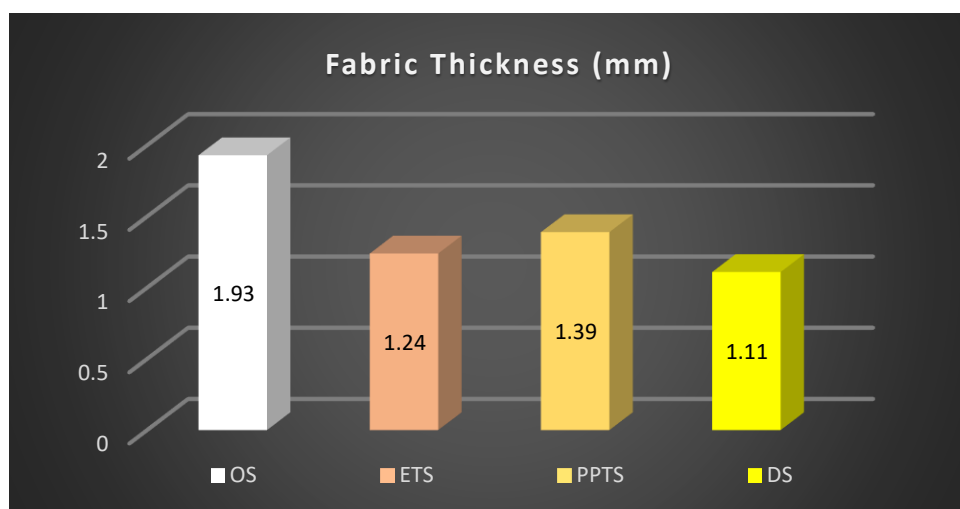
#### 4.2.1.2 Fabric Thickness

The fabric thickness and analysis of variance of the samples OS, ETS, PPTS and DS are shown in Table 18 and Figure 5.

**Table. 18**  
**Fabric thickness (mm)**

Sample	Mean	Standard Deviation	Loss/ Gain over original sample	Percentage of loss or gain over original sample	F test Value	P value
OS	1.9330	0.05498	-	-	206.34	0.001**
ETS	1.2430	0.09911	(-) 0.69	35.69		
PPTS	1.3950	0.05380	(-) 0.53	27.41		
DS	1.1110	0.09746	(-) 0.82	42.42		

\*\* -Significant at 1% level



**Figure. 5**  
**Fabric Thickness (mm)**

From Table 18 and Figure 5, it is clear that the mean thickness of the samples OS, ETS, PPTS and DS are 1.93, 1.24, 1.39 and 1.11 respectively. The fabric thickness decreased by 27.41 percent in PPTS, 35.69 percent in ETS and 42.42 percent in DS. The thickness of the sample ETS, PPTS and DS decreased when compared to original sample. The decrease in thickness is due to enzyme processing which removes the impurities present in the raw fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **206.34**.

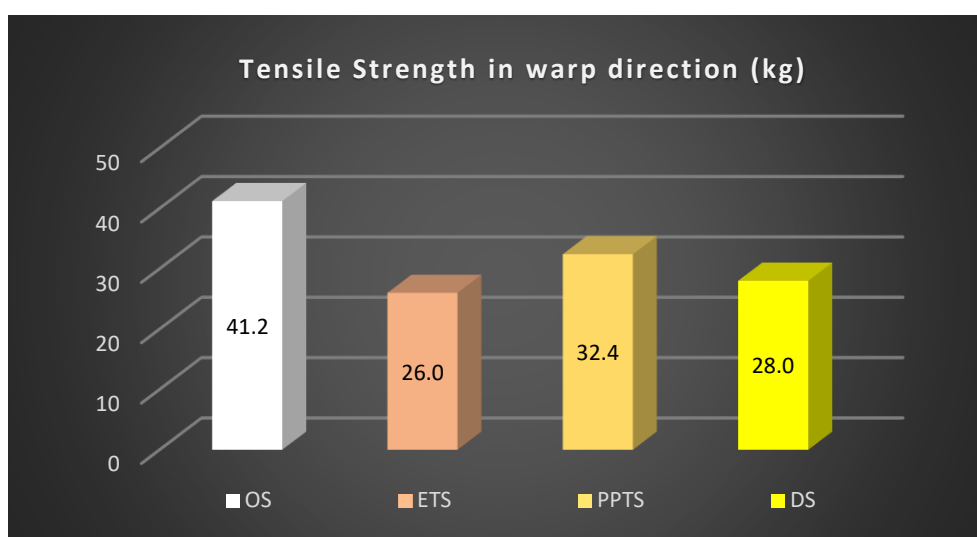
### 4.2.1.3 Tensile Strength (Warp)

Fabric strength and analysis of variance of the samples OS, ETS, PPTS and DS in warp direction is presented in Table 19 and Figure 6.

**Table. 19**  
**Fabric Strength in kg**

Sample	Mean (kg)	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	41.20	2.860	-	-	30.504	0.001**
ETS	26.00	2.582	(-) 15.2	36.89		
PPTS	32.40	5.985	(-) 8.8	21.35		
DS	28.00	3.018	(-) 13.2	32.03		

\*\* -Significant at 1% level



**Figure. 6**  
**Fabric Strength in Warp direction (kg)**

From Table 19 and Figure 6, it is clear that the mean Strength in warp direction of the samples OS, ETS, PPTS and DS are 41.20, 26.00, 32.40 and 28.00 respectively. The fabric Strength decreased by 36.89 percent in ETS, 32.03 percent in DS and 21.35 percent in PPTS. The Strength of the sample ETS, PPTS and DS decreased when compared to original fabric and it is due to enzyme processing which removes the impurities, lignin and hemicellulose particles on the fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **30.504**.

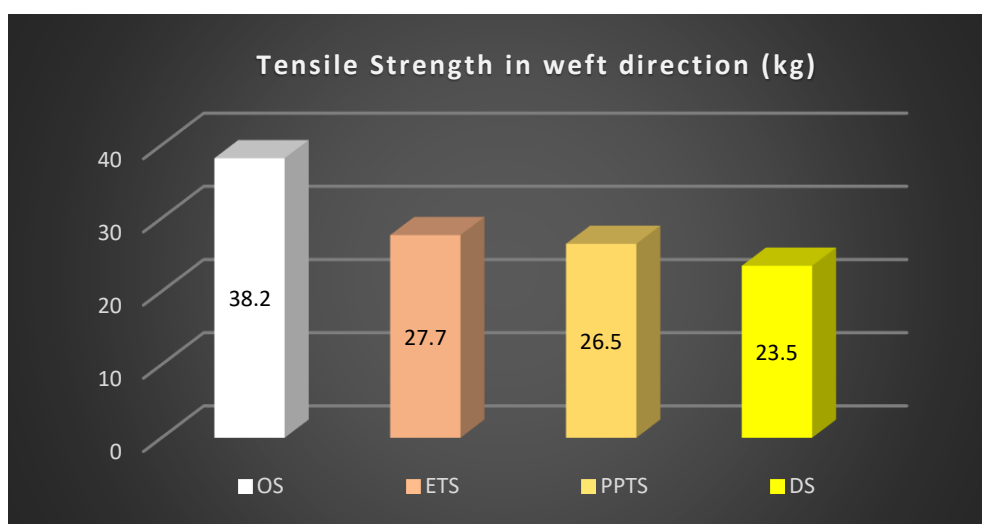
#### 4.2.1.4 Tensile Strength (Weft)

Fabric strength and the analysis of the variance of the sample OS, ETS, PPTS and DS in the weft directions are shown in Table 20 and Figure 7.

**Table 20**  
**Fabric Strength in kg**

Sample	Mean (kg)	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	38.20	3.011	-	-	60.234	0.001**
ETS	27.70	2.406	(-) 10.5	27.48		
PPTS	26.50	2.759	(-) 11.7	30.62		
DS	23.50	2.173	(-) 14.7	38.48		

\*\* - Significant at 1% level



**Figure. 7**  
**Fabric Strength in kg**

From Table 20 and Figure 7, it is clear that the mean Strength in weft direction of the samples OS, ETS, PPTS and DS are 38.20, 27.70, 26.50 and 23.50 respectively. The fabric Strength decreased by 27.48 percent in ETS, 38.48 percent in DS and 30.62 percent in PPTS. The Strength of the sample ETS, PPTS and DS decreased when compared to original fabric and it is due to enzyme processing which removes the impurities, sizing material, lignin and hemicellulose particles on the fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **60.234**.

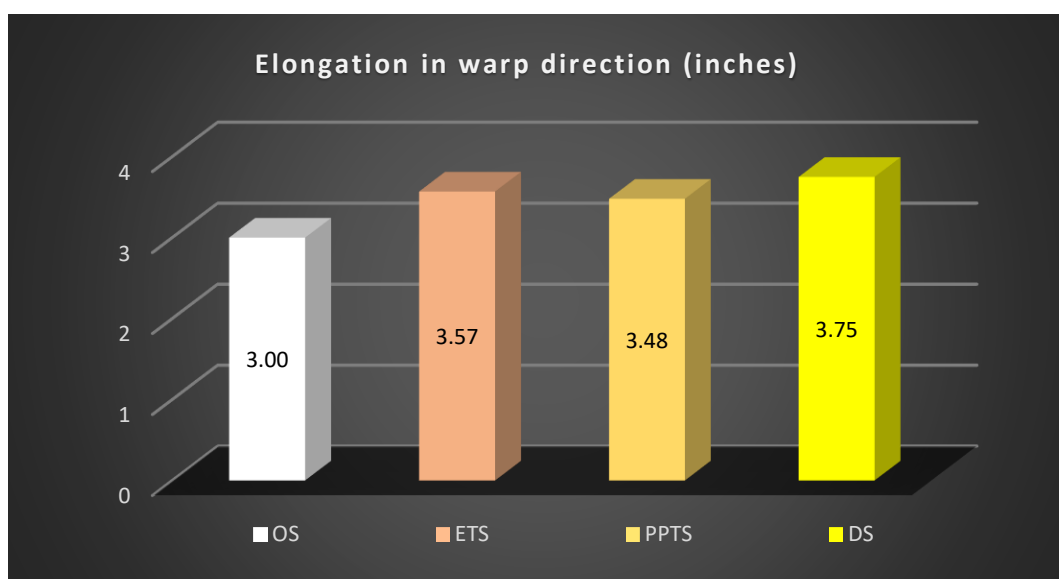
#### 4.2.1.5 Elongation in Warp Direction

Fabric elongation and analysis of variance of the samples OS, ETS, PPTS and DS in warp direction are shown in Table 21 and Figure 8.

**Table 21**  
**Fabric Elongation in warp (inches)**

Sample	Mean (inches)	Standard Deviation	Loss/ Gain over original sample	Percentage of loss or Gain over Original sample	F test Value	P value
OS	3.000	0.2357	-	-	22.772	0.001**
ETS	3.570	0.2452	(+) 0.57	19		
PPTS	3.480	0.2150	(+) 0.48	16		
DS	3.750	0.1354	(+) 0.75	25		

\*\*.-Significant at 1% level



**Figure. 8**  
**Fabric Elongation in warp direction (cm)**

From Table 21 and Figure 8, it is clear that the mean elongation in warp direction of the samples OS, ETS, PPTS and DS are 3.00, 3.57, 3.48 and 3.750 respectively. The fabric Elongation increased by 16 percent in PPTS, 19 percent in ETS and 25 percent in DS. The Strength of the sample ETS, PPTS and DS increased when compared to original fabric. It is due to enzyme processing which removes the impurities. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **22.772**.

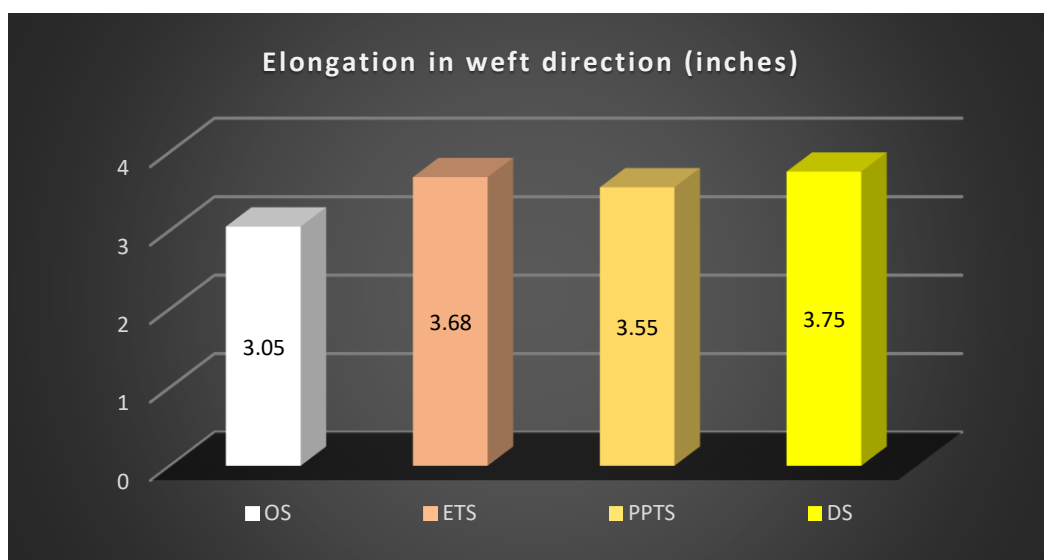
#### 4.2.1.6 Elongation in Weft Direction

The fabric elongation and analysis of variance of the samples are OS, ETS, PPTS and DS in weft direction are shown in Table 22 and Figure 9.

**Table 22**  
**Fabric Elongation in Inches**

Sample	Mean	Standard Deviation	Loss/Gain over Original	Percentage of Loss/Gain over Original	F test Value	P value
OS	3.050	0.2068	-	-	32.368	0.001**
ETS	3.680	0.1814	(+) 0.63	20.6		
PPTS	3.550	0.1841	(+) 0.5	16.3		
DS	3.750	0.1179	(+) 0.7	22.9		

\*\* - Significant at 1% level



**Figure. 9**  
**Fabric Elongation in Weft Direction (inches)**

From Table 22 and Figure 9, it is clear that the mean Elongation in warp direction of the samples OS, ETS, PPTS and DS are 3.00, 3.57, 3.48 and 3.750 respectively. The fabric Elongation increased by 16.3 percent in PPTS, 20.6 percent in ETS and 22.9 percent in DS. The Strength of the sample ETS, PPTS and DS increased when compared to original fabric. It is due to enzyme processing which removes the impurities. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **32.368**.

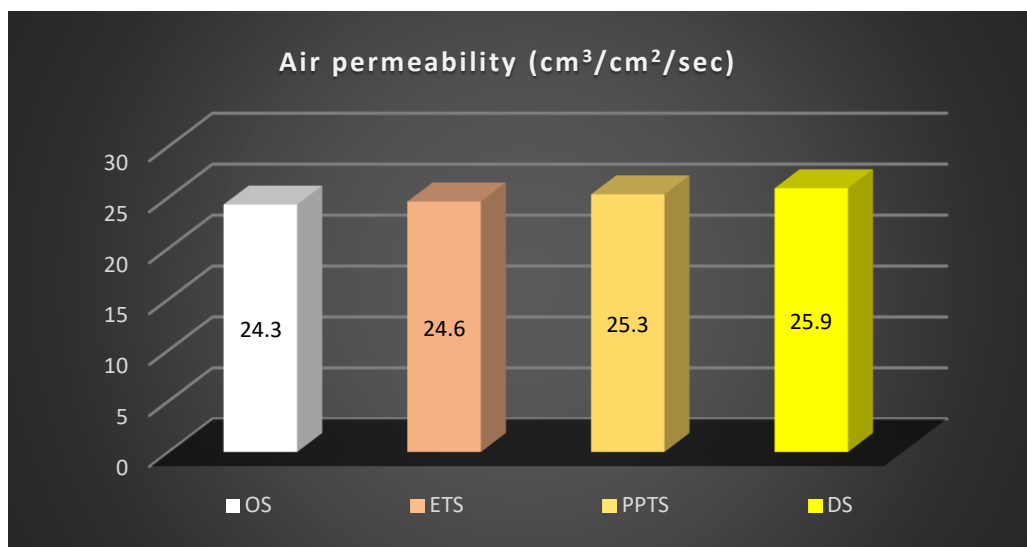
#### 4.2.1.7 Air Permeability

The air permeability of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 23 and Figure 10.

**Table 23**  
**Air-permeability Test (cm<sup>3</sup>/cm<sup>2</sup>/sec)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	24.30	0.258	-	-	77.37	0.001**
ETS	24.60	0.258	(+) 0.3	1.23		
PPTS	25.30	0.258	(+) 1	4.11		
DS	25.90	0.258	(+) 1.6	65.84		

\*\* -Significant at 1% level



**Figure. 10**  
**Air-permeability Test (cm<sup>3</sup>/cm<sup>2</sup>/sec)**

From the above table it is evident that the mean air permeability of sample OS, ETS, PPTS and DS are 24.30, 24.60, 25.30 and 25.90 respectively. There is no significant difference in terms of air permeability indicating the permeable factor was not affected in all the samples. Statistical analysis also proved that there is a significant difference at 1% level between all samples with a F value of **77.37**.

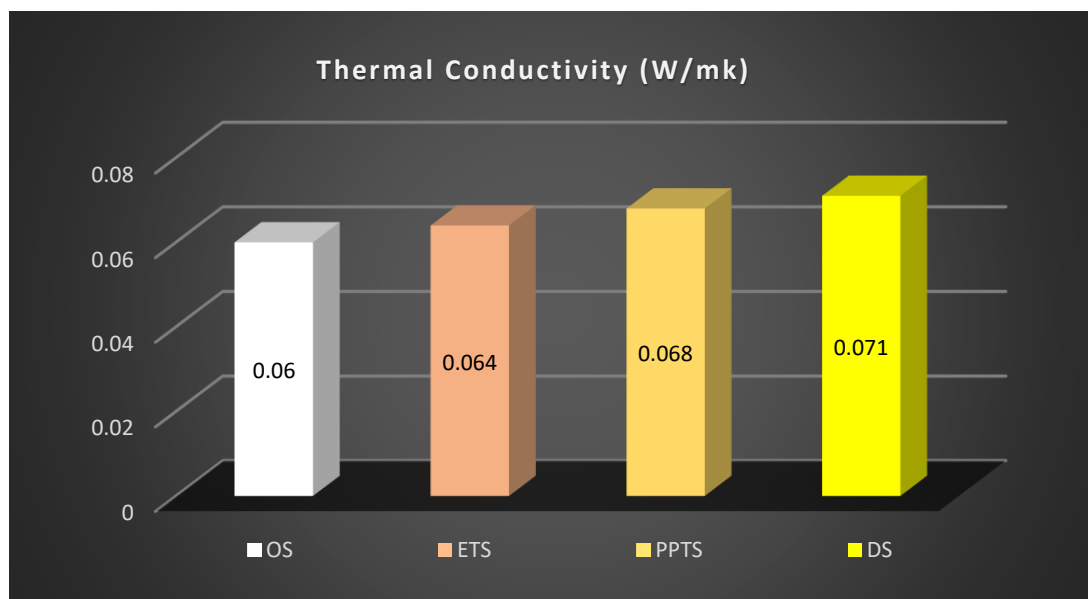
#### 4.2.1.8 Thermal Conductivity

Thermal conductivity of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 24 and Figure 11.

**Table 24**  
**Thermal Conductivity (W/mk)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	0.060	0.0025	-	-	34.375	0.001**
ETS	0.064	0.0025	(+) 0.004	6.66		
PPTS	0.068	0.0025	(+) 0.008	12.5		
DS	0.071	0.0025	(+) 0.011	18.33		

\*\* -Significant at 1% level



**Figure. 11**  
**Thermal conductivity (W/mk)**

From the Table 24 and Figure 11, it is cleared that the mean thermal conductivity of sample OS, ETS, PPTS and DS are 0.060, 0.064, 0.069 and 0.071 respectively. The samples were showed similar thermal conductivity properties indicating this factor was not affected in all samples. Statistical analysis also proved that there is a significant different 1% level between all samples with a F value of **34.375**.

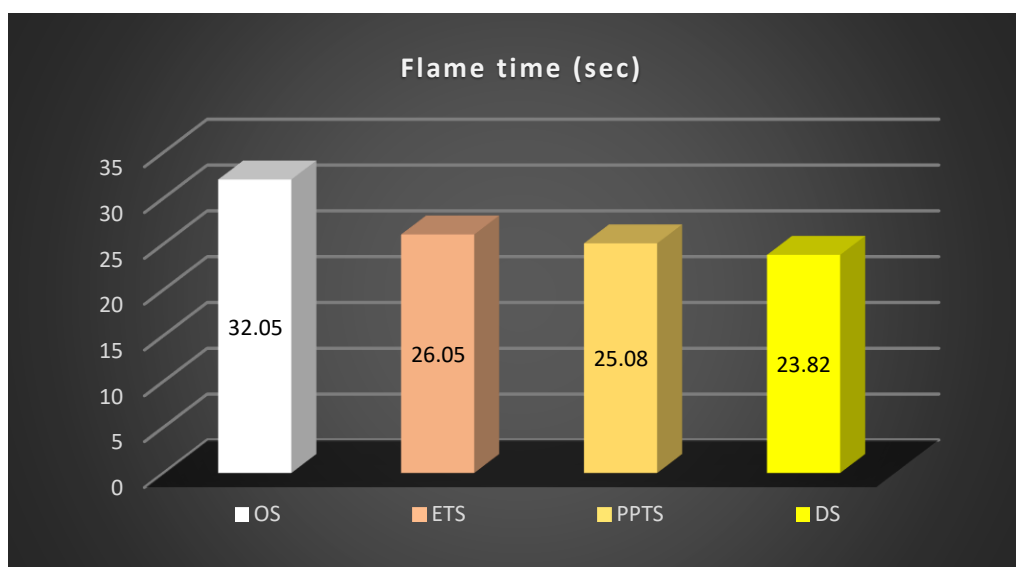
#### 4.2.1.9 Flammability Test

The flammability of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 25 and Figure 12.

**Table 25**  
**Flame Time (sec)**

Sample	Mean	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	32.05	-	-	57.024	0.001**
ETS	26.05	(-) 6	18.72		
PPTS	25.08	(-) 6.97	21.74		
DS	23.82	(-) 8.23	25.67		

\*\* -Significant at 1% level



**Figure. 12**  
**Flame time (sec)**

From the table 25 and figure 12, it is clear that the mean flammability of OS, ETS, PPTS and DS are 32.05, 26.05, 25.08 and 23.82 respectively. The flammability of sample OS, ETS, PPTS and DS have good flame retardant property. Statistical analysis also proved that there is a significant difference 1% level between all samples with a F value of **57.024**.

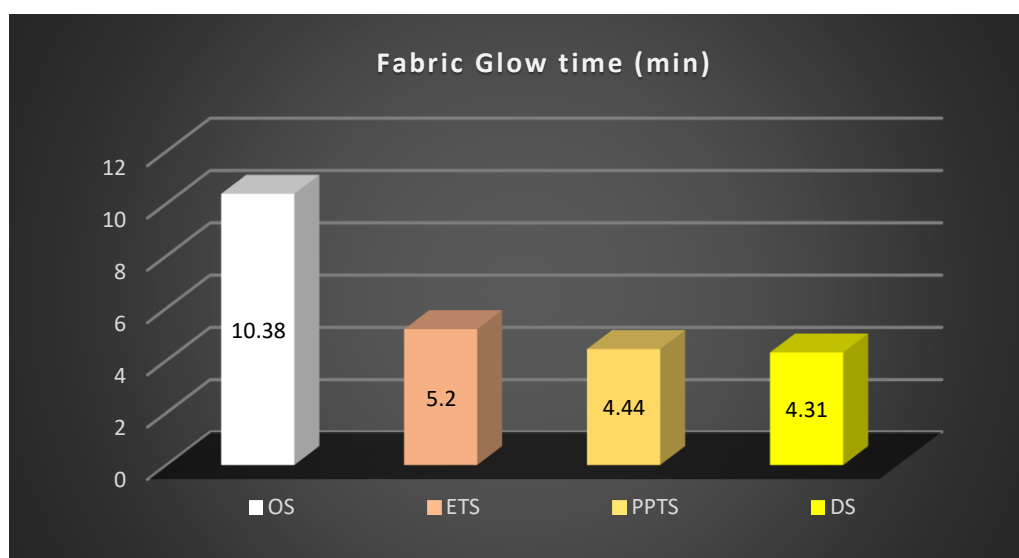
#### 4.2.1.10 Flammability Test

The flammability of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 26 and Figure 13.

**Table. 26**  
**Glow time (min)**

Sample	Mean	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	10.38	-	-	2357.50	0.001**
ETS	5.20	(-) 5.18	49.90		
PPTS	4.43	(-) 5.95	57.32		
DS	4.31	(-) 6.07	41.52		

\*\* -Significant at 1% level



**Figure. 13**  
**Fabric Glow Time (min)**

From the table 26 and figure 13, it is clear that the mean glow time of OS, ETS, PPTS and DS are 10.38, 5.20, 4.43 and 4.31 respectively. The fabric glow time of ETS, PPTS and DS increased by 49.90 percent, 57.32 percent and 41.52 percent when compared to original fabric. Comparing to other samples, DS sample has minimum glow time. Statistical analysis also proved that there is a significant different 1% level between all samples with a F value of **2357.50**.

## 4.2.2 Absorbency Evaluation

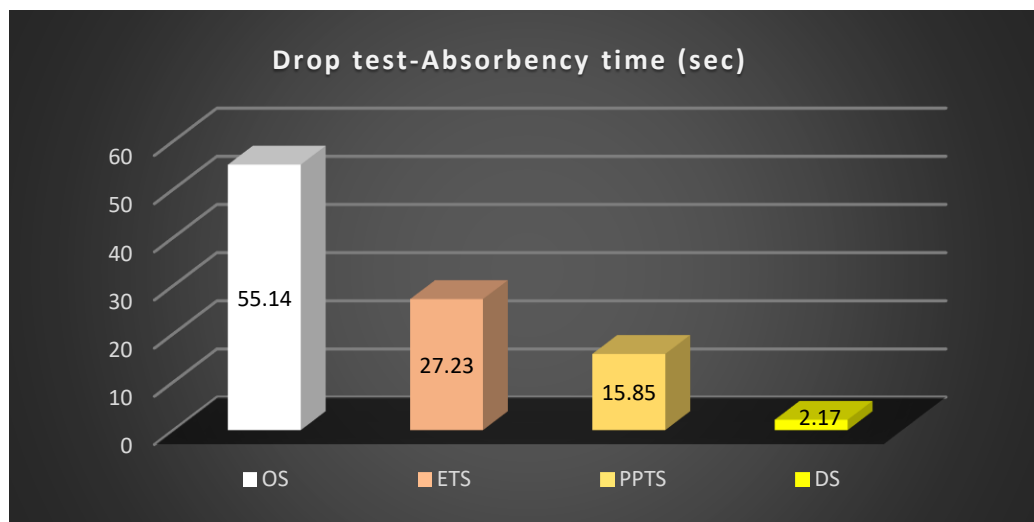
### 4.2.2.1 Drop Test

The drop level of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 27 and Figure 14.

**Table. 27**  
**Drop test (sec)**

Sample	Mean (sec)	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	55.14	2.74728	-	-	628.55	0.001**
ETS	27.23	3.18917	(-)27.91	50.61		
PPTS	15.85	3.77766	(-)39.56	71.74		
DS	2.17	0.45877	(-)52.97	96.06		

\*\*-Significant at 1% level



**Figure. 14**  
**Drop Test (sec)**

From the Table 27 and Figure 14, it is evident that the mean drop level of OS, ETS, PPTS and DS are 55.14, 27.23, 15.85 and 2.17 respectively. The absorbency of sample ETS, PPTS and DS increased by 50.61 percent, 71.74 percent and 96.06 percent when compared to the original fabric. The increase in absorbency of fabric is due to enzyme processing which removes impurities. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **628.55**.

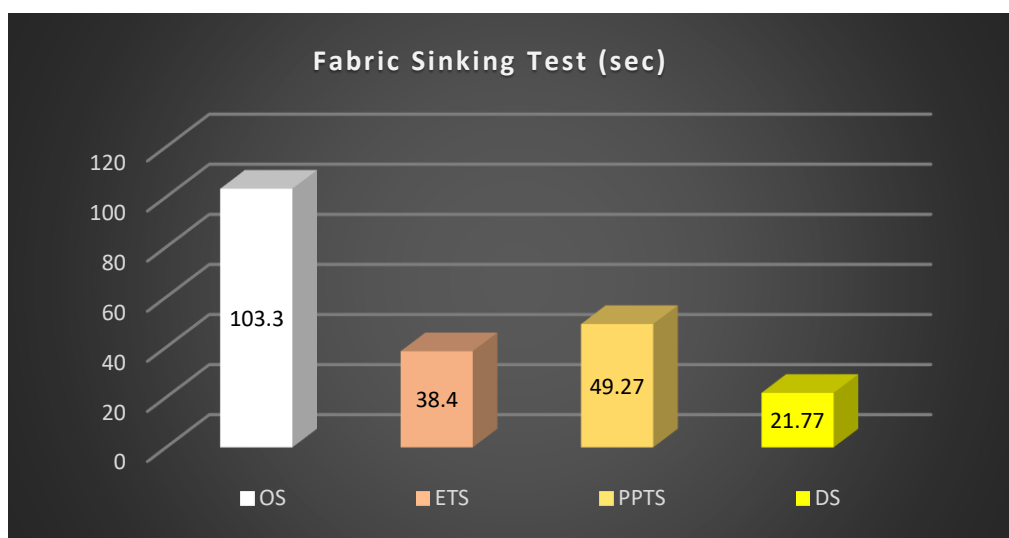
#### 4.2.2.2 Sinking Test

The sinking level of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 28 and Figure 15.

**Table 28**  
**Sinking test (sec)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	103.30	8.641	-	-	408.81	0.001**
ETS	38.40	2.404	(-) 64.9	62.82		
PPTS	49.27	6.015	(-) 54.03	52.30		
DS	21.77	2.253	(-) 81.53	78.92		

\*\* - Significant at 1% level



**Figure. 15**  
**Sinking Test (sec)**

From the Table 28 and Figure 15, it is clear that the mean sinking level of OS, ETS, PPTS and DS are 103.30, 38.40, 49.27 and 21.77 respectively. The sinking of fabric ETS, PPTS and DS increased by 62.82 percent, 52.30 percent and 78.92 percent when compared to the original fabric. The increases in sinking property of fabric due to enzyme treatment. DS sample has good absorbency compared to all fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **408.81**.

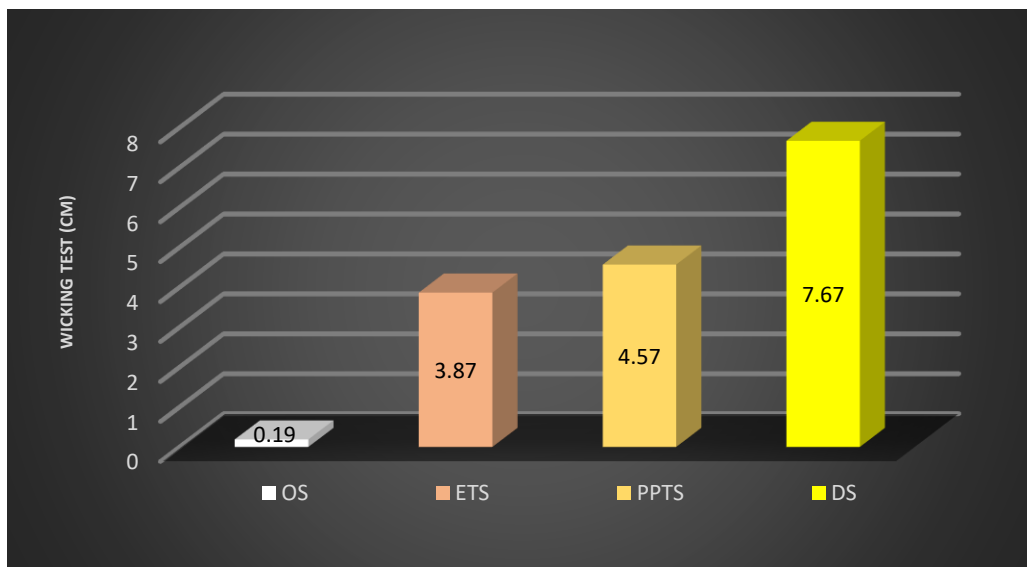
#### 4.2.2.3 Wicking Test

The wicking level of OS, ETS, PPTS and DS samples and analysis of variance are shown in Table 29 and Figure 16.

**Table 29**  
**Wicking test (cm)**

Samples	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	0.19	0.110	-	-	1000.33	0.001**
ETS	3.87	0.286	(+) 3.68	1936.8		
PPTS	4.57	0.316	(+) 4.38	2305.2		
DS	7.67	0.427	(+) 7.48	3936.8		

\*\*-Significant at 1% level



**Figure. 16**  
**Wicking Test (cm)**

From the Table 29 and Figure 16, it is evident that the mean Wicking level of OS, ETS, PPTS and DS are 0.19, 3.87, 4.57 and 7.67 respectively. The wicking property of the sample ETS, PPTS and DS increased by 1936.8 percent, 2305.2 percent and 3936.8 percent when compared to original fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **1000.33**.

### 4.2.3 Comfort Property Evaluation

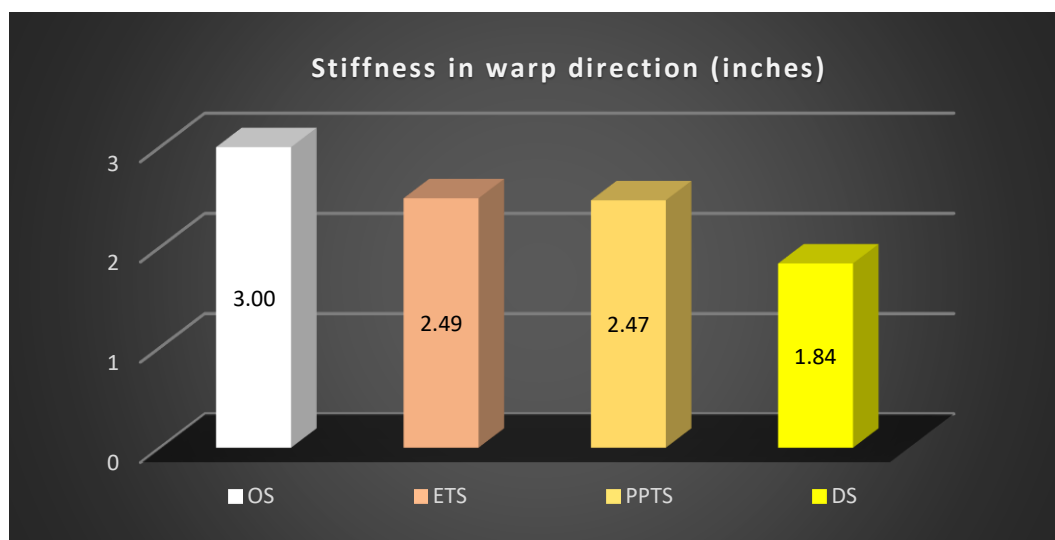
#### 4.2.3.1 Fabric Stiffness in Warp Direction

Fabric stiffness and analysis of variance of the samples OS, ETS, PPTS and DS in warp direction were shown in Table 30 and Figure 17.

**Table 30**  
**Fabric Stiffness in Warp (inches)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	3.000	0.3197	-	-	21.744	0.001**
ETS	2.490	0.4149	(-) 0.51	17.00		
PPTS	2.470	0.3057	(-) 0.53	17.66		
DS	1.840	0.2171	(-) 1.16	38.66		

\*\*-Significant at 1% level



**Figure. 17**  
**Fabric stiffness in warp direction (inches)**

From Table 30 and Figure 17, it is clear that the mean stiffness of OS, ETS, PPTS and DS are 3.000, 2.490, 2.470 and 1.840 respectively. The stiffness of the fabric increased when compared with original fabric. This is due to the deposition of dye particle increases; the fabric stiffness increases. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **21.744**.

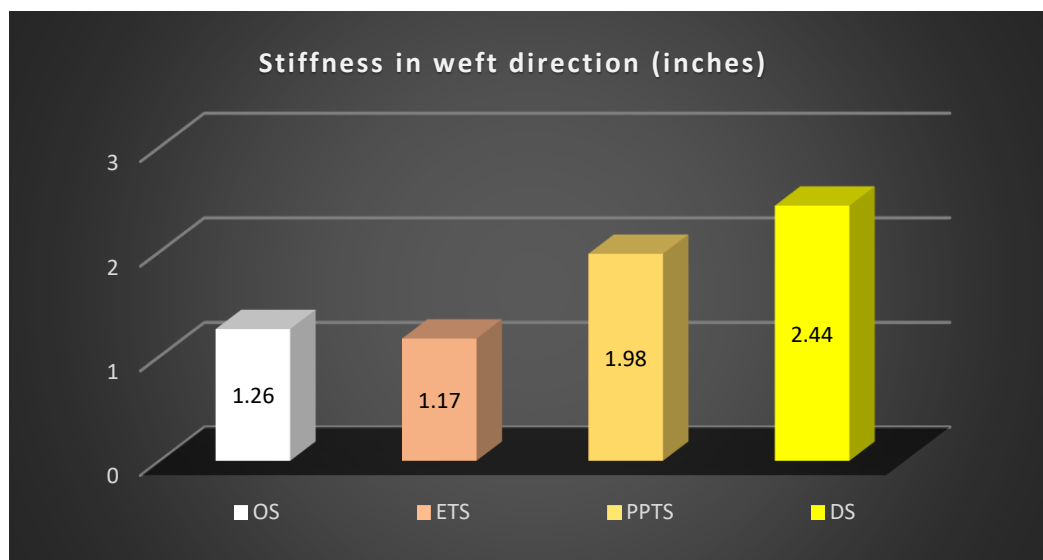
#### 4.2.3.2 Fabric Stiffness in Weft Direction

Fabric stiffness and analysis of variance of the samples OS, ETS, PPTS and DS in warp direction were presented in Table 31 and Figure 18.

**Table 31**  
**Fabric Stiffness in Weft (inches)**

Sample	Mean	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	1.260	0.1174	-	-	107.74	0.001**
ETS	1.170	0.1889	(-) 0.09	7.14		
PPTS	1.980	0.1619	(+) 0.72	57.14		
DS	2.440	0.2459	(+) 1.18	93.65		

\*\* -Significant at 1% level



**Figure. 18**  
**Fabric stiffness in weft direction (inches)**

From Table 31 and Figure 18, it is clear that the mean stiffness of OS, ETS, PPTS and DS are 1.260, 1.170, 1.980 and 2.440 respectively. The stiffness in weft direction of PPTS and DS was increased by 57.14 percent and 93.65 percent and ETS was decreased by 7.14 percent when compared with original sample. This is due to the enzyme treatment which removes impurities. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **107.74**.

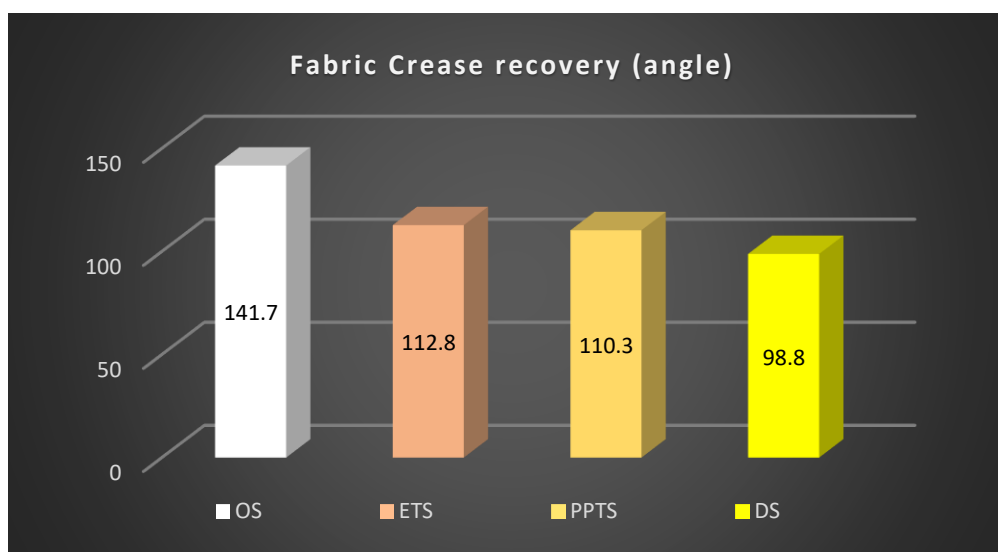
#### 4.2.3.3 Crease Recovery

The Fabric Crease Recovery test of OS, ETS, PPTS and DS samples and analysis of variance were shown in Table 32 and Figure 19.

**Table 32**  
**Fabric Crease Recovery (angle)**

Sample	Mean (angle)	Standard Deviation	Loss/ Gain over Original	Percentage of loss or Gain over Original	F test Value	P value
OS	141.70	11.662	-	-	48.508	0.001**
ETS	112.80	9.343	(-) 28.9	20.39		
PPTS	110.30	4.945	(-) 31.4	22.15		
DS	98.80	5.181	(-) 42.9	30.27		

\*\* -Significant at 1% level



**Figure. 19**  
**Fabric Crease Recovery (angle)**

From the Table 32 and Figure 19, it is marked that the mean Crease Recovery of OS, ETS, PPTS and DS are 141.7, 112.8, 110.3 and 98.8 respectively. The crease recovery of ETS, PPTS and DS is decreased by 20.39 percent, 22.15 percent and 30.27 percent when compared with original fabric. The decrease of crease recovery is due to enzyme treatment and dye absorbency on the fabric. Statistical analysis also proved that there is a significant different at 1% level between all samples with a F value of **48.508**.

## 4.2.4 Colour Fastness Test

### 4.2.4.1 Colour fastness to sunlight, crocking and washing

The Table 33 shows that the colour fastness to sunlight, crocking and washing of dyed cotton fabric.

**Table. 33**  
**Colour fastness to sunlight, crocking and washing**

Sample	Sunlight		Washing		Crocking				Pressing			
	Colour change	Staining	Colour change	Staining	Dry		Wet		Dry		Wet	
Colour change					Staining	Colour change	Staining	Colour change	Staining	Colour change	Staining	Colour change
DS	5	3	4	4	5	4	4	4	5	5	5	4

5- Excellent	4- Very good	3- Good	2- Fair	1- Poor
--------------	--------------	---------	---------	---------

The Table 33 shows, that the results of colour fastness test to sunlight, crocking and washing to wet and dry process of dyed fabric. Colour fastness to sunlight showed a good result. The colour fastness to washing showed a good result. In the wet condition the result was and in dry condition of the crocking test showed a result, and there was no colour bleeding.

Colour fastness to pressing in wet and dry conditions was also done. In dry pressing the fabric condition was excellent but in wet pressing the fabric showed little staining and showed good result.

#### 4.2.4.2 Spectrophotometer Evaluation

Whiteness, yellowness and brightness of the sample OS, ETS, PPTS and DS at 10° angle of observation are given in Table 34.

**Table. 34**

**Whiteness index, yellowness index and brightness index of *curcuma* dyed fabric**

<b>Fabric</b>	<b>Yellow Index (ASTM D1925)</b>	<b>Whiteness Index (Stephensen)</b>	<b>Brightness Index (TAPPI 452/ ISO 2470)</b>
<b>Standard</b>	4.344	81.248	81.217
<b><i>Curcuma</i> dyed fabric</b>	102.304	-43.154	4.508

**Table. 35**

**Colour co-ordinates and Colour strength of *curcuma* dyed fabric**

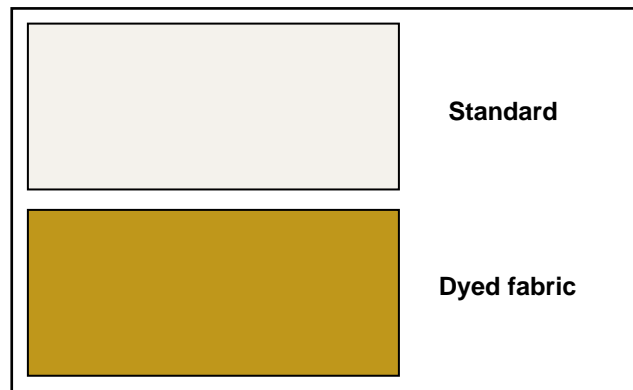
	<b>Standard</b>	<b><i>Curcuma</i> dyed fabric</b>
	<b>Colour co-ordinates</b>	
<b>L*</b>	95.964	64.640
<b>a*</b>	-0.030	4.300
<b>b*</b>	2.340	63.613
	<b>Colour strength</b>	
<b>K/S</b>	0.129	78.168
<b>In parts</b>	100.000	0.165
<b>In % age</b>	100.000	60768.20

From the Table 34 and Table 35, it is clear that colour strength of sample DS is the highest with K/s value of 78.168 followed by the standard value. The dyed sample showed best result on colour strength.

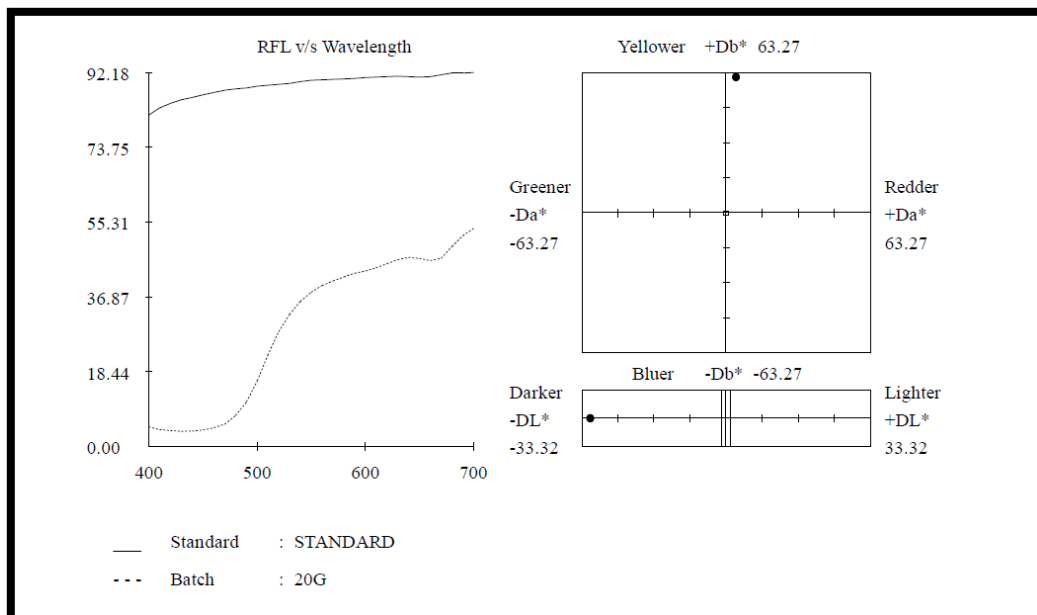
From the Table 35, the observations of L\* value proved that the dyed fabric to be dark with the values of 64.640 respectively when compared with standard value. The positive a\* and b\* values of all samples indicate that the dyed fabric fall under more yellowish category

with the respect  $a^*$  value, 4.300 dyed fabric showed the maximum value indicating higher content of yellow when compared to other sample. The  $b^*$  value indicating yellowness of dyed fabric is seen in 63.613.

Clearly indicates that surface modification of fabric colouration process the colour uptake K/s increased in respectively. The good colour strength was found on the dyed fabric. Among the K/s value showed upstanding of the result.



**Figure. 20**  
**Colour on Screen**



**Figure. 21**  
**Colour Difference Graph**

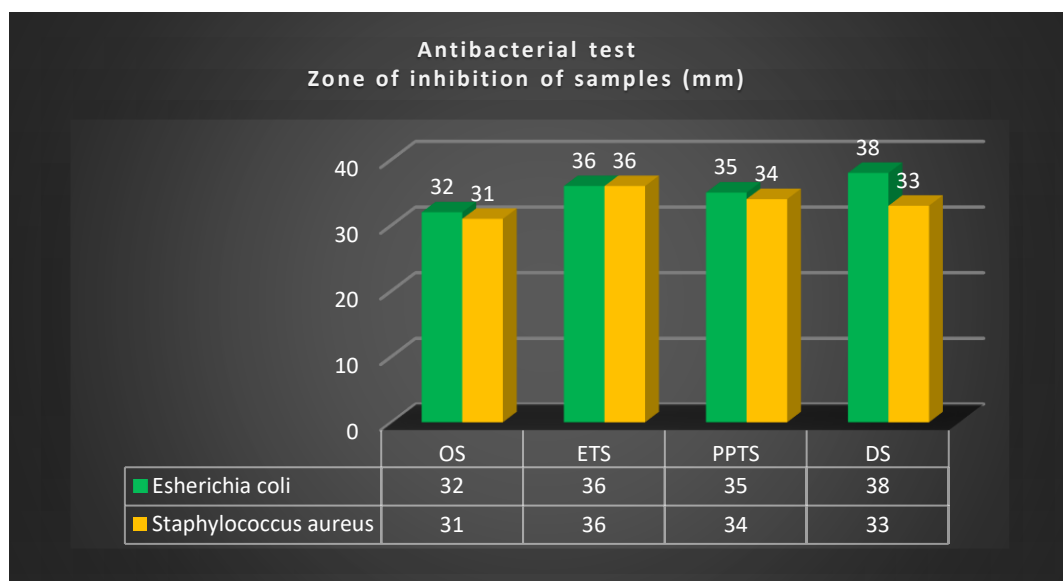
## 4.2.5 Functional Evaluation

### 4.2.5.1 Anti-Bacterial Test

The test plates were examined for the clear zone of inhibition around the Treated fabrics The zone of inhibition was measured in millimetre (mm). The results are tabulated below in Table 36.

**Table. 36**  
**Antibacterial Test (cm)**

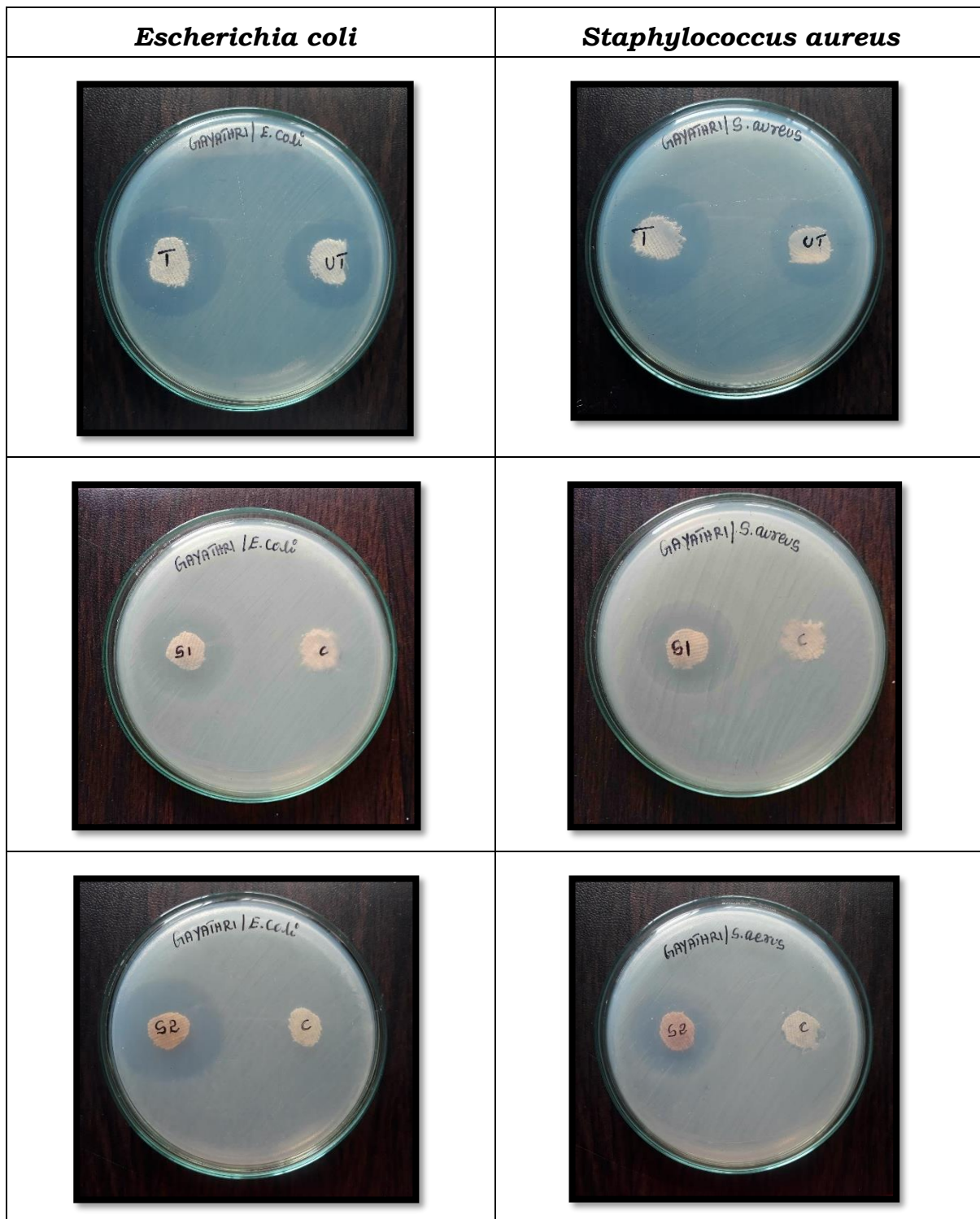
S. No.	Samples	Zone of inhibition (mm) of fabric samples	
		<i>Escherichia coli</i>	<i>Staphylococcus aureus</i>
1	OS	32	31
2	ETS	36	36
3	PPTS	35	34
4	DS	38	33



**Figure. 22**  
**Antibacterial Activity (cm)**

From the Table 36 and Figure 22, OS, ETS, PPTS and DS samples showed GOOD antibacterial activity in terms of inhibitory zones against test bacteria, *Escherichia coli* and *Staphylococcus aureus*. Durability of the finished fabrics shall be investigated as future study using AATCC-124 standard method.

Antibacterial activity (EN ISO 20645 Test Method)



**Plate XXI**  
**Antibacterial activity**

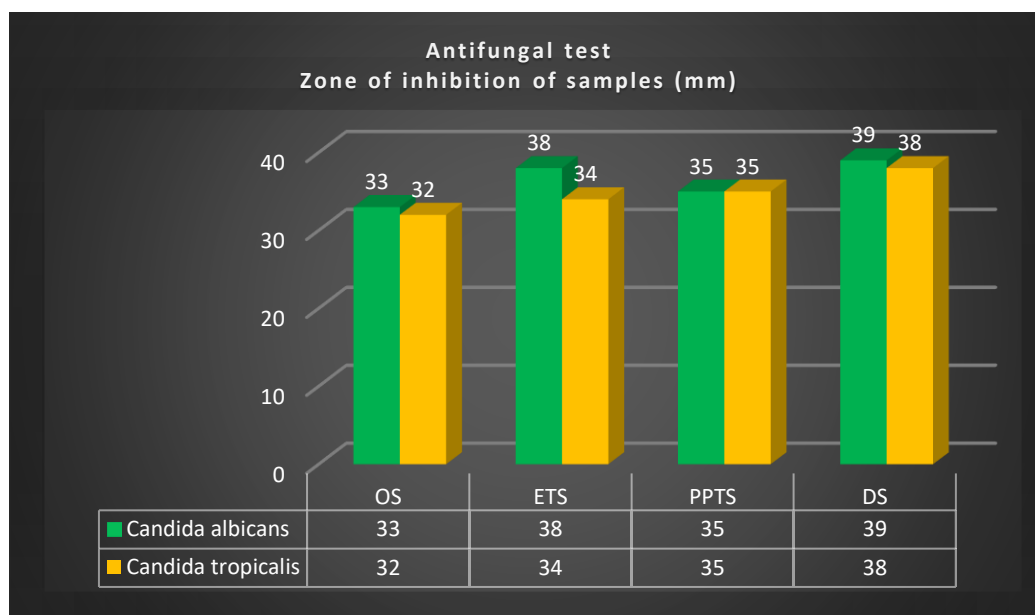
- T – Enzyme treated sample
- UT – Original sample
- S1 – Papaya peel treated sample
- S2 – Dyed sample

#### 4.2.5.2) Antifungal activity

The test plates were examined for the clear zone of inhibition around the Treated fabrics. The zone of inhibition was measured in millimetre (mm). The results are tabulated below in Table 37.

**Table. 37**  
**Antifungal activity (cm)**

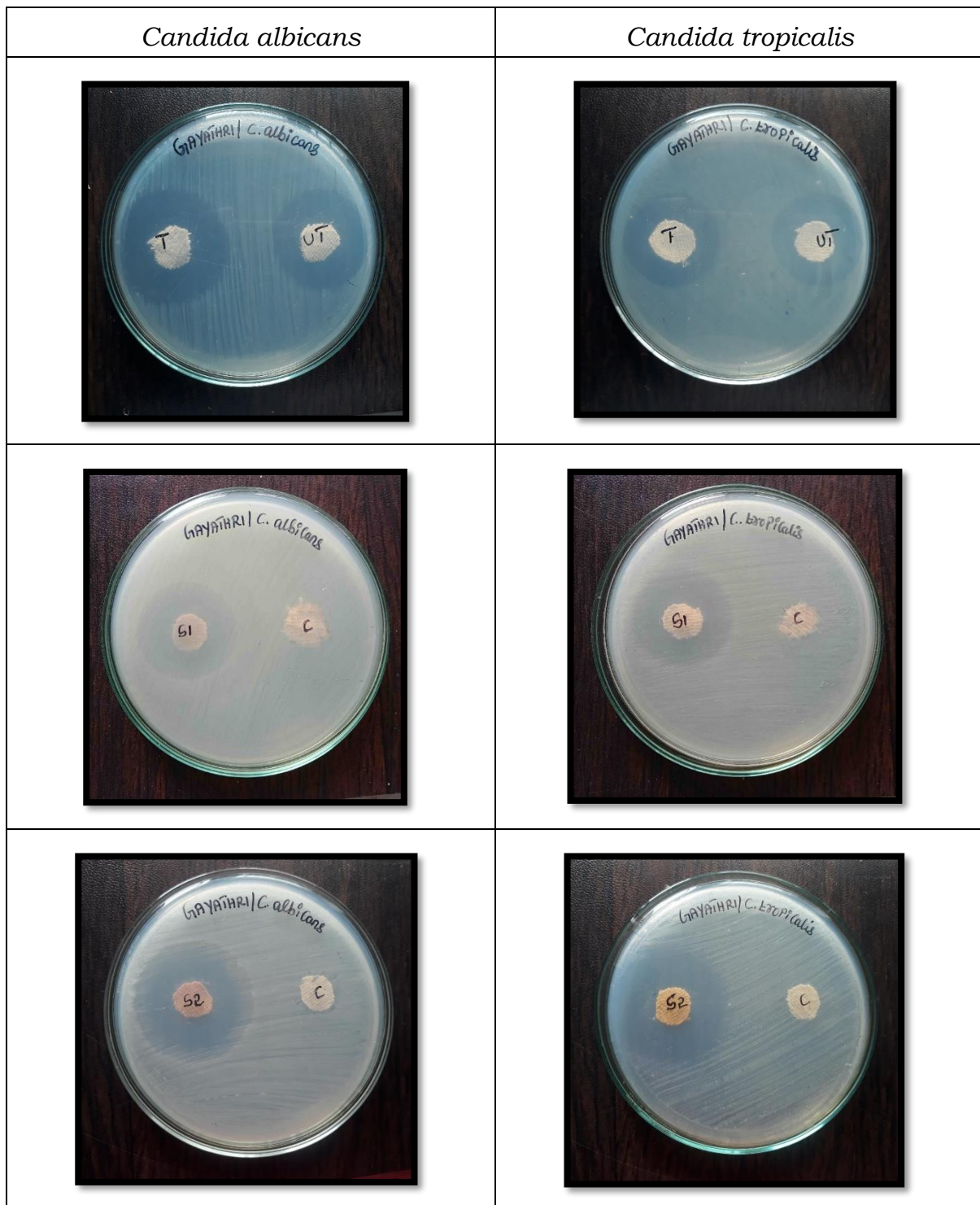
S.NO	SAMPLES	Zone of inhibition (mm) of fabric samples	
		<i>Candida albicans</i>	<i>Candida tropicalis</i>
1	OS	33	32
2	ETS	38	34
3	PPTS	35	35
4	DS	39	38



**Figure. 23**  
**Antifungal Activity (cm)**

From the Table 37 and Figure 23, OS, ETS, PPTS and DS samples showed GOOD antifungal activity in terms of inhibitory zones against test fungi, *Candida albicans* and *Candida tropicalis*. Durability of the finished fabrics shall be investigated as future study using AATCC-124 standard method.

## Antifungal activity



**Plate XXII**  
**Antifungal activity**

- T – Enzyme treated sample
- UT – Original sample
- S1 – Papaya peel treated sample
- S2 – Dyed sample

**END PRODUCT**

**BOLSTER**



**Plate XXIII**

## V. SUMMARY AND CONCLUSION

Traditionally textiles are made from yarn, which is developed by processing the fibres although many textiles can be made by the direct conversion of fibres. The quality of finished textile is determined by the properties such as length, strength and nature of its constituent fibres. Several natural fibres like cotton, jute, flax, ramie, hemp, sisal, manila hemp, wool and silk are some of the major fibres, which are widely being used throughout the world. Blended fibres are made by combining two or more fibres to create a new material fibre with specified qualities. Natural fibres are made from renewable resources and have a low carbon footprint. It is completely biodegradable (Samatoa, 2021).

Vetiver (*Chrysopogon zizanioides*) is a coarse, evergreen perennial grass that grows in huge, thick clumps up to 1.5 metres tall and sometimes up to 3 metres tall. Vetiveria grass is a valuable source of essential oil for which it is frequently farmed commercially. Vetiver, also known as khus grass, is a perennial grass native to India. Vetiver roots yield a pleasant essential oil that can be used as a perfume on its own. This volatile oil is used to make aroma compounds such as Vetiverol, Vetiverone, and Vetiveryl acetate. It is mostly utilised in the perfume, cosmetics, aromatherapy, food, and flavouring sectors in India. It is grown in Rajasthan, Uttar Pradesh, Karnataka, Tamil Nadu, Kerala, and Andhra Pradesh, with a yearly production of roughly 20 tonnes of oil.

Banana fibre, also known as musa fibre, is one of the strongest natural fibres on the planet. The natural fibre is biodegradable and manufactured from the stem of the banana tree. It is extremely durable. The fibre is made up of thick-walled cell tissue that is bound together by natural gums and is mostly made up of cellulose, hemicelluloses, and lignin. Banana fibre is similar to natural bamboo fibre, but it is reported to have higher spin ability, fineness, and tensile strength. Banana fibre, on the other hand, is making a resurgence in the fashion sector. Banana fibre has recently made a comeback in a variety of industries and is used all over the world for a variety of items ranging from tea bags to automobile tyres to saris and Japanese yen notes (Vivian Hendriksz, 2017).

Fabric can improve the liveability or workability of a small room by reducing noise and making music and even voice richer and more resonant (Shivendra Parmar, 2007). Textile finishing process which is carried out after the application of the finish to a textile fabric in which appropriate conditions are used to affect a chemical reaction.

The *Chrysopogon zizanioides* and banana fibre blended fabrics will be treated with various enzymes to get a smooth surface. Finishing treatments made the fabric softer, clean, increased pliability and thereby making the fabric more suitable for end-uses. Enzymes function as biological catalysts. Enzymes are readily biodegradable and therefore potentially harmless and environmentally friendly (Chatto Padhyay, 2008).

Dyes are one of the most important uses of plants. The majority of natural dyes are vegetable dyes from plant sources roots, berries, bark, leaves and wood and other organic sources such as fungi and lichens (Resonance et al., 2010). *Curcuma* was selected source for dyeing the fabric. The major advantages of natural dyes are that they are biodegradable, non-carcinogenic, non-mutagenic and colour soothing to human eyes. (Flint, 2008).

Hence the present study “**Development of Blended Woven Fabric Using Selected Cellulosic Fibres for Bolster**” was carried out with the following objectives to:

- To identify environment-friendly fibres
- To select suitable fabrication method
- To pre-treat the prepared fabric with bio-enzymes
- To dye the enzyme treated fabric with suitable natural source
- To evaluate the finished fabric with suitable testing method
- To develop a product using prepared fabric

### **Experimental Procedure**

#### ➤ **Selection of Cellulosic fibres**

- *Chrysopogon zizanioides*, *banana pseudo-stem* fibre and *Gossypium* fibre were selected for this study. These three cellulosic fibres were blended thoroughly in carding process.

#### ➤ **Manufacturing of yarn and fabric**

- A yarn was produced using the rotor spinning method and they produce a smoother and more consistent yarn than ring spinning.
- For fabric manufacturing, produced cellulosic blended yarn is can be used as weft yarn. A plain weave Structure was chosen to weave the fabric.

#### ➤ **Pre-treatment of fabric**

- In this study pre-treatment for fabric was done by two methods Bio-enzymatic treatment and papaya fruit peel treatment, it removes the impurities and added softness to the fabric.

➤ **Selection of source for natural dye**

- Dye from *Curcuma* paste was extracted by conventional method. Various parameters such as solvent, time and temperature were optimized for the extraction of dye.
- The dyed fabric was evaluated both subjectively and objectively.

**Finding of the Study**

Original fabric, pre-treated fabric and dyed fabric were evaluated by subjective and objective methods, such as mechanical, physical and comfort properties. The laboratory test was analysed statistically.

**Objective Evaluation**

- Fabric weight of ETS, PPTS and DS is 78.55 percent, 88.50 percent and 98.68 percent increased respectively when compare with original fabric and the maximum weight was found in DS-Dyed Fabric is 98.68 percent. It is statistically proved that the significant difference at 1% level of F value is **1972.83**.
- Thickness of the fabric reduced gradually after every treatment and the reduction of maximum in the finished sample DS is 42.42 percent. It is statistically proved that the significant difference at 1% level of F value is **206.34**.
- Tensile strength in warp of ETS, PPTS and DS samples reduces gradually when compare to original fabric. The maximum strength reduction sample ETS is 36.89 percent. It is statistically proved that the significant difference at 1% level of F value is **30.504**.
- Tensile strength in weft of ETS, PPTS and DS samples reduces gradually after every treatment. The maximum reduction DS sample is 38.48 percent. It is statistically proved that the significant difference at 1% level of F value is **60.234**.
- Fabric elongation in warp direction PPTS, ETS and DS is increased by 16 percent, 19 percent and 25 percent respectively. It is statistically proved that the significant difference at 1% level of F value is **22.772**.
- Fabric elongation in weft direction PPTS, ETS and DS is increased by 16.3 percent, 20.6 percent and 22.9 percent respectively. It is statistically proved that the significant difference at 1% level of F value is **32.368**.
- Fabric stiffness in warp direction of ETS, PPTS and DS samples by 17 percent, 17.66 percent and 38.66 percent was reduced gradually when compare to original

fabric. It is statistically proved that the significant difference at 1% level of F value is **21.744**.

- Fabric stiffness in weft direction of ETS, PPTS and DS samples by 7.14 percent, 57.14 percent and 93.65 percent was reduced gradually when compare to original fabric. It is statistically proved that the significant difference at 1% level of F value is **107.74**.
- The drop test result shows the absorbency of the ETS (50.61 percent), PPTS (71.74 percent) and DS (96.06 percent) increased when compared to original fabric. They were significant at 1% level of F value is **628.55**.
- The sinking test result shows the absorbency of the PPTS (52.30 percent), ETS (62.82 percent) and DS (78.92 percent) increased when compared to original fabric. They were significant at 1% level of F value is **408.81**.
- The wicking test result shows the absorbency of the ETS (1936.8 percent), PPTS (2305.2 percent) and DS (3936.8 percent) increased when compared to original fabric. They were significant at 1% level of F value is **1000.33**.
- The colour fastness test showed excellent result because *curcuma* as a colouring substance has good fastness.
- The crease recovery of the fabric reduced gradually after every treatment. It is statistically proved that the significant difference at 1% level of F value is **48.508**.
- Air permeability test indicating the permeability factor was not affected in all samples. It is statistically proved that the significant difference at 1% level of F value is **77.37**.
- In thermal conductivity test OF, ETS, PPTS and DS samples showed similar thermal conductivity property and it was not affected in all samples. It is statistically proved that the significant difference at 1% level of F value is **34.375**.
- Flammability test result shows DS (25.67 percent) has good flame retardant property when comparing other samples. It is statistically proved that the significant difference at 1% level of F value is **57.024**. Similarly Glow time of ETS, PPTS and DS decreased when compared to original fabric. DS sample doesn't hold fire for long period. It is statistically proved that the significant difference at 1% level of F value is **2357.50**.

## Conclusion

The selected cellulosic fibres such as *Chrysopogon Zizanioides* (Vetiver root fibre), *Banana pseudo-stem* fibres and *Gossypium* (Cotton fibres) were used to make a blended woven fabric. These fibres are eco-friendly and easily available in nature. *Chrysopogon Zizanioides* not only the natural fibres, but also have medical properties like anti-bacterial, anti-inflammatory and anti-allergic which are beneficial for the skin of the person using it as oil content. *Banana pseudo-stem* fibres are usually low-cost fibres with low density with high specific properties. Each and every part of banana plant gives fibres of various strength, colour and long staple length. Cotton is the most important natural and cellulosic textile fibre in the world, to produce apparel, home furnishing and industrial products.

Pre-treatment process was done for produced blended woven fabric to remove impurities and enhance the softness of the fabric. Enzymes are used in bio-softening process for improving the low-stress mechanical properties such as tensile linearity, stiffness and compression energy of finished fabric. Bio-enzymes solution was used to treat the fabric in dip and dry method. Similarly, Papaya fruit peels were used as a natural enzyme to soften the woven fabric in tanning method. Natural dyes are not only biodegradable, but also have medicinal properties like anti-bacterial, anti-inflammatory and anti-allergic which are beneficial for the skin of the person using it. It is ensured that the discharge of the dyeing unit is devoid of any toxic chemicals and heavy metals protecting the precious water sources (Flint, 2008).

## Further study

- *Chrysopogon ziznioides* fibres have medical properties like anti-allergic and anti-bacterial which is ensured that the cellulosic blended woven fabric could be carried out for medicinal textiles products.
- In this study, myrobolan had proved good efficiency in dye fixation, in further studies could also be carried out using other mordants, herbs, extraction method and type of materials.
- The same study can be done on knitted and woven fabrics.

## **BIBLIOGRAPHY**

### **BOOKS,**

- Amyes, Sebastian G B, 2013, “Bacteria: A Very Short Introduction”, Pp:50.
- Anand S, Subash Anand, Richard Horrocks A, 2000, “Hand Book Of Technical Textiles”, Wood Head Publishing, Pp:152.
- Bhat, P. (2000). Natural dyes and eco-friendly. Industrial and technical consultancy. (p. 1-2).
- Bhattacharyya, N. (2010). Natural dyes for textile and their eco-friendly application. IAFC. (Pp. 3-4).
- Choudhury, R., R.k. (2006). Textile preparation and dyeing. Science publishers. (p.232).
- Dinah Eastop, Agnes Timar-Balazy, 2012, “Chemical Principle Of Textile Conservation”, Pp:101.
- Flint, (2008), “Eco-colour: Botanical Dyes for Beautiful Textiles”. Murdoch Books, P.87.
- Gerd Weissenbach, 2004, “Issue In The Analysis And Testing Of Textile Composites With Large”, Pp: 54.
- Gray Kavin Hyde, 2007, “Functional Textiles via Self Assembled Nanolayers and Atomic Layer Deposition”, Pp:5.
- Guljarani, M.c., & gupta, D. (2001). Introduction to natural dyes. Gov of india publishers. (Pp. 9-10)
- Harbhajan Singh, 2006, “Mycoremediation: Fungal Bioremediation”, Pp:420.
- Hunger, k. (2007). Industrial dyes chemistry properties. John wiley and sons. (P.348).
- Jill Condra, Dianne R, Jackman, Mary K, 2003, “The Guide For Interiors”, Pp: 118.
- Mishra S R, 2005, “Morphology of Fungi”, Pp:1.
- Mullik Premlatha, 2006, “Text Book of Textile Designing”, New Age International Publication, Pp: 51.
- Senthil Kumar, 2013, “Textile for Industrial Application”, Pp: 119.
- Song, G. (2011). Improving comfort in clothing. Elsevier.

## JOURNALS,

- A. N. Gulati M.Sc. & A. J. Turner M.A., (1929). "*A Note on the early History of Cotton*". Journal of the Textile Institute Transactions.20. Pp:1
- Abdullah Nur Uddin Rony, (2022). "*Technical Properties of Cotton Fibre*". Textile Engineering College, Noakhali. Accessed 30 January 2022.
- Alagirusamy Ramasamy A. Das, (2015). "*Conversion of fibre to yarn*", Research gate-textiles and fashion, Chapter-8, Pp:162.
- Alagirusamy, R., (2015). "*Conversion of Fibre to Yarn*". Textiles and Fashion. Pp:159-189.
- Alkaya, Emrah, and Göksel N. Demirer., (2014). "*Sustainable textile production: a case study from a woven fabric manufacturing mill in Turkey*". Journal of Cleaner Production 65. Pp:595-603.
- Aly, A. S., A. B. Moustafa, and A. Hebeish., (2004). "*Bio-technological treatment of cellulosic textiles*". Journal of Cleaner Production 12.7. Pp:697-705.
- Ammayappan, L., Jose, S., & Chakraborty, S. (2013). "*Colouration of textiles by natural dyes*". Pp. 32-33.
- Anand Kumar Varma S., Suvalakshmi A., Manjula K R., (2021). "*Development of High-Performance Air Purier using Human Hair and Vetiver (Chrysopogon Zizanioides) as Filter Media*". May 2021.
- Ashok Athaye, (2013), "*Camouflage Textiles for Productive Clothing*", Vol No:6, Pp:44.
- Asif Mahmood., (2020). "*Smart lean in ring spinning-a case study to improve performance of yarn manufacturing process*", The Journal of The Textile Institute.
- Atul Kumar; Singh B P; Jain R K; Sharma A K, (2013). "*Banana fibre (Musa sapientum): A Suitable raw material for handmade paper industry via Enzymatic Refining*". International Journal of Engineering Research & Technology (IJERT). Vol. 2 Issue 10, October-2013.
- Balakrishnan, S., G. L. D. Wickramasinghe, and UG Samudrika Wijayapala., (2019). "*Investigation on improving banana fiber fineness for textile application*". Textile Research Journal 89.21-22. Pp: 4398-4409.

- Balan and Vandana, (2010). "*Development of preparatory processes for making of banana fibre blended fabrics and their evaluation*", SNDT Womens University. Accessed on 1 March 2013.
- Balasanka. Dr., (2013). "*Traditional and Medical Uses of Vetiver*".
- Balda, Sanjeev, (2021). "*Banana fibre: a natural and sustainable bioresource for eco-friendly applications*". *Clean Technologies and Environmental Policy* 23.5. Pp: 1389-1401.
- Bhat, V. (2012). "*Modern dyeing technique for eco-friendly environment*". *Colourage*. Vol.59, Pp.43-48.
- Britannica, The Editors of Encyclopaedia, (2020). "*Natural Fibre*". *Encyclopedia Britannica*. Accessed on 29 March 2022.
- Cd, Midhun Dominic, (2021), "*Thermoplastic starch nanocomposites using cellulose rich Chrysopogon zizanioides nanofibers*". *International Journal of Biological Macromolecules* 191. Pp:572- 573.
- Chahal, Khusminder Kaur, Sonia Kaushal, and Amanpal Kaur Sandhu., (2015). "*Chemical composition and biological properties of Chrysopogon zizanioides (L.) Roberty syn. Vetiveria zizanioides (L.) Nash-A Review*". *Indian Journal of Natural Products and Resources (IJNPR) [Formerly Natural Product Radiance (NPR)]* 6.4 (2). Pp:251-260.
- Chakraborty. J. N., (2014). "*Fundamentals and Practices in Coloration of Textiles*". ScienceDirect.
- Chattopadhyay D P, (2008), "*Basic enzymology and applications of cellulases in textile processing*". *Fibre2fashion.com*. Accessed May 2008.
- Chattopadhyay D P, (2008). "*Basic enzymology and applications of cellulases in textile processing*". The Department of Textile Chemistry in the Faculty of Technology & Engineering in M. S. University, Vadodara, India.
- Chelliappan, Brindha, and K. Madhanasundareswari., (2021), "*Production and optimization of growth conditions for invertase enzyme by aspergillus spin solid state fermentation (SSF) using papaya peel as substrate.*" *Journal of Microbiology, Biotechnology and Food Sciences*. Pp: 266-269.
- Choudhury A K (2006), "*Textile Preparation and Dyeing*". Science Publisher. Enfield, NH, USA, pp. 276, Pp:777–789.

- Saravana Bavan. D., Mohan Kumar. G. c., (2014). “*Tensile and Thermal Degradation Properties of Vetiver Fiber Composites*”. Procedia Materials Science. Volume 5, Pp:605-611.
- Danso, H., (2021). “*Properties of Plantain Pseudo-Stem Fibres, Plantain Bunch Fibres and Rice Husk for Construction Application*”. Mater Circ Econ 3. Pp:15.
- Ding & Qijun, (2021). “*Understanding the evolution of cellulose fibers during enzyme treatment.*” Industrial Crops and Products 171. Pp: 113983.
- Doshi and Amrita, (2017). “*Banana fiber to fabric: Process optimization for improving its spinnability and hand*”. Diss. Maharaja Sayajirao University of Baroda (India).
- Dudai, N., E. Putievsky, D. Chaimovitch and M. Ben-Hur, (2006). “*Growth Management of Vetiver (Vetiveria zizanioides) under Mediterranean Conditions*”. Journal of Environmental Management, 81. Pp: 63-65.
- Elisabeth Heine; Hartwig Hoecker, (2001). “*Bioprocessing for smart textiles and clothing*”. Comprehensive Biotechnology (Second Edition). Science Direct.
- El-Mogahzy Y (2004), “*An integrated approach to analysing the nature of multicomponent fibre blending*”, Text Res J, 74(8). Pp:701–712.
- Gautam Basu & Alok Nath Roy, (2007), “*Blending of Jute with Different Natural Fibres*”, Journal of Natural Fibres, Volume 4, 2008-Issue 4.
- Gavira, C., Watteau, F., Lainé, J.-M., Bourgaud, F., & Legendre. L., (1942). “*Evaluation of Vetiver Volatile Compound Production under Aeroponic-Grown Conditions for the Perfume Industry*”. Molecules 2022, 27, 1942.
- Grover & Madhuri, (2021). “*Potential therapeutic effect of Chrysopogon zizanioides (Vetiver) as an anti-inflammatory agent.*” Environmental Science and Pollution Research 28.13. Pp:15597-15606.
- Haigler C.H., Betancur L., Stiff MR., & Tuttle J.R., (2012). “*Cotton fiber: a powerful single-cell model for cell wall and cellulose research*”. Front. Plant Sci. 3. Pp:104.
- Hall, A.J., (2001). “*The standard hand book of textiles*”, 8<sup>th</sup> edition, wood head publishing ltd., England, pp.29.
- Ibrahim N. A., (2011). “*4 - Dyeing of textile fibre blends*”. Handbook of Textile and Industrial Dyeing. Volume 2, Pages 147-172.
- Japan Echo Inc., (2005). “*Banana Stem Become Denim-like Cloth*”. Domestic Japanese News Source. 1-6.

- Johnston & Francis J., (2020). "*Mordant.*" Access Science, McGraw-Hill Education.
- Julissa Rojas-Sandoval, (2020). "*Chrysopogon zizanioides (vetiver)*", November 2020.
- Khan, Anish, (2020). "*Extraction and characterization of vetiver grass (Chrysopogon zizanioides) and kenaf fibre (Hibiscus cannabinus) as reinforcement materials for epoxy based composite structures.*" Journal of Materials Research and Technology 9.1. Pp: 773-774.
- Khan, Farhan A., & Shoib Arif, (2006). "*Development and applications of animal amylases for enzymatic desizing of woven fabric*". Biological Sciences-PJSIR 49.2. Pp: 103-105.
- Kim & Su-yeon, (2007). "*New developments of enzymatic treatments on cellulosic fibers*". Vol. 972, ISSN: 0097-6156
- Kirici, S., (2011). "*To study of essential oil and agricultural properties of Vetiver (Vetiveria zizanioides) in the Southeastern of Mediterranean*". Advances in Environmental Biology, Pp. 447.
- Kushagri Singh & Kavita Singh, (2019). "*Applications of Targeted Nano Drugs and Delivery Systems*", Science Direct.
- Lal, R. K., (2020). "*Genetics of essential oil yield and their component traits in vetiver (Chrysopogon zizanioides (L.) Roberty)*". J. Med. Plants. Studies 8.4. Pp: P-56.
- Madhuri Grover, Tapan Behl, Tarun Virmani, Saurabh Bhatia, Ahmed Al- Harrasi & Lotfi Aleya, (2021). "*Chrysopogon zizanioides—a review on its pharmacognosy, chemical composition and pharmacological activities*". Environmental Science and Pollution Research.
- Maria Clerya Alvino Leite, André Parente de Brito Bezerra, Janiere Pereira de Sousa, Felipe Queiroga Sarmiento Guerra, Edeltrudes de Oliveira Lima, (2014). "*Evaluation of Antifungal Activity and Mechanism of Action of Citral against Candida albicans*". Evidence-Based Complementary and Alternative Medicine, Article ID 378280, Pp: 9.
- Martinez, J., P.T.V. Rosa, C. Menut, A. Leydet, P. Brat, D. Palet and, M.A.A. Meireles, (2004). "*Valorization of Brazilian Vetiver (Vetiveria zizanioides (L.) Nash ex Small) Oil*". J. Agric. Food Chem., 52. Pp: 65786584.
- Mazharul Islam Kiron, (2015). "*Technical Properties of Cotton Fibre*". Textile Engineering College, Noakhali.

- Neha Gupta & Bharti P. K., (2013). "State of Art on Yarn Manufacturing Process & its defects in Textile Industry". International Journal of Computational Engineering Research, Volume. 3, Issue. 4. Pp:47-57.
- Paramasivam & Suresh Kumar, (2020). "Extraction, characterization and enzymatic degumming of banana fiber." Journal of Natural Fibers. Pp: 1-10.
- Phan & Trung Nghia, (2021). "Root biomechanical properties of *Chrysopogon zizanioides* and *Chrysopogon nemoralis* for soil reinforcement and slope stabilisation." Land Degradation & Development 32.16. Pp: 2-3.
- Pitimaneeyakul, Uraiwan, (2009). "Banana fiber: Environmental friendly fabric". Proceedings of the Environmental Engineering Association of Thailand.
- Prakash et al., (2012). "Study of Thermal Comfort Properties of Cotton/Regenerated Bamboo Knitted Fabrics". African Journal of Basic & Applied Sciences 4 (2). Pp: 60-66.
- Prusti, A.K., Purohit, A., Nayak., A. & Das., N.B. (2010). Colourage. (Vol. 1, p.55).
- Ramdhonee, A. and Jeetah, P. (2017). "Production of wrapping paper from banana fibres". Journal of Environmental Chemical Engineering, 5. Pp: 4298–4306.
- Roberty L, (2022). "*Chrysopogon ziznioides*". Flora & Fauna web, National Parks.
- Rossol & Evelyn, (2019). "The Viability of Banana Fiber-based Textiles in the Fashion Industry". Diss. Kent State University, 2019.
- Salleh, J., Mohd Yusoh, M. K. and Ruznan, W. S. (2015). "Tensile strength of some natural-fibre composites". Pertanika Journal of Tropical Agricultural Science, 38 (4), Pp: 575-582.
- Samanta, A.K., & Agarwal, P., (2009). "Application of natural dyes on textiles". Indian journal of fibre and textile research. Pp: 384-399
- Santosha, P. V. Ch. R. K., Sa, S. S. G. A. and Manikanth, V. (2018). "Effect of fibre loading and thermal properties of banana and pineapple leaf fibre reinforced polyester composites". Materials Today: Proceeding. Pp: 5631–5635.
- Shivendra Parmar & Tanveer Malik, (2007), "Home Textiles-A Review", Fibre2fashion.
- Smitha Gingade, Thania Sara Varghese, Ponnuchamy Manivel, (2015). "Cultivation of Vetiver [*Vetiveria ziznioides* (Linn)]", Research Gate.
- Stephanie Steele, (2019). "What is banana fibre and how do you make textiles from it?". The sustainable fashion collective.com. Accessed on 3 June 2019.

- Subagyo, Asmanto, and Achmad Chafidz. (2018). *"Banana pseudo-stem fiber: Preparation, characteristics, and applications"*. Banana nutrition-function and processing kinetics. IntechOpen. Pp: 1-19.
- Subash, Mira Chares & Muthiah Perumalsamy, (2022). *"Enzymatic Degumming of Banana Fibers by Enterobacter cloacae PMC04 for Fineness Improvisation: An Eco-friendly Approach"*. Journal of Natural Fibers. Pp: 1-18.
- Thilagavathi G., Rajendra Kumar, Jeevarekha T., Radhai Rajendran, (2005). *"Cellulose Enzyme Softening"*. Researchgate.net.
- Thyavihalli Girijappa YG., Mavinkere Rangappa S., Parameswaranpillai J., & Siengchin S., (2019). *"Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites"*. A Comprehensive Review. Front. Mater. 6:226.
- Uddin & Faheem, (2019). *"Introductory Chapter: Textile Manufacturing Processes"*. Textile Manufacturing Processes, edited by Faheem Uddin, IntechOpen,.
- Vigneswaran, C., (2015). *"Banana fiber: scope and value added product development"*. Journal of textile and apparel, technology and management 9.2 (2015).
- Vigneswaran, C., Pavithra, V., Gayathri, V., and Mythili, K., (2015). *"Banana fibre: scope and value-added product development"*. Journal of Textile and Apparel, Technology and Management, 9 (2), Pp: 83-87.
- Vijay N Patil, Laga S K, Wasif A I, (2011). *"Studies In Properties Of Cotton Fabric Finished With Sodium Hexametaphosphate"*, Vol.No:8, Pp:47.
- Vishnu Arrora, (2010). *"textile chemistry"*, Abhishek Publication, Pp: 182
- Wegier A, Alavez V and Daniel Pinero, *"Cotton: Traditional and Modern Uses"*, (2016). Springer Science Business Media New.
- Weigmann & Hans-Dietrich H., (2021). *"cotton"*. Encyclopedia Britannica. 4 Oct. 2021.
- Yong J, Tan PY, Nor Hafiz Hassan, Tan S. N., (2010). *"A Selection of Plants for Greening of Waterways and Waterbodies in the Tropics"*. Singapore: Chung Printing. Pp: 480.

## WEB LINKS,

- Air-permeability - <https://www.satara.com/>.
- Alicia Zelazko, 2021 - <https://www.britannica.com/topic/natural-fiber>
- Aravin Periyasamy, 2022 - <http://gpktt.weebly.com/classification-of-textile-fibers.html>
- Flammability - <https://www.element.com/>
- <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.377.453&rep=rep1&type=pDS>
- <https://fabriclore.com/blogs/fabric-wiki/banana-fiber-information-on-banana-fiber>
- <https://fabriclore.com/blogs/fabric-wiki/banana-fiber-information-on-banana-fiber>
- [https://plants.ces.ncsu.edu/plants/chrysopogon zizanioides/](https://plants.ces.ncsu.edu/plants/chrysopogon_zizanioides/)
- <https://sewport.com/fabrics-directory/banana-fabric>
- <https://www.intechopen.com/chapters/68157>
- <https://www.linkedin.com/pulse/pre-treatment-process-woven-fabric-shahriar-shovon>
- <https://www.rxlist.com/vetiver/supplements.htm>
- <https://www.sciencedirect.com/science/article/pii/S2211812814006713>
- <https://www.sciencedirect.com/science/article/pii/S2211812814006713>
- <https://www.sciencedirect.com/topics/engineering/enzymatic-treatment>
- Image Reference - <https://textilevaluechain.in/news-insights/the-textile-value-chain-of-industry-facing-liquidity-issues-itf/>
- Jenny Newman, 2015 - <https://www.humphriesweaving.co.uk/woven-fabric-structure/>
- Sohanur Rahman Sobuj, 2015 - <https://textilestudycenter.com/plain-weave-definition-and-plain-weave-classification/>
- Thermal conductivity - <https://www.sigmatest.org/>
- <https://doi.org/10.1016/j.mspro.2014.07.306>.
- <https://doi.org/10.1016/j.mspro.2014.07.306>.
- Aryan Rathore, 2022 <https://www.textileschool.com/129/cotton-fibers-the-king-of-fibers/>
- Avneet Kaur, (2015). "Banana Fibre: A revolution in textiles". Fibre2fashion.com. <https://www.fibre2fashion.com/industry-article/7654/banana-fibre-a-revolution-in-textiles>. Accessed November 2015

- <https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/antibacterial-activity>
- <https://textilelearner.net/technical-properties-of-cotton-fiber/>
- Roberty, 2021, <https://pfaf.org/user/Plant.aspx?LatinName=Chrysopogon+zizanioides>
- <https://www.researchgate.net/publication/293600312-Cellulase-enzyme-softening>
- <https://www.britannica.com/topic/cotton-fibre-and-plant>. Accessed 29 March 2022.

## APPENDIX



**1) Original sample**



**2) Enzyme treated sample**



**3) Papaya peel treated sample**



**4) Dyed sample**