UTILIZATION OF ECO-FRIENDLY BAMBOO-COTTON FIBER BLENDS FOR PROTECTIVE AND HEALTHCARE TEXTILES

Thesis

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By

Vandana Sharma

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Vandana Sharma

December, 2009 — ***(Vandana Sharma)***

Pantnagar — *Authoress*

Dr. Alka Goel
National Fellow/Professor

Department of Clothing & Textiles
College of Home-Science
G.B. Pant Univ. of Agric. &
Tech., Pantnagar-263 145
Distt. U. S. Nagar
Uttarakhand, INDIA

CERTIFICATE

This is to certify that the thesis entitled **"Utilization of Eco-Friendly Bamboo-Cotton Fiber Blends for Protective and Healthcare Textiles"** submitted in partial fulfilment of the requirements for the degree of **Doctor of Philosophy** with major in **Clothing and Textiles** and minor in **Social Sciences** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Ms. Vandana Sharma, Id. No. 34021**, under my supervision and no part of the thesis has been submitted for any other degree or diploma.

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Pantnagar
December, 2009

(Alka Goel)
Chairperson
Advisory Committee

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Ms. Vandana Sharma, Id. No. 34021**, a candidate for the degree of **Doctor of Philosophy** with major in **Clothing and Textiles** and minor in **Social Sciences** agree that the thesis entitled **"Utilization of Eco-Friendly Bamboo-Cotton Fiber Blends for Protective and Healthcare Textiles"** may be submitted in partial fulfilment of the requirements for the degree.

(Alka Goel)
Chairperson

(Shahnaz Jahan)
Member

(Neelam Bhardwaj)
Member

(A.K. Shukla)
Member

Ex-Officio Member
Head of the Department

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Introduction

Chapter 1 **INTRODUCTION**

The driving force for the fiber development, especially in the past two decades has been ever increasing application for natural material in non-conventional sector such as automotive components, **medical textiles,** protective textiles, geo-textiles etc. All the above application sectors exploit the excellent performance of the natural materials such as heat reduction, comfortness, soft handle, breathability and biodegradable properties.

Today, the tendency toward cleanliness as a social phenomenon and the demand for sophisticated medical technology, antibacterial materials have attracted attention, and these are immensely required in the household field, medical field etc.

The term blend in textile refers to an intimate mixture of fibers of different composition, length, diameters, and colour, spun together into yarn. At present textile industry uses different kind of fibers as its raw material. Some of these fibers were known and used in earlier years of civilization as well as in modern times. Other fibers have acquired varied degrees of importance in recent years. The commercial value of any fiber depend largely to the extent to which it possess certain properties or qualities, such as tensile strength, elasticity, fineness, cohesiveness and sufficient length, all of which facilitate the process of spinning into yarn, availability in sufficient quantity and are economically viable for production. A number of natural fibers can not be used for manufacturing of textile fabrics because they lack in basic properties, required for textile fibers i.e. strength, cohesiveness, minimum staple length and pliability.

Blending is a very important process in textiles, can be defined as mixing of different fibers taken from two or more dissimilar families. Blending may be useful to obtain better texture, handle and appearance in case of apparel use of textile. Blending exploits the outstanding positive attribute of each fiber and at the same time offers an effective means of minimizing the negative characteristics present in the fiber. When different types of fibers are combined or blended, the properties of individual fibers combine to produce modification in the blended yarn. **Gordon (2006**) opined that blending improves yarn characteristics as reflected in the improvement of efficiency of spinning, weaving and processing. Blending is a way to make an expensive fabric go further and therefore be more affordable.

Cotton fiber is widely and easily available in India. Cotton is the most used fiber/fabric for making healthcare and hygiene products but it lacks antimicrobial properties. Bamboo plants are grown at many places in India such as Uttarakhand, Madhya Pradesh, West Bengal, North-east like Assam, Meghalaya, Tripura, Sikkim, etc. but manufacturing facility for developing bamboo fiber from bamboo plant is not available in India. Because of this reason, bamboo fiber has to be imported from China, which increases its cost. Bamboo fiber is a man-made cellulosic fiber having antimicrobial property but its cost is little higher as compared to cotton fiber. So, to enhance the performance at reasonable price, blending of both the fibers has been done. Through blending, percentage of bamboo fiber has been saved and its anti-bacterial property has been successfully incorporated into the cotton fiber.

1.1 Statement of the Problem

Textile goods are widely used in everyday clothing and medical materials; and there is a great demand for fiber/fabric materials having antimicrobial effects.

Micro organisms create and aggravate problems in hospitals and other environments by transmitting diseases and infections through clothing and bedding etc. The axillae and perineal regions of the body are more susceptible to microbial growth that leads to undesirable body odour. It is reported that synthetic (i.e. polyester etc) or polyamide fibers (i.e. wool, silk, nylon etc) retain more odour causing micro organisms than cellulosic fibers and are also subjected to the growth of pathogenic micro organisms. Besides microorganisms deteriorate cellulosic fibers and reduce the wearing life of the material. They adhere to the surface of the fibers; gradually corrode inwards layer by layer disintegrating the primary and secondary walls of the fibers causing considerable damage. It may be noted that bacteria are usually active at pH 7.0-8.0 and fungi at pH 4.0-6.5 **(Fouda, 2005).** Fungal growth on textile materials is more rapid at relative humidity (RH) greater than 80% **(Rajendran and Anand, 1999).** Similarly, a large number of fungi have been isolated on exposed cotton textiles. Thus, micro organisms exist in abundant quantities on textile materials which propagate diseases and infections, thereby, causing damage to fibers under normal usage and storage conditions. In order to combat these adversities, it is highly desirable to impart antibacterial, antifungal and mildew resistance properties to textile materials.

Antimicrobial materials i.e. fabrics, polymers and even toys can be divided into two categories based on the ability against micro organisms, i.e., biocide and biostatic functions. Biocide functions refer to the inactivation of micro organisms on the materials or total kill, while biostatic properties indicate the inhibition of the micro organisms' growth by the materials or partial kill. Biostatic fabrics would be more appropriate for aesthetic and hygienic type applications of textile products.

Nowadays, various synthetic fiber materials, such as polyester, polyamide and polypropylene, having characteristics of antibacterial effects are known, and a heavy silver-based inorganic antibacterial agent is primarily used as an antibacterial agent which has high degree of safety to humans, antibacterial effects on various bacteria, a long-term duration of antibacterial effects and excellent thermal resistance. A fiber containing a silver-based antibacterial agent is produced by melt-spinning. However, uniform incorporation of antibacterial finish into a fiber is difficult in many cases, yarns are likely to be snapped during a spinning process, the texture of a fiber surface deteriorates, and the strength of the fiber is decreased. Until then, these are widely used for making apparels, non-woven textiles and filters and some of them are used in medical products. However, they are not satisfactory products due to problems of water absorbency.

A cellulosic fiber such as rayon cannot possess antibacterial effects because chemical components used in the viscose production process decompose silver-based antibacterial agents. By using a binder, it is possible to fix a silver-based antibacterial agent on the surface of a cellulosic fiber such as rayon. However, due to the binder, the texture of fiber and moisture absorbency greatly deteriorates. Washing durability of this finish is poor.

A natural fiber such as cotton does not exhibit sufficient antibacterial effects due to its constituent components. **Beliakova and Hebeish (1998)** discussed the process for preparing an antibacterial formulation by reaction of carboxymethyl starch with trimethylolated melamine in the presence or absence of cupric ions to render cotton fabric antibacterial. The cellulose has been modified chemically with biocides accompanied by redox reaction to achieve durable and regenerable antibacterial activity on cotton and other cellulosic fabrics. The finish poly-hexamethylene biguanide hydrochloride imparts antibacterial property to cotton and cotton blended materials that are effective against a broad spectrum of bacteria, fungi and yeasts and also durable up to 50 launderings **(Rajendran and Anand, 1999).**

Rayon and cotton fibers are most suitable for making healthcare and hygiene products used in hospitals such as surgical gowns, caps, masks, patient dress and doctor-nurse uniform in view of its excellent water absorbency properties. However, cotton fiber does not exhibit sufficient antibacterial effects since cotton is a natural material itself and its constituent components interfere with antibacterial effects. On the other hand, synthetic fibers having incorporated antibacterial effects do not have water absorbency properties, and thus are not suitable for medical use, and cannot satisfy the requirements for medical products. Accordingly, demands for imparting antibacterial effects to cellulose fiber become intensified. It is well known that many infectious diseases such as tuberculosis, whooping cough etc., can be prevented by wearing antibacterial fabrics-protective clothing.

But the problem with all the above materials is that the antibacterial activity in the fiber or fabric has been imparted through incorporating antibacterial agent in the spinning dope or attached superficially with the help of binder etc. Except, cellulosic fibers or fabrics, all other materials especially synthetic fibers are non-biodegradable and so their disposal has become very difficult. Textile customers all over the world are demanding eco-friendly textiles; hence manufacturers and exporters are becoming more aware of the fascination and commercial value of eco textiles. The only way to produce the eco textile product is to turn towards the nature.

Further, as a general clothing material complying with society's tendency toward cleanliness, the importance of the bamboo fiber increases more and more. Bamboo fiber possesses inherited antibacterial property and the antibacterial effect of the bamboo fiber is excellent as compared with conventional products, and its degradation is especially remarkable. As a natural cellulose fiber, it can be 100% biodegraded in soil by micro-organism and sunshine.

In view of the needs for medical textiles especially for healthcare and hygiene products, the natural cellulosic fiber cotton and man-made cellulosic fiber bamboo have been chosen for present study to prepare blends of different ratios. In this way antibacterial and biodegradable cotton-bamboo blended apparels will be prepared which could be utilized to fulfill the demand of medical textiles.

Thus, all else being equal, the product that is manufactured in an environmentally safe way will have an unbeatable edge in tomorrow's market place. Blending of cotton, a natural cellulosic fiber and bamboo, regenerated cellulosic fiber will be one step in this direction. The main objective of blending of cotton with bamboo is to create a good quality fabric having outstanding performance in both antibacterial and biodegradable sense, by avoiding use of synthetic fibers those having no antibacterial and biodegradable qualities required for medical textiles.

1.2 Objectives of the study

The present study has been designed with the following objectives:

1. To find out the raw materials and articles used for existing medical textiles and evaluation of their physical properties.
2. To assess the physico-chemical properties of bamboo fiber and their comparision with other fibers used in existing medical textiles.
3. To blend bamboo and cotton fibers in different ratios, preparation of yarns and woven fabrics and evaluation of their physical properties.
4. To evaluate the antimicrobial and bio-degradable properties of pure and blended bamboo-cotton fabrics.
5. To prepare protective and healthcare textiles from pure and blended bamboo-cotton fabrics and analysis of their cost.

1.3 Scope and Significance of study

Technical Textiles is the fastest growing branch of textile industries worldwide with bright prospects. The total global sale of Technical Textiles in 2005 was of US$72 billions and is expected to reach US$126 billion by 2010. Asia is the chief producer and consumer of Technical Textiles **(Anonymous[1], 2007).**

Medical textiles are one of the most rapidly expanding sectors in the technical textile market. Medical Textiles are the products and constructions used for medical and biological applications and are used primarily for first aid, clinical and hygienic purposes. There has been a sharp increase in the use of natural as well as synthetic fibers in producing various medical products.

The consumption of Medical Textiles worldwide was 1.5 million tons in 2000 and is growing at an annual rate of 4.6%. In the Indian market, size of medical textiles was estimated to be INR 23.3 billion in 2007-08 and is expected to grow at a rate of 20% per annum. The share of meditech, a part of healthcare sector in Indian technical textiles market is found to be 5% **(Basu *et al.*, 2008)**.

India has always been dependent on imported textile products for surgical and extra corporeal applications. An unorganized sector of manufacturers has been catering largely to the third and the biggest segment of healthcare and hygiene products. Here too many MNCs like Johnson & Johnson, Smith & Nephew, Kimberly Clark and

Beiersdorf are the major players as they manufacture special type of bandages and wound care products compared to the simple ones made by Indian companies. With the Indian healthcare industry undergoing major expansion, the medical textile market too is poised for a boom. Many foreign medical textiles manufacturers are expected to set up their base in India **(Holla and Swaminathan, 2000).**

Bamboo plant is a renewable resource, grown widely throughout Asia, with unique properties that are retained in the manufacture of bamboo fibers, yarns and textiles. Chemically manufactured bamboo regenerated cellulosic fiber is sometimes called bamboo rayon because of the many similarities in the way it is chemically manufactured.

The raw material bamboo is well-selected from non-polluted region in Yunnan and Sicuan Province, China. They are all 3-4 years old, new bamboo, of good character and ideal temper. The whole distilling and production process in the plant is green process without any pollution. The company manufactures bamboo fiber strictly according to ISO9000 and ISO 14000. It produces natural and eco-friendly fiber without any chemical additive **(Anonymous[2], 2007)**.

Scientists found that bamboo owns a unique anti-bacterial bio-agent named "bamboo Kun". This substance combined with bamboo cellulose molecules tightly all along during the process of being produced into bamboo fiber. Bamboo fiber has particular and natural functions of anti-bacterial and deodourization **(Anonymous[3], 2007)**.

Bamboo fiber/fabric possesses excellent function of anti-bacterial, even after fifty washings. Scientific tests result shows that over 70% death rate of bacteria after being incubated on bamboo fiber/fabric **(Anonymous[2], 2007).** The naturally occurring bacteriostatic property also helps to prevent cultivation of yeasts, molds and fungus on the clothing **(Anonymous[4], 2007).** Bamboo fiber's natural anti-bacterial function differs greatly from that of chemical antimicrobial treatments. The later often tend to cause skin allergy when added to apparel.

Bamboo's organic and natural fiber properties make bamboo apparels hypoallergenic and non-irritating to the skin, making it a pleasant alternative for anyone with skin sensitivities or other allergies and dermatitis, sometimes associated with exposure to the chemicals used to give other materials similar properties. Bamboo fabric even has an inherent UV protection factor. They resist wrinkling and have passed flammability requirements without the addition of formaldehyde (a carcinogen), which is added to polyester/cotton blend fabrics to give them those qualities.

Bamboo fibers give human skin a chance to breathe free. Bamboo fiber has ability to breathe and posses' coolness. The cross-section of the bamboo fiber is filled with various micro-gaps and micro-holes (each of which acts as an insulator) offering excellent moisture absorption and increased ventilation. With this unparalleled micro-structure, bamboo fiber apparels can absorb and evaporate human sweat in a split second. Because this reason, it doesn't stick to the skin. Its extraordinary natural breathability keeps the wearer comfortable and dry for longer. According to authoritative testing figures, apparels made from bamboo fibers are 1-2 degrees lower than normal apparels in hot summer **(Anonymous[2], 2007).** At a microscopic level, bamboo fiber has a round cross-section. Because of this, it is very smooth and sits perfectly next to the skin.

Bamboo garments are also useful during winter, as the air circulates easily and moisture escapes, keeping person warm, dry and comfortable. Most of us have heard that several thin layers are warmer than one thick layer but if those layers don't breathe, one can soon start feeling clammy and moisture rashes can appear on the skin **(Anonymous[5], 2007).** Bamboo fabric keeps the wearer more comfortable in all temperatures – 'Air Conditioned Clothing'

As a natural cellulose fiber, it can be 100% biodegraded in soil by microorganism and sunshine. Therefore, bamboo fiber is praised as "the natural, green, and eco-friendly new-type textile material of 21st century" **(Anonymous[2], 2007)**.

Bamboo fabrics are made from pure bamboo fibers/yarns, which have excellent wet permeability, moisture vapor transmission property, soft hand, better drape, easy dyeing and splendid colours. It is a newly founded, great prospective green fabric. The bamboo fiber has incomparably wide foreground on application in sanitary material such as sanitary towel, gauze, mask, absorbent pads, food packing and so on. In the **medical scope**, it can be processed into the products of bamboo fiber gauze, operating coat, and nurse dress etc **(Anonymous[6], 2007)**.

The research and development efforts need to be strengthened for the production of bamboo fibers in India as till today it is being imported. So, the cost of bamboo fiber is slightly higher than cotton fiber, the most used fiber for making healthcare and hygiene products in India. The cost of good quality cotton fiber of sufficient length is around Rs. 60/kg where as the cost of bamboo fiber after importing in India is around Rs. 210/kg, therefore through blending with cotton the antimicrobial properties will be utilized.

1.4 Limitations of the study

- Only cotton and bamboo fibers will use for blending as work will carry out in depth i.e. pure and blends.
- Only 10s count yarn will be prepared for the present study to be use as constant.
- Out of various weave structures, only plain weave structures will used to prepare the fabrics, as to obtained consistent results.
- Out of various microorganisms, only two bacteria's and two fungi's will use for antimicrobial assessment of fabrics.

1.5 Organization of thesis

The study is presented in five chapters. The first chapter "Introduction" deals with the statement of the problem, objectives, scope and significance of the study and organization of thesis. Review of literature regarding present work has been presented in chapter II. The chapter "Review of Literature" includes information about cotton fiber and bamboo fiber along with their properties, fiber processing and blending, physical properties of yarn, fabric weaving, physical properties of fabric, microbes at the interface of textiles and skin, required conditions for the growth of microbes and their effect on textiles, antimicrobial finish with its benefits, classification, mechanism. Chapter III "Materials and methods" deals with the materials used and the methodology followed for conducting the present research study. Result obtained during the course of investigation are described in IV chapter "Results and Discussion" along with appropriate tables, figures, plates and sample sheets. Last chapter V is "Summary and Conclusion" which summarized the conclusion of the present research work. The Literature consulted and cited in the body of present research has been enlisted in the section under "Literature cited", which is followed by relevant Appendices.

Review of Literature

The present chapter attempted to give a brief account of literature reviewed which has direct or indirect bearing on the present investigation. The available review of literature has been organized under following sections:

2.1 Medical textiles

2.2 Cotton fibers

2.3 Regenerated cellulosic bamboo fibers

2.4 Fiber properties required for quality yarn making

2.5 Processing and blending of fibers

2.6 Physical properties of yarns

2.7 Fabric formation through weaving

2.8 Physical properties of fabrics

2.9 Microbes at the interface of textiles and skin

2.10 Environmental concerns

2.1 Medical textiles

The driving force for the fiber development, especially in the past two decades has been ever increasing application for natural materials in non-conventional sector such as automotive components, **medical textiles,** protective textiles, geo-textiles etc. These applications bring out the excellent performance such as heat reduction, comfortness, soft handle, breathability and biodegradable properties of the natural materials **(Kumar, 2007)**.

The term "Medical Textiles" literally means textiles used for medical purposes. Textiles apart from being a vital part of human life has since long been used in medical field, though the term has been coined very recently. Textile materials have a range of properties such as flexibility, elasticity, strength and cohesiveness etc., based on these properties research work has been going on rapidly around the world towards the application of textiles in medical field.

Specialists from physicians to textile chemists and textile engineers are applying this broad range of properties of textile materials in medical technology **(Gopalakrishnan *et al.,* 2007).**

In India, the technical textiles market is expected to reach Rs 42,006 crore by 2007-2008 and according to another report the market size will reach Rs 78,060 crore by 2014-15. Medical textiles are expected to grow at a rate of 20% per annum. The share of meditech, a part of healthcare sector in Indian technical textiles market is found to be 5% **(Basu and Balasubramaniyan, 2008)**.

Textile products are used in medical and healthcare sector in various forms. The complexity of applications has increased with research and developments in the area of medical textiles. The surgical gown, operating room garments and drapes require special antibacterial properties combined with the wearer's comfort. Other major uses of medical textiles are incontinence diapers, sanitary napkins and baby diapers. Wound dressing, bandages and swabs are also widely used conventional medical textiles.

Textiles are also being used as sutures, orthopedic implants, vascular grafts, artificial ligaments, artificial tendons, heart valves and even as artificial skins. Recent advances in medical textiles to be used as extracorporeal devices are also significant; these include artificial kidney, artificial liver, mechanical lungs etc. New materials are finding specialized applications like antimicrobial and antifungal fibers and additives used in barrier fabrics, abdominal post-operative binders, applications in neurodermatitis treatment and various other wound management and surgical treatments.

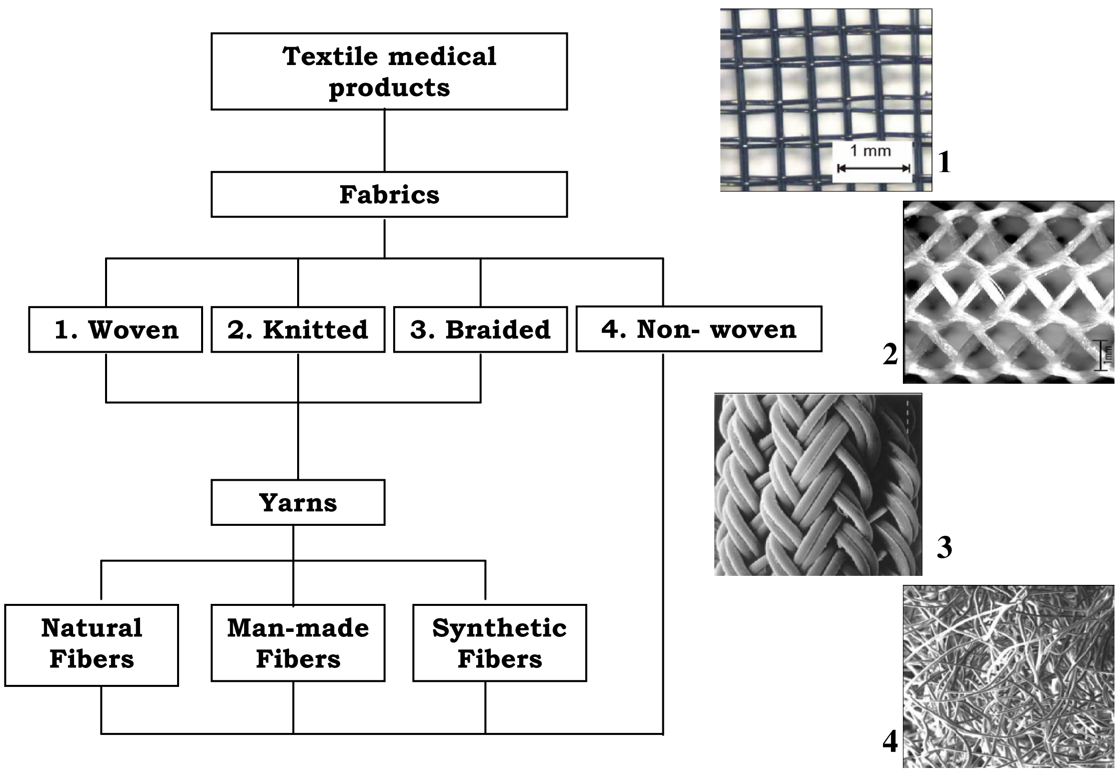
Although the type of fiber used and the fabric structure varies with the specific end use, all medical fibers must be non-toxic, non-carcinogenic, non-allergic and capable of being sterilized without suffering chemical or physical damage **(Thamotharan *et al.*, 2008)**

2.1.1 Classification of medical textiles

- **Protective and healthcare textiles**: surgeons' wear, operating drapes and staff uniforms etc.
- **External devices**: wound dressings, bandages, pressure garments, prosthetic socks etc.
- **Implantable materials**: sutures, vascular grafts, artificial ligaments etc.

- **Hygiene products**: incontinence pads, nappies, tampons, sanitary towels etc.
- **Extracorporeal devices**: artificial liver, artificial kidney, artificial lung, etc. (**Anonymous, 2001**)

2.1.2 Constituent Elements of Medical Textile Products



2.1.3 Fibers used for medical and healthcare application

Textiles materials that are used in medical applications include fibers, yarns, fabrics and composites. Depending upon the application, the major requirements of medical textiles are absorbency, tenacity, flexibility, softness and at times biostability or biodegradability **(Meena *et al.*, 2008).**

2.1.3.1 Various applications of different fibers in medical field are shown as follows:

S. No.	Fiber	Application in medical field
1	Cotton	Surgical clothing gowns, beddings, sheets, pillow covers, uniforms, surgical hosiery
2	Viscose	Caps, masks, wipes
3	Polyester	Gowns, masks, surgical cover drapes, blankets, cover stock
4	Polyamide	Surgical hosiery
5	Polypropylene	Protective clothing
6	Polyethylene	Surgical covers, drapes
7	Glass	Caps, masks
8	Elastomeric	Surgical hosiery

2.1.4 Healthcare & hygiene products

An important area of textile is the healthcare and hygiene sector among other medical applications. The range of products available for healthcare and hygiene is vast and are typically used either in the operating theatre or in the hospital wards for hygiene, care and safety of the staff and patients. They could be washable or disposable.

2.1.4.1 Operating theatre

This includes surgical gowns, caps and masks, patient drapes and cover cloth of various sizes.

a) Surgical gown

It is essential that environment of operating theatre is clean and strict control of infection is maintained. A possible source of infection to the patient is the pollutant particle shed by the nursing staff, which carries bacteria. Surgical gowns should act as barrier to prevent release of pollutant particles into air. Traditional surgical gowns are woven cotton goods that not only allow the release of particles from the surgeons but also a source of contamination generating high levels of dirt (lint). Nowadays, disposable non woven surgical gowns have adopted to prevent these sources of contamination to patients and are often composites materials of non-woven made up of natural fibers such as cotton and polyethylene films.

b) Surgical masks

They should have higher filter capacity, high level of air permeability, lightweight and non-allergic.

c) Surgical caps

These are made from non-woven materials based on cellulose.

d) Surgical drapes and cover clothes

These are used to cover patients or to cover working areas around patients. These should be completely impermeable to bacteria and also absorbent to body perspiration and secretion from wound.

2.1.4.2 Hospital ward

This includes beddings, clothing, mattresses and covers, incontinence products, clothes and wipes. In hospital cross infection should be prevented and hence traditional woolen blankets were replaced by cotton leno woven blankets. Incontinence products for patients are available in both diaper and flat sheet forms with later used for bedding. Clothes and wipes are made of tissue paper on non-woven bonded fabrics, which may be finished with an antiseptic finish **(Meena *et al.*, 2008).**

2.1.5 Different healthcare and hygiene products and their fiber and fabric types

Product application	Fiber type	Fabric type
Surgical clothing, Gowns	Cotton, Polyester, Viscose rayon, Polypropylene	Non-Woven/Woven
Caps, Masks	Viscose rayon, Polyester, Viscose, Glass	Non-Woven Non-Woven
Surgical covers, Drapes cloth	Polyester, polyethylene, Polyester, polyethylene	Non-Woven/Woven Non-Woven/Woven
Beddings, Blankets, Sheets, Pillow covers	Cotton, Polyester Cotton Cotton	Woven, Knitted Woven Woven
Clothing uniforms, Protective clothing	Cotton, Polyester Polyester, polypropylene	Woven Non-woven
Incontinence diaper sheet, Coverstock, absorbent layer, outer layer	Polyester, polypropylene Wood fluff Super absorbents Polyethylene fiber	 Non-woven Non-woven Non-woven
Cloths/Wipes	Viscose rayon	Non-woven
Surgical Hoisery	Polyamide, Polyester, Cotton, Elastomeric yarns	Non-woven Knitted

2.2 Cotton fibers

Cotton is a fiber that grows from the surface of seeds in the pods, or bolls, of a bushy mallow plant. It is composed basically of woody substance called cellulose.

Cotton has been cultivated for more than 5000 years. Archeological findings indicated that cotton was grown and used for textile purposes in the Indus Valley well before 2100 B. C., Mexico by 3500 B. C., in Peru by 2500 B. C., and in the southwestern United States by 500 B. C. Fragments of fiber and bolls dating from 5800 B. C. were found in Mexico, although there is a question as to whether cotton was used as textile that early. Cotton was used extensively in the Medo-Persian Empire and may have been used in ancient Egypt as well. It was introduced into the Mediterranean countries by the Arabs and into other parts of Europe by the crusaders. The use of cotton in England is mentioned in writings of the thirteenth century, although its use did not become general until the first half of the sixteenth century. In the United States, cotton was cultivated by the colonists in the early seventeenth century. The impetus of the industrial revolution, represented in the cotton industry by the invention of the carding machine and the spinning mule in England and by the invention of the cotton gin in the United States, resulted in vastly increased cotton production and manufacturing.

Cotton fabrics have been so well known and so extensively used throughout the world for hundreds of years that the spinning of the cotton fiber into yarn, the weaving of cotton yarn into fabric, and many of the finishing processes used for cotton goods come first to mind and naturally serve as foremost examples in a study of fiber and fabric. Cotton has been of service to mankind for so long that its versatility is almost unlimited. New uses are constantly being discovered. Cotton is considered nature's most economical fiber; it is low priced as a raw material and as a finished product. It can be used to serve many purposes. Not only is cotton a textile in its own right, but its by-products form the base for some of the man-made textile fibers **(Corbman, 1983).**

2.2.1 Production of cotton fiber

Cotton grows in any part of the world where the growing season is long. Cellulose will not form if the temperature is below 70°F. Cotton grows on bushes three to four feet high. The blossom appears, falls off, and the boll begins its growth. Inside the boll are seeds from which the fibers grow. When the boll is ripe, it splits open and the fluffy white fibers stand out like a powder puff.

The fibers range from ½ to 2 inches in length, depending on the variety. There has been a decline in the use of the short staple; most production is now a medium-long staple, $1^{1}/_{32}$ to $1\ ^{2}/_{32}$ inches.

Cotton is picked by hand or by machine. After picking, the cotton is taken to gin to remove the fibers from the seed. The fibers, called lint, are pressed into the bales weighing 500 pounds, ready for sale to a spinning mill **(Hollen and Saddler, 1973)**.

2.2.2 Properties of cotton

2.2.2.1 Color of fiber

Cotton fiber is generally white or yellowish in color.

2.2.2.2 Shape

The length of an individual cotton fiber is usually from 1,000 to 3,000 times its diameter. The diameter may range from 12 to 30 microns. In cross section the shape of the fiber varies from a U-shape to a nearly circular form. Seen in microscopic cross section, the fiber displays a hollow, central canal known as the lumen.

The mature cotton fiber has a natural twist, called *convolutions*. This twist gives the cotton fiber the appearance of a twisted ribbon and it makes cotton easier to spin. In spite of the twisted shape of the cotton fiber, it is relatively uniform in its size.

2.2.2.3 Luster

The luster of cotton is low.

2.2.2.4 Strength

Cotton fiber is relatively strong due to the intrinsic structure of layers of criss-crossed, minute, spiraled fibrils that compose the fiber cell. Strength of the cotton is 3 to 5 g/d. Cotton is 10 to 30% stronger when wet than dry.

2.2.2.5 Density and specific gravity

Cotton is a fiber of relatively high density, having a specific gravity of 1.54 g/cc.

2.2.2.6 Elasticity and resilience

Like most other cellulosic fibers, the elasticity and elastic recovery of cotton is low. Not only does cotton stretch relatively little but it also does not recover well from stretching. Its resilience is low.

2.2.2.7 Absorbency and moisture regain

Cotton is an absorbent fiber. Its good absorbency makes cotton comfortable in hot weather, suitable for materials where absorbency is important (such as diapers and towels), and relatively slow to dry, because the absorbed moisture must be evaporated from the fiber. The percentage moisture regain of cotton is 7 to 8%.

2.2.2.8 Dimensional stability

Cotton fibers exhibit neither shrinkage nor stretching in their natural state. Woven or knitted cotton fabrics may shrink in the first few launderings because the laundering releases tensions created during weaving or finishing. The relaxation of these tensions may cause changes in the fabric dimensions.

2.2.2.10 Heat and electrical conductivity

Cotton conducts electricity, and thus does not build up static electrical charges. It has moderately good heat conductivity, which makes the fabric comfortable in hot weather.

2.2.2.11 Effect of heat; combustibility

Cotton is not thermoplastic and will not melt. Exposure to dry heat at temperatures above 300°F, however, does cause gradual decomposition and deterioration of the fiber. Excessively high ironing temperatures cause to scorch or turn yellow.

Cotton is combustible. It burns upon exposure to the flame and will continue to burn when the flame has been removed. Burning cotton fabric smells like burning paper, and a fluffy, gray ash residue remains. It is not possible to distinguish cotton from other cellulosic fibers by burning **(Tortora, 1982)**.

2.2.2.12 Effect of acids

Cotton decomposes with strong acids in both hot and cold conditions. Even weak, cold, hot acids weaken fibers if allowed to dry on them.

2.2.2.13 Effect of alkalis

Cotton has an excellent resistance to alkalis. It swells in caustic alkali but is not damaged. It can be washed repeatedly in soap solutions without harm.

2.2.2.14 Effect of organic solvents

Cotton is highly resistant to most of the organic solvents like petrol, carbon tetrachloride, benzene, etc., these can be safely used for removal of stains and for dry-cleaning **(Vatsala, 2003)**.

2.2.2.15 Insects

Cotton is not attacked by moth grubs or beetles.

2.2.2.16 Micro-organisms

Cotton is attacked by fungi and bacteria. Mildews, for example, will feed on cotton fabric, rotting and weakening the material. They have a characteristic musty smell, and stain the fabric with naturally produced pigments **(Cook[1], 2005)**.

2.3 Regenerated cellulosic bamboo fibers

Botanically categorized as a grass and not a tree, bamboo just might be the world's most sustainable resource. It is the fastest growing grass and can shoot up a yard or more a day. Bamboo reaches maturity quickly and is ready for harvesting in about four years. Bamboo does not require replanting after harvesting because its vast root network continually sprouts new shoots which almost zoom up, pulling in sunlight and greenhouse gases and converting them to new green growth. Bamboo grows in a natural way without the need for petroleum-guzzling tractors and poisonous pesticides and fertilizers **(Anonymous[7], 2007).**

Bamboos are a group of woody perennial evergreen plants in the true grass family *Poaceae*, subfamily *Bambusoideae*, tribe *Bambuseae*. Some of its members are giant, forming by far the largest members of the grass family. Although bamboo is a grass, many of the larger bamboos are very tree-like in appearance and they are often called "bamboo trees". The reason bamboos are so different from trees is they lack a vascular cambium layer and meristem cells at the top of the culm. The vascular cambium is the perpetually growing layer of a tree's trunk beneath the bark that makes it increase in diameter each year. The meristems make the tree grow taller **(Anonymous[8], 2007).**

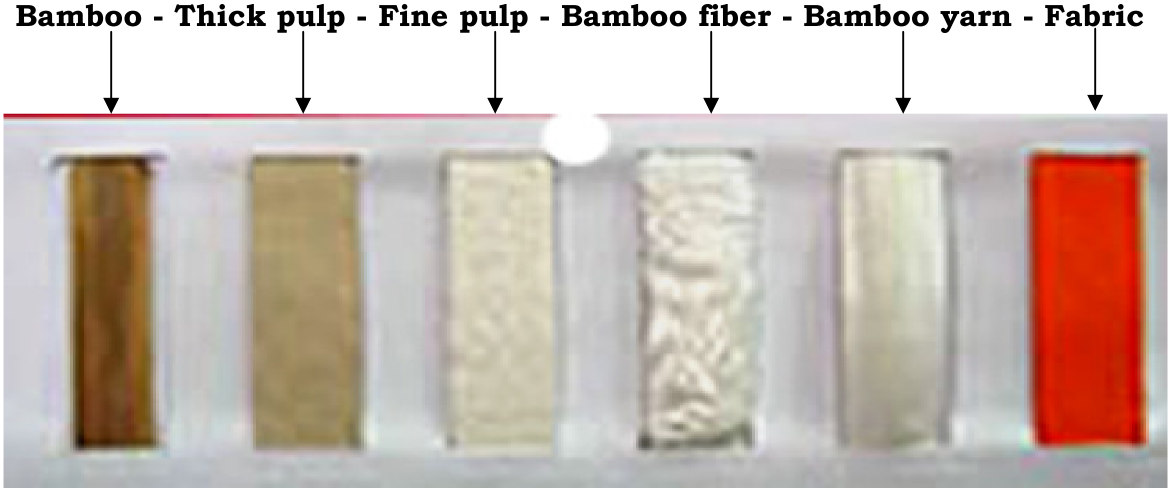
Common name	**Local names**	**Botanical name**	**Availability in India –regions**
Bamboo	Baans (Hindi) Veduru (Telugu) Biduru (Kannada)	*Bambusa vulgaris*	Largely in Uttarakhand and in other states also like Madhya Pradesh, West Bengal, North-East etc.

Bamboo fiber is a kind of regenerated cellulosic fiber, which is produced from bamboo pulp as raw material. Firstly, bamboo pulp is refined from bamboo through a process of hydrolysis-alkalization and multi-phase bleaching. After that, Bamboo pulp is processed and converted into bamboo fiber. The fineness and whiteness degree of bamboo fiber is similar to classic viscose.

Further more it owns high abrasion-proof capacity. Bamboo fiber spins nicely. This fiber is a natural cellulose fiber, can achieve natural degradation in the soil, and it won't cause any pollution to the environment. Bamboo can be spun purely or blended with other materials such as cotton, hemp, silk, Lyocell (Tencel) etc.

2.3.1 Fiber to fabric production flow of bamboo

Bamboo - Thick pulp - Fine pulp - Bamboo fiber - Bamboo yarn - Fabric



Chemically manufactured bamboo is sometimes called bamboo rayon because of the many similarities in the way it is chemically manufactured and similarities in its feel and hand.

The general process for producing regenerated bamboo fiber is furnished below:

Preparation: Bamboo leaves as well as the soft, inner pith from the hard bamboo trunk are extracted and crushed;

Steeping: The crushed bamboo cellulose is soaked in a solution of 15% to 20% sodium hydroxide at a temperature between 20°C to 25°C for one to three hours to form alkali cellulose.

Pressing: The bamboo alkali cellulose is then squeezed mechanically to remove excess sodium hydroxide solution.

Shredding: The alkali cellulose is mechanically shredded to increase surface area and make the cellulose easier to process.

Ageing: The processed cellulose is then left to dry for 24 hours. During this process, the shredded alkali cellulose is allowed to stand in contact with the oxygen of the ambient air. Because of high alkalinity, the alkali cellulose is partially oxidized and degraded to lower molecular weights. This degradation is to be controlled to produce chain lengths shorter enough to give proper viscosities in the spinning solution.

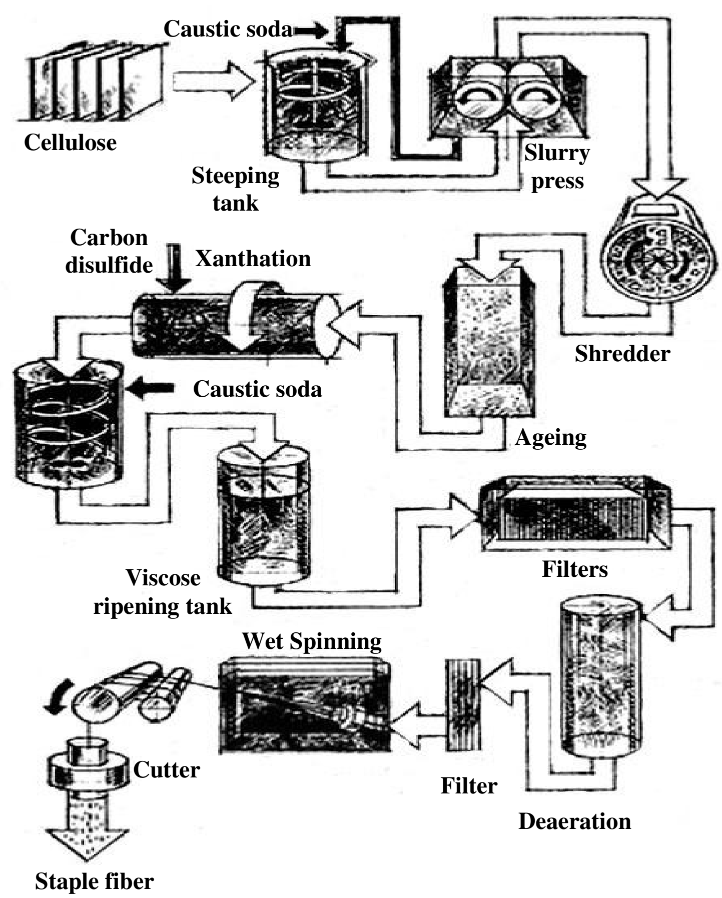


Fig. 2.1 Flow chart for the manufacturing process of bamboo fiber

Xanthation: Carbon disulfide is added to the bamboo alkali cellulose to sulfurize the compound causing it to jell. Any remaining carbon disulfide is removed by evaporation due to decompression and cellulose sodium xanthate is the result.

Dissolving: A diluted solution of sodium hydroxide is added to the cellulose sodium xanthate dissolving it to create a viscose solution consisting of about 5% sodium hydroxide and 7% to 15% bamboo fiber cellulose.

Spinning: After subsequent ripening, filtering and degassing, the viscose bamboo cellulose is forced through spinneret nozzles into a large container of a diluted sulfuric acid solution which hardens the viscose bamboo cellulose sodium xanthate and reconverts it to cellulose bamboo fiber threads, which are spun into bamboo fiber yarns to be woven into reconstructed and regenerated textile products of bamboo **(Subrata, 2008)**.

2.3.2 Advantages of bamboo fiber

2.3.2.1 Natural anti-bacterial

It's a common fact that bamboo can thrive naturally without using any pesticide. It is seldom eaten by pests or infected by pathogen. Bamboo owns a unique anti-bacteria and bacteriostasis bio-agent named "bamboo Kun". This substance combined with bamboo cellulose molecule tightly all along during the process of being produced into bamboo fiber.

Bamboo fiber has natural functions of anti-bacteria, bacteriostasis and deodourization. It is validated by Japan Textile Inspection Association that, even after fifty times of washing, bamboo fabric still possesses excellent function of anti-bacteria or bacteriostasis. Its test result shows over 70% death rate, after bacteria being incubated on bamboo fiber/fabric.

Bamboo fiber's natural anti-bacteria function differs greatly from that of chemical antimicrobial. The later often tend to cause skin allergy when added to apparel **(Saravanan and Prakash, 2007)**.

Bamboo fiber/fabric can kill 98% *Staphylococcus aureus*, *Colon bacillus*, *Dysentery bacillus*, *Candida albicans*, *Aspergillus niger* and so on in one hour. Because of this reason, it could be made into face mask, sanitary towel, medical gauze, bandage, surgical clothes, nurse clothes, innerwear, T-shirt, Shirt etc.

2.3.2.2 Green and biodegradable

Bamboo grows quickly, requiring few farming inputs and no pesticides. When compared to other fibers such as cotton, it is far more sustainable. Cotton requires huge amounts of water and extensive use of pesticides that pollute the environment. Bamboo takes up more greenhouse gasses and releases more oxygen, and does not need replanting or fertilizers, and its roots are very good at stabilizing erosion prone soil.

It produces natural and eco-friendly fiber without any chemical additives. More importantly, bamboo fiber is a unique biodegradable textile material. As a natural cellulosic fiber, it can be 100% biodegraded in soil by microorganism and sunshine. The decomposition process doesn't cause any pollution to the environment. "Bamboo fiber comes from nature, and completely returns to nature in the end" **(Anonymous[6], 2007).**

2.3.2.3 Water absorbent

In textile form, bamboo retains many of the properties it has as a plant. Bamboo is highly water absorbent, able to take up three times its weight in water. It has an excellent wicking ability that will pull moisture away from the skin so that it can evaporate. In warm, humid and sweaty weather, bamboo clothing helps to keep the wearer drier, cooler and more comfortable and doesn’t stick to the skin. Because of this reason, it can be made into super wipers, turkish towel, cleaning towel etc.

2.3.2.4 Soft feel

Bamboo fiber/fabric is softer and smoother than cotton and can be comfortable directly next to the skin. Many people who experience allergenic reactions to other natural fibers, such as wool or hemp, do not complain of this issue with bamboo. The fiber is naturally smooth and round without chemical treatment, meaning that there are no sharp spurs to irritate the skin. Strong and stable strength both vertically and horizontally plus a good dependence which leads to natural look and elegance.

2.3.2.5 Breathable and cool

Bamboo fiber, gives our skin a chance to breath free…

Bamboo fiber has unusual breath ability and coolness. Because the cross-section of the bamboo fiber is filled with various micro-gaps and micro-holes, it has much better moisture absorption and ventilation. With this unparalleled micro-structure, bamboo fiber apparel can absorb and evaporate human sweat in a split second. Just like breathing, such garments make people feel extremely cool and comfortable in the hot summer. It is never sticking to skin even in hot summer. Apparels made from bamboo fibers are 1-2° lower than normal apparels in hot summer. Apparel made from bamboo fiber is crowned as “Air Conditioning Dress”.

Bamboo fiber non-woven products will have excellent performance on water absorption, and easy to dry, that’s the best and most important for wipes. Because of the natural anti-bacterial character, it is an excellent material for medical utilization.

2.3.2.6 Bamboo natural anti-UV

Bamboo natural anti-UV character (different from the man-made additive) is quite healthy and appreciated in the damaged environment today.

With modern industrial development, the atmospheric ozone constantly undermined, leading to increased surface ultraviolet radiation. The UVA, UVB-band feed melanin generation, resulting in cerebral cortex aging and even cause cataracts, skin cancer and other ailments. Because of this reason, it could be made into outer wear, curtain, sunshade (beach umbrella), etc.

2.3.2.7 Antistatic

A characteristic of bamboo fiber is such that it absorbs moisture due to micro-gaps and static electricity is hard to be generated. Bamboo fiber does not contain free electron and thus it is antistatic, so it fits very well next to the human skin but not clinging it. It flows lightly over the body.

2.3.3 End uses of bamboo fiber

2.3.3.1 Bamboo intimate apparels

Include sweaters, bath-suits, mats, blankets; towels have comfortable hand, special luster and bright colours, good water absorbency. Bamboo fiber has anti-bacteria function, which is suitable to make innerwear, tight t-shirt and socks. Its anti-ultraviolet nature is suitable to make summer clothing, especially for the protection of pregnant ladies and children from the hurt of ultraviolet radiation.

2.3.3.2 Bamboo non-woven fabric

Bamboo non-woven fabric has wide prospects in the field of hygiene materials such as sanitary napkin, masks, mattress and food-packing bags due to its anti-bacteria nature.

2.3.3.3 Bamboo sanitary materials

Include bandage, mask, surgical clothes, and nurses' wears and so on. The bamboo fiber has natural effects of sterilization and bacteriostasis, therefore it has incomparably wide foreground on application in sanitary material such as sanitary towel, gauze mask, absorbent pads, food packing and so on.

In the medical scope, it can be processed into the products of bamboo fiber gauze, operating coat and nurse dress, etc. Because of the natural antibiosis function of the bamboo fiber, the finished products need not to be added with any artificial synthesized antimicrobial agent, so it won't cause the skin allergy phenomena, and at the same time, it also has competitive prices in the market.

2.3.3.4 Bamboo decorating series

Bamboo fiber has the functions of antibiosis, bacteriostasis and ultraviolet-proof. It is very advantageous for utilization in the decorating industry. Along with the badly deterioration of atmosphere pollution and the destruction to the ozonosphere, the ultraviolet radiation arrives the ground more and more. Long time exposure to ultraviolet radiation will cause skin cancer. But, the wallpaper and curtains made from bamboo fiber can absorb ultraviolet radiation in various wavelength, thus to lessen the harm to human body farthest. Bamboo decorating product won't go moldy due to the moisture. Curtain, television cover, wallpaper and sofa slipcover can all be made with bamboo fibers.

2.3.3.5 Bamboo bathroom series

Bamboo towel and bath robe have soft and comfortable hand feeling and excellent moisture absorption function. Its natural antibiosis function keeps bacterium away so that it won't produce bad odour **(Anonymous[6], 2007).**

2.4 Fiber properties required for quality yarn making

According to **Hollen and Saddler (1973)**, the fibers are the fundamental units used in the making of textile yarns and fabrics. The performance of a fabric depends considerably on the physical properties of fibers of which it is made. Fiber properties are determined by the nature of the external structure, the chemical composition and the internal structure. Fiber properties contribute to the characteristics of the fabric as do the yarn, the finish and the method of construction.

2.4.1 Fiber fineness

Fineness is one of the most important properties of the fibers that are made into textile products. The fiber fineness has a number of effects on the properties of the yarn and hence the fabric that is made from it. The finer the fiber the finer is the yarn that can be spun from it **(Saville, 2004)**. **Goswami *et al.*, (1977)** also stated that the property of fineness or coarseness of textile fibers has been recognized as one of the most important of all the fiber characteristics affecting processing behavior and yarn properties. According to **Hollen and Saddler (1973)**, the fineness of natural fiber is measured in microns whereas fineness of man made fiber is measured in denier. Denier is weight in grams of 9000 meters of fiber or yarn**.** Man-made fiber can have any diameter that the manufacturer chooses and the selections are generally related to the projected use of the fiber. In man made fibers, diameter is controlled by the size of spinneret holes and by stretching during or after spinning. It helps in determining the yarn quality characteristics.

2.4.2 Fiber length

According to **Saville (2004),** after fineness, length is the most important property of a fiber. Suitable for use in textiles, fibers must have greater length than diameter and be flexible and strong to withstand the strain of the various manufacturing processes. In general a longer average fiber length is to be preferred because it confers a number of advantages. Firstly, longer fibers are easier to process. Secondly, more even yarns can be produced from longer fibers because there are less fiber ends in a given length of yarn. Thirdly, a higher strength yarn can be produced from longer fibers for the same level of twist. Alternatively a yarn of the same strength can be produced but with a lower level of twist, thus resulting a softer yarn. An increase in fiber length generally improves yarn regularities and textile properties, reduces yarn hairiness and also improves abrasion resistance.

2.4.3 Fiber crimps

According to **Sharma and Goel (2007),** number of crimps refers to waves, blends, twists or coils along the length of the fiber. Fiber crimp increases cohesiveness, resiliency and resistance to abrasion. It increases the warmth, absorbency, skin contact and comfort but reduces luster. Fiber crimp could be beneficial in reducing fiber breakage during carding.

2.4.4 Fiber strength and elongation

Fiber strength is generally expressed as tenacity. It is the breaking load divided by linear density of the unstrained material expressed as gram per tex **(ISI Handbook of textile testing, 1982).** Fiber strength is generally considered to be next to the fiber length which influences processing and product performance. The cotton having higher strength generally results in improvement in durability of the products. The resultant strength of the blended yarn is mainly dependent on the strength of the individual fiber **(Basu, 2001).**

According to **Joseph (1984),** tensile strength of a textile fiber, i.e., its ability to break when stretched (pulled) is one of its important properties. When some load is applied to a textile fiber it lengthens. As the load applied is increased gradually, the elongation also increases until it breaks. But before it breaks, it passes through different regions. In the first region (of perfect elasticity), if the load applied is removed, the original length of the fiber is regained instantaneously (elongation vanishes). This region is also called Hooke's law region in which the strain (the ratio of increase in length to the original length is proportional to the stress force per unit area of cross section acting on the fiber). As the load is increased and when the hooke's law region is crossed, the fiber is elongated further with increased load, but after removing load, there is a delayed recovery from elongation (creep). As the load is again increased and the fiber is stretched beyond the second region, a third region is reached in which the elongation of the sample is the permanent, i.e., it does not recover when the load is removed. When the load is increased again, the fiber breaks and the load required to break the fiber is called the breaking load. Thus the breaking load required to break the fiber determines the strength of fiber, higher the breaking load, higher will be the strength of fiber**.** In case of fiber the breaking load is designated as tenacity and is expressed in terms of gm/denier.

Chellamani[1] *et al.* (2006) stated that tenacity of bamboo fiber is more or less same as that of viscose. However, breaking elongation of bamboo fiber is higher by about 7% (absolute values) as compared to viscose fiber. At fiber stage, bamboo & viscose are weaker than cotton by about 20%.

2.4.5 Moisture regain of fiber

Most textile fibers have certain amount of water as an integral part of their chemical structure. This water is called moisture regain and is expressed as a percentage of weight of the moisture free fiber. The relation of fiber strength to moisture content is another important consideration in evaluating fiber behavior. Some fibers are stronger in wet than dry, other are weaker when wet, and still other exhibit no change. Fibers which are weaker when wet requires special handle and care during laundering. Fiber with good moisture regain will accept dyes and finishes more readily than fibers with low regain and are comfortable in wear. Few fibers have no regain at all and this creates some problems in processing **(Joseph, 1984).** Moisture affects strength, extension and electrical conductivity of a fiber **(Basu, 2001).**

2.4.6 Fiber cross-sectional shape

According to **Hollen and Saddler (1973)**, cross-sectional shape is important while considering luster, bulk, body, texture and hand or feel of a yarn and fabric. This shape may be round, dog-bone, triangular, lobal, bean shaped and flat or straw like.

2.5 Processing and blending of fibers

Primitive people discovered that a succession of short fibers could be twisted into continuous yarn. The value and character of a yarn are determined by **(1)** kind and quality of fiber; **(2)** amount of processing necessary to produce fineness and **(3)** amount of twist, which increases tensile strength in the finished yarn.

The formation of yarn from staple fibers by spinning becomes possible when they have surfaces capable of cohesiveness. This quality is exemplified by the natural twist of the cotton fibers which enables them to entwine around each other. Flexibility permits the fibers to be twisted around one another **(Corbman, 1983)**.

The development of short fibers, or staple, into yarn, when stated in terms of basic manufacturing processes, is as follows: carding, combing, drafting, twisting and winding. As the fibers pass through these processes, they are successively formed into lap, sliver, roving, and finally yarn. Here are the manufacturing operations in which these stages occur:

2.5.1 Carding

According to **Kaplan (2002),** carding is by far the most important process in spinning. “Card is the heart of the spinning mill” and “well carded is half spun” are two proverbs of the experts. These proverbs inform the immense significance of carding in the spinning process. High production in carding to economize the process may leads to reduction in yarn quality. Latest machines achieve the production rate of 60-100 kg/hr, which used to be 5-10 kg/hr up to 1970. The purposes of carding are:

1. To open the flocks into individual fibers
2. Cleaning or elimination of impurities/dust/short fibers
3. Reduction of neps
4. Fiber blending
5. Fiber orientation or alignment
6. Sliver formation

2.5.2 Combing

According to **Vatsala (2003),** combing process is used to upgrade the raw material. The basic operation of comber is to improve the mean length or staple length by removing the short staple fiber (shorter of 1-4 inches length). It influences yarn evenness, strength, smoothness, cleanness and visual appeal. **Joseph (1984)** opined that for high quality yarns of outstanding evenness, smoothness, fineness and strength the fibers are combed as well as carded. In the combing operation several card slivers are combined and then drawn into the combing machine where they are once again, spreaded as a web. As the web is formed there is further cleaning and straightening of the fibers take place. Short fibers are removed during combing. After combing the fibers are pulled from the combing wires and formed into combed sliver. This combed sliver produce yarns of high quality.

2.5.3 Drawing out

Drawing out is the final process of quality improvement in the spinning mill. Its influence on quality especially on evenness is very important. If draw frame is not set properly, it will also result in drop in yarn strength and yarn elongation at break. The faults in the sliver that come out of draw frame can not be corrected. It will pass into the yarn **(Vatsala, 2003).**

According to **Bhalero (1997),** drawing is a means for further mixing of carded or combed fibers in sliver form prior to final spinning. This is done by means of a number of operations involving drawing out (drafting) of the sliver and the use of doubling (assembling a number of slivers together). The drawing process regularizes and gradually reduces the thickness of the material to a roving of suitable thickness for spinning of the required yarn.

2.5.5 Roving

Sliver from drawing machine is then taken to roving machine to slenderize its diameter. It is reduced to one-fourth of its size. The process and the product are called 'roving'. The fineness and intimacy of blending of yarn to some extent depends on the number of times slivers are doubled and redrawn during roving **(Vatsala, 2003)**.

2.5.6 Spinning

Spinning is the action which spirals, grouped and overlaps the fibers into a continuous elongated strand. All natural fibers require some preparation before spinning. The aim of preparation is to extract, clean and parallelize them for the drawing and twisting action of spindle. The word spinning also refers to the extrusion of vicious materials to form long filaments of chemical origin **(Encyclopedia Americana, 1971).**

The spinning of fibers is a very important factor for cotton, wool and man made staple fibers while it not so, for man made filaments. The essential requirement for spinnability is the friction to hold the individual fibers together in the yarn and to prevent slippage. There must be a natural tendency of the individual fibers to stick together and bring the fiber surface into contact with each other **(Shenai, 1991).**

According to **Simpson and Crawshaw (2002),** the ultimate aim of spinning is to produce yarn of the required linear density (count), having good evenness, tensile properties and a minimum number of faults. Yarn of good quality can be spun on ring frame. Ring frame is the main machine where the strands of fibers are actually converted into the form of yarn and the desired amount of twist is inserted. Therefore this machine is generally called as spinning machine. Ring frame technology is a simple and old technology, but the production and quality requirements at the present scenario puts in a lot of pressure on the technologist to select the optimum process parameters and machine parameters, so that a good quality yarn can be produced at a lower manufacturing cost.

2.5.7 Blending of fibers

It is important to observe that the production of staple yarn is, of course, not limited to composition from one kind of fiber. The staple of two or more different kinds of fibers may be combined, or blended. When different types of fibers are blended, the properties of these fibers are also combined, though modified, in the blended yarn.

Blended yarns are those in which two or more generic types of fibers are used. These different types of fibers can be combined in the following ways:

- Two or more different types of fibers can be blended into a single yarn.
- Single yarns, where each single yarn is of a different type, can be plied together to form a combination ply yarn.
- Single or ply yarn of one yarn of another fiber type and woven into a fabric.

A blend is 'a single yarn from a blend or a mixture of different fiber species'. According to the above definition, only the fiber type of blend or combination cited above qualifies as a blended yarn. Further, only a fabric made from such yarns qualifies as a blended fabric.

The blends normally consist of two or three fibers. Such blending of two or more fibers offer an effective means of projecting the positive attributes or aspects of each of the constituent fibers. The manmade could be blended amongst themselves or with the natural fibers. A factor of importance in preparing blended yarns is that the different fibers must be cut to the length required by the particular yarn making machinery to be used; if natural fibers are involved, any manmade fiber used with them must be cut to the average length of the natural fiber, so that they can be blended easily and thoroughly with other staple fibers.

Blending is based on the measurement of the major fiber characteristics and quantitatively proportioning and combining the compatible properties in a judicious way to achieve the desired yarn and fabric properties. A complete understanding of the mechanism of translation of different properties of the constituent fibers of the blend into yarn properties is the key to the optimum utilization of such fibers.

Blending, however, needs to be carried out in such a way that the fibers in a blended yarn are thoroughly dispersed and intermingled. Any deficiency in proper blending of fibers, results not only in poor yarn properties but also fabric defects like fabric streakiness when dyed.

Blends can be developed to provide consumers with special performance characteristics and/or to meet predetermined end use requirements. They may be designed specially for appearance; to combine appearance and performance etc.

2.5.7.1 Objectives of Blending

The blending of two or more dissimilar fibers has become very common. The main objectives of blending are:

a) Improvement in functional properties

One of the primary reasons of blending is certainly an improvement in the functional properties of the fabrics such as higher tensile strength, uniformity, better appearance, increased wear life, wrinkle resistance, dimensional stability, elasticity, comfort, and aesthetic appeal. A 100% single fiber yarn cannot possibly impart all these desirable properties of the fabric.

b) Improved process performance

The addition of fine fibers to a blend increases the number of fibers in the cross-section of a given count of yarn which leads to extension of the spinning limit. The longer fibers in the blend, in the same way, make it possible to spin finer counts.

c) Decorative or colour effect

Some fibers have distinctive appearance, luster or texture and fiber may vary for their affinity for dye. Fibers can be combined to improve the aesthetic appearance or color effects of the blended yarn/fabric.

d) Economy

Blends of fibers sometimes restored to an economic consideration. The prices of manmade are much more stable than that of natural fibers. Price stability can enable the mills to pursue optimization of their fiber purchase programme. The manmade and their blends can, therefore, provide this much needed stability.

2.6 Physical properties of yarns

2.6.1 Yarn twist

Sardag and Kalaoglu (2006) stated that twisting is one of the most important and expensive process in textile industry. Twisting not only provides yarn from the individual fibers but also influences their performance characteristics. Twisting determines the structure of yarn, strength and handle properties of the resultant product. Furthermore it affects the volume, quality and hairiness of the yarn.

According to **Saville (2004),** twist is the measure of spiral turns given to yarn to hold its constituents together. Twist is primarily introduced into staple yarn in order to hold the constituent fibers together, thus giving strength to the yarn. The effect of the twist are two fold as the twist increases, the lateral force holding the fibers together is increased so that more of the fibers can contribute to the overall strength of the yarn. Secondly as the twist increases, the angle that the fibers make with the yarn axis increases, so preventing them from developing their maximum strength which occurs when they are oriented in the direction of the applied force. The overall result is that there is a point as twist is increased where the strength of the yarn reaches a maximum value after which the strength is reduced as the twist is increased still further. According to **Sivakumar (2007),** the properties of yarn are influenced by twist because the angle between the yarn axis of the fiber varies with the twist in the yarn. If yarns of different count are to have similar properties, the twist must be proportional to diameter of yarn. Therefore twist multiplier is the ratio of the twist to diameter of yarn.

2.6.2 Yarn count

Basu (2001) stated that yarn count can be defined as mass per unit length or length per unit mass of yarn. It is the measure of yarn fineness. **Atlah and Kadoglu (2006)** found that yarn count has the maximum influence on hairiness. Yarn hairiness chart therefore bears a close correspondence with irregularity chart. Coarse region has more hairiness than finer portions of yarn. Hairiness reduces with increase in twist because of shorter spinning triangle and more effective twisting of surface fibers into yarn.

2.6.3 Yarn strength and elongation

Vidyasagar (2000) reported that the strength of a yarn is governed partly by the strength of the individual fibers of which it is made up and partly by the degree to which they cling together and resist drawing or slipping over each other as the yarn is pulled lengthwise. Tensile strength varies from fiber to fiber considerably but the textile industry requires that it shall be at least 1gm/denier. **Chellamani[2] *et al.*, 2006** observed that the yarn strength is generally influenced by fiber strength.

2.6.4 Yarn evenness

Yarn evenness is the variation in weight per unit length of the yarn or as the variation in its thickness. The greater the uniformity of a spun yarn the higher is its strength and the more uneven a yarn, the lower is its strength. Non-uniformity of the yarn itself is reflected in a similar lack of uniformity in the distribution of twist which in turn has a negative effect on the strength **(Saville, 2004).**

2.6.5 Yarn hairiness

Sivakumar (2007) stated that protruding fibers, loops and loosely wrapped wild fibers constitutes hairiness. Hairiness is a unique feature of staple fiber yarns that distinguishes it from filament yarns. Generally hairiness have some negative impact on fabric properties i.e. pilling, it creates fuzzy and hazy appearance, printed goods lack in sharpness of print, sewing breakage will be high with hairy yarns. In spite of these drawbacks, hairiness has some beneficial effects. It adds to the textile character of the fabric and contributes to comfort, liveliness, skin friendliness and warmth. Hairiness necessitates a precise yarn hairiness measurement and control. The distribution of hair length is use of the most important choice of yarn. Three following stated points have considerable influence on yarn hairiness:

1. Yarn parameter

Atlah and Kadoglu (2006) found that yarn count has the maximum influence on hairiness. Yarn hairiness chart therefore bears a close correspondence with irregularity chart, with coarse region having more hairiness than finer portions. Hairiness reduces with increase in twist because of shorter spinning triangle and more effective twisting in of surface fibers in to yarn with firmly bound fibers, chances of release due to abrasion at traveler/ring junction is minimized.

2. Process Parameter

Pillay (2007) found that fiber parallelization reduces hairiness. Hairiness comes down with increase number of draw frame passages because with more draw frame passages, fiber orientation is increased and fiber hooks reduces. As a result fiber extends along the length of strand is increased which is the reason for reduction in hairiness. For the same reason combed yarn have less hairiness than the carded yarn. Further with combing short fiber content is reduced which is another reason of low hairiness. A compact roving by use of front zone floating condenser at speed frame will bring down hairiness, as this will reduce strand width at ring frame.

3. Strand width

Chauhan (2009) stated that strand width at the front roller nip has the maximum influence on hairiness. Strand width is much wider than final yarn diameter and as a result twist does not flow right up to nip of front roller. If the strand width is reduced twist will flow closer to front roller nip and spinning triangle will be smaller and fiber in selvedge will be integrated better in to yarn.

2.7 Fabric formation through weaving

According to **Vatsala (2003),** fabric is the final product of the processed fibers. There are several methods of fabric manufacturing in vogue today such as weaving, knitting, lace-making, felting, knotting, braiding, needle punching, moulding, etc. Of these, weaving is one of the major methods of fabric manufacturing that has been in practice since prehistoric times.

According to **Lord and Mohamed (2005),** weaving is the process of interlacing two or more set of yarns at right angles to each other on a loom. The essential parts of loom are warping beam, cloth beam, harness or heddle frame, shuttle and reed. Shedding, picking, battening, taking up and letting off are the main operation of weaving. Fabric can be woven from yarns on a simple hand loom or on a highly complex totally automated power loom. In either case the fabric that is produced will be made by interlacing one yarn with another **(Tortora, 1982).**

Weaving has undergone a sea change during the last two decades. Today the weaving machines operate so efficiently that they handle many yarns; excellent fabric quality and maximum profitability are the two major requirements in today's competitive fabric forming system. Fabric quality is measured by two parameters such as fabric properties and fabric defects **(Bahera, 2003).**

In present study for preparation of pure and blended reusable woven fabrics, plain weave was selected. The plain is sometimes referred to as the tabby, homespun, or taffeta weave. It is the simplest type of construction and is consequently inexpensive to produce. On the loom, the plain weave requires only two harnesses. Each filling yarn goes alternately under and over the warp yarn across the width of the fabric. On its return, the yarn alternates the pattern of interlacing. If the yarns are close together, the plain weave has a high thread count, and the fabric is therefore firm and will accordingly wear well.

As the manufacture of the plain weave is relatively inexpensive, it is used extensively for cotton fabrics. The appearance of the plain weave may be varied by differences in the closeness of the weave, by different thicknesses of yarn, or by the use of contrasting colors in the warp and filling.

There is a wide variety of fabrics made of the plain weave constructed from every type of yarn composed of every kind of fiber. Plain woven fabrics range in weight and compactness from thin lightweights to compact heavyweights. **(Corbman, 1983)**

2.8 Physical properties of fabrics

Fabric properties that affect the performance of fabric are:

2.8.1 Fabric count

In woven fabric the warp yarns are commonly referred to as 'ends' and the number of warp threads per inch width of cloth stated as so many 'ends per inch'. The thread of weft called 'picks'. A fabric count is therefore described in terms of 'ends and picks'. A higher count fabric usually has higher fabric strength as compared to lower count, and a lower strength for a given weight. Fabric count is expressed as ends x picks/inch^2 (**Angappan and Gopalkrishnan, 2002**).

2.8.3 Fabric weight

Fabric weight is the weight of the fabric in grams per square meter. Weight is an important fabric property when comparing two similar fabric constructions. It has no limit but does affect many of the fabric properties **(Ghosh, 1997).** The weight of a fabric can be described in two ways, either as the "weight per unit area" or the "weight per unit length". Weight of fabric is influenced by the weight of the fiber, spinning, weaving and finishing process because in these some processess weight is added to the fabric. The bending rigidity which is a measure of the weight required to bend the fabric is related quite closely to the fabric weight and thickness. Heavier and thicker fabrics have higher blending rigidity **(Booth, 1996).**

2.8.3 Fabric thickness

According to **Angappan and Gopalkrishnan (2002),** fabric thickness is mainly used for checking the conformity to the specification in the study of fabric properties such as thermal insulation, resiliency, dimensional stability, fabric stiffness and abrasion. The thickness of fabric is measured at pressure of $2g/cm^2$ and it can be used to monitor the consistency of fabric.

2.8.4 Fabric stiffness

Fabric stiffness indicates the resistance of the fabric to bending and it is a key factor in the study of handle and drape (**Angappan and Gopalkrishnan, 2002**). Quantitatively the stiffness of a fabric is measured in terms of the bending length (**Tarafdar and Ali, 1999**). Bending length is one of the factors that determine the manner in which fabric drapes. It is related to the quality of the stiffness that is appreciated by visual examination of the draped material. The cloth having high bending length tends to drape stiffly **(ISI Handbook of Textile Testing, 1982).**

2.8.5 Fabric drape

When a fabric is chosen for dress material then its properties like appearance, luster, smoothness/roughness, stiffness/limpness and good or poor draping qualities are given more priorities over its technical merits. According to **Stump and Fraser (1996),** draping qualities are related to fabric stiffness. How a fabric bends under its own weight is one indication of its drapability. A highly drapable fabric is one that hangs well and whose hangs can be arranged in folds. Its ability to undergo large recoverable, draping deformation by bulking gracefully in to rounded folds of single and double curvature. **Basu (2001)** opined that fabric drape is an outstanding property of textile material. The drapability of fabric also depends on weaves, cover factor, finish, etc.

2.8.6 Fabric abrasion resistance

Abrasion is important aspects of wear which can be defined as the rubbing away of the component of fibers and yarn of the fabric. When fabrics are rubbed against the surface, abrasion of the fiber surface occur due to friction. The abrasion wear of the material depends on the construction of the yarn or fabric. Moreover the type of the fiber determines the abrasion resistance of fabric. Thus the life of the fabric depends upon resistance to abrasion. Abrasion resistance of fabric is measured in terms of weight loss (**Kariayappa *et al.,* 2007**). It is stated in **Annual book of ASTM Standards (2006)** that the resistance to abrasion is greatly affected by the conditions of the tests, inherent mechanical properties of the yarn, the construction of the fabric and the type, kind and amount of finishing material added to the fibers, yarn or fabric. The amount of abrasion is determined by giving the percent loss in weight after a definite number of rubs. Thus the life of the fabric depends upon the resistance to abrasion.

2.8.7 Fabric pilling

According to **Sivaramakrishnan (2004),** pilling is the formation of undesired fiber bolls on the surface of the fabric. Pilling occurs when loose fibers in the fabric are worked to the fabric surface after it has been subjected to abrasion. Pilling is the mechanical action that causes fibers to migrate out of the fabric body to the fabric surface. Further action causes the surface fiber to rotate around other protruding fiber forming pills. The rate of the pill breaking off is directly related to the tenacity of the fibers used in fabric.

Chiwesha and Crews (2000) stated that fabric pilling is a complex phenomena comprised of several stages and influenced by a variety of factors. Factors influencing fabric pilling include fabric type, cross sectional shape, yarn type and construction method used to make fabric.

2.8.8 Thermal insulation

According to **Tortora (1982),** fiber heat conductivity, the thickness of the fabrics and the ability of the fabric to entrap still air within the fabric are related to thermal insulation. Still air provides excellent insulation. If the yarn structure and the fabric structure permit the entrapment of still air, a fabric may provide warmth by insulating the body. According to **Frydrych *et al.*, (2002)** thermal properties determine the elementary function of garment. Thermal insulation is a very important factor in estimating apparel comfort for the user. This property is determined not only by the physical parameters of fabric but also by structural parameters such as weave and drape.

2.8.9 Fabric crease recovery:

According to **Saville (2004),** creasing is the phenomena of development of folds or deformation not removable or recoverable completely. This phenomenon in the first instance is influenced by the type of fiber used in its construction. The fibers like wool/silk have a good resistance to creasing whereas; cellulosic materials such as cotton, viscose and linen have very poor resistance to creasing. The recovery or resistance towards creasing largely depends on the resiliency and elastic property of the material of the fabric itself.

2.8.10 Fabric strength

The strength of fabric is measured as tensile strength, tearing strength and bursting strength. The breaking or tensile strength is a measure of the resistance of the fabric to a tensile load or stress in either warp or weft direction. According to **Tortora (1982),** tensile strength measures textile strength in terms of pounds of weight required per square inch to break yarn or fabric. This measure is applied more frequently to woven fabrics than to fiber. The breaking strength of a fabric should always be several time greater than the maximum likely to be encountered in use because during the life time of most textile articles strength will diminished by the action of rubbing, flexing and chemical attacks. The tearing strength is a measure of the resistance to tearing off either the warp or weft series of yarn in a fabric. **Kothari (1999)** has stated that tear resistance is one of the important properties of the fabric. The tear strength of a fabric refers to its resistance to tearing force or the force required to start or continue to tear a fabric under specified conditions. Resistance to tearing has importance in clothing fabrics such as those used for shirtings, blouses, interlinings etc. It is not suited for knitted and non-woven fabric. According to **Tortora (1982),** tear strength is more closely related to the serviceability of the fabric than its tensile strength. In testing tearing strength, few yarns are subjected to stress. Bursting strength of a fabric shows the strength against a multidirectional flow of pressure. Bursting strength measure the strength of both warp and weft yarns simultaneously. They further reported that strength affects the quality of fabric to a great extent **(Basu, 2001).**

2.9 Microbes at the interface of textiles and skin

Clothing and textiles can be an excellent substrate for microbial growth, because they are made of organic materials providing a good base for microbial attachment. They are in permanent contact with microorganisms from the environment and the human skin, and human sweat provides nutrients for the growth **(Teufel *et al.,* 2007).**

Most textile materials are conductive to cross infection or transmission of disease caused by microorganisms. The most trouble causing organisms are fungi and bacteria. The growth of microorganisms on textiles can lead to functional, hygienic and aesthetic difficulties. Microbes may severely disrupt manufacturing processes, textile dyeing, printing and finishing operations through reduction of viscosity, fermentation and mould formation **(Harini *et al.,* 2007)**.

Under certain conditions, especially at high humidity, microbes rapidly multiply and can then cause fabric discolouration, bad odour problems and even health concerns ranging from simple discomfort to physical irritation, allergic sensitization, toxic responses, infection and disease **(Teufel *et al.,* 2007).**

There are numerous ways to attack the microbially related problems. Many times the problem can be eliminated by proper choice of fabric composition, the use of sterilization procedures and barrier packaging **(Harini *et al.,* 2007)**.

2.9.1 Microbes

Microbes are the tiniest creatures not seen by the naked eye. They include variety of micro-organisms like bacteria, fungi, algae and viruses. Bacteria are the unicellular organisms, which grow rapidly under warmth and moisture. Some specific types of bacteria are pathogenic such as *Staphylococcus aureus* and *Escherichia coli* which causes cross infection. Fungi, molds or mildew are complex organisms with slow growth rate. They stain the samples and deteriorate their performance properties **(Gomathi and Manoharan, 2009).**

Man is host to variety of pathogenic bacteria, fungi, protozoa and viruses. The micro-organism of the skin flora are so firmly entrenched in the sweat glands, sebaceous glands and the hair follicle that no amount of bathing or scrubbing can totally remove them. Moist regions of the skin harbour yeasts and other fungi **(Adelberg *et al.,* 1976).**

Wesley and Musselwhite (1975) stated that the study shows that bacterial growth persists in human body throughout the year irrespective of the seasons. Even the "clean" skin shows up a typical population ranging between 100-1000 microbes/cm^2 of the skin; microbes at these levels cause neither health problem nor the odour.

2.9.2 Required conditions for the growth of microbes

According to **Saravanan (2005)**, all the conditions that required for the growth of these organisms are satisfied in textile materials as follows:

2.9.2.1 Nutrients

Soil, dust and some finishes can all be sources of nutrients for micro-organisms. Perspiration contains salts, amino acids, carboxylic acids and other essential nutrients. Dead skin cells or oils secreted from the body skin and degraded compounds from the textile material are good sources of nutrients for the microbial growth.

2.9.2.2 Water

It has been estimated that perspiring human beings give off an average of 100 ml/hr of water, which accumulates in clothing and bedding. A humid environment will provide enough water to support the fungal growth. Bacteria require more water and damp conditions.

2.9.2.3 Oxygen

The atmosphere provides a ready source of oxygen.

2.9.3 Effects of microbes on textiles

In ideal situation, with all required conditions, a single bacterium can multiply into 1.6 million in just eight hours, which can ultimately causes odour, discolouration of textiles and possible infection on skin. The associated odours are the results of these micro-organisms digesting nutrients in the perspiration and releasing volatile pungent waste products **(Wesley and Musselwhite, 1975).**

Sarkar *et al.* (2003) stated that textiles made from natural fibers are generally more susceptible to bio-degradation in comparison to those made from synthetic man-made fibers. The products such as starch, protein derivatives, fats and oils used in the finishing or in the sizing bath can also promote microbial growth.

Shah and Khanna (2006) stated that bacteria are capable of generating odours over a shorter period of time than fungi as it grows much slowly. It can be assumed that odour generated on damp textiles over a period of a day or less is bacterial in origin. The musty odour developed over longer period is more likely to be caused by fungi. With repeated launderings of textile materials, the bacterial propagation increases by about 30% more colonies on 15 times laundered fabric than the unlaundered ones **(Rajendran and Anand, 1999).**

2.9.4 Antimicrobial finish

The term **antimicrobial** refers to a broad range of technologies that can provide varying degrees of protection for textile products against micro organisms. Fabrics and protective clothing used in area where there might be danger of infection from pathogens can benefit from antimicrobial finishing. These include hospitals, nursing homes, schools, hotels, museums, and crowded public areas **(Harini *et al.*, 2007)**.

According to **Anonymous (2002)**, antimicrobial finishing is one of the specialty finishes given to the textiles which can restrict the growth of micro-organisms on the textiles**. Kumar and Krishnaveni (2007)** stated that though the use of antimicrobial finishes have been known for decades, it is the only the recent couple of years that several attempts have been made on finishing textiles with antimicrobial compounds.

Different technical fibers and various specialty finishes have been developed and are also commercially available to withstand various environmental conditions. Antimicrobial finishing is one of those types of speciality finishes given to textiles.

Micro-organisms are the major hindrance, which are the causative agents of deterioration, staining, odour and health hazard. So it becomes very important to finish garments with some speciality chemicals, which can restrict the growth of these micro-organisms so that human being could live in a world of hygiene and freshness **(Menezes, 2001).**

According to **Sampath (2003),** a poll study in USA showed 61% of human makes an effort to buy antimicrobial products. Textile magazines throughout Europe and Asia have reinforced the problems of micro-organisms. The poll study also indicated that the market is ready for antimicrobial products and the demand has grown dramatically since 1998.

2.9.4.1 Benefits of the antimicrobial finish

- Gives freshness to the fabrics.
- Eliminates odour produced by micro-organisms.
- Controls staining because of the microbial growth.
- Increases the life of the fabric by controlling the growth of microbes.
- Improves hand for most of the fabrics.
- No skin irritation and consequently no skin disease.

2.9.4.2 Classifications of antimicrobial finishes

There are primarily two major classifications of antimicrobial finishes:

1) Leachable antimicrobial finishes

These are not chemically bonded with the fabric and can be removed by contact with moisture. The vast majority of the antimicrobials fall under this type especially conventional antimicrobials. They leave the textile and chemically enter or react with the micro-organism acting as a poison. These have the potential to cause a variety of problems like rashes, skin irritations by crossing the skin barrier. Another serious problem is their allowance for the adaptation of micro-organism over time **(Harini *et al.*, 2007).**

Leachable antimicrobial finishes chemically act on the microbes and destroy them. These products act as bullets and hence are used up by the microbes slowly losing their effectiveness **(Menezes, 2001).**

2) Non leachable antimicrobial finishes

These are molecularly bonded with the fabric. They stay affixed to the textile and physically stab the membrane and electrocute the micro-organisms on contact to kill those **(Harini *et al.*, 2007).** These agents do not leach or diminish over time or act like a sword and therefore do not lose its effectiveness. They are used in textiles that are likely to have human contact or where durability is of value. These finishes are permanent and remain functional throughout the life of the substrate **(Menezes *et al.*, 2001).**

2.9.4.3 Mechanism of antimicrobial finish

Basically, there are three mechanisms by which antimicrobial agents provide protection to textiles and wearer.

1) Controlled release mechanism

The majority of the antimicrobial finishes function by the controlled release mechanism. In this mechanism, the antimicrobial agent is slowly released from a reservoir either on the fabric surface or in the interior of the fiber. This 'leaching' type of mechanism can be very effective against microbes either on the fiber surface or in the surrounding environment. However, eventually reservoir will be depleted and the finish will no longer be effective. In addition, the antimicrobial agent that is released to the environment may interfere with other desirable microbes.

Products such as **Copper naphthenate, Copper-8-quinolinate, Tributyl tin oxide, Dichlorophene, 3-lodopropynybutylcarbamate etc** show a very broad spectrum of activity against bacteria and fungi, but suffer from the application and durability problems.

A novel approach to the controlled release of the antimicrobials is the **'MICROENCAPSULATION'.** These capsules are incorporated either in the fiber during primary spinning or as coatings on the fabric surface. In this technique, the active agent is sandwiched between two protective plastic layers and migrates to the outer layer as needed when the agent is leached out by water or degraded by ultraviolet radiation. This is achieved by breaking covalent bonds in the chemically modified fiber during laundering or photochemical exposure. The reservoir of microencapsulated antibacterial agent is not unlimited although the surface remains active for long time.

2) Barrier or blocking mechanism

The barrier or blocking mechanisms for protecting fabrics from microbiological attacks are effected through:

- Either inert physical barrier films or coatings those are impervious to the transmission of micro-organisms through the fabric.
- The use of films or coatings that have direct surface contact activity against microbial growth.

The only antibacterial finish based on the barrier concept of direct surface-contact activity has so far been an **organosilicon polymer** containing pendant quaternary-ammonium groups that form biobarriers on the fabric. When a microbes contacts the organofunctional silane treated surface of the fabric, the cell is physically ruptured by a sword like action and then electrocuted by a positively charged nitrogen molecule. It does not cross the skin barrier and does not affect the normal skin bacteria, cause rashes or skin irritations. This antimicrobial technology has been verified by its use in consumer and medical goods including socks, surgical drapes and carpets without any human health or environmental problems.

2.9.4 Antibacterial textiles

Recently, **Kawoll®**, a homogenous mixture of kapok hollow fibers and wool fibers, has been applied for bed covers. It has a positive effect on microclimate by moisture-absorbing capacity and an unusually high content of air. The kapok fiber also shows antimicrobial activity.

The most important criteria for the selection of additives are (a) their extremely low solubility in water, alkali and acid, (b) their chemical stability against strong acids, bases, and oxidants, and (c) their thermal stability. Additives should have no negative influences on the spinning process and fiber properties. They must have a migration capability from the fiber interior to its surface and should have excellent toxicologic and environmental properties.

Antibacterial activity of small ions like silver, zinc, copper and quaternary ammonium compounds is well documented. Silver impregnated textiles are used as wound dressings for infected wounds or wounds at high risk of infection.

Dye molecules can be used as bridges to bind functional antimicrobial groups to chemically stable synthetic polymers. Quantitative antimicrobial evaluations of treated fabrics reveal that there are significant reductions in bacterial load on surface contact. Ofloxacin, penicillin and other antibiotics have been applied to polyester grafts. A collagen coating was used for binding chloramphenicol and rifampicin. A firin sealant was employed to bind gentamycin. More recently, ciprofloxacin and ofloxacin were used unmodified as dyes for polyester fibers. Pad heating was employed as well.

Another technique is the use of antibacterial agents in the spinning process of viscose fibers. Modal fibers are obtained by adding the antibacterial agent to the spinning dope. By the incorporation technique a homogenous distribution of the additive within the cellulose matrix of the fiber can be achieved.

Halamine-modified cotton has been used for protection textiles in workers exposed to pesticides. Halamine-modified cotton is also capable of suppressing a great variety of micro-organisms including Staphylococcus aureus, a leading cause of infections in hospitals, or Salmonella species.

Since body odours largely depend on the skin flora, Halamine-modified cotton may also be used for odour control.

Cylodextrin-prepared textiles can be used within transdermal therapeutic systems. Another application is their use as transdermal collector systems in toxicology monitoring of personnel at high risk, to diminish bacterial contamination of sweat glandrich skin areas (odour-defebding textiles), and as antibacterial textiles **(Shanmugasundaram, 2007).**

Fabrics made from viscose fibers containing polysilicic acid and aluminium silicate have been given urea peroxide treatment to make them antibacterial as well as deodourant **(Rajendran et al., 1999).** Some recent developments in antibacterial products include a process involving the preparation of antibacterial resins containing phenol derivatives. The resins exhibited higher antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* **(Fouda, 2005).**

A new approach aims at developing an ecofriendly natural antimicrobial finish from plant extracts. Neem, Pomegranate, and Prickly chaff flower are found to contain active antimicrobial substances that can control the growth of microbes. But they exhibit poor wash durability. However, further work on bonding the active substances on textile substrates would help to resolve the issue. Since these substances are of natural origin, they can be a suitable alternative for harmful chemicals.

Another new approach to antibacterial fabric is **Bamboo fiber/fabric.** It's a common fact that bamboo can thrive naturally without using any pesticide. It is seldom eaten by pests or infected by pathogen. Scientists found that bamboo owns a unique anti-bacteria and bacteriostasis bio-agent named "bamboo Kun". This substance combined with bamboo cellulose molecules tightly all along during the process of being produced into bamboo fiber. Bamboo fiber has particular and natural functions of anti-bacteria, bacteriostasis and deodourization. Bamboo fiber/fabric possesses excellent function of anti-bacteria, even after fifty washings. Scientific tests result shows that over 70% death rate of bacteria after being incubated on bamboo fiber/fabric **(Anonymous[2]. 2007).** The naturally occurring bacteriostatic property also helps prevent cultivation of yeasts, molds and fungus on the clothing **(Anonymous[4]. 2007).**

2.10 Environmental concerns

The eco-friendly fiber and fabrics are generally gaining importance in recent time is due to environmentalist movement throughout the world. Briefly **"Eco-Textiles"** are those products which do not transmit during use under various conditions any toxic products that may directly damage the environment. In this definition the products from degradation of such eco-friendly textiles are also included. Consumers in the developed countries are perpetually looking for biodegradable and eco-friendly textiles to preserve the natural environment flora and fauna**.** The need of the hour is an eco-friendly process that can combine with an eco-friendly fiber and serve the modern human society in a better way **(Amsamani and Anganathan, 2007).** After the EARTH summit in Rio-de-Janerio, the eco-friendliness and biodegradability are the two key words moving around all the corners of the consumer products **(Bandhopadhyay and Salaskar, 1997).**

Currently, the only antimicrobial textiles being used in the field of medicine are disposable and non-woven. Some of the treatments being used are harmful to our environment not only because of the chemicals used in the treatments but also because the treated textiles are not reusable **(Bonin, 2008)**. The U.S. EPA has also determined that hospitals generate millions of tons waste annually **(Zins, 2006)**. Therefore it is a need of hour to use bio-degradable and eco-friendly fibers with inherited antimicrobial properties to develop such textiles which may easily degrade in nature without disturbing the environment flora and fauna. To address the growing concerns about the environment, present study was carried out to develop the reusable woven protective and healthcare textiles from biodegradable fibers, which reduced the amount of chemicals and trash being disposed of in landfills.

Materials

and

Methods

Chapter 3 MATERIALS AND METHODS

This chapter consists of materials used and the methodology followed for conducting the present research work. The work was carried out in two phases, i.e. Phase I (Fig. 3.1)-survey work and Phase II (Fig. 3.2)-experimental work, under the following sections:

3.1 Data and sample collection

3.2 Evaluation of physical properties of woven samples collected from different hospitals

3.3 Collection of selected fibers

3.4 Evaluation of physical properties of selected fibers

3.5 Evaluation of chemical properties of selected fibers

3.6 Processing of fibers and preparation of pure and blended yarns

3.7 Evaluation of physical properties of yarns

3.8 Preparation of woven fabrics

3.9 Evaluation of Physical properties of woven fabrics

3.10 Assessment of antimicrobial activity of woven fabrics

3.11 Assessment of bio-degradability rate of woven fabrics

3.12 Assessment of visual appearance of woven fabrics

3.13 Cost Calculation of woven fabrics

3.14 Development of protective and healthcare textiles

Fig. 3.1 Plan of work for PHASE-1 (Survey work)

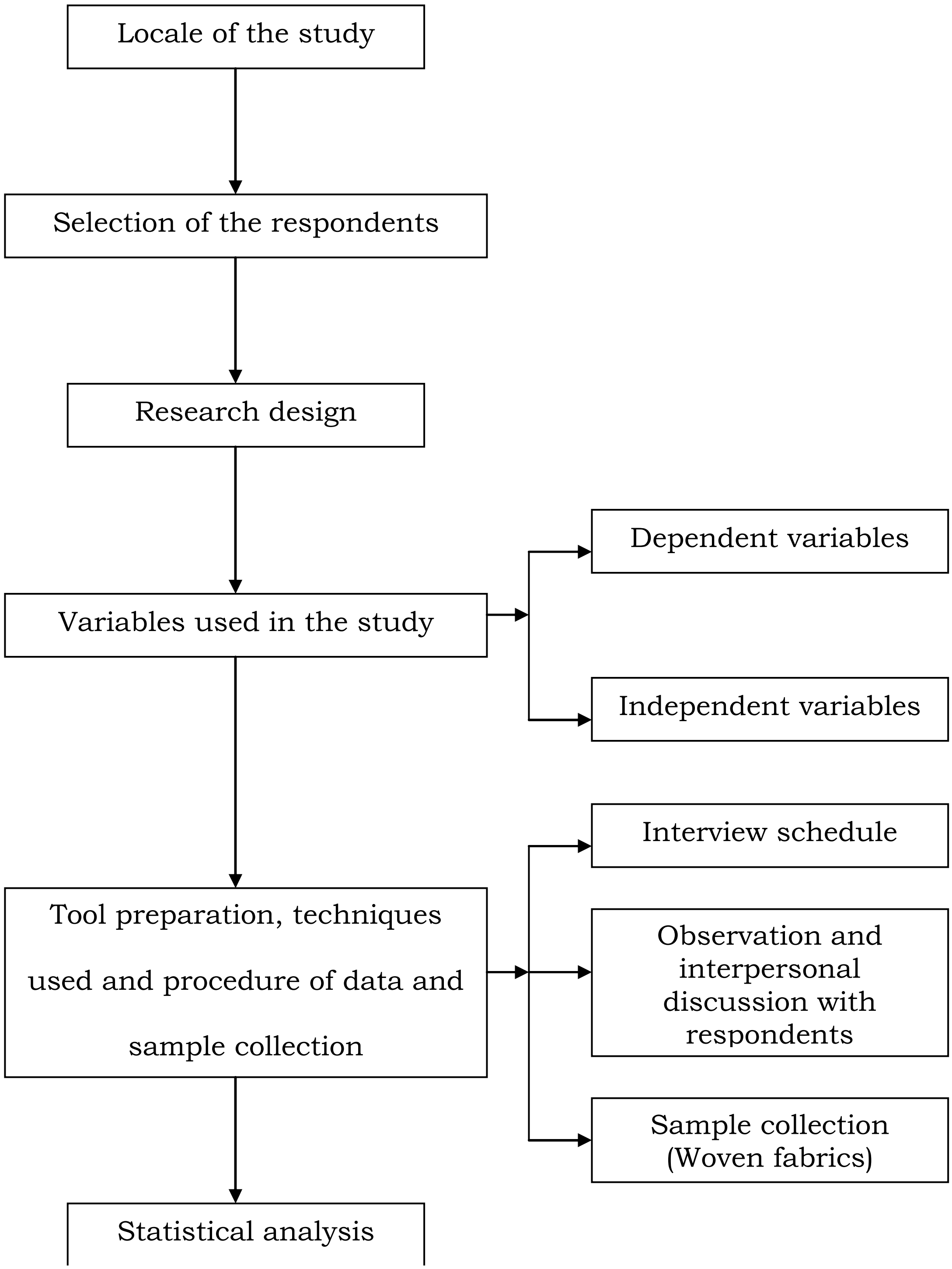
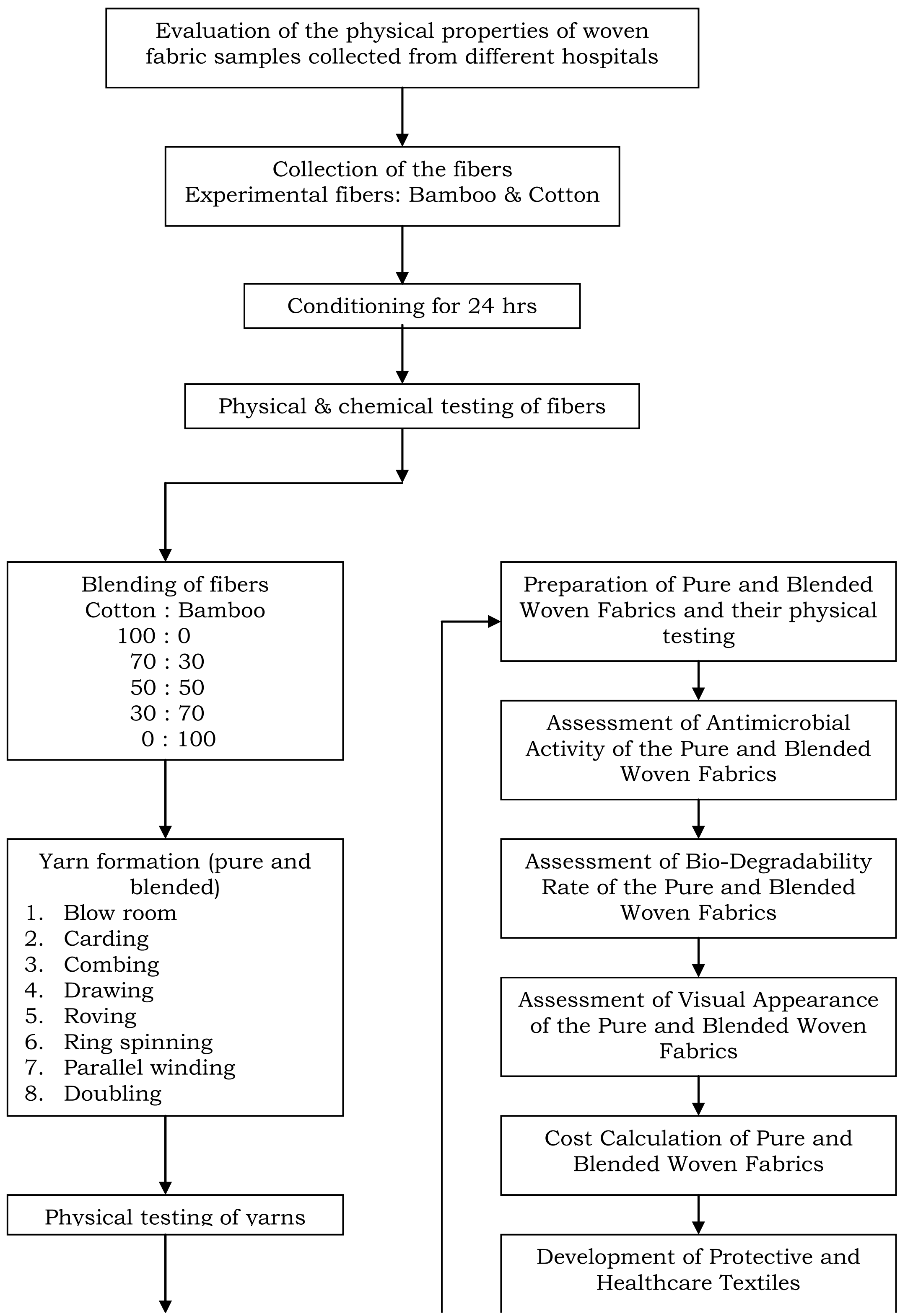


Fig. 3.2 Plan of work for PHASE-2 (Experimental work)



3.1 Data and sample collection

Data (status of protective, healthcare and hygiene products in hospitals) and sample (woven fabrics used as protective, healthcare and hygiene products in hospitals) collection was considered as the Phase-1 i.e. survey work, for the present study.

3.1.1 Locale of the study

Udham Singh Nagar district (Uttarakhand) and Ghaziabad district (Uttar Pradesh) was selected as locale of the study because these places were easily assessable to the researcher. Hospitals are constructed everywhere as the casualties increases and every hospital need to give best services to its patients. Protective and healthcare products are one of the medium which safeguard doctor and patient against each other's infections.

3.1.2 Selection of the respondents

Thirty hospitals were selected for the present study through random sampling technique. Sample size is a definite plan for obtaining a sample from a given population keeping in view the nature of study, type of sampling technique, size of population and time available etc. The respondents were owner of the hospital, doctors, administrative and maintenance staff as they know much better about the facilities they are providing, materials used and other items related to their care and maintenance, to provide best services to the patients. Out of total 30 hospitals, 15 hospitals were situated in U. S. Nagar district of Uttarakhand and remaining 15 hospitals were under the Ghaziabad district of Uttar Pradesh.

3.1.3 Research design

Research design is a plan that specifies the sources and types of information relevant to the research problem, and approach for gathering and analysis of data. It also includes time and cost of budget as most of the studies is conducted under these two constraints. In a study, research design is needed because it facilitates the various research operations in systematic manner. Hence, in the present study both descriptive and experimental designs were planned.

Descriptive designs was chosen to find out the status of the hospitals with the help of some questions like type of hospital, background of the hospital owner i.e. medical/non-medical, establishment date, medical facilities provided etc.

Experimental design was planned to gather the in-depth knowledge regarding the existing protective and healthcare products used in the hospitals, type of materials used for making these products etc. in order to develop new improved antimicrobial fabric for making different protective and healthcare textiles in hospitals for the protection of society from infections.

3.1.4 Variables used in the study

Variables are the characteristics of the conditions that are manipulated, controlled or observed by the researcher. Variables under study are categorized into two groups' *viz.*, dependent variable and independent variables.

3.1.4.1 Dependent variables

Dependent variables were measured as the change imposed by the independent variables or the dependent variable is the event studied and expected to change when the independent variable is changed.

3.1.4.2 Independent variable

Independent variables are those whose values are controlled or selected by the person conducting experiments to determine its relationship to an observed phenomenon (the dependent variable).

Variables

Dependent variables

- Doctors' awareness regarding protective and healthcare products
- Clothing requirements for doctors', nurses', staff and patients'
- Buying places/shops/market

Independent variables

- Status of the hospital
- Location of the hospital
- Type of staff etc.

3.1.5 Tool preparation, techniques used and procedure of data and sample collection

To gather information from respondents; tool was prepared in the form of questionnaire. A questionnaire consists of a number of questions printed or typed in definite order on a form or set of forms. The questionnaire was divided into two parts namely – general information and specific information.

Two techniques used in the study for collection of data were:

- Interview schedule
- Observation cum interpersonal discussion with respondents

3.1.5.1 Interview schedule

Structured interview schedule method was adopted for the collection of data as it involves the presentation of oral-verbal stimuli and reply in terms of oral verbal responses. Under this method, non-response remains very low, more effective control over the samples is possible, personal information can easily be obtained and the language of the interview can be adapted to the ability of the person which helps in avoiding the misinterpretations. It can be combined with observation method and some supplementary information can also be collected which is helpful in interpreting the results.

The assistance of key informants was availed for locating and interviewing the respondents. Before obtaining the information, the respondents were explained about the purpose of interview and study as a whole. Various aspects which were beyond their level of understanding were explained to the respondents in the simple language.

Pre-testing of the interview schedule was done on four hospitals. The researcher herself visited and conducted the interview. On the basis of pre-testing, necessary modifications were made in the interview schedule. Interview schedule is given in *Appendix I.*

3.1.5.2 Observation and interpersonal discussion with respondents

Observation method was used with the interview schedule. Observation and interpersonal discussion proved to be very beneficial in order to collect the relevant information regarding protective and healthcare textiles such as the kind of textiles, preferred qualities, cost/product, fibers used, purchasing frequency, problems faced in their care and maintenance, etc., for developing suitable fabric with added properties on the basis of existing fabric construction parameters for the welfare of the society.

3.1.5.3 Sample collection

Woven fabric samples were collected at the time of data collection with the permission of hospital Incharge. Swatches of fabrics and garments used as surgical gowns, doctors-nurses uniform, lab coats etc. were collected for evaluation of their physical properties.

3.1.6 Statistical analysis

The collected data was first tabulated, analyzed and used for making simple comparisons. Since 30 hospitals were selected for the study therefore, only percentage was calculated to drive conclusion in tables with the help of following formula:

$$P = n/N \times 100$$

Where,

n = frequency of a particular cell

N = total number of the respondents in that particular cell

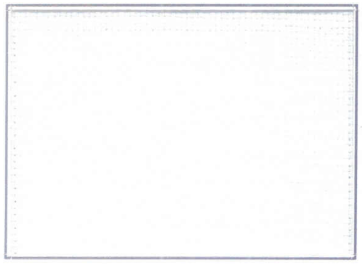
P = percentage

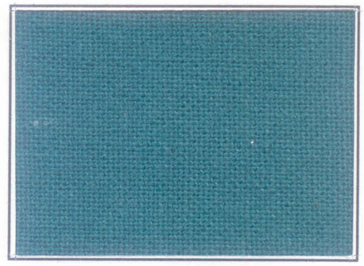
3.2 Evaluation of Physical Properties of woven fabric samples collected from different hospitals

Different woven fabric samples collected from different hospitals were checked against certain properties to find out the parameters on the basis of which the fabric was manufactured. The woven fabric samples were tested for different properties *viz.*, weave, fabric count, fabric weight per unit area, crimp percentage of raveled yarn, yarn count, TPI, Twist direction and fiber identification (microscopic test, burning test & chemical tests). Out of total 30 hospitals, only four hospitals (three from Ghaziabad District and one from Udham Singh Nagar District) were agreed to provide the fabric samples of protective and healthcare textiles. The woven fabric samples collected from different hospitals are shown in Sample sheet 3.1. List of machines, instruments, chemicals & reagents used for testing are given in *Appendix II and III* respectively.

Sample Sheet No. 3.1

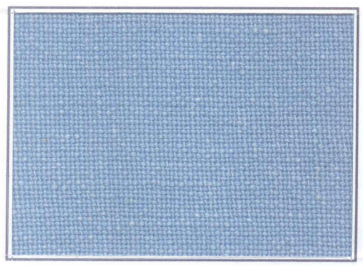
WOVEN FABRIC SAMPLES COLLECTED FROM DIFFERENT HOSPITALS

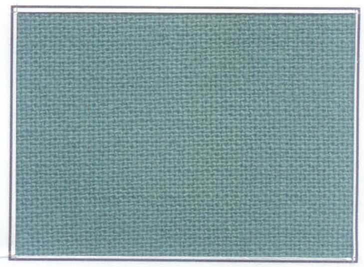

Fabric Sample 1


Fabric Sample 2

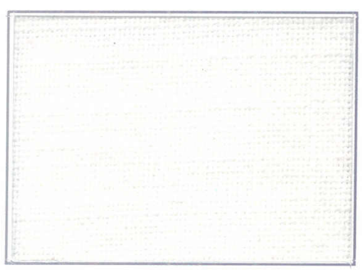
Samples from Narendra Mohan Hospital, Mohan Nagar

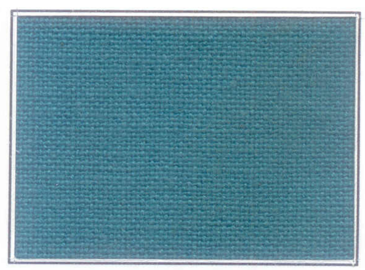

Fabric Sample 3


Fabric Sample 4

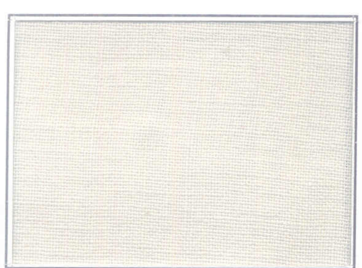

Fabric Sample 5

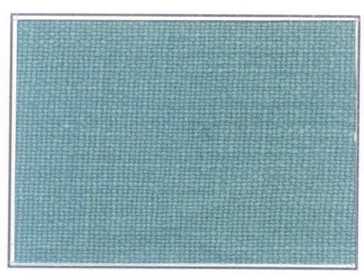
Samples from Jeevan Hospital, Modinagar


Fabric Sample 6


Fabric Sample 7

Samples from Lok Priya Hospital, Modinagar


Fabric Sample 8


Fabric Sample 9

Samples from Sri Ram Hospital, Haldwani

Table 3.1 Properties checked for the fabric samples collected from different hospitals

S. No.	Stages of property checking	Property checked
1.	Fiber stage	Fiber identification 1. Microscopic test 2. Burning test 3. Chemical test
2.	Yarn stage	1. Yarn count 2. Twist direction 3. Twist per inch
3.	Fabric stage	1. Weave 2. Fabric Count 3. Fabric weight per unit area 4. Yarn crimp (%)

The procedures used to assess the above mentioned properties of the woven fabric samples were same as the procedures used to evaluate the properties of selected fibers and their pure and blended yarns and woven fabrics.

In order to avoid the repetition, all the methods are explained under the heading evaluation of the properties of fibers, yarns and fabrics.

3.3 Collection of selected fibers

The natural cellulosic fiber; cotton and man-made cellulosic fiber; bamboo were selected for the present study to find out the best suitable ratios of blends for preparation of protective and healthcare textiles for the medical field.

Cotton fibers were procured from T. T. Textiles, Gajroula (U. P.) and bamboo fibers which were available in super white colour, similar in fineness and staple length as that of cotton were obtained from Shayan home, Muradnagar (U. P.). The cost of cotton fiber was Rs. 60/kg and bamboo fiber was Rs. 210/kg (Sample sheet 3.2).

3.4 Evaluation of physical properties of selected fibers

The selected fibers were tested for the physical properties *viz.*, length (cm), fineness (denier), strength (gm/denier), elongation (%), diameter (micron), crimp (no./cm), burning test, microscopic appearance and whiteness index. The following procedures were used for this purpose.

3.4.1 Fiber length

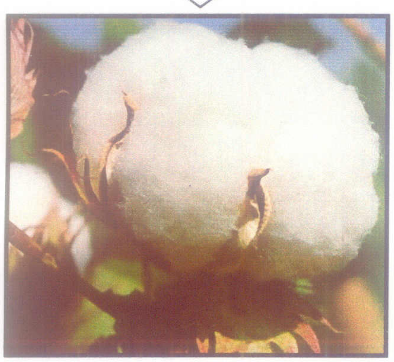
Fiber length of the collected fiber samples was analyzed according to the single fiber method as explained by **Booth (1996).** This is a basic method requiring a minimum amount of apparatus which includes good lightning source, a microscope slide over a scale and medicinal paraffin to control the fibers but it requires a lot of time and patience. Each fiber was taken and gently straightened over the slide with the tips of the little finger; the length was then recorded. Thirty cotton fiber samples were

Sample Sheet No. 3.2

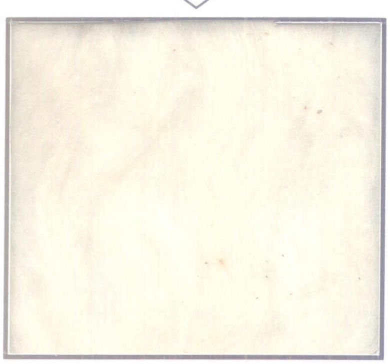
SELECTED FIBRES & THEIR SOURCES


Cotton Plant


Bamboo Plant


Cotton Bud


Bamboo Shoot


Cotton Fibers


Bamboo Fibers

selected randomly and their length was measured, and average value was calculated. Bamboo fibers were available in cut staple length but due to the variation in the length, fiber length was measured by using the same procedure.

3.4.2 Crimp

The crimp frequency was evaluated on the basis of the number of complete waves in the unit length **(Sharma and Goel, 1995)**. The crimp parameter laser was used to measure the crimp per unit length. Ten readings of each fiber samples i.e. cotton and bamboo fibers respectively were taken and the crimp/cm in the fiber samples was calculated by the following formula:

$$\text{Crimp/cm} = \frac{\text{Number of crimp}}{\text{Length of fiber in cm}}$$

3.4.3 Fiber strength, elongation and fineness

Fiber strength, elongation and fineness of the cotton and bamboo fibers were determined using Fafegraph-M, which is a semi-automatic microprocessor controlled tensile tester based on the principle of constant rate of extension. This instrument is connected with Vibromate-M and provided a joint operation which gives the computerized fiber testing results for fineness (denier), tensile strength and elongation [DTE].

Fiber was first tested on the Vibromat-M for fineness (denier). The fiber was taken out and hanged at the clamp with suitable retention clips of 65 mg/denier weight. The denier of the fiber was displayed on the screen of the monitor. Then to find out the tensile strength and elongation, the same fiber sample was clamped between the two jaws of Fafegraph-M with the help of forceps. The two jaws were separated at the gauge length of 20 mm. The fiber was fixed between the jaws. The lower jaw moved downward till the breaking of fiber took place. Both the jaws were opened immediately and lower jaw moved upward again to 20 mm gauge length. The DTE was displayed on computer screen after every test. Ten readings were taken for each sample and average values with detailed statistical analysis were obtained from the printer attached with the machine.

3.4.4 Diameter

The projection microscope is the standard method for measuring the diameter of fibers **(Saville, 2004).** Diameter of cotton and bamboo fibers were evaluated as per test method number **IS: 744-1977** given in **ISI handbook of Textile testing (1982).** A suitable random and representative sample was conditioned for 24h in a suitable testing atmosphere. Slides of fibers were prepared by carefully fixing the fibers with the help of glycerin and covered with a cover glass, carefully avoiding air bubbles, and finger prints. Each fiber slide was then brought in to the field by means of mechanical stage of the microscope. Screen was set in such a manner that the transparent ruler affixed across became perpendicular to the fiber image and the ruler was then moved through its guide until a centimeter division coincided with one edge of the image. Screen measurement was taken under 250X magnification and distance between the two edges of the image was noted. Twenty observations were taken for each fiber. Then, the mean fiber diameter (D), in microns was calculated from the following formula:

$$D = 2 \text{ x } [D_o + c \sum fd/n]$$

Where,

D_o = assumed origin

C = class interval

$\sum fd$ = algebraic sum of the values

n = total number of the observation

3.4.5 Fiber identification

3.4.5.1 Burning test

The burning test was carried out to find the fiber type present in the yarns taken out from the woven fabric samples collected from different hospitals and to distinguish between the fibers samples collected for the present thesis work. The burning test was done according to the test method **AATCC 20-1973.** For this, the experimental fibers and yarns taken out from the woven fabric samples (both warp way and weft way) were moved slowly towards flame and reaction of the fiber to heat were observed. One end of the specimen was then pushed directly into the flame to determine the burning characteristics of the fibers. After removing from the flame, the fibers burning characteristics were again observed and the burning odour was noted. Specimen was then allowed to cool and the characteristics of the ash were noted.

3.4.5.2 Microscopic appearance

Fiber samples collected for the present thesis work as well as the fibers teased out from the yarns taken out from the woven fabric samples collected from different hospitals was checked against both longitudinal and cross-sectional view.

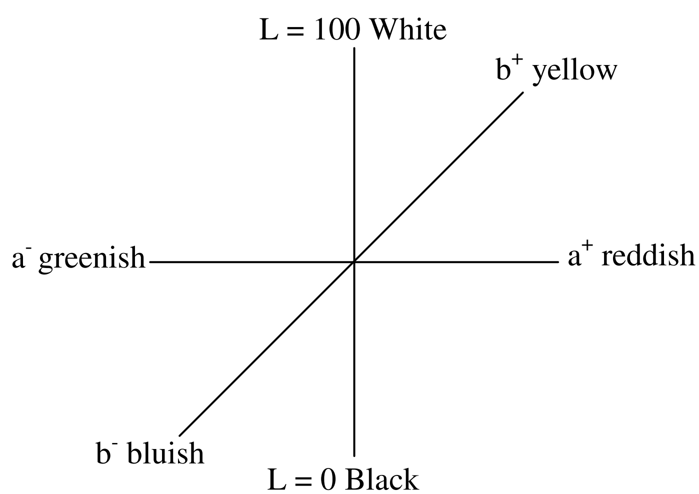
The longitudinal microscopic appearance of the collected fiber samples i.e. cotton and bamboo respectively as well as the fibers teased out from the yarns which were taken out from the woven fabric samples, was studied by using "Nikon Eclipse E1000 microscope. Slides were prepared by mounting the fiber with the help of glycerin and a colourless mineral oil. Photomicrographs of detailed microscopic structure of experimental fibers were taken only directly from the CCD camera attached to the microscope whereas the longitudinal structure of the fibers teased out from the yarns which were taken out from the woven fabric samples, shown under microscope was drawn manually on the paper and compared with photomicrographs of the common textile fibers given in **AATCC 20-1973**.

The cross-sectional microscopic appearance of the collected fiber samples i.e. cotton and bamboo respectively as well as the yarns which were taken out from the woven fabric samples, was studied according to this test method **AATCC 20-1973**. Parallel bundles of experimental fibers and yarns (both warp way and weft) were taken. Stainless steel plate having very fine hole in the centre was taken for preparing the slides. Then a loop of copper wire was passed from the hole and the bundles of experimental fibers and yarns was then caught in the loop and pulled through the hole with some extra, readily identifiable other fibers to fill up the hole. Then a smooth cut was made with the help of the sharp razor blade on both sides of the plate. Mount the slide with a drop of mounting fluid, covered with cover slip and examined at 250X under the microscope using transmitted light. The cross-sectional structure of the experimental fibers and yarns shown under microscope was drawn manually on the paper and compared with photomicrographs of the common textile fibers given in **AATCC 20-1973.**

3.4.6 Whiteness index

Whiteness index (WI) is the measurement of degree of whiteness of any material. Whiteness index of cotton and bamboo fibers was measured with the help of Hunter lab colorimeter. The instrument is based on the principle of reflectance. It consisted of a closed lighted chamber with a circular opening at the bottom. Below this opening, there was a movable stand on which the fiber bundle was mounted in such a way so that no light could pass beyond it. The readings were recorded on the digital monitor of the instrument which is explored by the chart below. Various readings under the headings L, a, and b were given by the instrument. L value represents the mathematical approximation of the non linear black white response of the eye. A perfect white has an L value of 100 and a perfect black has L value of zero, 'a' and 'b' identified the hue and chroma of the material. Plus value of 'a' indicates redness and minus value greenness. The plus value of 'b' indicates yellowness and minus value blueness. Whiteness index gives an overall value for the whiteness effect produced by all L, a, b values and was calculated by the given formula:

$$WI = \frac{L}{100}(L - 5.72b)$$



Whiteness Index Chart

Where,

L = 100 (Specimen purely white)

L = 0 (Specimen purely black)

a^+ = Specimen towards reddish

a^- = Specimen towards greenish

b^+ = Specimen towards yellowish

b^- = Specimen towards bluish

3.5 Evaluation of chemical properties of selected fibers

3.5.1 Chemical composition

The chemical composition of cotton and bamboo fibers was determined. These samples were tested for the cellulose content (%), ash content (%), fat content (%), nitrogen content (%), crude protein (%), moisture content (%), moisture regain (%) and pH.

3.5.1.1 Cellulose content

Samples were extracted with 95 percent alcohol benzene solution for four hours in soxhlet apparatus. Excess solvent was removed; thimble and samples were washed with alcohol to remove the benzene. Then samples were removed from thimble and dried in air. Air dried samples were taken in beaker containing 150 ml of distilled water and heated in hot water bath for 3 hours with the change of water at 1 hour interval. Samples were filtered, washed with hot distilled water and air dried. These extracted fiber samples were placed in crucibles, moistened with cold distilled water at 10°C and chlorinated by passing gas. After three minutes of chlorination, samples were stained again and chlorinated for 2 minutes. Then alcohol was added to dissolve excess chlorine. Alcohol monoethanolamine solution (97 vol. of 95 percent ethyl alcohol and 1 vol. of monoethanol amine) was added to cover the samples completely and left for 2 minutes. Chlorination and extraction treatment were repeated until the samples became white. Finally the samples were washed with ether to facilitate drying. The air dried specimens of homocellulose were taken in separate beaker. These were digested with 17.5 percent of NaOH solution at 20°C for 15 minutes. After caustic soda treatment, the samples were filtered and the residue was transferred into crucible. The samples were again extracted with more volume of 8.3 percent of NaOH solution at 20°C followed by washing with distilled water. The remaining residue in the crucibles were treated with 10 percent acetic acid for 3 minutes and washed with distilled water until the residue was free from acid. The water was removed from the crucibles and the samples were dried in the crucibles to constant weight at 105°C in an oven.

The loss in weight will give the percentage of cellulose in the samples. The cellulose content for each fiber sample was then calculated by using the given formula.

$$\text{Cellulose (\%)} = \frac{W_2}{W_1} \times 100$$

Where,

W_2 = weight of cellulose

W_1 = weight of initial sample

3.5.1.2 Ash content

Cotton and bamboo fiber's ash content was determined as per the method given by **Skinkle (1972)**. Muffle furnace procedure was used to determine the ash content. Two gram of fiber samples was taken in crucible and placed in muffle furnace at 800°C until the carbonization was carried out and the ignition was completed. The crucible was then transferred to desiccator and weighed. The ash content for each fiber sample was calculated by using the given formula.

$$\text{Ash (\%)} = \frac{c - b}{a} \times 100$$

Where,

a = weight of dry sample

b = weight of empty crucible

c = weight of crucible and ash

3.5.1.3 Fat content

Fat content of cotton and bamboo fiber samples were measured by solvent extraction as given in **IS 199: 1973** mentioned in **ISI handbook of Textile testing (1982).** Fiber sample of 5 gm was weighed accurately and placed in oven at 105±3°C for drying the fiber samples to constant mass. After that, the fiber samples were placed in a dry and clean thimble (previously extracted in a soxhlet extractor with chloroform). Then, the thimble was placed with the test specimen in the soxhlet extractor. Adequate quantity of the chloroform was taken in the soxhlet extraction flask and the soxhlet extraction apparatus was assembled. 10 to 20 ml of solvent was further added and then the flask was heated on a water bath or electric hot plate at such a rate that at least six hot extraction occur per hour, keeping the volume of solvent fairly constant by adding enough of it to make up for any loss due to evaporation. Extraction was continued for four hours. Apparatus was then disconnected and bulk of the solvent was removed by means of the removal apparatus. The extract was then evaporated carefully to dryness in the flask on a steam bath, removing the last traces of the solvent by means of a jet of clean air. Further the samples were dried in the drying oven at 110°C to constant mass, cooled in desiccator and then determined the mass of the samples to an accuracy of 0.05g.

Percentage of the fat content was calculated using the following formula:

$$\text{Fatty matter, percent, on dry mass basis} = \frac{b}{a} \times 100$$

Where,

b = mass in g of the extract, and

a = oven dry mass in g of the test specimen

3.5.1.4 Moisture content and moisture regain

The amount of moisture in a fiber sample can be expressed as moisture content and moisture regain. Moisture regain is the weight of water in a material expressed as percentage of the oven dry weight whereas, moisture content is the weight of water in a material expressed as a percentage of the total weight **(Saville, 2004 and Booth, 1996).** Moisture content or moisture regain of cotton and bamboo fiber samples were measured by oven dry weight method as given in **ASTM D 629 - 99 (2006).** Fiber sample of 1 gm weight was kept in oven at 110°C for one hour. It was then left for cooling in a desiccator for 10 minutes and weighed. This procedure was repeated until a constant reading was obtained. The percent moisture content and percent moisture regain was calculated by the given formulas:

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

$$\text{Moisture regain (\%)} = \frac{W_1 - W_2}{W_2} \times 100$$

Where,

W_1 = Original weight of sample

W_2 = Dry weight of sample

3.5.1.3 Crude protein and nitrogen content

The crude protein and nitrogen content of the collected fiber samples i.e. cotton and bamboo fibers respectively was calculated by Micro-Kjeldhal procedure **(AOAC, 1975).** One gram cotton and bamboo fiber samples were digested with 10 gm digestion mixture (containing potassium sulphate and copper sulphate in 96:4 ratio) and 30 ml of concentrated sulphuric acid in a kjeldhal flask separately. The samples were digested till clear light green colour was obtained. The volume of digested samples was made up to 100 ml with distilled water. An aliquot of 10 ml was distilled with 20 ml of 40 percent sodium hydroxide. The ammonia released was absorbed in 25 ml of 4 percent boric acid solution containing few drops of mixed indicator (bromocresol green and methyl red in the ratio of 2:1). Distillation was done for 25 minutes when a light blue colour was obtained. The distillate was titrated against standardized 0.1N sulphuric acid. Simultaneously a blank was run under identical conditions using sucrose in place of sample. The nitrogen present in both the fiber samples was computed using the following formula:

$$\text{Nitrogen content (\%)} = \frac{(S - B) \times N \times 0.014 \times V}{V_1 \times W} \times 100$$

Where,

S = Titre value of sample (ml)

B = Titre value of blank (ml)

N = Normality of sulphuric acid

W = Weight of sample (gm)

V = Volume made (ml)

V_1 = Volume of aliquot distilled (ml)

Crude protein content for the fiber samples was calculated as percent using a conversion factor of 6.25.

3.5.1.4 pH

The pH of the collected fiber samples for the present work i.e. cotton and bamboo respectively was measured separately as per the test method number (IS: 1390-1961) given in **ISI handbook of textile testing (1982).** For taken the pH of the collected fiber samples aqueous extract was prepared using the cold method. Freshly prepared distilled water having the initial pH value ranged in between 6 and 7 was used. Otherwise the pH of distilled water was brought down to 6 using sodium hypochlorite. Five gram of each fiber sample was mixed with 50 ml of distilled water having pH between 5 and 6.5. Fiber samples were then allowed to wet for at least 10 minutes. After that, aqueous extract was decanted and the pH of the aqueous extract decanted from cotton and bamboo fiber samples was measured by the help of pH meter. Four readings were taken for each fiber sample and the average was calculated.

3.5.2 Fiber identification using solubility relationship

Fiber identification using solubility relationship was performed as per the test method given in **ASTM D 276 – 00a (2006).** This test method covered the identification of fibers by determining their solubility or insolubility in various reagents. Different chemical reagents used included sulphuric acid (2% & 98%), nitric acid (2% & 69-70%), hydrochloric acid (35-38%), formic acid (98-100%), acetic acid, oxalic acid (20% & 80%), sodium hydroxide (20% & 80%), sodium carbonate (20% & 80%), borax (20% & 80%), hydrogen peroxide (30%), sodium hypochlorite (4%), acetone, phenol, meta cresol, dimethyl formamide, spirit, carbon tetrachloride, ammonia solution (30%), and their effect on collected fiber samples was evaluated at room temperature (27°C) and on boiling temperature for solubility.

Fiber samples teased out from the warp and weft yarns of the collected woven fabric samples were checked against different chemicals such as acetone, acetic acid, hydrochloric acid (conc.), nitric acid (conc.), phenol, sodium hydroxide and sulphuric acid (conc.) for the confirmation of the fiber used to make the protective and healthcare textiles.

3.5.3 Colour reactions

Colour reactions experiment as given by **Mauersberger (1954)** was carried out on collected fiber samples i.e. cotton and bamboo fibers respectively, for the purpose of identification and distinction of one fiber from the other. The fiber samples were subjected to various chemical reagents like zinc chloride and iodine reagent, iodine and sulphuric acid reagent, malachite green reagent, and methylene blue reagents to study the effect of chemical reagents' colour on fibers. Prior to treatment, one gram of fiber samples was soaked in water for 12 hours, then dried and treated with various reagents. After treatment, fibers were washed in cold water, air dried and the colour of the fibers were noted.

1. Iodine and sulphuric acid reagent

This reagent was used for differentiating vegetable fibers i.e. cotton, etc. and certain man-made fibers i.e. viscose fibers, etc. This reagent was prepared by dissolving 1 gm of Iodine and 3 gm of potassium iodide in 60 ml of water followed by dilution with 10 parts of water. The sulphuric acid was prepared by mixing 3 parts of glycerin and 1 part of water to 3 parts of concentrated sulphuric acid. First the fibers were stained in the iodine solution, then with sulphuric acid and the colour reaction was noted down.

2. Zinc-chloride-iodine reagents

It is general reagent for vegetable fibers. Twenty grams of zinc chloride was dissolved in 10 ml of water for preparing solution A; 2.1 grams of potassium iodide and 0.1 gram of iodine were dissolved in

5ml of water for preparing the solution B. Both the solutions were mixed together and kept in dark. Both the cotton and bamboo fibers were treated with the mixed solution individually, and the colour reactions were noted down.

3. Malachite green

The solution was prepared by dissolving malachite green (0.2 gm) in 200 ml of water. Both the cotton and bamboo fibers were immersed in this solution separately and boiled for 20 seconds, followed by washing with water and dried.

4. Methylene blue

The fiber samples were immersed for 20 minutes in a cold solution of 0.1 percent methylene blue and were then washed in warm water until no more methylene blue bleeded from the fibers.

3.6 Processing of fibers and preparation of pure and blended yarns

Cotton was purchased in a clean form as raw cotton contained many impurities like dirt, vegetable matter etc. Therefore, the cotton slivers were collected to reduce the waste percentage and also eliminated the stage of fiber cleaning. Bamboo fibers in the staple form manufactured through the man-made fiber process was very clean when purchased. Cotton spinning system of SYBLY spinning mills, Modinagar was used for processing of fibers and preparation of ten different kinds of yarn samples i.e. five different 2-ply yarns for warp and five different single ply yarns for weft. Processing sequence of manufacturing of ring spun warp and weft yarns in cotton spinning system are shown in Plate no 3.1. Five blend proportions of pure cotton and bamboo fibers were processed to prepare pure and blended 2-ply warp and single ply weft yarns (Table 3.2).

Table 3.2 Different blend proportions used to prepare pure and blended cotton and bamboo yarns

S. No.	Fibers used	Blend proportion
1.	Cotton-Bamboo	100:0
2.	Cotton-Bamboo	70:30
3.	Cotton-Bamboo	50:50
4.	Cotton-Bamboo	30:70
5.	Cotton-Bamboo	0:100

Firstly the fiber bundles were opened manually and then sandwich mixing or blending were done. Under this process the fibers were weighed and layers of both the fibers were placed one over another to confirm uniform blending. As cotton and bamboo fibers absorb moisture, hence they easily adopt to the atmospheric conditions. Air temperature inside the mixing and blow room area was maintained around 25°C and the relative humidity (RH%) was maintained around 45 to 60 %, because high moisture content in the

Plate 3.1: Processing sequence of ring spun warp and weft yarns on cotton spinning system

fiber leads to poor cleaning, and dryness of the fiber leads to fiber damages which ultimately reduces the spinnability.

After proper mixing and blending, these materials were fed into the blow room for further processing. The pure and blended fibers were then processed through various machines in cotton spinning system to develop requisite kind of pure and blended yarns. Technical process parameters used for fiber processing and yarn preparation at spinning plant are given in Table 3.3.

Table: 3.3 Technical parameters used for fiber processing and yarn preparation at spinning plant

Blow Room	Shell roll Speed	10 rpm
Card	Licker in roll speed	900 rpm
	Cylinder	450 rpm
	Doffer	40 rpm
Draw Frame	Front roller speed	400 m/min
Simplex (roving)	Spindle speed	1000 rpm
Ring Frame	Spindle speed	17,000 rpm
Winding frame	Front roller speed	500 m/min
Doubling frame	Spindle speed	8000 rpm

3.6.1 Blow-room

Blow room section consists of a sequence of different machines to carry out certain basic operations such as opening, cleaning, mixing or blending, microdust removal, uniform supply to the carding machine and recycling the waste. In the blow room, fibers were opened into small flocks which increased the volume of the flocks whereas, the number of the fibers remains constant i.e. the specific gravity of the materials was reduced. As both the fibers were purchased in clean form so there was no need for extra cleaning, this eliminated the process of dedusting. Dedusting is a very important step in the blow room operations as it cleans the atmospheric air. Fibers of required ratios were fed into the blow room machine so that they can be converted into the homogenous lap, which was then transferred to the carding machine.

3.6.2 Carding

"Card is the heart of the spinning mill" and "Well carded is half spun" are two proverbs which inform the immense significance of carding in the spinning process. Carding was done to open the flocks into individual fibers, cleaning of impurities, reduction of neps, elimination of dust and short fibers, fiber blending, fiber orientation or alignment and sliver formation.

In carding process, the lap prepared in the blow room was transferred to the carding machine where it was passed through a beater section and drawn on a rapidly revolving cylinder covered with very fine hooks or fine brushes. As the cylinder rotated, the fibers were pulled by the cylinder through the small gap under the brushes; the teasing action removed the remaining trash, disentangled the fibers, and arranged them in a relatively parallel manner in the form of a thin web. This web was then drawn through a funnel-shaped device that molded the web into a round rope like mass called card sliver, which was then stored in a cane in the form of coils.

3.6.3 Drawing

The slivers produced by the carding machine were loose ropes of fibers and the density was irregular since the thickness of the sliver varied along its length **(Collier, 1970).** Therefore, the several carded slivers were processed on draw frame with a view to improve: the uniformity of sliver fed, to make the fibers parallel to each other and to the axis of the sliver. The draw frame has several pairs of rollers, each advanced set of which revolves at a progressively faster speed. This action pulled the fibers lengthwise over each other, thereby produced longer and thinner slivers. After several stages of drawing out, a sliver of small diameter was obtained and then this condensed sliver was taken to the slubber, where rollers similar to those in the drawing frame draw out the fibers further. Then the slubbings was passed to the spindles, where the first twist was given and was then wound on bobbins.

Thus, the major tasks of draw frame are enumerated as under:

Equalizing: One of the main tasks of the draw frame was to improve evenness over short medium & especially long runs. It was performed by a first process namely doubling and by a second process namely auto leveling. The draft & the doublings had the same value & lied in the range of 6 to 8.

Parallelizing: To obtain an optimal value for strength in the yarn, the fibers were arranged parallel in the fiber strand (the draw frame has the task of creating this parallel arrangement, where every drafting step lead to straightening of the fibers).

3.6.4 Passing of slivers through simplex frame

The bobbins prepared at the drawing stage were then taken on the roving/simplex frame, where further drawing out and twisting was taken place until the diameter of a pencil lead was obtained. The sliver attenuation was done between the draw frame and ring frame. The major objectives of using simplex frame to spin yarn were: to draft the finished sliver to achieve desired fineness, to insert the twist as minimum as possible to hold the fibers properly and bind the drafted fibers onto the bobbin. The material obtained after processing of the slivers on simplex frame was called 'roving'. These roving were weak and needed some strength to withstand the strain. Thus, the strength to the rove was given by inserting a small amount of twist. Therefore, insertion of twist was another important function of the speed frame. The third function of speed frame was to form a suitable package for spinning.

3.6.5 Ring spinning on ring frame

Yarns prepared for the present work was developed through ring spinning method. Technical parameters used for spinning of yarn are given in Table 3.4. The roving, on bobbins, was placed on the spinning frame. The drafting system of ring frame consists of similar components as the drafting system of simplex frame. For twisting & winding, it consists of a ring on which a steel clip prominently called as traveler, runs at the speed of little lesser to spindles. The bobbins on which yarn was to be wound were mounted on spindles. With the help of ring, traveler, spindle & bobbins, drafted fiber strand was twisted & wound on to bobbins. In order to manufacture yarn of desired fineness, the following steps were followed:

- Yarn roving was drafted to 20 to 35 times
- To give adequate strength, twist was inserted in drafted strand of fibers
- Then the twisted yarn was wounds on to the bobbin

After the completion of ring spinning, pure and blended single yarns for warp and weft were obtained. Then the bobbins of the weft yarns were taken to the winding machine, where the yarns from the bobbins were wound over the cones.

4.6.6 Doubling

Double ply warp yarns were required for the present work. Therefore, in order to produce a stronger or fuller warp yarn, two single yarns wound on the bobbins prepared through ring spinning process were taken to the doubling frame and were doubled together by twisting them round each other in the opposite direction to the original twist on the doubling machine. Finally the double ply warp yarns were wound over the cones **(Welford, 1969).**

Table 3.4 Technical parameters used for spinning of yarns

Weight/meter of Lap		400 g/m
Width of Lap		38 inches
Hank of card sliver		0.110
Draw frame hank		0.115
Simplex roving hank		1.3
Ring Frame count (for warp yarns – single ply)		19.5s – 20s
	(for weft yarns)	9.5s – 10.2s
Doubling frame count for warp yarns – double ply		2/19.5s
Turns per inch for 20s count (single ply) for warp yarns		16.5
Turns per inch for 2/20s count (double ply) for warp yarns		13.20
Turns per inch for 10s count for weft yarns		11.5
Twist direction		
For warp yarns:	Single ply	Z
	Double ply	S
For weft yarns		Z

3.7 Evaluation of physical properties of yarns

The pure and blended yarns of cotton and bamboo fibers, suitable for weaving purpose were prepared by ring spinning method.

These yarns were tested for different physical properties *viz.,* yarn count, twist direction, twist per inch, yarn unevenness, yarn imperfection, yarn hairiness, yarn strength and elongation percent at break. Physical properties of pure and blended cotton and bamboo yarns were also tested for significance of variation using analysis of variance (ANOVA); one way classification technique.

3.7.1 Yarn count

The count of the yarns which were raveled from the woven fabric samples (collected from different hospitals) as well as the pure & blended yarns prepared for the present thesis work were checked using beesley balance **(Booth, 1996).** Beesley balance consists of a simple beam with a sample hook at one end and a pointer at the other. The beam was initially leveled to bring the pointer opposite the datum line. A standard weight was hung in a notch on the beam arm on the pointer side of the pivot. Template given with the balance was used to cut the samples of the yarn in short length. These short length yarn samples were then added to the hook until the pointer was opposite to the datum line. Then these short length yarn samples were counted, which directly gave the count of the yarn. The count was the number of the short length yarn samples required to balance the beam. Ten readings for each sample were taken and the average was calculated.

The count of the yarn samples was also calculated on Paramount digi COUNT machine, which is a high precision electronic weighing balance interfaced with computer to evaluate the count of yarn directly in any systems. Software CD is provided with to interface the balance with computer. A lea of 120 yards of yarn was put on electronic weighing balance of this instrument. 10 observations were taken for each yarn samples and average yarn count was directly noted from computer.

3.7.2 Twist direction

The direction of the twist was observed by holding the yarn in a vertical position. If the spirals conformed to the slope of the letter S, the yarn had S twist; if they conformed to the slope of the letter Z, the yarn had Z twist **(Corbman, 1983 and Booth, 1996).**

3.7.3 Twist per inch (T.P.I.)

The twist per inch was measured by yarn twist tester. According to the method described by **Skinkle (1972) and Booth (1996),** yarn samples have a nominal length of 10 inches were held between two clamps of the twist tester. The revolution counter was set at zero position. The rotating jaw was rotated in the direction as per the twist direction of the yarn to untwist the yarn. To ensure the removal of twist, a needle was passed between yarns. The total number of turns registered on the revolution counter was then divided by 10 to obtain the turns per inch in the yarn sample under test. 10 readings for each sample were taken and the average was calculated.

3.7.3 Yarn unevenness, imperfection and hairiness

The unevenness, hairiness and imperfections of the pure and blended warp and weft yarn samples were determined as per the test method **ASTM D 6197–99** given in **Annual Book of ASTM Standards (2006).** Primier tQ Quali Center Ver. M 3.0.2 machine, which is an electronic measuring device, was used for the test. It consists of a device to apply uniform tension to yarn during testing and suitable counter for recording the number of thin places, thick places, neps, hairiness and imperfection present in the yarn. Required parameters were fed initially like the warp and weft count before the test was started. The bobbin of sample was placed on the stand. After threading the tester, the test was started; 100 m of yarn was passed at a constant speed of 25 m/minute. Unevenness of all pure and blended yarn samples was measured in terms of thick (+50%) places, thin (-50%) places and number of neps (+200%). imperfection (which is the sum of thick, thin and neps) and hairiness was also showed by the machine. Five readings for each yarn sample were taken and the calculated average values for unevenness, imperfection, and hairiness were directly noted down from the computer screen attached with the instrument.

3.7.4 Yarn strength and elongation

Yarn strength and elongation of pure and blended yarn samples was determined as per the single strand test method **IS: 1969-1968** mentioned in **ISI Handbook of Textile Testing (1982).** "Electronic Tensile Tester" (Model No.3095) was used, for determining the Breaking strength and elongation of pure and blended yarn samples. This machine is equipped with a microprocessor controlled tensile tester based on the principle of constant rate of extension. This instrument gives computerized testing results of tensile strength and elongation of the warp and weft yarn samples. Gauge length of 20 cm was set between the two clamps of the tensile testing machine. The specimen was then gripped between two clamps of the tensile testing machine and a continual increasing load was applied longitudinally to the specimen by moving lower clamp downwards until the specimen ruptured. Ten readings were taken for each warp and weft yarn sample. Finally average value of breaking strength and elongation were taken directly by the computer.

3.8 Preparation of woven fabrics

Woven fabrics using pure and blended warp and weft yarns were prepared on power loom. A total of five types of pure and blended woven fabrics of cotton-bamboo fibers were prepared (Table 3.5). End and picks per inch, and plain weave design structure of fabric were kept constant for all woven fabrics for comparison of quality characteristics.

Table 3.5 Different blend proportions used to prepare pure and blended cotton-bamboo woven fabrics

S. No.	Fabric type	Blend proportion	
		Warp yarn (2-ply)	Weft yarn (single ply)
1.	100:0 C:B	100:0	100:0
2.	70:30 C:B	70:30	70:30
3.	50:50 C:B	50:50	50:50
4.	30:70 C:B	30:70	30:70
5.	0:100 C:B	0:100	0:100

C:B = Cotton:Bamboo

3.8.1 Preparation for weaving

In the weaving operation, the lengthwise yarns which run from the back to the front of the loom formed the basic structure of the fabric and known as *warp*. The crosswise yarns were the *filling,* also referred to as the *weft* or the *woof.*

Yarns intended for the warp were passed through many operations as spooling, warping and slashing, to prepare them to withstand the strain of the weaving process. In spooling, the yarns were wound onto the larger spools or cones, which were placed on a rack called a creel. From this creel, the yarns were wound on the warp beam, which was similar to huge spool. These yarns were unwound to be put through a slashing, or sizing, bath. The slasher machine covered every yarn with a coating to prevent chafing or breaking during the weaving process. The sized yarns were then wound on a final warp beam and were ready for the loom **(Corbman, 1983).**

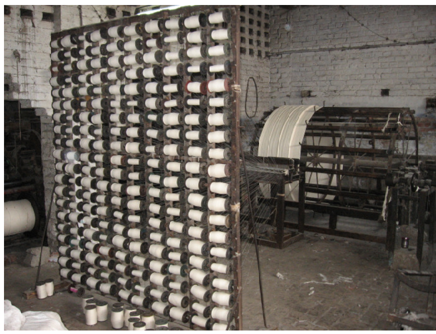
3.8.2 Essentials of the weaving operations

The warp beam was mounted at the back and the warp yarns were conveyed to a cylinder called the cloth roll, which was at the front of the loom and on which the fabric was rolled as it was constructed. Supported on the loom frame between the warp beam and the cloth beam, the warp yarns were interlaced by the filling yarns that run in the width of the cloth, thus producing the woven fabric. Processing sequence for the weaving of pure and blended cotton-bamboo fabrics on power loom machine is shown in Plate no 3.2 and technical parameters used for weaving of fabrics are given in Table 3.6.

Four operations were performed in sequence for making woven fabrics whose descriptions are as follows:

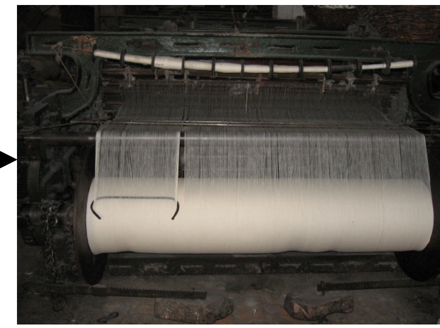
- **Shedding:** specific warp yarns were raised by means of the harness
- **Picking:** filling yarns were inserted through the shed
- **Beating up:** filling yarns were pushed firmly in place by means of the reed

Plate 3.2: Processing sequence for weaving of pure and blended bamboo-cotton fabrics on power loom machine

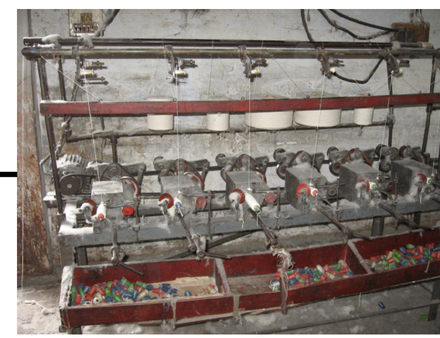


Spooling on creel machine: To prepare the warp beam

Mounting of the warp beam at the back of the loom



Passing of the warp yarns from warp beam to the cloth beam through denting procedure



Preparation of the bobbins for weft yarn

Preparation of the woven fabrics through shedding, picking and beating operations

Prepared woven fabric

- **Taking up and letting off:** finished woven fabrics were wounded the on the cloth beam and more of the warp yarns were then released from the warp beam.

Table: 3.6 Technical parameters used for weaving of fabrics

Width of the fabric	36 inch
Reed space	37.5 inch
Denting for the body of the fabric	2/dent
Denting for the selvedge of the fabric	4/dent (32 ends each side)
Ends per inch (EPI)	36
Picks per inch (PPI)	36
Speed of the power loom	90 rpm

3.9 Physical properties of pure and blended woven fabrics

Pure and blended woven fabric samples were tested for various physical properties like structural properties *viz.,* weave, fabric count (number of ends x picks per inch^2), GSM or weight of the fabric (gm/m^2), and yarn crimp percentage, mechanical properties, i.e., breaking strength (kgf/cm), elongation (%), tearing strength (kg), abrasion resistance (%), pilling (grade) and dimensional stability (%), aesthetic properties, i.e., fabric thickness (mm), fabric stiffness (or bending length in cm), fabric drape or drape coefficient (%), and crease recovery (°), and comfort properties i.e., thermal conductivity (Tog), air permeability (ft^3/ft^2/min), wettability and water vapor permeability ($g/m^2/day$), to ensure whether the product manufactured meets the desired quality level, conform the laid down specifications and are suitable for their intended purpose. Physical properties of pure and blended cotton-bamboo fabrics were also tested for significance of variation using analysis of variance (ANOVA); one way classification technique.

3.9.1 Weave

Woven structures of different fabrics were checked using pick glass. Fabrics were laid flat on a smooth table without any crease and folds. Pick glass was set on the top of the fabric and the interlacing of warp and weft was determined in the form of point diagram on graph paper. Boxes on graph paper were filled when warp crosses the weft; otherwise boxes were left empty in the case of weft. This process was repeated until the defined repeat design of the weave used to make the woven fabric was made.

3.9.2 Fabric count (number of ends x picks per inch^2)

Fabric count or thread count or cloth count was determined by counting the number of warp yarns and filling yarns in a square inch of fabric **(Corbman, 1983).** Fabric was held without tension on a smooth table top, and was made free from folds and wrinkles. The pick glass was used for determination of the number of ends and picks per inch of fabrics. The pick glass was mounted on the fabric.

The stand of this glass had a slot of one square inch through which the number of ends and picks per inch of fabric samples were counted directly **(Angappan and Gopalkrishnan, 2002).** Ten readings of warp and weft for each sample was taken and calculated the average thread count of the fabric as the sum of the warp end and filling pick counts **(ASTM: D 3775-03a)**

3.9.3 GSM or weight of the fabric (gm/m^2)

Fabric weight per unit area of the different woven fabric samples was taken on Paramount digi COUNT. Circular specimens of 100 square cm of a fabric were cut very accurately with the help of the circular GSM cutter provided with this instrument which has four blades that cut the fabric when the hand wheel was rotated by applying slight pressure on it. Then the circular specimens were weighed on a digital balance having a 0.01 g sensitivity which was attached with instrument itself. The value in grams multiplied by 100 straight away gives the GSM of the fabric. 10 observations were taken for each fabric sample and average weight was noted down directly from computer as GSM of fabric.

3.9.4 Yarn crimp percentage

Percentage crimp is defined as the mean difference between the straightened thread length and the distance between the ends of the thread, while in the cloth, expressed in percentage **(Booth, 1996).**

Shirley crimp tester was used to measure the crimp-free length of a yarn specimen removed from a fabric. Rectangular strips were carefully marked on the cloth and each strip was cut. Three strips in warp way and three strips in weft way were cut and from these strips 10 yarns (both warp way and weft way) were removed. The counts of the warp and weft yarns were first determined and the correct tension was calculated. The sliding weight on the balancing head was adjusted to the required tension. The sample of yarn removed from fabric was then placed in the clamps with each end a set distance into the clamp. The moveable jaw was then moved slowly to the right until the index marks on the balancing head and the frame were in line. Then the length of the yarn corresponding to the red mark on the moveable grip was noted from the base scale **(Saville, 2004).** Then the crimp percentage of the yarn samples removed from the woven fabrics was calculated by the following formula:

$$\text{Percentage crimp} = \frac{L_1 - L_0}{L_0} \times 100$$

Where,

L_1 = distance between ends of the yarns as it lies in the fabric

L_0 = straightened length of yarn

3.9.5 Fabric thickness (mm)

Thickness of a fabric is one of the basic properties giving information on its warmth, heaviness or stiffness in use **(Saville,**

2004). Thickness of the pure and blended fabric samples was checked according to the test method **IS: 7702-1975** given in **ISI Hanbook of Textile Testing (1982)**. Fabric thickness was measured as a distance between the reference plate on which specimen rests and a parallel circular pressure foot that exerts a specified pressure on the area under test. Shirley's thickness tester was used to measure thickness of the woven fabric samples. The pressure foot and reference plate were cleaned and thickness gauge was set at zero, all the crease and folds were removed from the sample. The sample was positioned under pressure foot and reference plate and the gauge reading was noted after each 30 seconds. Ten readings from different places of each sample were taken and average was calculated.

3.9.6 Fabric stiffness or bending length

Fabric stiffness test was used to measure the bending stiffness of a fabric by allowing a narrow strip of the fabric to bend to a fixed angle under its own weight **(Saville, 2004).**

The resistance of fabric to blending (stiffness) was studied according to the centilever test method **IS: 6490-1971** given in **ISI Handbook of Textile Testing (1982)**. "Eureka Stiffness Tester" was used to measure the stiffness of the fabric. Rectangular warp way and weft way test specimens of 25x200 mm were cut from different portions of the fabric with the help of the template given with instrument. The lengthwise direction of specimens were kept parallel to the warp or weft direction for each the stiffness was to be determined. The specimen was placed lengthwise on the platform with the scale on top of it and the zero of scale coinciding with the leading edge of the specimen. The specimen and scale were then pushed forward, gently and slowly until the leading edge of specimen projected beyond the edges of the platform and increased part of the specimen hanged like a cantilever and bent under its own weight. The specimen was not pushed forward when its tip reached the level of inclined plane. The length of the overhanging portion was read from the scale. Same test was repeated for 5 samples both warp and weft way and average bending length was calculated by following formula as given in the test method:

$$\text{Bending Length (cm)} = \frac{L}{2}$$

Where,

L = the mean length of overhanging portion in cm

3.9.7 Fabric drape

Drape is one of the subjective performance characteristics of fabric that contributes to aesthetic appeal **(IS: 8357:1977).** It is an important property of textile materials which allows fabric to orient itself into graceful folds or pleats as a result of force of gravity. Drape of fabric was determined by using the instrument called drape meter and was expressed in term of “drape coefficient”. A circular specimen of diameter 10 inch was sandwiched between two horizontal discs of smaller diameter, and the unsupported annular ring of fabric was allowed to hang down under the action of gravity. A planar projection of the contour of the draped specimen was recorded on a light-sensitive paper i.e. ammonia paper. The drape pattern obtained was cut along the outline and its weight was taken **(Angappan and Gopalkrishnan, 2002).** By measuring the following weight, drape coefficient (F %) was calculated as per the method suggested in **IS: 8357:1977.**

Thus, Drape coefficient (F %) = $\frac{w}{W - a / A - a} \times 100$

Where,

W = mass per unit area of the paper

w = mass of the draped pattern

a = area of circle of 12.5 cm diameter = 122.8 cm^2

A = rea of the circle of 25 cm diameter = 491.1 cm^2

3.9.8 Abrasion resistance

The abrasion resistance of the pure and blended woven fabric samples was determined using “Martindale Abrasion Tester” as the loss in weight after specified numbers of abrasion cycle, as per the test method **ASTM D 4966–98** given in **Annual Book of ASTM Standards (2006).** Four circular specimens of 1.5 in. (38 mm) in diameter from each fabric sample were cut and weighed. Specimen holder was then assembled by placing the specimen face down into the specimen holder. The specimen holders were than placed in the machine and given a multidirectional movement. The samples were rubbed against a standard fabric. After 5000 cycles the samples were taken out and the mass loss difference before and after abrasion was reported as weight loss or as a percentage calculated by the formula:

$$\text{Abrasion loss (\%)} = \frac{\text{A - B}}{\text{A}} \times 100$$

Where,

A = weight of the sample before abrasion

B = weight of the sample after abrasion

3.9.9 Pilling

Pilling is a condition that arises in wear due to the formation of little 'pills' of entangled fiber clinging to the fabric surface giving it an unsightly appearance **(Saville, 2004).** Martindale abrasion tester was used to test the pilling of pure and blended woven fabric samples, as per the test method **ASTM D 4970–05** given in **Annual Book of ASTM Standards (2006).** Four circular specimens of 1.5 in. (38 mm) in diameter from each fabric sample were cut and weighed. Specimen holder was then assembled by placing the specimen face down into the specimen holder. The specimen holders were than placed in the machine and given a multidirectional movement. The samples were rubbed against a standard abrading fabric. After 5000 cycles the samples were taken out and the extent of pilling was assessed visually by comparing the tested samples with the ASTM D3512/photographic standards and subjectively samples were rated using rating standards and the following scale:

5 – No pilling

4 – Slight pilling

3 – Moderate pilling

2 – Severe pilling

1 – Very severe pilling

3.9.10 Thermal conductivity (Tog)

Thermal conductivity test was done on the basis of two plate method. In this method the specimen under test was placed between the heated lower plate and insulated top plate **(Saville, 2004).** Sasmira thermal conductivity apparatus was used for testing the thermal insulation properties of pure and blended fabric samples. Guard box was switched on and thermostat was set at 50°C and waited till temperature stabilized at 51°C. After then, hot plate heater too was switched on and the thermostat was set at 50°C and the temperature of the hot plate rose up to a maximum of about 53°C. Circular specimen was cut using round plate template. Fabric specimen was then placed on hot plate and covered with round plate.

Temperature of the hot plate was then allowed to drop to 51°C and with the help of standard stop watch the time (second) taken by hot plate to cool down from 51°C to 50°C was noted down. Five such readings were taken for each fabric sample to find out average cooling time in seconds. The clo value was calculated using the following formula:

$$\text{Clovalue} = \frac{\text{Time}}{2 \times 240}$$

The "clo" value was then converted into more frequently used "Tog" value by the given formula:

Tog = 0.645 x clo

3.9.11 Crease recovery (°)

Crease recovery or wrinkle recovery of pure and blended woven fabric samples was tested by determining the angle of recovery after the removal of creasing force as per the test method **IS: 4681-1968** given in **ISI Handbook of Textile Testing (1982).** "Eureka Crease Recovery Tester" was used to determine the crease recovery of fabric samples. Wrinkle free warp way and weft way rectangular specimen of 15 X 40 mm size was cut and folded in half, placed folded specimen on the lower plate of the loading device and the load was applied gently for five minutes. After the load was removed, specimen was directly transferred to the clamp of instrument (which was mounted in the centre of dial) by holding one limb of the specimen in tweezers and the other limb in the clamp of the instrument. The specimen was allowed to recover from the crease. The dial of the instrument was rotated to keep the free edge of the specimen in line with the knife edge. After one minute (the period allowed for recovery) the recovery angle in degrees was read on the engraved scale. Five samples (each for warp and weft way) were tested and mean values for the nearest degree for the warp way and weft way direction of the test fabrics were calculated.

3.9.12 Breaking strength (kgf/cm) and elongation of fabrics (%)

Breaking strength and elongation of pure and blended woven fabric samples was determined as per the raveled strip test method **IS: 1969-1968** given in **ISI Handbook of Textile Testing (1982).** "Electronic Tensile Tester" (Model No.3095) was used, for determining the Breaking strength and elongation of pure and blended fabric samples. The machine is equipped with a microprocessor controlled tensile tester based on the principle of constant rate of extension. This instrument gives computerized testing results of tensile strength and elongation of the woven fabric samples.

Sample size of 25 cm x 5 cm was taken out in both warp and weft directions and the yarns at the edges were ravelled away to obtain specified width. Required parameters were fed to the instrument before the test was started. Gauge length of 20 cm was set between the two clamps of the tensile testing machine. The specimen was then gripped between two clamps of the tensile testing machine in such a manner that the same set of yarns was gripped by both the clamps and a continual increasing load was applied longitudinally to the specimen by moving one of the clamps until the specimen ruptured. Ten readings were taken for each sample, both in warp and weft direction. Finally average value of breaking strength and elongation were taken from the computer.

3.9.13 Tearing strength of fabric (kg)

Tearing strength of pure and blended woven fabric samples was measured using Trouser-Shaped Test piece – Single Tear test method **IS 7016 (Part 3): 1981.** "Innolab Tensile Strength Tester TS – 06" was used to determine the tensile strength of the woven fabric samples. Rectangular test specimens of 20 cm x 5 cm were taken and a longitudinal slit of 10 cm in length was made in it beginning from the middle of the width. The test machine was adjusted to give the required rate of traverse and appropriate load capacity was also applied. Recorder was set at zero and gauge length of 10 cm was set between the two clamps of the tensile testing machine. The specimen was then placed symmetrically in the jaws, with one tongue in each of the jaws and the uncut end of the test piece remaining free. Care was taken to ensure that each tongue was fixed in a jaw, so that the beginning of the tear was parallel to the direction in which the tearing force was applied. Test machine was then started at the specified rate of traverse and continued the tearing until the test piece was completely torn. Reading displayed on the screen as force in kgs was noted down. Ten reading were taken for each sample, both in warp and weft direction, and average was calculated.

3.9.14 Dimensional stability (%)

Three test specimens measuring 500 mm X 500 mm for each sample were taken from different portion of the fabric sample. The samples were marked with three sets of marks in warp and weft direction respectively. Every mark was 350 mm apart from each other and 50 mm apart from all edges **(Saville, 2004).** Care was taken to protect the marks, by putting fine pointed nib at each end of the marks, from extension or distortion during treatment **(IS: 9–1963).** The fabric samples were first washed in warm water in order to remove any significant amounts of sizing present in the fabric samples. The samples were then immersed in a beaker containing 0.3% solution of soap (surf excel) in water at 40°C., and the beaker and contents were left in a warm place for at least 2 hours. The samples were removed, rinsed, squeezed and allowed to dry while spread smooth on a pad of cotton sheeting, and ironed. After ironing, samples were measured. The average distance between the point on pair of marks in warp and weft directions for each test specimen was noted **(Skinkle, 1972).**

The percentage dimensional change between the datum points on every pair of marks both in warp and weft direction was calculated as per the formula given in the test method **IS: 9–1963** of **ISI Handbook of Textile Testing (1982).**

$$S\ (\%) = \frac{a-b}{a} \times 100$$

Where,

S = percentage dimensional change

a = distance between datum points on a pair of marks before treatment

b = distance between the same datum points after treatment

3.9.15 Air permeability ($ft^3/ft^2/min$)

Air permeability of pure and blended cotton and bamboo fabrics were determined by "Air Permeability Tester" (Instrument ID: AP-01). In air permeability tester, the airflow through a given area of fabric is measured at a constant pressure drop across the fabric of 10 mm head of water **(Saville, 2004).**

Specimen size of 10 cm X 10 cm was taken. The specimen was clamped over the air inlet of the apparatus with the use of rubber gaskets and air was sucked through it by means of a pump. The air valve was adjusted to give a pressure drop across the fabric of 10 mm head of water and then the digital rotometer reading (lph) was noted from the instrument. Five rotometer readings were taken for each sample. Finally the air permeability of each sample was calculated in ($ft^3/ft^2/min$) by the given formula:

$$A = k \times R$$

Where,

A = air permeability in $ft^3/ft^2/min$

k = constant (5.469)

R = rotometer reading in lph

3.9.16 Wettability

Spray test was conducted to test the wettabilty of the pure and blended woven fabric samples. In this test a small scale mock rain shower was produced by pouring water through a spray nozzle. The water falls onto the specimen was mounted over a six inch diameter embroidery hoop and fixed at an angle of 45°C. The test was carried out by pouring 250 cm^3 of water at 27°C ± 2°C steadily into the water funnel. The distance from the bottom of the spray to the center of the fabric was six inch. After finishing of spraying, the sample holder was removed and the surplus water removed by tapping the frame six times against a solid object, with the face of the sample facing the solid object. The tapping was done in two stages, three taps at one point of the frame and three times at an opposite point. The assessment of the water repellency of fabric was given by the spray rating. The American Association of Textile Chemist and Colourist rating recommends the use of a chart of photographs against which the actual fabric samples were compared **(Booth, 1996).**

The American Association of Textile Chemist and Colourist rating followed were:

Rating	**Description**
100	No sticking or wetting of the upper surface
90	Slightly random sticking or wetting of the upper surface
80	Wetting of the upper surface at the spray point
70	Partial wetting of the whole upper surface
50	Complete wetting of the whole upper surface
0	Complete wetting of the whole upper surface and lower surface

Five tests were made for each sample and the mean of five readings were reported.

3.9.17 Water vapour permeability (g/m²/day)

Water vapour permeability of pure and blended cotton and bamboo fabrics were determined as per the water method using test dish given in **ASTM E 96-95.** Water vapour permeability is defined as the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

In the water vapour permeability test, each test dish was filled with sufficient distilled water to give a 10 mm air gap between the water surface and the fabric. A wire sample support was placed on each dish to keep the fabric level. Contact adhesive was applied to the rim of the dish and the specimen, which was 96 mm in diameter, was carefully placed on top with its outside surface uppermost. The cover ring was then placed over the dish and the gap between cover ring and dish sealed with PVC tape. A dish which was covered with the reference fabric was also set up in the same way. All the dishes were then placed in the standard atmosphere and allowed to stand for at least 1h to establish equilibrium. Each dish was then weighed to the nearest 0.001 g and time was also noted.

Finally the water vapour permeability of each fabric sample was calculated in ($g/m^2/day$) by the formula given in **Saville (2004).**

$$WVP\ (g/m^2/day) = \frac{24M}{At}$$

Where,

M = loss in mass (g)

t = time between weighings (h)

A = internal area of the dish (m^2)

$$A = \frac{\pi d^2 \times 10^{=6}}{4}$$

Where,

d = internal diameter of the dish (mm)

3.10 Assessment of antimicrobial activity of the woven fabrics

In the present study, the qualitative antibacterial and antifungal effects of the pure and blended woven fabrics were determined by **AATCC Test Method 147-1998** (Parallel Streak Method for Bacteria) and **AATCC Test Method 30-1998** (Agar Plate Method for Fungus). For the qualitative tests, *Staphylococcus aureus* MTCC 1144 (Gram +ve), *Escherichia coli* MTCC 724 (Gram –ve), *Aspergillus niger* MTCC 2425 and *Trichoderma reesei* MTCC 4096 (cloth damaging pathogenic and non-pathogenic fungi respectively) were used. When effective antibacterial and antifungal activity was determined in parallel streak method for bacteria and agar plate method for fungus, **AATCC 100-1974** Test Method was applied for the determination of reduction in bacterial and fungal counts quantitatively. Antimicrobial assessment was done on fabric samples in two stages i.e. before washing and after washing. Before washed fabric samples were those samples which were taken directly from the loom or grey fabric without any treatment where as after washed fabric samples were that which were washed in launderometer having MLR 50:1 at 40±2°C for half an hour

(IS: 687–1979). Five gram soap i.e. surf excel powder per litre were used for preparing the soap solution.

3.10.1 Qualitative assessment of antimicrobial activity

3.10.1.1 Qualitative assessment of antibacterial activity

The AATCC test method 147-1998 Antibacterial activity assessment of textile materials: Parallel streak method was selected for qualitative assessment of antibacterial activity of pure and blended woven fabric samples. In this test method, sterilized specimen of the test fabrics were placed on AATCC agar which had been streaked with a test bacterium. After incubation an interrupted growth along the streaks of inoculum beneath the specimen and a clear zone of inhibition beyond its edge indicated antibacterial activity of the fabric.

Rectangular test specimens having dimensions 25 x 50 mm were used. A 50 mm length permitted the specimen to lie across 5 parallel inoculum streaks each of diminishing width from about 8mm to 4mm wide.

Test organism culture was prepared by transferring the culture i.e. *S. aureus* and *E. coli* (which was grown on nutrient agar slants at 37±2°C for 24 hours) using a 4mm inoculating loop in nutrient broth, which was incubated at 37±2°C for 24 hours and shook for half an hour on shaker machine before preparing the test inoculum.

Sterilized nutrient agar (15±2ml) was poured into pre-sterilized standard flat bottomed petri dish and allowed the agar to set firmly before inoculation. Inoculum was prepared by transferring 1.0±0.1ml of a 24 hr broth culture into 9.0±0.1ml of sterile distilled water contained in a test tube and mixed well before use. Five parallel streaks, approximately 60 mm in length and 10 mm apart from each other covering the central area of the standard petri dish, were made using the 4 mm inoculating loop, which was loaded with the diluted inoculum without refilling the loop. Care was taken not to break the agar surface while making the streaks. Sterilized test specimen was gently pressed transversely across the five inoculum streaks to ensure intimate contact with the agar surface with the help of the sterilized forceps. Sterile metal ring was placed over the test specimen for preventing it from curling. Test was set in duplicate. Then, the plates were incubated at 37±2°C for 24 hours and the observations were noted. Recipe for preparing the nutrient broth and nutrient agar is described below:

Nutrient Broth

Composition:

Peptone	– 5 gm
Beef Extract	– 3 gm
Distilled Water	– 1000 ml

The entire ingredients were weighed and transferred into the conical flask containing distilled water. The solution was then mixed properly and heated to dissolve the ingredients. pH of the solution was checked with the help of pH meter and was adjusted to 7.0 ± 0.1 with 1*N* NaOH solution.

Nutrient Agar

Nutrient agar was prepared by adding 1.5 percent bacteriological agar to nutrient broth. The quantity of the agar used to solidify the different media depends on its quality and may vary from 15 to 20g/litre.

Nutrient broth and agar were sterilized (sterilization was done in autoclave at $15lb^s/inch^2$ pressure; temp. 121.6°C for 15 minutes) in conical flasks plugged with cotton plugs or rubber caps, and covered with the help of paper and rubber bands.

Note: All the glass wares such as conical flasks, test tubes and glass rods were sterilized at 160°C for three hours in an oven by putting them in brown paper bag and opened in laminar flow only at the time of use. Similarly all the test specimens, forceps, metal rings and distilled water were sterilized at $15lb/inch^2$ pressure (Temp. 121.6°C) for 15 minutes in autoclave to reduce the chances of contamination.

Evaluation

The level of antibacterial activity was assayed by examining the extent of bacterial growth in the contact zone between agar and test specimen. The average width of a zone of inhibition along a streak on either side of the test specimen was calculated using the following equation:

$$W = \frac{T - D}{2}$$

Where,

W = Width of the clear zone in mm

T = Total diameter of fabric specimen and clear zone

D = Diameter of the fabric specimen

It should be noted that the size of the clear zone is a measure of the diffusibility, as well as of antibacterial activity.

3.10.1.2 Qualitative assessment of antifungal activity

The AATCC test method 30-1998: Antifungal Activity, Assessment on Textile Materials: Mildew and Rot Resistance of Textile Materials through Agar plate method was selected for qualitative assessment of antifungal activity of pure and blended woven fabric samples. According to this test method, there were two important considerations when evaluating textile materials in relation to fungal growth:

1) The actual deterioration of the textile product (rot), and
2) Growth not necessarily deteriorating the product but making it unsightly (mildew) often with an unpleasant and musty odour.

Circular test specimens having a diameter 3.8 ± 0.5 cm (1.5 ± 0.2 inch.) were used.

Inoculum of test organism i.e. *A. niger* and *T. reesei* was prepared by adding scrapings from ripe (7-14 days) fruiting culture from potato dextrose agar plates to a conical flask containing 50±1ml of sterile distilled water and 15-20 glass beads. Flask was then shook thoroughly on orbital shaker for half an hour to bring the spores into suspension and then this suspension was used as an inoculum.

Sterilized potato dextrose agar (15±2ml) was poured into pre-sterilized standard flat bottomed petri dish and allowed the agar to set firmly before inoculation. An inoculum of 1.0±0.1ml was distributed evenly over the surface of the agar. Sterilized test specimen was gently pressed on the agar surface. Then, 0.2±0.1ml of the inoculum was applied evenly over each test specimen by means of a sterilized pipette. Test was set in duplicate. All specimens were then incubated at 28±1°C for seven days. Potato Dextrose broth and agar was prepared as per the method given by **Rao (1986).**

Potato Dextrose Broth

Composition:

Potatoes, peeled and diced	– 200 gm
D - Glucose	– 20 gm
Distilled Water	– 1000 ml

Peeled and diced potatoes (200 g) were boiled for 1 hour in a liter of water. The extract was filtered and made up the volume to one liter. Twenty gram D – Glucose was added to this solution to prepare the broth.

Potato Dextrose Agar

Potato Dextrose agar was prepared by adding 15 g bacteriological agar to Potato Dextrose broth. Potato Dextrose agar was sterilized (sterilization was done in autoclave at $15lb^S/inch^2$ pressure; temp. 121.6°C for 15 minutes) in conical flasks plugged with cotton plugs or rubber caps and covered with the help of paper and rubber bands.

Evaluation

The level of antifungal activity was assayed by examining the percentage of surface area of the discs covered with the growth of the fungi, using a 50 X microscope, in accordance with the following scheme.

Observed growth

- No growth (size of the growth-free zone in mm was reported)
- Microscopic growth (visible only under the microscope)
- Macroscopic growth (visible to the eye)

3.10.2 Quantitative assessment of antimicrobial activity

The AATCC test method 100 - 1974 Evaluation of antibacterial finishes on fabrics was selected for quantitative assessment of antibacterial and antifungal activity of pure and blended woven fabric samples.

Circular fabric swatches of 4.8±0.1 cm diameter were taken.

Quantitative antimicrobial activity of fabrics were also tested for significance of variation among pure and blended cotton-bamboo fabrics at different contact hours by using analysis of variance (ANOVA); two way classification techniques.

3.10.2.1 Quantitative assessment of antibacterial activity

Fabric swatch survival test was carried out to find out how fabrics are able to resist the survivability of bacteria. Starting from 0 hours to 120 hours of incubation, the survival of known test bacterial concentration in all fabric samples was assayed over every 24 hours time.

Circular test specimens were inoculated with 1ml test inoculum as prepared in Point no. 3.10.1.1 with the help of sterile pipette. The number of swatches used for absorbing the 1ml inoculum for each fabric was also noted. After inoculation of the fabric swatches, the entire conical flask was closed with cotton plug, wrapped with the help of paper and tied with rubber bands, and placed in incubator at 37±2°C for desired period.

Sampling at "0" contact time: For "0" contact time sampling, as soon as the fabric swatches were inoculated, 100 ml distilled water was added and shook vigorously for half an hour and serial dilution were prepared. From appropriate dilution (10^5), 100µl was placed on nutrient agar with the help of micro-pipette, spread well with sterilized L-shaped glass rod spreader and then incubated for 24 hours at 37°C. After 24 hours, the number of colonies was recorded and presented as colony forming units (cfu).

Sampling at 24 to 120 hours contact time: After having contact of desired time period with bacteria, 100 ml distilled water was added and shook vigorously for half an hour and serial dilutions were prepared. From appropriate dilution (10^5), 100µl was placed on nutrient agar with the help of micro-pipette, spreads well with sterilized L-shaped glass rod spreader and then incubated for 24 hours at 37°C. After 24 hours, the number of colonies was recorded and presented as colony forming units (cfu).

3.10.2.2 Quantitative assessment of antifungal activity

Fabric swatch survival test was carried out to find out how fabrics are able to resist the survivability of fungi. Starting from 0 hours to 336 hours of incubation, the survival of known test fungal concentration in all fabric samples was assayed over every 48 hours time.

Circular test specimens were inoculated with 1ml test inoculum as mentioned in Point no. 3.10.1.2 with the help of sterilized pipette. The number of swatches used for absorbing the 1ml inoculum for each fabric was also noted. After inoculation of the fabric swatches, the entire conical flask was closed with cotton plug, covered with paper and tied with rubber bands and placed in incubator at 28±2°C for desired period.

Sampling at "0" contact time: For "0" contact time sampling, as soon as the fabric swatches were inoculated, 100 ml distilled water was added and shook vigorously for half an hour and serial dilutions were prepared. From appropriate dilution (10^2 for *A. niger* and 10^3 for *T. reesei*), 100µl was placed on potato dextrose agar with the help of micro-pipette, spread well with sterilized L-shaped glass rod spreader and then incubated for 48 hours at 28°C. After 48 hours, the number of colonies was recorded and presented as colony forming units (cfu).

Sampling at 48 to 336 hours contact time: After having contact of desired time period with fungi, 100 ml distilled water was added and shook vigorously for half an hour and serial dilution were prepared. From appropriate dilution (10^2 for *A. niger* and 10^3 for *T. reesei*), 100µl was placed on potato dextrose agar with the help of micro-pipette, spread well with sterilized L-shaped glass rod spreader and then incubated for 48 hours at 28°C. After 48 hours, the number of colonies was recorded and presented as colony forming units (cfu).

Evaluation: Viable colonies of bacteria/fungi on the agar plate were counted and the reduction in number of bacteria/fungi was calculated using the following formula:

$$R = \frac{B - A}{B} \times 100$$

Where,

R	=	percent reduction in bacteria/fungi
B	=	Number of CFU of bacteria/fungi recovered from the inoculated test swatches in the flask immediately after inoculation (at "0" contact time)
A	=	Number of CFU of bacteria/fungi recovered from the inoculated test swatches in the flask incubated for desired time period i.e. 24 to 120 hours period for bacteria and 48 to 336 hours period for fungi

Four replicates of each fabric sample were performed for each bacteria i.e. *E. coli* and *S. aureus,* and fungi i.e. *A. niger* and *T. reesei.*

3.11 Assessment of bio-degradability rate of the woven fabrics

To assess the bio-degradability rate of the pure and blended woven fabrics, soil burial test was performed for 25 days. Four fabric specimens with dimensions 15 ± 1.0 cm X 4.0 ± 0.5 cm were taken from each fabric sample. Soil beds were prepared by placing the air-dried test soil in suitable container to a depth of 13.0 ± 1.0 cm and ought to optimum moisture content by gradual addition of water accompanied by mixing to avoid puddling. After allowed it to stand for 24 hr, the test soil was sieved through a mesh screen of 6.4 mm (0.25 in.). The moisture content of the soil during the test period was maintained between 25 ± 5% by covering the soil container with a suitable lid. Then fabric specimens were buried horizontally on 10.0 ± 1.0 cm of soil spaced at least 2.5 cm apart and then specimens were covered with 2.5 ± 0.5 cm of test soil. The temperature was maintained at 28 ± 1°C during the test period. Fabric specimens were removed at every 5 day interval; gently washed with water, dried at room temperature and conditioned in an atmosphere of 64 ± 2% humidity, and a temperature of 24 ± 3°C for 24 hour **(AATCC: 30-1998)**.

The percent weight loss (four readings for each) for the bio-degradability assessment was calculated by using the given formula:

$$\text{Weight loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 = Initial weight of sample

W_2 = Weight of sample at every five day interval

Bio-degradability rate of fabrics were also tested for significance of variation among pure and blended cotton-bamboo fabrics at different time (days) interval by using analysis of variance (ANOVA); two way classification techniques.

3.12 Assessment of visual appearance of the woven fabrics

The suitability of the pure and blended woven fabric samples made from cotton and bamboo fibers for different protective and healthcare textiles was assessed through visual evaluation done by 10 percent of the total respondents as mentioned in Point no. 3.1. The respondents were doctors of the respective hospitals. The respondents evaluated the woven samples visually on the basis of luster, hand/feel, fabric suitable for the type of garment/article, which includes bed sheets, pillow cover, lab coat, patient dress, surgical gown, nurse's uniform, cap and masks and overall appearance. The performa for the visual assessment of the woven fabric samples is given in *Appendix* IV.

Marks were given to each article on the basis of their suitability to the article, luster, hand feel and appearance for the particular fabric. Marks were given out of 8 for each criterion as there were eight articles listed for protective and healthcare textiles. There were four criterions to be judged for each article which made the total of 32 marks (8 x 4 = 32). Each article was evaluated separately for every criterion and percentage of total marks for each article was calculated to select the best article for the respectable fabric category. Then, rank was assigned to the articles on the basis of percentage obtained i.e. article which got highest percentage got rank I, whereas lowest percentage article got rank VIII. For the particular fabric, the article which got rank I was selected for the product development.

3.13 Cost calculation of the woven fabrics

Whenever, a new type of fabric is manufactured, its feasibility to see the sustainability in market is to be checked. To check the feasibility of fabrics, their cost was calculated by simple arithmetic procedure. Cost of one meter woven fabric sample was calculated by adding cost of yarn manufacturing charges (which included cost of raw material, fiber processing charges and spinning charges), and weaving and finishing charges (which included weaving preparation charges, loom charges and the cost of clipping off the extra yarns from the fabric surface).

3.14 Development of protective and healthcare textiles

Five articles, which got highest rank for the respectable fabrics were selected for the product development.

Line drawing: Firstly the line drawing of each article given in Designer sheet 1, 2 & 3 with their description, was drawn with the help of adobe photoshop software, which showed the basic look of the final article.

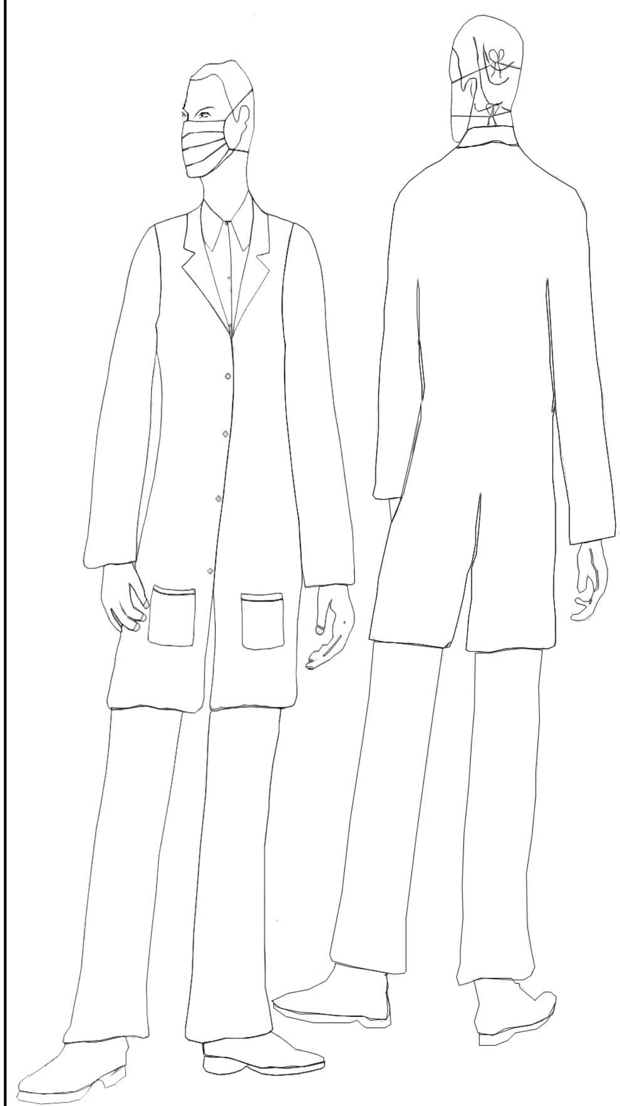
Body measurements: The measurements of five average built men were taken and average was calculated for preparing the drafting of particular article. The average measurement chart is given in *Appendix* V.

DOCTORS' LAB COAT AND MASK

Description of the dress

a) Doctors' lab coat

- It is a one piece garment of thigh length with full sleeves for extra protection against microbes.
- Opened front bodice fastened with buttons.
- Two pockets in front to carry the material.
- Coat collar attached with neckline.
- Slit in the centre at back for ease.



Front view **Back view**

b) Mask

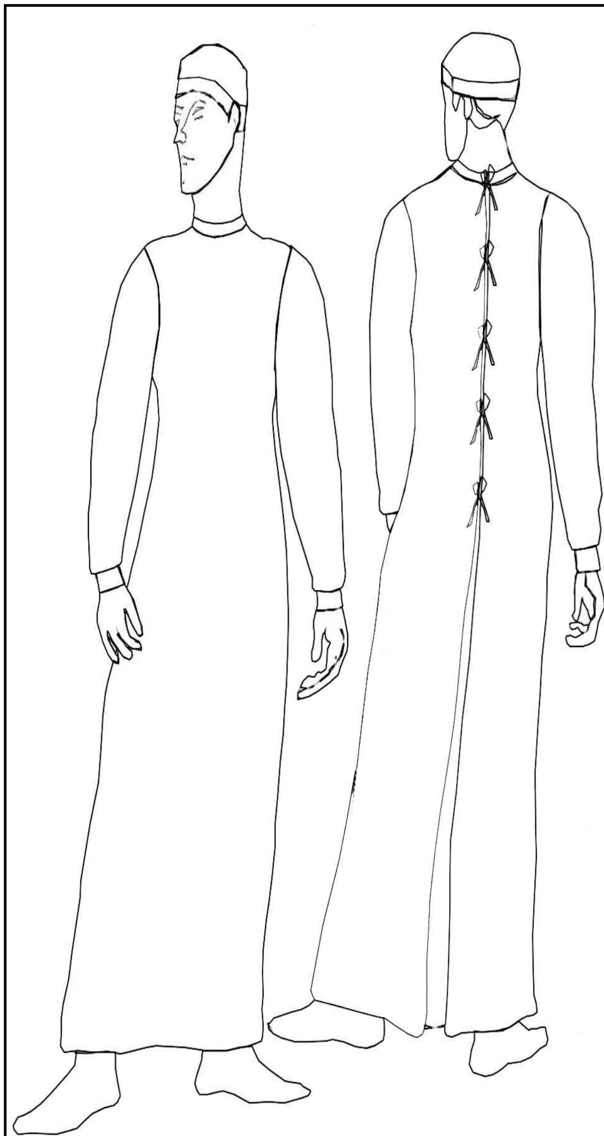
- Made up of rectangular piece with three horizontal pleats setting the product according to the face of the wearer.
- Have strings on both sides of mask to tie it at the back of the head, to keep it in place when required.

Designer sheet 2

SURGICAL GOWN AND CAP

Description of the dress

c) Surgical gown



- It is a one piece ankle length garment with full sleeves for extra protection against microbes.
- Opened at back fastened with strings.
- With high neckline to cover the neck completely.
- Cuff attached at the lower end of the sleeves to cover the wrist completely.

d) Cap

- Made up of a circular top attached with broad rectangular band to fully cover the head.
- Having elastic at the back, to keep the cap in place while working.

Designer sheet 3

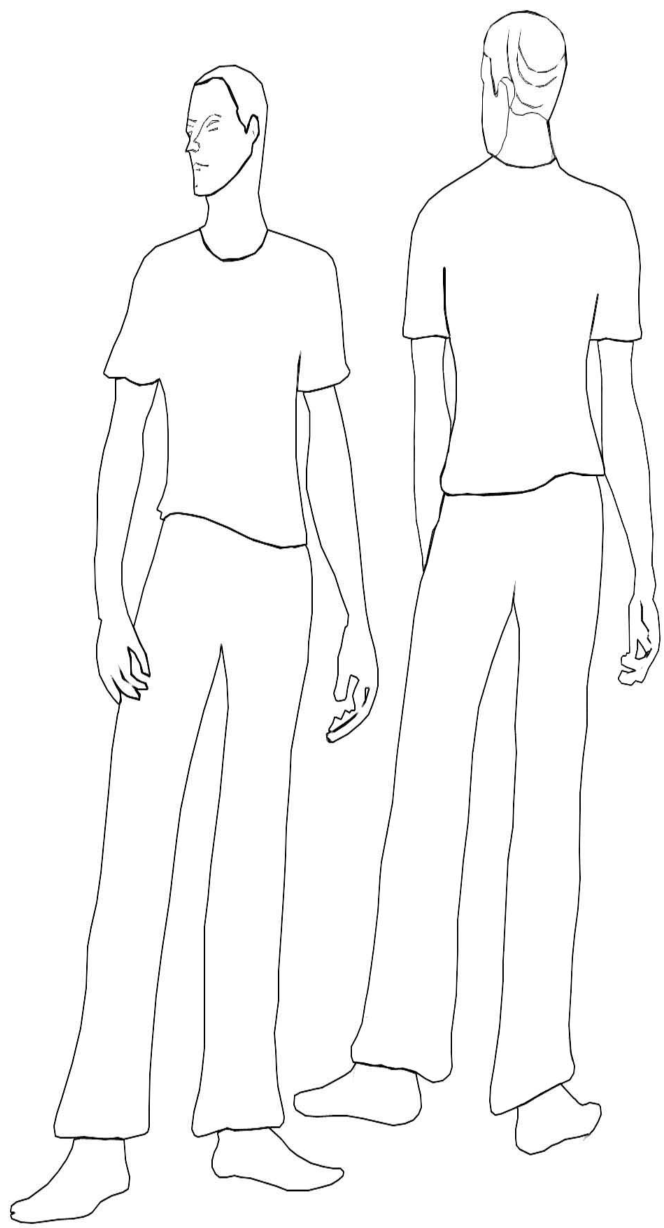
PATIENT DRESS

Description of the dress

This dress is consisted of two parts i.e. top and trouser

a) Top

- Loosely fitted garment with short sleeves to provide extra comfort to the wearer.
- Slits prepared at the lower side of the top for ease.
- Round neck finished with shape facing of optimum depth was made, to facilitate wearability.



Front view **Back view**

b) Trouser

- Pyjama cut trouser was made for comfort purpose.
- String was provided to tie the trouser, so that wearer can adjust the trouser according to his/her comfort level

Preparation of drafting, cutting and stitching: Form the average body measurements; drafting of each article was prepared using drafting of gent's garments i.e. gent's shirt, pant cut pyjama, sleeve, cuff and collar given in **Zarapkar (1999)**. Drafting of each article is given in *Appendix VI*.

After then, cut layout patterns for each article was laid on the fabric and pinned properly before cutting. After cutting of the fabric, pieces were stitched to develop the final articles.

Results and Discussion

RESULTS AND DISCUSSION

The results obtained during the course of investigation are described in this chapter with the help of appropriate tables, figures, plates and sample sheets. The results of the present investigation are presented and discussed in the following sections:

4.1 Data and sample collection

4.2 Evaluation of physical properties of woven samples collected from different hospitals

4.3 Selected fibers

4.4 Evaluation of physical properties of fibers

4.5 Evaluation of chemical properties of fibers

4.6 Fiber processing and preparation of pure and blended yarns

4.7 Evaluation of physical properties of yarns

4.8 Preparation of pure and blended woven fabrics

4.9 Evaluation of physical properties of woven fabrics

4.10 Assessment of antimicrobial activity of the woven fabrics

4.11 Assessment of degradability rate of the woven fabrics

4.12 Assessment of visual appearance of the woven fabrics

4.13 Cost Calculation of woven fabrics

4.14 Development of protective and healthcare textiles

4.1 Data and sample collection

4.1.1 General information

The present study was designed to develop the protective and healthcare textiles with added antimicrobial and biodegradable properties. Therefore, it was necessary to gain the in-depth knowledge regarding different protective and healthcare textiles presently used in the medical field. Knowledge regarding different protective and healthcare textiles was collected after survey in hospitals from two districts. Names of the hospitals surveyed i.e. 15 hospitals from the Udham Singh Nagar district of Uttarakhand and remaining 15 hospitals from the Ghaziabad district of Uttar Pradesh, are given in *Appendix VII*. It was found from both the districts that 13.3% hospitals were public and 86.7% hospitals were private.

It was found that all the 30 hospitals from both the districts were registered hospitals. Out of Ghaziabad District 26.7% hospitals were registered and established in between 1961-1980, 56.3% were registered and established from the year 1981-2000 and the remaining 20% were registered and established in between 2001-2009 whereas from Udham Singh Nagar District 6.7% hospitals were registered and established in between the year 1961-1980, 40% were registered and established from the year 1981-2000 and the remaining 53.3% were registered and established in between 2001-2009.

It was found from Ghaziabad District that 53.4% hospitals were registered under CMO i.e. Chief medical officer, Ghaziabad, 33.3% were registered under ROC i.e. Registrar of companies and remaining 13.3% hospitals were registered under government. In the case of Udham Singh Nagar District 73.3% hospitals were registered under the Medical Council of Rudrapur, 13.3% were registered under Medical Council of Dehradoon, 6.7% were registered under the sub region firms, Kumoun region, Haldwani and remaining 6.7 % hospitals were registered under the government.

It is clear from the Table 4.1 that all hospitals from both the districts deal in multiple specialties/health problems.

It is clear from the Table 4.2 that from the Ghaziabad district only 13.3% hospitals were having only general room facility, 86.7% hospitals were having both types of room facilities i.e. general and private whereas 13.3% hospitals were also having other room facilities like Intensive care unit and semi-private rooms. In the case of Udham Singh Nagar District, 6.7% hospitals were having only general room facility, 6.7% hospitals were having only private room facility whereas remaining 86.7% hospitals were having both types of room facilities i.e. general and private.

Table 4.1 Distribution of the respondents based on the type of specialties/health problems deals with in their hospitals

N = 15

S. No.	Hospitals with specialties	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	General problem	14	93.3	8	53.3
2.	ENT problem	15	100	5	33.3
3.	Heart problem	13	86.7	7	46.7
4.	Gynecology problem	15	100	10	66.7
5.	Eye problem	7	46.7	6	40
6.	Neuro problem	10	66.7	2	13.3
7.	Pathology problem	11	73.3	6	40
8.	Dental problem	8	53.3	4	26.7
9.	Skin problem	10	66.7	4	26.7
10.	Pediatrics problem	13	86.7	4	26.7
11.	Nephrology problem	7	46.7	5	33.3
12.	Radiology problem	12	80	4	26.7
13.	Orthopedic problem	15	100	6	40
14.	Any other	1	6.7	3	20

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

Table 4.2 Distribution of the respondents based on the type of room facilities in the hospitals

N = 15

S. No.	Type of room facilities	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%
1.	General	2	13.3	1	6.7
2.	Private	-	-	1	6.7
3.	Both	13	86.7	13	86.7
4.	Any other	2	13.3	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

It was found from Ghaziabad district that only 33.3% hospitals were having separate department who is responsible for the care and maintenance of the hospital while 66.7% hospitals were no such kind of department whereas from Udham Singh Nagar District only 6.7% were having such department while 93.3% were having no such department.

4.1.2 Specific information

It is clear from the Table 4.3 that all hospitals from both the districts required multiple protective, healthcare and hygiene products. It is clear from the data that 100% and 80% respondents from Ghaziabad district and Udham Singh Nagar District respectively were using doctors' lab coat, 100% respondents from both the districts were using doctor's-nurses surgical gown, bed sheet-pillow cover, blankets, towels, caps, masks and gloves whereas only 86.7% respondents from both the districts were using patient dress. It was found that government hospitals were not using patient dress whereas private hospitals were using all products and keeps their patients satisfied.

It is clear from the Table 4.4 that from Ghaziabad district and Udham Singh Nagar district, 6.7% and 13.3% respondents respectively procured the protective, healthcare and hygiene products directly from the factory, 93.3% and 66.7% respondents respectively procured the products from whole sale market whereas 20% and 40% respondents respectively procured the products from retailers. However, no respondent was importing any such product.

Table 4.3 Distribution of the respondents based on the use of protective, healthcare and hygiene products

N = 15

S. No.	Protective, healthcare and hygiene products	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	Doctors' lab coat	15	100	12	80
2.	Doctors'-nurses surgical gown	15	100	15	100
3.	Patient dress	13	86.7	13	86.7
4.	Bed sheet-pillow cover	15	100	15	100
5.	Blankets	15	100	15	100
6.	Towels	15	100	15	100
7.	Cap and mask	15	100	15	100
8.	Gloves	15	100	15	100
9.	Any other	-	-	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

Table 4.4 Distribution of the respondents based on the place of procurement of protective, healthcare and hygiene products

N = 15

S. No.	Place of procurement	Ghaziabad district		Udham Singh Nagar District	
		n	%*	N	%*
1.	You produce of your own	-	-	-	-
2.	Directly from factory	1	6.7	2	13.3
3.	From whole sale market	14	93.3	10	66.7
4.	From retailers	3	20	6	40
5.	Import	-	-	-	-
6.	Any other	-	-	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

Out of Ghaziabad district, 6.7% respondents procured the products from Naveen general store, Modinagar, 13.3% respondents were purchasing the products from Govt. approved shops like khadi ashrams, 13.3% respondents were procuring the products from shiva khadi bhandar, Ghaziabad, 26.7% respondents were procuring the products from Ghaziabad surgical agency, Ghaziabad and 40% respondents were procuring the products from various shops as per their rate contracts. In the case of Udham Singh Nagar district 26.7% respondents were purchasing the products from Bajaj textiles, Rudrapur, 13.3% respondents were procuring the products from Kapoor surgicals, Rampur, 26.7% respondents were purchasing the products from Balaji surgicals, Haldwani, 13.3% respondents were purchasing the products from Govt. approved shops like khadi ashrams, 6.7% respondents were procuring the products from Ruchi surgicals, Rudrapur, 6.7% respondents were procuring the products from Batra cloth house, Rudrapur and 13.3% respondents were procuring the products from various shops as per their rate contracts.

It is clear from the Table 4.5 that from Ghaziabad district, 86.7% respondents were procuring the products in readymade form while 66.7% respondents were purchasing the fabrics as per their requirements and the products were stitched by the local tailors on payment basis. It was found from Udham Singh Nagar district that

93.3% respondents were procuring the products in readymade form while 6.7% respondents were purchasing the fabrics from the market as per their requirements and got it stitched by the local tailors on payment basis.

Table 4.5 Distribution of the respondents based on the form of protective, healthcare and hygiene products

N = 15

S. No.	Form of protective, healthcare and hygiene products	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	Readymade	13	86.7	14	93.3
2.	Fabric form	10	66.7	1	6.7

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

Table 4.6 Distribution of the respondents based on the qualities they prefer in protective, healthcare and hygiene products

N = 15

S. No.	Qualities of protective, healthcare and hygiene products	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	Softness	11	73.3	14	93.3
2.	Air permeability	4	26.7	5	33.3
3.	Absorbency	5	33.3	5	33.3
4.	Comfort	7	46.7	10	66.7
5.	Easy to handle	7	46.7	4	26.7
6.	Drapability	4	26.7	5	33.3
7.	Any other	-	-	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

It is clear from the data presented in Table 4.6 that all the (100%) respondents preferred multiple qualities in the protective, healthcare and hygiene products. The product cost range is presented in Table 4.7. It is clear from the data that all the protective, healthcare and hygiene products used in the hospitals were available in various prices depending upon the quality of raw materials used. Therefore, the ranges of products cost helped to know the lowest and highest cost of the particular product.

Table 4.7 Cost range per product

S. No.	Name of the products	Ranges of cost in Rs./- product from Ghaziabad district	Ranges of cost in Rs./- product from Udham Singh Nagar district
1.	Doctors' lab coat	175 to 350/-	105 to 450/-
2.	Doctors'-nurses surgical gown	150 to 400/- separately for Doctor's and nurses	200 to 400/- separately for Doctor's and nurses
3.	Patient dress	150 to 350/-	100 to 400/-
4.	Bed sheet-pillow cover	110 to 185/- for bed sheet and 35 to 50/- for pillow cover	100 to 125/- for bed sheet and 20 to 40/- for pillow cover
5.	Blankets	200 to 425/-	150 to 500/-
6.	Towels	25 to 50/-	10 to 50/-
7.	Cap and mask	5 to 50/-	5 to 10/-
8.	Gloves	8 to 30/-	8 to 15/-
9.	Any other	-	-

It is clear from the Table 4.8 that cotton and wool fiber were preferred by all the respondents from both the districts for protective, healthcare and hygiene products.

Table 4.8 Distribution of the respondents based on the type of fibers preferred for protective, healthcare and hygiene products

N = 15

S. No.	Fiber preferred	Ghaziabad district		Udham Singh Nagar District	
		n	%*	N	%*
1.	Cotton	15	100	15	100
2.	Wool	15	100	15	100
3.	Silk	-	-	-	-
4.	Synthetic	-	-	-	-
5.	Any other like blends	-	-	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

It is evident after survey that from the Ghaziabad district and Udham Singh Nagar District only 20% and 26.7% respondents respectively were aware of plain weave used for making protective, healthcare and hygiene products. They had no idea about any other weave. Remaining 80% and 73.3 % respondents respectively had no idea about the weaves as they do not had textile background.

It was found that none of the respondents from both the districts had any idea regarding the pre-treatments/finishing given to the products at the time of manufacturing. It was also found that all the respondents from both the districts respectively procured the products in dyed form but they had no idea regarding the type of dyes applied on them.

It is evident after survey that from the Ghaziabad district and Udham Singh Nagar district only 26.7% and 20% respondents respectively were having separate department for the care and storage of protective, healthcare and hygiene products whereas remaining 73.3 % and 80% respondents respectively had no such department. It was found that in the case of both districts the numbers of personnels working in care and storage department were ranging from 2-4 only.

It is evident from Table 4.9 that all the respondents from the both the districts, changed the linens of the patients and other items used by the doctors/nurses daily, 53.3% respondents from Ghaziabad district and 46.7% respondents from Udham Singh Nagar district changed the products after 2 days which included doctors lab coat, surgical gowns, patient dress, bed sheet-pillow cover and blanket, 26.7% respondents from both the districts changed the products after every 4 days which included surgical gowns, patient dress and bed sheet-pillow cover, only 6.7% respondent from Ghaziabad district changed the product after a week which included doctors lab coat whereas 33.3% respondents from both the districts changed the product as and when required which included doctors lab coat, patient dress, bed sheet-pillow cover and blanket. It is clear from the data that time duration for changing the articles varied depending upon the condition of patient's and hospitals. In case of the items changed as and when required (the period may vary from one day to seven days) may increased the chances of the multiplication of the pathogenic microbes i.e. *Pseudomonas, Staphylococcus aureus, E. coli, Streptococcus, Candidacies, Aspergilus niger*, etc. generally found in the hospital environment which ultimately affected the health of doctor's, nurse's, patient's, and other staff. It was found that disposable caps, masks and gloves which were used in hospitals were discarded after every use, increases the percentage of waste in the landfills whereas other items were washed, sterilized and reused again.

Table 4.9 Distribution of the respondents based on the duration of time at which the linens of the patients and other items used by doctors/nurses are changed

N = 15

S. No.	Time duration	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	Daily	15	100	15	100
2.	After 2 days	8	53.3	7	46.7
3.	After 4 days	4	26.7	4	26.7
4.	After a week	1	6.7	-	-
5.	As and when required	5	33.3	5	33.3
6.	Any other	-	-	-	-

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

It was found that all the respondents from both the districts gave after treatment to the products which generally included washing and sterilization to control the infection or kill the pathogenic (disease causing) microbes discharged from the user's body or came in contact to the products from hospital environment. All the hospital products were washed by the washer man. But due to lack of proper knowledge, washer man was unable to clean the products completely. Due to this reason sterilization was done in the hospitals to clean the products completely and the sterilization was normally done at 15 lb/inch^2 pressure (temp. 121.6°C) for 15-20 minutes in an autoclave machine.

It is evident from the data that multiple practices were performed at the hospitals for maintaining the care and hygiene of the products. All the respondents from both the districts were performed washing of the products, 93.3% respondents from Ghaziabad district and 73.3% respondents from Udham Singh Nagar district used to sterilize these products, 80% and 93.3% respondents respectively used to dry the products completely before every use and 93.3% respondents from both the district carried ironing practice also.

It was found that 93.3% respondents from Ghaziabad district and 73.3% respondents from Udham Singh Nagar district were using naphthalene balls at the time of product storage whereas 60% and

46.7% respondents respectively were applying sprays like finit, hit, etc. at the time of product storage to keep the insect away from the products.

It is apparent from the data that 80% respondents from Ghaziabad district and 60% respondents from Udham Singh Nagar District were getting information about new and improved protective, healthcare and hygiene products from books/magazines/journals, 73.3% and 86.7% respectively were getting information from company's personnels, 13.3% respondents from Ghaziabad district were getting information from newspaper whereas only 6.7% respondents from Udham Singh Nagar District were getting information from fairs and exhibitions.

It was found that all the hospitals from both the districts were ready to adopt the new products. It is clear from the data that 93.3% respondents from both districts were ready to buy the new products on the basis of their affordability whereas 80% respondents from Ghaziabad district and 73.3% respondents from Udham Singh Nagar District were ready to adopt the new product providing better services like anti-bacterial, anti-U.V., etc.

It is evident from Table 4.10 that all the respondents from both the districts preferred most of the items in white color because stains were more visible on white colour. In addition to white colour all the respondents from both the districts preferred to use cherry red colour for the blanket. They preferred cap & masks in light blue and green color. Besides that, 46.7% respondents from Ghaziabad district and 40% respondents from Udham Singh Nagar district preferred green color for surgical gowns and patient dress whereas 13.3% and 20% respondents from both the districts also preferred light blue color for surgical gowns, patient dress and bed sheet-pillow covers.

Table 4.10 Distribution of the respondents based on the preference of colour for protective, healthcare and hygiene products

N = 15

S. No.	Time duration	Ghaziabad district		Udham Singh Nagar District	
		n	%*	n	%*
1.	White	15	100	15	100
2.	Light green	7	46.7	6	40
3.	Light blue	2	13.3	3	20
4.	Yellow	-	-	-	-
5.	Pink	-	-	-	-
6.	Any other	15	100	15	100

n – Number of respondents
* Total of percentage exceeds from 100 due to multiple responses

Data gathered from both the districts showed that the size/dimensions of the doctor's lab coat and doctor's-nurse's surgical gown were according to the size of person concerned. Patient gowns were stitched in all three sizes i.e. small, medium and large as every patient has its own body structure. Bed-sheets were approximately of 6 x 3 feet in size, pillow cover were approximately of 28 x 20 inches in size, blankets were approximately of 6 x 4 feet in size whereas towels, caps, masks, gloves were directly taken from the market in the standard available sizes.

It was found that all the respondents from both the districts preferred strings as fasteners to be used in the products as they remained smooth on the user's body except doctor's lab coat where buttons were used as fasteners. It is clear from the data that all the respondents from both the districts purchased the products as and when required. They were satisfied with the performance of the products as they were easy to care and handle. None of the respondents from both the districts suggested any measure to improve the quality of protective, healthcare and hygiene products as they had no idea in this field.

Doctors/patients of all the hospitals from both the districts were satisfied with the products those were purchased by the hospitals administration for them as they provided good services in all respects. These hospitals collect the used products (i.e. OT products and ward products) separately to avoid cross infection. Administration of these hospitals ensures the quality of the protective, healthcare and hygiene products used in their hospitals.

It is clear from the data collected that staff of all the hospitals from both the districts need training regarding hygiene practices, as isolating infected and colonized patients, and practicing stringent handwashing policies, help in reducing the spread of a wide range of infections, caused by microbes. These respondents required training in the field of care and maintenance of the products, as the use of optimum amount of detergents, soaps, etc., increases the life of the product. From Ghaziabad district and Udham Singh Nagar district, 80% and 73.3% respondents respectively required training regarding the properties of the products such as absorbency, thermal insulation, etc., which provide comfort to wearer. Majority of respondents (80%) from both the districts required training regarding sterilization of the products, as proper sterilization kill the microbes present on the product, thus, can be used safely.

It is apparent from the data that both the districts have almost the same standards, in keeping their doctors, nurses, staff and patients satisfied. In the phase II of the present study, protective and healthcare textiles were developed as per existing fabric construction parameters of protective and healthcare textiles. Therefore, some woven fabric samples used for making protective, healthcare and hygiene products were collected from different hospitals at the time of survey for their evaluation.

4.2 Evaluation of physical properties of woven samples collected from different hospitals

Nine woven fabric samples collected from different hospitals were evaluated to know the type of fibers used in the fabrics and their fabric construction parameters. The important properties tested were fiber identification i.e. microscopic test, burning test and chemical test, yarn properties i.e. yarn count, twist direction and twist per inch, and fabric properties i.e. weave structure, fabric count, GSM of the fabrics and raveled yarn crimp percentage.

4.2.1 Fiber properties

It was very important to know the type of fiber and their characteristics, used for making the fabrics as it ultimately affects the fabric properties.

4.2.1.1 Microscopic view

Fibers teased out from warp and weft yarns of all the woven fabric samples were tested for their longitudinal and cross-sectional view respectively. Flat, twisted ribbon like structure was found longitudinally in all the woven fabric samples whereas bean or ear shaped, like a collapsed tube structure was found cross-sectionally which confirmed that in all the woven fabric samples cotton fiber was used. **Corbman (1983)** also stated that cotton fiber resembles like a collapsed, spirally twisted tube with a rough surface under the microscope.

4.2.1.2 Burning test

It was found that the fibers from all the woven fabric samples were ignited very readily when approached to flame, burnt quickly with yellow flame, continued to burn rapidly and had afterglow even after removed from flame, were having a characteristic burning paper odor and small, fluffy, soft grey ash at the end which confirmed that in all the woven fabric samples cotton fiber was used. **Vatsala (2003)** also stated that cotton fiber or yarn blazes quickly when it comes in contact with the flame because the cellulose ingredient is highly flammable. The ash is light and feathery and has a vegetable odor similar to that of burned paper.

4.2.1.3 Chemical test

The chemical test of all woven fabric samples (fibers) was conducted at room temperature as well as at boiling temperature. It was noticed that fibers taken out from all the woven fabric samples remained unaffected with phenol, sodium hydroxide and acetone whereas swelled with acetic acid, hydrochloric acid (concentrated), nitric acid (concentrated), sulphuric acid (concentrated) at room temperature. No further change was noticed with acetic acid and acetone, swelled slightly with phenol and sodiun hydroxide, dissolved partially in hydrochloric acid whereas in nitric acid (concentrated) and sulphuric acid (concentrated) fiber samples dissolved completely within 2 minutes at boiling temperature which confirmed that in all the nine woven fabric samples cotton fiber was present. **Collier (1970)** stated that acids destroy the vegetable fibers.

After evaluation of fiber properties it was found that cotton is the prime fiber used for making protective and healthcare textiles. This might be due to the fact that cotton is the most important natural cellulosic textile fiber, abundantly present in the world and its properties are well suited for garment production.

4.2.2 Yarn properties

The results of yarn properties i.e. yarn count, twist direction and twist per inch in yarn are presented in Table 4.11.

4.2.2.2 Yarn count

It is evident from Table 4.11 that yarn counts of warp and weft yarns were ranging from 5.5s to 25.33s and 5.0s to 21.3s respectively whereas most of the warp and weft yarn counts lied around 10s. It is clear from the data that slight coarse yarn was used for making protective and healthcare textiles. **Corbman (1983)** also stated that yarn counts up to Ne 20 are called coarse yarns and are responsible for producing open construction fabrics.

Table 4.11 Yarn properties of the woven fabric samples

Fabric Samples	Yarn Properties									
	Yarn count		Twist direction				Twist per inch			
	Warp	Weft	Warp		Weft		Warp		Weft	
			2-ply	Single ply	2-ply	Single ply	2-ply	Single ply	2-ply	Single ply
1	5.5	5.0	S	Z	S	Z	.25	5.5	1.6	8
2	5.7	5.7	S	Z	-	Z	11	18	-	7
3	6.8	8.1	S	Z	-	Z	13.25	18.5	-	9.5
4	8.6	10.2	S	Z	-	Z	15	18	-	15
5	10.2	9.6	-	Z	-	Z	-	14	-	9
6	7.25	9.4	S	Z	-	Z	16	19	-	12.6
7	8.9	9.1	S	Z	-	Z	13.7	16.2	-	11.5
8	25.3	21.3	-	Z	-	Z	-	16	-	9.5
9	7.6	8.0	S	Z	S	Z	12.8	20.8	14.24	17.8

4.2.2.3 Twist direction

Out of nine different warp yarn samples, seven samples were 2-ply and two samples were single ply yarns, whereas in weft direction, seven samples were single ply and two samples were 2-ply yarns. It showed that mostly 2-ply yarns were used in the warp direction and single ply yarns were used in weft direction as more strength is required in warp yarn during weaving process. In single yarns **Z** twist was present as the spirals of the yarn conformed to the central part of the letter Z and **S** twist was present in 2-ply yarns as the spirals formed by the twist conformed to the central part of the letter S. Z-twist is the standard twist used whereas S-twist is used for making ply yarns in which reversal of direction is desired **Anonymous (1974)**.

4.2.2.4 Twist per inch

It is evident from the data that in 2-ply yarns, higher twist was present in single yarns and lower twist was present in 2-ply yarn resulted in coarser count 2-ply yarn in comparision to finer single ply yarn. It was noticed that twists per inch in 2-ply warp yarns were almost similar to their corresponding weft way single yarns.

It was found that almost same count yarns were used in warp and weft direction for weaving the fabrics but mostly 2-ply yarns were used in warp direction having higher twist in their single yarns and lower twist in their plied form giving strength while weaving where as single yarns were used in weft direction which required less strength as well as under less tension than warp yarns during weaving.

4.2.3 Fabric properties

The results of fabric properties i.e. weave structure, fabric count, fabric weight per unit area and crimp percentage of raveled yarn are presented in Table 4.12.

Table 4.12 Fabric properties of the woven fabric samples

Fabric Samples	Fabric Properties					
	Weave structure	Fabric count (EPI X PPI/inch²)		Fabric weight per unit area (gm/m²)	Yarn crimp (%)	
		EPI	PPI		Warp way	Weft way
1	Basket weave	28.7	33.5	188.65	9.65	9.25
2	Plain weave	41.2	36.2	222.50	9.50	9.60
3	Plain weave	40.6	40.6	254.50	10.05	9.95
4	Plain weave	41.4	41.2	213.85	10.50	9.10
5	Plain weave	45.8	40.0	212.85	11.10	10.85
6	Plain weave	33.4	40.0	202.60	11.00	10.50
7	Plain weave	38.6	38.2	204.70	10.55	10.15
8	Plain weave	63.0	51.8	136.45	11.25	10.45
9	Plain weave	46.8	33.6	243.50	10.50	10.70

4.2.3.1 Weave structure

Out of nine woven fabric samples, eight woven fabric samples had plain weave structure whereas only one sample was made with basket weave. This showed that plain weave is the prime weave used for making protective and healthcare textiles. According to **Vatsala (2003),** plain weave is the simplest weave to produce and consequently inexpensive.

4.2.3.2 Fabric count

It is evident from Table 4.12 that the ends per inch (EPI) and picks per inch (PPI) of the woven fabric samples were ranging from

28 to 63 and 33.5 to 51.8 respectively whereas most of the ends per inch and picks per inch were ranged in between 33 to 40. It is clear from the data that almost balance weave constructions were found in most the fabric samples.

4.2.3.3 Fabric weight per unit area

It is clear from Table 4.12 that fabric weight per unit area of the woven fabric samples ranged between 136.45 to 254.50 gm/m^2 and most of the fabric weight per unit area of the fabric samples lied around 200 gm/m^2.

4.2.3.4 Yarn crimp percentage

It is apparent from Table 4.12 that crimp percentage of the raveled warp yarns varied from 9.5% to 11.25% and warp yarn crimp percentage of maximum samples were around 10% where as crimp percentage of the raveled weft yarns ranged between 9.25% to 10.85% and most of the weft yarn crimp percentage were lied around 10%. It is clear from the data that slightly higher yarn crimp percentage was seen in warp direction as the warp yarns were pressed over and under the filling yarns by the up-and-down motion of the harnesses.

According to **Angappan and Gopalkrishnan (2002),** crimp is related to length which indicated the quantity of yarn required to produce a given length of fabric and also helped in calculating the fabric cost.

4.3 Selected fibers

After testing the nine different woven fabric samples collected from different hospitals, it was found that cotton was the prime fiber used for making the protective and healthcare textiles. **Lewin (2007)** stated that fabrics developed from cotton fiber combined durability with attractive wearing qualities and comfort. Cotton can withstand repeated washings and is ideal for garments that must be laundered often.

Like a house, a hospital contains an immense amount of textiles with the added threat of high numbers people coming to the hospital. All textiles provide a growing environment to microbes. Infact, natural fibers such as cotton and wool are especially susceptible to microbial growth and even dust mites because they retain oxygen, water, and nutrients. In hospitals, both patient and employees are at risk for cross-transmission of diseases and other health issues **(Bonin, 2008)**. So, alone cotton is not sufficient to protect the patient and employees of hospitals from microbes.

Now a day's antimicrobial and eco-friendly fibers/fabrics are gradually gaining importance due to environmentalist's movement throughout the world. So while selecting the fibers for present study, the above stated points were kept in mind and two eco-friendly fibers cotton and bamboo were selected. Besides cotton, the selection of bamboo fiber was done because of excellent permeability, soft and comfortable feel, fine luster and special antibacterial and bio-degradable properties which made it an ideal raw material for making protective and healthcare textiles.

Cotton was easily available in India at reasonable prices (Rs. 60/kg) whereas bamboo fiber was imported from China at Rs. 210/kg, which made it slightly costlier than cotton. Thus in view of adding anti-microbial property in cotton and bringing down the cost of the final product, bamboo and cotton fibers were blended together for the preparation of protective and healthcare textiles. In this way scope for a natural anti-bacterial and biodegradable textiles, can be broaden through blending, spinning and weaving which in turn will ensure the availability of these textiles to every hospitals at affordable rates.

4.4 Evaluation of physical properties of fibers

In the present study, the physical properties of selected fibers were evaluated to find out their suitability for medical textiles. Selected fibers were tested in terms of length (cm), fineness (denier), strength (gm/denier), elongation (%), diameter (micron), crimp (no./cm), microscopic appearance and whiteness index, using standard test procedures. The comparable physical properties of experimental fibers are presented in Table 4.13.

Table: 4.13 Physical properties of selected fibers

S. No.	Properties	Cotton Fiber	Bamboo Fiber
1	Fiber length (cm)	2.8	3.8
2	Fiber crimp (no./cm)	3.0	4.0
3	Dry fineness (Denier)	1.56	1.46
4	Wet fineness (Denier)	1.54	1.63
5	Dry tenacity (gm/denier)	2.23	2.64
6	Wet tenacity (gm/denier)	3.64	2.48
7	Dry elongation (%)	7.40	24.20
8	Wet elongation (%)	9.12	23.34
9	Diameter (micron)	15.31	13.32
10	Whiteness index (WI)	25.8	23.5
	L value	83.3	84.0
	A value	-0.9	-1.2
	B value	9.2	9.8

4.4.1 Fiber length

The length of the fiber is of fundamental importance, giving rise to the expression "the longer the fiber, the stronger the yarn", and if the fibers are long enough, there will be a fewer ends protruding from the surface of the twisted yarn which results in smooth surfaced fabric. As the shorter ends of the fibers protruded out from the surface of fabric attracts dirt particles, entangled with each other and forms pill on the surface of fabric, creating discomfort when worn next to the skin.

It is evident from Table 4.13 that mean length of cotton fiber was 2.8 cm and bamboo fiber was 3.8 cm which was in accordance with **Chellamani[1] *et al.* (2006),** who had reported the length of cotton and bamboo fiber as 2.83 cm and 3.8 cm respectively. Bamboo fiber was available in cut staple length. The result of length of both the fibers was somewhat same, which was found as an advantage during blending, processing and spinning of quality yarn.

4.4.2 Fiber crimp

Number of crimps/cm in cotton fiber was found 3.0 whereas in bamboo fiber it was 4.0. After testing, very slight difference in crimps/cm was found among both the fibers. **Cook[2] (2005)** stated that fibers having 1.5 denier may have 5 crimps per cm. Fiber with higher crimp value provide better cohesion during processing of fiber, especially for formation of web during carding and spinning operation **(Debnath, 1975)**. **Gupta (1992)** has also stated that fiber crimp could be beneficial in reducing fiber breakage during carding.

4.4.3 Fiber fineness, strength and elongation

Dry and wet fineness of cotton fiber was observed as 1.56 and 1.54 denier respectively whereas the dry and wet fineness of bamboo fiber was reported as 1.46 and 1.63 denier respectively. The results of the present study indicated that both cotton and bamboo fibers are comparable in their fineness. Therefore, the fineness of both the fibers can be utilized as an advantage in proper blending of fibers and to prepare good quality protective and healthcare textiles. According to **NIIR report (2006)**, fiber fineness can contribute the extent of 80% product performance.

Besides fineness, the selected fibers were also checked for both dry and wet strength because the strength of the fiber alters when wet thus affects the fabric properties. It is evident from the Table 4.13 that the dry and wet tenacity of the cotton fiber was 2.23 and 3.64 gm/denier respectively. According to **Tortora (1982)**, the tensile strength of the cotton fiber ranges from 3 to 5 gm/denier and its strength increased by 10 to 30% in wet conditions because after absorbing water, fiber swell and collapsed ribbon-like structure assumes a tube-like structure, like a hose pipe. The dry and wet tenacity of bamboo fiber was 2.64 and 2.48 gm/denier respectively. According to **Saravanan and Prakash (2007),** the dry and wet tensile strength of the bamboo fiber was 2.33 and 1.37 CN/dtex respectively. Tenacity value of both the fiber clearly indicates that the bamboo fiber had slightly high strength than cotton fiber in dry state whereas the strength of cotton was increased than bamboo fiber in a wet condition. **Lewin (2007)** stated that an accurate knowledge of the tensile behavior of textile fibers is essential to select the proper fiber for specified end-use applications. Cotton is the only significant textile fiber whose strength increases with humidity while most others are weakened by increased moisture.

Sometimes, tenacity alone is not sufficient to form an opinion about the strength of the fiber. The fiber should also have good elasticity so as to enable it to withstand sudden impacts and not to break easily when bent or pulled. Therefore, it is important to measure elongation percent at break along with tenacity value. The values for cotton fiber elongation in dry and wet state were observed as 7.40% and 9.12% respectively (Table 4.15). **Lewin (2007)** stated that elongation at break for most cotton fiber ranges from 6-9%. An elongation of about 5% at low humidity will increase to about 10% when the relative humidity is almost at the saturation point.

In case of the bamboo fiber, the values for fiber elongation in dry and wet state were observed as 24.20% and 23.34% respectively. According to **Saravanan and Prakash (2007)**, the dry elongation at break of the bamboo fiber was 23.8%. The results obtained for experimental fibers were in close proximity to the data presented by **Chellamani[1] *et al.* (2006)**. According to them, the values for the fineness, strength and elongation of the 38 mm long bamboo fiber were 1.5 denier, 2.5 gm/denier and 22.0% respectively whereas the elongation of 28.3 mm long cotton fiber was around 5.8%. The values of cotton fiber fineness and its single fiber strength were not presented by them. It was observed from the data that cotton fibers have low elongation with high tenacity whereas bamboo fiber has high elongation with slightly lower wet tenacity than cotton fiber. The results of present investigation showed that strength of bamboo fiber was declined in wet conditions therefore proper care must be taken during wet treatment of this fiber. Blending bamboo fiber with cotton fiber is a good option for increasing its strength as higher strength of the fiber translates into stronger yarn and fabric; and plays an important role in subsequent processing. Thus, a garment made with fibers having good strength demonstrates good stability when washed.

4.4.4 Fiber diameter

A slight variation in the diameter of cotton and bamboo fiber was observed. It was noticed that the diameter of cotton and bamboo fiber was 15.31 micron and 13.32 micron respectively (Table 4.13). **Sharma and Goel (2007)** stated that fiber diameter plays an important role in determining the performance and hand of the fabric. Coarse fiber gives roughness, stiffness and body to the fabric whereas fine fibers give softness and pliability to the fabric.

In general, small diameters are relatively used for clothing fibers. Cotton fiber diameter usually ranges between 12 to 30 microns in width **(Tortora, 1982)**.

4.4.5 Fiber identification

4.4.5.1 Burning test

It was found that both cotton and bamboo fiber respectively ignited very readily when approached to flame, burnt quickly with yellow flame, continued to burn rapidly even after removed from flame. Both fibers were having a characteristic burning paper odor and small, fluffy, soft grey ash at the end. This might be due to the fact that both are celulosic fibers and are highly flammable. Therefore, these fibers should not be used in close proximity to flame.

4.4.5.2 Microscopic view

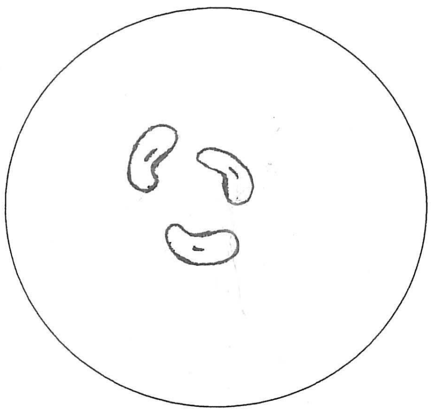
Knowledge of fiber structure obtained by observing the fibers under microscope and noticing its characteristics are helpful in understanding the fiber and fabric behavior. Cross-sectional and longitudinal views of cotton and bamboo fibers are presented in Plate 4.1.

In case of cotton fiber cross-sectional view appeared as bean shaped with lumen in the centre. **Cook[1] (2005)** stated that cotton appears as a bean or ear shaped, like a collapsed tube when viewed cross-sectionally. The cross-sectional view of the bamboo fiber was irregular with serrated edges and micro holes present in between. **Subrata (2008)** stated that the cross section of the bamboo fiber is filled with micro-gaps and micro-holes which help in moisture absorption and ventilation.

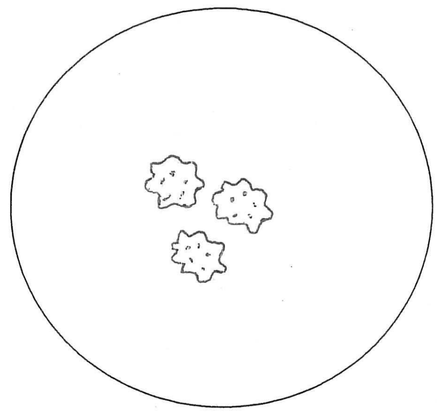
The cotton fiber looked like spirally twisted tube when viewed longitudinally under microscope whereas lengthwise striations were

Plate 4.1 Microscopic views of the selected fibers

Cross-Sectional View of Cotton and Bamboo Fibers



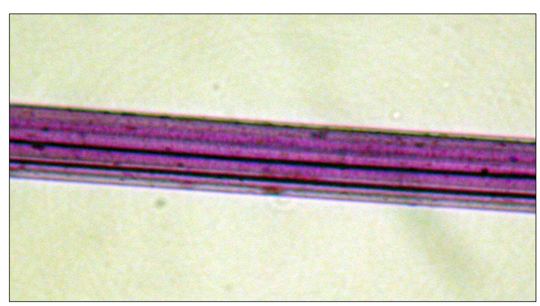
COTTON FIBER



BAMBOO FIBER

Longitudinal View of Cotton and Bamboo Fibers

COTTON FIBER



BAMBOO FIBER

found in case of bamboo fiber. **Corbman (1983)** stated that cotton appears as a flat, twisted ribbon-like when viewed longitudinally.

4.4.6 Whiteness index

The values of L, a, b and Whiteness index of selected fibers are shown in Table 4.13. The L value of cotton and bamboo fibers was 83.3 and 84.0 respectively. **Tortora (1982)** stated that cotton fiber is generally white to yellowish in color. The value of 'a' was -0.9 for cotton fiber and -1.2 for bamboo fiber. Negative value of "a" of both the fibers showed greenish effect present in them. The value of 'b' was 9.2 for cotton fiber and 9.8 for bamboo fiber. Almost same positive values of 'b' were found in both cotton and bamboo fibers which showed the presence of yellowish effect in both the fibers. Above all, the whiteness index was high in cotton i.e. 25.8 than bamboo i.e. 23.5 which showed that cotton was whiter than bamboo fiber.

4.5 Evaluation of chemical properties of fibers

Knowledge of chemical properties of textile fibers is of immense importance because textiles are made up from fibers which are constituted of carbon, hydrogen, oxygen, nitrogen, in few cases sulphur also, in different combinations; as a result fibers behave differently with different substances. Besides that, textiles are subjected to treatment with water, soaps, detergents, solvents, as well as chemicals which are alkaline, acidic, oxidizing or reducing in nature, and or with heat and so many other agents which are chemical in nature, in their use and care. Therefore, behaviour or reaction of textiles to these agents is important for application of finishes as well as to the consumers.

4.5.1 Chemical constituents of cotton and bamboo fibers

The cotton and bamboo fiber samples were analyzed for cellulose content (%), ash content (%), fat content (%), nitrogen content (%), crude protein (%), moisture content (%), moisture regain (%) and pH. Results of chemical constituents of cotton and bamboo fibers are shown in Table 4.14.

Table: 4.14 Chemical constituents of selected fibers

Chemical composition	Fibers	
	Cotton	Bamboo
Cellulose content (%)	95.5	79.55
Ash content (%)	1.35	0.31
Fat content (%)	1.14	0.26
Nitrogen content (%)	0.47	0.11
Crude protein (%)	2.9	0.7
Moisture content (%)	4.69	8.33
Moisture regain (%)	4.93	9.09
pH	6.79	7.01

4.5.1.1 Cellulose content

The cellulose content of cotton and bamboo fibers was reported as 95.5% and 79.5% respectively. The percentage value of cellulose content observed for cotton and bamboo fibers are in close proximity with the value as observed by **Rowel (2000)** who has reported the cellulose content of cotton and bamboo fibers as 85-96% and 26-43% respectively. According to **Shenai (1991)**, the amount of cellulose content for cotton fiber is 94.0% which showed that most part of cotton fiber is made up of cellulose molecules. The cellulose content of the bamboo fiber was less than cotton fiber and this might be happened because of the breaking down of the cellulose molecule during ageing and ripening processes.

4.5.1.2 Ash content

The ash content of cotton and bamboo fibers was reported as 1.35% and 0.31% respectively. **Fan (2005)** stated that the amount of ash for cotton fiber is about 1-1.5%.

4.5.1.3 Fat content

Fat content of the cotton fiber was found 1.14% whereas fat content of bamboo fiber was 0.26%. **Fan (2005)** stated that a small amount of fatty material, which is mostly cottonseed oil, is found in cotton. This probably comes from cotton seeds that are slightly damaged during ginning.

4.5.1.4 Nitrogen content and crude protein

The average value of the nitrogen content present in cotton and bamboo fibers was 0.47 % and 0.11 % respectively**.** The average value of the crude protein present in cotton and bamboo fiber, which was calculated on the basis of percent nitrogen in the respective fiber, was 2.9% and 0.7% respectively.

According to **Sadov *et al.* (1973),** the nitrogen content in cotton varies from 0.2 to 0.44 per cent depending on the origin of the cotton. **Fan (2005)** stated that a small amount of vegetable protein is present in cotton and the value of protein present in mature cotton fiber is 1% whereas in immature cotton it is 2%.

4.5.1.6 Moisture content and moisture regain

Moisture content of cotton fiber was recorded as 4.69% whereas for bamboo fiber it was recorded as 8.33%. The average value of moisture regain for cotton and bamboo fiber was 4.93% and 9.09% respectively. It is clear from the data that moisture content and moisture regain of bamboo fiber was higher than cotton fiber. It was happened during the manufacturing of bamboo fiber where natural cellulose fibers were dissolved, resulting in some depolymerization and reduced crystallinity of the cellulose molecule. According to **Tortora (1982)**, the moisture regain of cotton fiber is around 7%. **Saravanan and Prakash (2007)** stated that the moisture regain of the bamboo fiber is around 13.03%.

According **NIIR report (2006)** moisture uptake from the atmosphere is believed to take place in amorphous region by means of hydrogen bonding between molecules of water and the hydroxyl group in the cellulose. When water molecule enters in this amorphous region, the individual cellulose molecules are pushed farther apart from each other and as a result fiber gets swell when wet. According to **Grover and Hamby (1988),** fibers that permits some moisture absorption are comfortable to wear and less likely to build up static electricity. It is clear from the data that both fibers have good absorbency, ultimately provide absorbent fabrics, which provide comfort to the patients/doctors during use.

4.5.1.7 pH

It is evident from the data that pH value of cotton (6.79) is less than pH value of bamboo fiber (7.01). Results showed that the solution obtained from cotton has acidic pH which is an indication of an excess amount of hydronium ions present in aqueous extract collected from cotton fiber sample whereas bamboo fiber have basic pH which is an indication of excess amount of hydroxide ions present in aqueous extract collected from bamboo fiber sample **(Fan, 2005)**. It is clear from the data that both the fibers were neither highly acidic nor highly basic in nature as the pH of both the fibers fall around pH 7 and at this point it is called as neutral pH.

4.5.2 Effect of chemical reagents

An attempt had been made in the present study; to study the effect of various chemical reagents and textile solvents on cotton and bamboo fibers. Both fibers were treated with different chemicals at room temperature as well as at boiling temperature and their solubility was checked and noticed. The results of effect of the chemical reagents on fibers are presented in Table 4.15 (a), Table 4.15 (b), Table 4.15 (c) and Table 4.15 (d).

4.5.2.1 Acids

The effects of different acids on cotton and bamboo fibers are presented in Table 4.15 (a). It is clear from the data that cotton fiber remained unaffected with dilute sulphuric acid and nitric acid (2%) at room temperature but slight swelling of cotton fiber was observed on heating. In case of bamboo fiber, dilute sulphuric acid and nitric acid (at room temperature) caused slight disintegration after two minutes whereas it dissolved partially on heating after ten minutes.

Concentrated (98%) sulphuric acid caused slight swelling in cotton fiber at room temperature whereas on heating cotton fiber dissolved completely within two minutes. In the case of bamboo fibers, fiber dissolved completely in concentrated (98%) sulphuric acid only at its room temperature. **Mauersberger (1954)** has also stated that concentrated sulphuric acid dissolved the cotton and regenerated cellulosic fibers.

Table: 4.15 (a) Effect of different acids on selected fibers

Acids	Fibers	Observations	
		Solubility at room temperature	**Solubility at boiling temperature**
Dilute Sulphuric acid (2%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Showed slight disintegration	Dissolved partially
Concentrated Sulphuric acid (98%)	Cotton	Swelled slightly	Dissolved completely
	Bamboo	Dissolved immediately	-
Dilute Nitric acid (2%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Showed slight disintegration	Dissolved partially
Concentrated Nitric acid (69-70%)	Cotton	Swelled slightly	Dissolved completely
	Bamboo	Showed slight disintegration	Dissolved completely
Hydrochloric acid (35-38%)	Cotton	Swelled slightly	Dissolved partially
	Bamboo	Showed slight disintegration	Dissolved completely
Formic acid (98-100%)	Cotton	Swelled completely but remain insoluble	No further change on heating
	Bamboo	Swelled completely but remain insoluble	No further change on heating
Acetic acid	Cotton	Swelled slightly	No further change on heating
	Bamboo	Swelled slightly	No further change on heating
Oxalic acid (20%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Swelled completely but remain insoluble	No further change on heating
Oxalic acid (80%)	Cotton	Swelled slightly	Swelled completely but remain insoluble
	Bamboo	Swelled completely but remain insoluble	No further change on heating

Concentrated (69-70%) nitric acid caused slight swelling in cotton fiber at room temperature whereas on heating, cotton fiber dissolved completely within two minutes. In the case of bamboo fiber, fiber showed slight disintegration after two minutes at room temperature whereas on heating the fiber got dissolved within two minutes.

Treatment with hydrochloric acid (35-38%) caused slight swelling of cotton fiber at room temperature and on heating cotton fiber dissolved partially whereas bamboo fiber showed slight disintegration after two minutes with hydrochloric acid (35-38%) at room temperature and on heating the fiber got dissolved within five minutes.

Sadov *et al.* (1973) stated that the degradation of cellulosic fibers by acids consists of the hydrolysis of the glycosidic linkages. According to **Tortora (1982)**, cellulosic fibers are damaged by strong mineral acids such as sulphuric acid, hydrochloric and nitric acid, etc. and are harmed by diluted concentrations of these substances also, if allowed to dry on them.

Treatment with formic acid (98-100%) caused swelling of both the fibers i.e. cotton and bamboo fibers at room temperature but the fibers remained insoluble and no further change was observed in cotton and bamboo fibers on heating (Table 4.15 a).

It is evident from the data that cotton and bamboo fibers both swelled slightly at room temperature when treated with acetic acid whereas on heating no further change was observed in both the fibers.

Cotton fiber remained unaffected by the action of oxalic acid (20%) at room temperature but slight swelling of cotton fiber was observed on heating whereas oxalic acid (20%) at room temperature caused complete swelling without solublization of bamboo fiber but no further change was observed on heating in the case of bamboo fiber.

At room temperature, slight swelling was observed after 5 minutes in cotton by oxalic acid (80%) whereas on heating cotton fiber swelled. In the case of bamboo fiber, fiber swelled at room temperature but remained insoluble whereas on heating no further change was observed.

Corbman (1983) stated that cotton is not damaged by volatile organic acids such as formic acids and acetic acids whereas it is tendered by nonvolatile organic acids such as oxalic acid.

4.5.2.2 Alkalies

The effects of different alkalies on cotton and bamboo fibers are presented in Table 4.15 (b). Cotton and bamboo fibers both remained unaffected with sodium hydroxide and sodium carbonate (20% and 80%) at room temperature whereas slight swelling was observed after five minutes on heating in the case of both fibers i.e. cotton and bamboo fibers respectively. This might be due to the high resistance of glycosidic linkage of the cellulose molecule to alkalies **(Sadov *et al.*, 1973)**.

Table: 4.15 (b) Effect of different alkalies on selected fibers

Alkalies	Fibers	Observations	
		Solubility at room temperature	Solubility at boiling temperature
Sodium hydroxide (20%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Unaffected	Swelled slightly
Sodium hydroxide (80%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Unaffected	Swelled slightly
Sodium carbonate (20%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Unaffected	Swelled slightly
Sodium carbonate (80%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Unaffected	Swelled slightly
Borax (20%)	Cotton	Shrunk but remain insoluble	Swelled completely but remain insoluble
	Bamboo	Swelled completely but remain insoluble	Swelled completely with slight disintegration
Borax (80%)	Cotton	Shrunk but remain insoluble	Swelled completely but remain insoluble
	Bamboo	Swelled completely but remain insoluble	Swelled completely with slight disintegration

It was observed that cotton fiber shrunk but remained insoluble whereas bamboo fiber swelled completely but remain insoluble at room temperature with borax (20% and 80%). On heating, cotton fiber swelled but remained insoluble whereas bamboo fiber swelled and showed slight disintegration after five minutes on heating with borax (20% and 80%). A mild soap and luke warm water is therefore recommended while laundering garments made from cotton-bamboo blends.

Cook[1] (2005) and **Tortora (1982)** stated that cotton has an excellent resistance to alkalies. It swells in sodium hydroxide but not damaged whereas weak alkalies such as borax and soap also have no harmful effect on cotton. It can be washed repeatedly in soap solutions without any harm.

4.5.2.3 Oxidizing bleaching agents

The effects of different oxidizing bleaching agents on cotton and bamboo fibers are presented in Table 4.15 (c). Cotton fiber remained unaffected with hydrogen peroxide (30%) at room temperature but slight swelling of fiber was observed after five minutes on heating. In the case of bamboo fiber, fiber swelled completely but remained insoluble with hydrogen peroxide (30%) at room temperature whereas on heating no further change was observed in the fiber.

Table: 4.15 (c) Effect of oxidizing bleaching agents on selected fibers

Oxidizing bleaching agents	Fibers	Observations	
		Solubility at room temperature	Solubility at boiling temperature
Hydrogen peroxide (30%)	Cotton	Unaffected	Swelled slightly
	Bamboo	Swelled completely but remain insoluble	No further change on heating
Sodium hypochlorite (4%)	Cotton	Unaffected	Dissolved completely
	Bamboo	Swelled completely but remain insoluble	Dissolved completely

It is apparent from observations that cotton fiber remained unaffected with sodium hypochlorite (4%) at room temperature whereas bamboo fiber swelled completely but remained insoluble. As **Corbman (1983)** also stated that all types of oxidizing bleaches such as hydrogen peroxide, sodium hypochlorite and sodium perborate, etc. can safely be used on cellulosic fibers. But in the present study, it was observed that on heating both cotton and bamboo fibers dissolved completely after 5 minutes with sodium hypochlorite (4%) solution. It is clear from data that 4% sodium hypochlorite harmed both the fibers on heating. Therefore, either lesser conc. sodium hypochlorite must be used i.e. 1%, 2% etc. or used sodium hypochlorite only at room temperature for bleaching. Care must be taken about the amount of bleach used as well as the temperature of the water to avoid degradation and yellowing of cellulosic fibers.

4.5.2.4 Other solvents

Affect of different other solvents on cotton and bamboo fibers are presented in Table 4.15 (d). Both cotton and bamboo fibers remained unaffected with acetone and spirit at room temperature as well as on heating. Both the fibers remained unaffected with phenol at room temperature whereas on heating slight swelling in cotton fibers and complete swelling in bamboo fibers were observed. It was found that only slight swelling of cotton and bamboo fibers after five minutes was observed with meta cresol, di-methyl formamide, carbon tetrachloride and ammonia solution (30%) at room temperature. Cotton as well as bamboo fibers swelled completely but remained insoluble with di-methyl formamide, carbon tetrachloride and ammonia solution (30%) except meta cresol which dissolved both the fibers after ten minutes on heating.

Table: 4.17 (d) Effect of different other solvents on selected fibers

Other solvents	Fibers	Observations	
		Solubility at room temperature	**Solubility at boiling temperature**
Acetone	Cotton	Unaffected	Unaffected
	Bamboo	Unaffected	Unaffected
Phenol	Cotton	Unaffected	Swelled slightly
	Bamboo	Unaffected	Swelled completely but remain insoluble
Meta cresol	Cotton	Swelled slightly	Dissolved partially after 10 min.
	Bamboo	Swelled slightly	Dissolved partially after 10 min.
di-methyl formamide	Cotton	Swelled slightly	Swelled completely but remain insoluble
	Bamboo	Swelled slightly	Swelled completely but remain insoluble
Spirit	Cotton	Unaffected	Unaffected
	Bamboo	Unaffected	Unaffected
Carbon tetrachloride	Cotton	Swelled slightly	Swelled completely but remain insoluble
	Bamboo	Swelled slightly	Swelled completely but remain insoluble
Ammonia Solution (30%)	Cotton	Swelled slightly	Swelled completely but remain insoluble
	Bamboo	Swelled slightly	Swelled completely but remain insoluble

According to **Vatsala (2003)**, cellulosic and regenerated cellulosic fibers are highly resistant to most of the organic solvents like, petrol, carbon tetrachloride, benzene etc. These can be safely used for removal of stains and for dry cleaning. According to **Lewin (2007)**, ammonia is used as cellulose solvent and causes only swelling of the cellulose molecule.

4.5.3 Colour reactions

The results of different colour reagents on cotton and bamboo fibers are given in Table 4.16.

Table: 4.16 Colour reactions of selected fibers

S. No.	Colour Reagents	Colour Obtained	
		Cotton fiber	Bamboo fiber
1.	Iodine and sulphuric acid reagent	Light yellow	Light turquoise green
2.	Zinc-chloride-iodine reagent	Yellow	Blackish grey
3.	Malachite green	Turquoise green	Turquoise green
4.	Methylene blue	Blue	Blue

Both experimental fibers responded differently to above stated color reagents. It is clear from the Table 4.16 that with iodine and sulphuric acid reagent, cotton fiber acquired light yellow colour whereas bamboo fiber turned light turquoise green colour. It was observed that with zinc-chloride-iodine reagent cotton fiber became yellow whereas bamboo fiber turned blackish grey. It was observed that both cotton and bamboo fiber obtained turquoise green colour with malachite green reagent whereas both cotton and bamboo fiber obtained blue colour with methylene blue colour reagent. Findings of all these results of colour reaction can be used as identification of these fibers as well as for differentiation of cotton from bamboo in a blended item. The similar observation of colour reaction had been reported by **Mauersberger (1954)**.

4.6 Processing of fibers and preparation of pure and blended yarns

The present study explains the possibilities of producing cotton-bamboo fiber blended yarns through ring spinning system working on economical production speed.

Processing of fibers for preparing pure and blended 2-ply warp and single ply weft yarns was done by weighing and processing cotton and bamboo fibers in five different ratios i.e., 100:0, 70:30, 50:50, 30:70 and 0:100. Different steps including conditioning of fiber, fiber opening, blending, carding, ring spinning, winding and doubling were used for preparation of pure and blended warp and weft yarns. The pure and blended 2-ply warp and single ply weft yarns were prepared on the basis of the data obtained by evaluation of the different yarn properties of the nine different woven fabric samples collected from different hospitals. The technical parameters used for spinning of yarns are given in Table 3.4 (Chapter 3- Materials and Methods).

The ultimate aim of spinning is to produce the even yarn of required count which possesses tensile properties with minimum number of faults. When fibers were twisted together into yarn the twist provided the force that held the individual fibers together. Finer the fiber, fine yarn could be spun from it. Pure and blended cotton-bamboo warp and weft yarn samples prepared for the present study are shown in Sample sheet no. 4.1.

4.7 Evaluation of physical properties of yarns

Yarn occupies the intermediate position in the manufacture of fabric from raw material. Yarn testing is therefore very important, both for estimating the quality of raw material and for controlling the quality of fabric produced. The results of the important characteristic of yarn being tested i.e. yarn count, twist direction, twist per inch, yarn unevenness, yarn imperfection, yarn hairiness, yarn strength, elongation percent at break are presented in Table 4.17. The detailed ANOVA tables for different yarn testing properties are given in *Appendix VIII.*

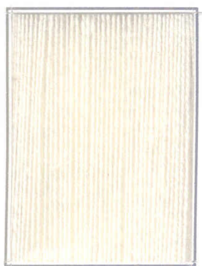
4.7.1 Yarn count

The yarn counts of pure and blended yarns were kept constant while spinning. Warp yarns (2-ply) of 2/20s Ne and single ply weft

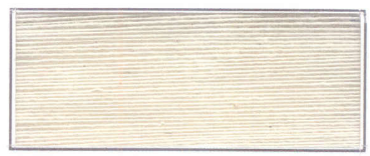
PURE AND BLENDED COTTON-BAMBOO YARN SAMPLES

2-ply warp yarns | **Single ply weft yarns**

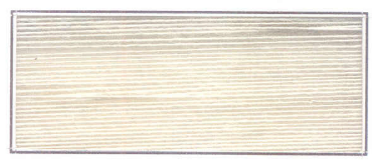
100:0
Cotton:Bamboo

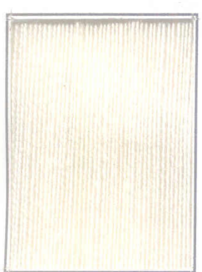


70:30
Cotton:Bamboo

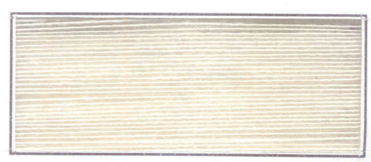


50:50
Cotton:Bamboo





30:70
Cotton:Bamboo



0:100
Cotton:Bamboo

Table 4.17 Yarn properties of the pure and blended cotton-bamboo fiber ring spun yarns

S. No.	Yarn Properties		Yarn Samples									
			Warp yarns (Cotton:Bamboo)					Weft yarns (Cotton:Bamboo)				
			100:0	70:30	50:50	30:70	0:100	100:0	70:30	50:50	30:70	0:100
1	Yarn count	Single ply	20.00	21.39	21.43	21.66	20.08	9.88	10.70	10.77	10.82	10.48
		2-ply	10.00	10.72	10.78	10.80	10.28	-	-	-	-	-
2	Twist direction	2-ply	S	S	S	S	S	-	-	-	-	-
		Single ply	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
3	Twist per inch	2-ply	13.7	14.6	14.5	15.1	13.9					
		Single ply	18.1	18.8	18.6	18.9	18.3	13.28	13.28	13.28	13.28	13.28
4	Yarn unevenness (U %)		13.05	12.18	11.87	12.25	12.34	13.23	12.28	14.03	12.17	11.36
5	Yarn imperfections/km	Thin places/km (-50%)	18	8	3	0	0	13	8	3	3	0
		Thick places/km (+ 50%)	288	260	237	148	120	283	230	225	218	100
		Neps/km (+ 200%)	48	80	96	104	108	102	101	96	65	88
	Total		354	348	336	252	228	398	339	324	286	188
6	Yarn hairiness/km		10.40	10.39	10.37	10.23	9.38	7.19	6.88	6.80	6.01	6.01
7	Yarn strength (gm/denier)		1.383	1.083	0.844	0.875	0.898	1.037	0.960	0.681	0.782	0.642
8	Elongation at break (%)		5.43	6.09	6.29	8.29	14.10	4.97	5.69	5.95	8.63	14.62

yarns of 10s Ne were prepared. Negligible difference was observed in yarn counts among all pure and blended warp and weft yarns after testing, which might be due to the difference in fiber fineness (Table 4.17).

According to **Saville (2004)**, the finer the fiber, the finer is the yarn that can be spun from it. **Basu (2001)** stated that yarn count governs the appearance and behavior of the fabric. Fine yarn produces fine and smooth fabric.

4.7.2 Twist direction

It is apparent from the Table 4.17 that twist direction was in accordance with the twist direction set at the time of spinning i.e. Z twist for single yarns and S twist for 2-ply yarns. **Goswami *et al.* (1977)** also stated that single yarns are generally twisted in Z or anticlockwise direction, whereas the S or right handed twist is very common in plied yarns.

4.7.3 Twist per Inch (TPI)

Pure and blended 2-ply warp yarns of 2/20s count were made by plying and twisting of two single yarns of 20s count. Twist per inch i.e. 16.5 TPI for single ply warp yarns, 13.20 TPI for 2-ply warp yarns and 11.5 TPI for single ply weft yarns were kept constant for all blend ratios of cotton and bamboo. Negligible difference was observed in twist per inch among all pure and blended warp and weft yarns after testing (Table 4.17).

Sardag and Kalaoglu (2006) observed that 2-ply yarns are more regular, because the longitudinal variations in the individual ends are balanced and the spot defects are compensated. They have higher strength, elongation and abrasion resistance when compared with their singles.

4.7.4 Yarn unevenness, imperfection and hairiness

The pure and blended warp and weft yarns of cotton and bamboo fibers were tested for their unevenness. It is clear from the Table 4.17 that the average value of unevenness in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended 2-ply warp yarns were 13.05, 12.18, 11.87, 12.25 and 12.34% whereas for single ply weft yarns it was found as 13.23, 12.28, 14.03, 12.17 and 11.36% respectively. Slight unevenness was found which was more or less same for all pure and blended cotton-bamboo 2-ply warp yarns and single ply weft yarns.

Imperfections for all pure and blended yarns was the sum of thick place/km (+50%), thin place/km (-50%) places and number of neps/km (+200%). It is clear from the Table 4.17 (Fig. 4.1) that the average value of thin places in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended 2-ply warp yarns were 18/km, 8/km, 3/km, 0/km and 0/km respectively, for thick places it was observed as 288/km, 260/km, 237/km, 148/km, 120/km respectively whereas the neps were 48/km, 80/km, 96/km, 104/km and

108/km respectively. Therefore, the total imperfection/km in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended 2-ply warp yarns were 354/km, 348/km, 336/km, 252/km and 228/km respectively.

It is clear from the Table 4.17 (Fig. 4.1) that the average value of thin places in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended single ply weft yarns were 13/km, 8/km, 3/km, 3/km and 0/km respectively, for thick places it was observed as 283/km, 230/km, 225/km, 218/km, 100/km respectively whereas the neps were 102/km, 101/km, 96/km, 65/km and 88/km respectively. Therefore, the total imperfection/km in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended single ply weft yarns were 398/km, 339/km, 324/km, 286/km and 188/km respectively.

Statistically, significant difference was observed among the means all pure and blended cotton-bamboo 2-ply warp and single ply weft yarn samples for imperfections/km, with 1.95 CD value for 2-ply warp yarns *(Appendix VIII, a)* and 1.92 CD value for single ply weft yarns respectively *(Appendix VIII, b)* at 5% level of significance.

The above stated result shows that yarn imperfections decreased significantly with the increased percentage of bamboo in blends. Yarn imperfections in warp and weft yarns respectively were found maximum in 100:0 cotton-bamboo followed by 70:30, 50:50, 30:70 and 0:100.

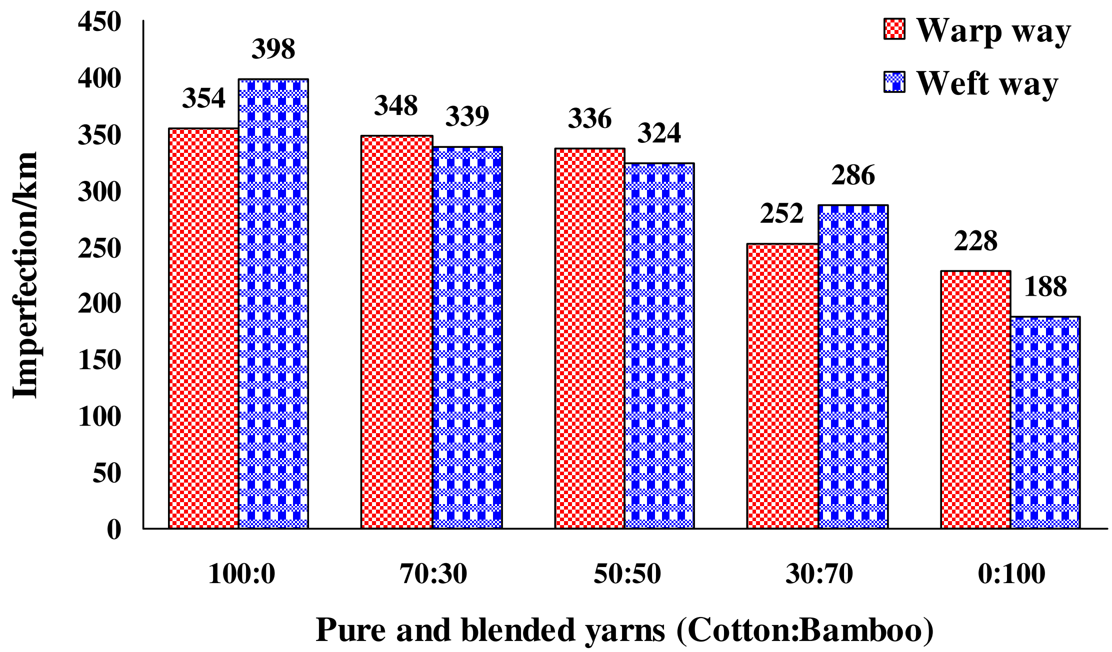


Fig. 4.1 Imperfections of pure and blended yarns

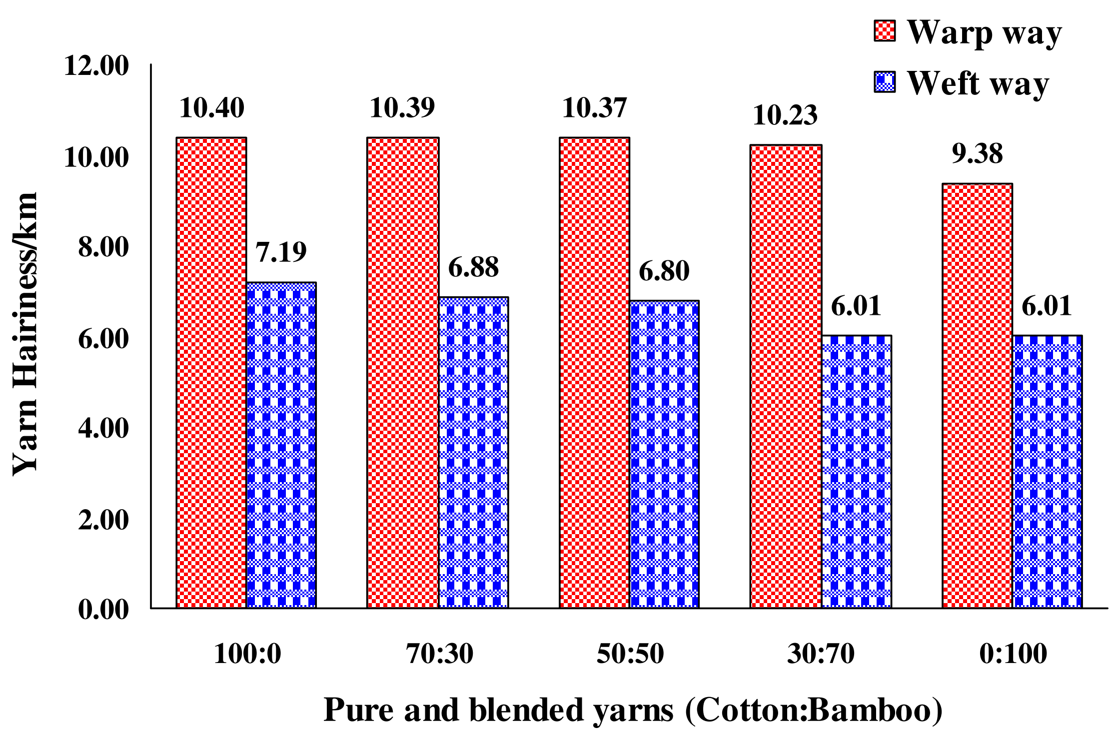


Fig. 4.2 Hairiness of pure and blended yarns

It is evident from the Table 4.17 (Fig. 4.2) that the average value of hairiness/km in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended 2-ply warp yarns were 10.40/km, 10.39/km, 10.37/km, 10.23/km and 9.38/km respectively. Significant difference was observed among the means of 2-ply warp yarn samples. However, non-significant difference was observed among the means of 100:0 and 70:30; and 70:30 and 50:50 cotton-bamboo 2-ply warp yarns samples. The value of CD for pure and blended 2-ply warp yarns at 5% level of significance for hairiness/km was 0.02 *(Appendix VIII, c)*.

The average value of hairiness/km in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended single ply weft yarns were 7.19/km, 6.88/km, 6.80/km, 6.01/km and 6.01/km respectively. Significant difference was observed among the means of single ply weft yarn samples. However, non-significant difference was observed among the means of 70:30 and 50:50; and 30:70 and 0:100 cotton-bamboo 2-ply warp yarns samples. The value of CD for pure and blended single ply weft yarns at 5% level of significance for hairiness/km was 0.09 *(Appendix VIII, d)*. It was observed that in 2-ply warp and single ply weft yarns, the number of hairs was found to be decreased significantly with the increased percentage of bamboo in the blends. **Chauhan (2009)** stated that yarn count and twist have considerable influence on hairiness. Hairiness reduces with increase in twist per inch. Higher the twist per inch, lesser will be the amount of hairs present on the surface of the yarns.

4.7.5 Yarn strength and elongation

It is evident from Table 4.17 (Fig.4.3) that in 2-ply warp yarn samples, yarn strength varies from 1.383 to 0.898 gm/denier for 100:0 and 0:100 cotton-bamboo blended 2-ply warp yarns. It was 1.083 for 70:30, 0.844 for 50:50 and 0.875 gm/denier for 30:70 cotton-bamboo blended 2-ply warp yarns. In single ply weft yarn samples, yarn strength varies from 1.037 to 0.642 gm/denier for 100:0 and 0:100 cotton-bamboo blended single ply weft yarns. It was 0.960 for 70:30, 0.681 for 50:50 and 0.782 gm/denier for 30:70 cotton-bamboo blended single ply weft yarns.

Statistically, significant difference was observed among the means all pure and blended cotton-bamboo 2-ply warp and single ply weft yarn samples for yarn strength, with 0.001 CD value for 2-ply warp yarns *(Appendix VIII, e)* and 0.003 CD value for single ply weft yarns respectively *(Appendix VIII, f)* at 5% level of significance.

According to **Nijhawan and Nijhawan (2007)**, the yarn derives its strength from the strength of fibers. Therefore the limiting tenacity of the yarn will be equal to the tenacity of fiber from which the yarn is spun. It is significant to realize that the other fiber properties like length and fineness are only helpful in the transfer of

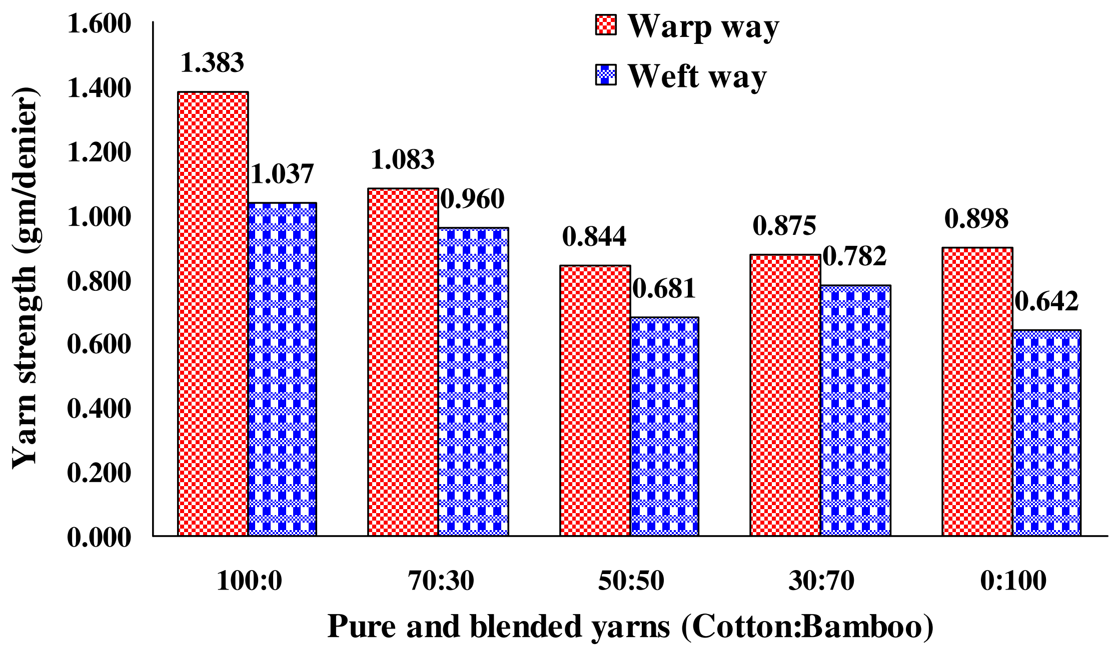


Fig. 4.3 Breaking strength of pure and blended yarns

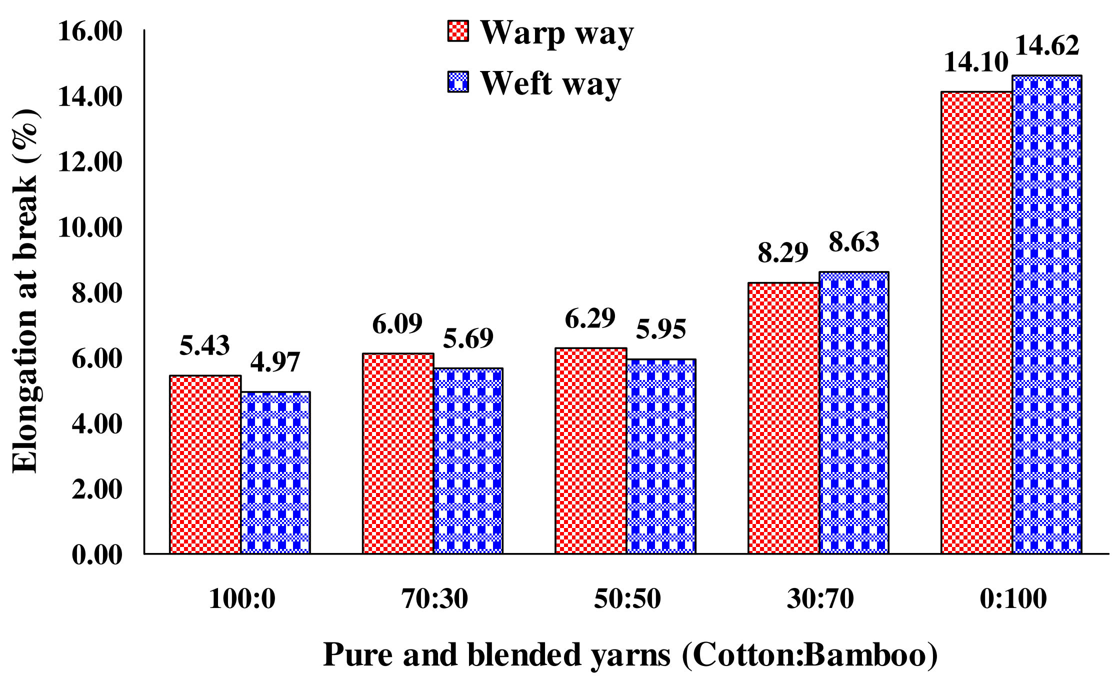


Fig. 4.4 Elongation at break (%) of pure and blended yarns

fiber tenacity to the yarn tenacity. The quality of yarn depends upon the quality of fiber and the spinning operation. The quality of fabric depends upon the quality of fiber and yarn. **Grover and Hamby (1988)** opined that greater the unevenness of the yarn, the lesser its strength will be.

It is clear from the Table 4.17 (Fig. 4.4) that the elongation percent at break in 100:0, 70:30, 50:50, 30:70 and 0:100 of cotton-bamboo blended 2-ply warp yarns were 5.43, 6.09, 6.29, 8.29 and 14.10% respectively. Statistically, significant difference was observed among the means of 2-ply warp yarn samples except in between 70:30 and 50:50 cotton-bamboo 2-ply warp yarn samples. The value of CD at 5% level of significance for elongation percent at break was 0.2 *(Appendix VIII, g)*.

The elongation percent at break in single ply weft yarn samples were 4.97, 5.69, 5.95, 8.63 and 14.62% respectively**.** Statistically, significant difference was observed among the means of single ply weft yarn samples for elongation percent at break with 0.01 CD value at 5% level of significance *(Appendix VIII, h)*. It is clear from the data that in 2-ply warp yarn samples and single ply weft yarn samples, yarn strength decreased and elongation percent at break was increased with the increasing percentage of bamboo fiber in the yarn samples. The required value for strength and elongation percent at break for carded cotton yarn of 2/20 count for weaving is around

17 gm/tex and 4.5% respectively **(Anonymous[9], 2009)**. **Chellamani (2006)** stated that as compared to cotton, bamboo yarns are weaker by 20%.

4.8 Preparation of woven fabric samples

The present study defines advantages of producing cotton-bamboo fiber blended reusable woven anti-microbial and bio-degradable fabrics through power loom, which not only be beneficial to both medical industry workers and patients but protect our environment as well.

Five woven fabric samples of cotton-bamboo fiber (pure and blended) i.e. 100:0, 70:30, 50:50, 30:70, 0:100 were made on power loom working on economical production speed, on the basis of the data obtained by evaluation of the fabric properties of the nine woven fabric samples collected from different hospitals.

It was observed that 100% bamboo fabric was very soft and smooth followed by 30:70, 50:50, 70:30, 100:0 pure and blended cotton-bamboo fabrics. Besides that luster of fabrics were found to be increased with increased content of bamboo in blended fabric. Resultant fabric samples were having very soft, smooth, lustrous even surfaced without any slubs or knots. Therefore these pure and blended cotton-bamboo woven fabric samples were found quite suitable for preparation of protective and healthcare textiles. Pure and blended cotton-bamboo woven fabric samples of different ratios are shown in Sample sheet no. 4.2.

4.9 Evaluation of physical properties of woven fabrics

Fabric construction contributes to the end use of the textile products such as appearance, hand, strength, dimensional stability, absorbency, warmth etc. **(Anonymous, 1974).** Therefore, to ensure the desired quality level, confirmed prescribed specifications and their suitability for their intended purpose, pure and blended woven fabric samples were tested for various properties which includes: Structural properties: weave, fabric count, GSM (gm/m^2), and yarn crimp percentage.

Mechanical properties: breaking strength (kgf/cm), elongation (%), tearing strength (kg), abrasion resistance (%), pilling (grade) and dimensional stability (%).

Aesthetic properties: fabric thickness (mm), fabric stiffness/bending length (cm), fabric drape (%), and crease recovery (°).

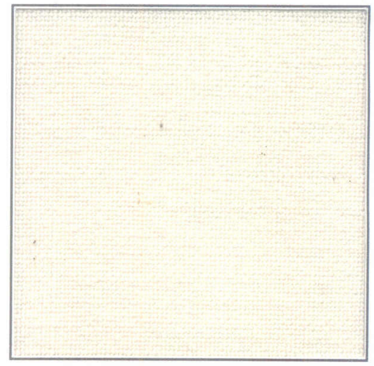
Comfort properties: thermal conductivity (Tog), air permeability ($ft^3/ft^2/min$), wettability and water vapour permeability ($g/m^2/day$) etc.

Their results are presented in Table 4.18. The detailed ANOVA tables for different fabric testing parameters are given in *Appendix IX*.

Sample Sheet No. 4.2

PURE AND BLENDED COTTON-BAMBOO WOVEN FABRIC SAMPLES

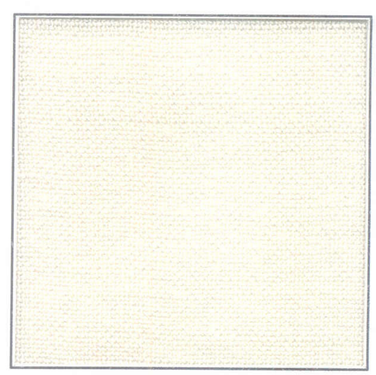
100:0 Cotton:Bamboo



70:30 Cotton:Bamboo

50:50 Cotton:Bamboo

30:70 Cotton:Bamboo



0:100 Cotton:Bamboo

Table 4.18 Fabric properties of the pure and blended cotton-bamboo woven fabrics

Fabric Properties			Fabric samples				
			100:0 C : B	70:30 C : B	50:50 C : B	30:70 C : B	0:100 C : B
Structural properties	Weave		Plain	Plain	Plain	Plain	Plain
	Fabric count (Ends x Picks/inch^2)		38.3 x 41	39.3 x 41.3	39.3 x 42.3	40.3 x 41.3	39 x 41.3
	Fabric weight per unit area (gm/m^2)		206.10	197.50	196.80	196.20	195.50
	Yarn crimp (%)	Warp way	10.80	10.75	10.60	10.45	10.00
		Weft way	10.39	10.39	11.03	10.39	7.06
Mechanical properties	Breaking strength (kgf/cm)	Warp way	10.14	9.30	8.47	8.72	8.79
		Weft way	13.94	10.45	9.26	10.10	10.35
	Elongation at break (%)	Warp way	23.49	25.56	27.35	26.63	31.99
		Weft way	17.00	20.35	17.86	22.40	27.06
	Tearing strength (kg)	Warp way	6.1	4.1	3.6	3.0	2.8
		Weft way	4.3	4.0	3.0	2.8	2.6
	Abrasion resistance after 5000 cycles (%)		2.87	2.80	2.66	1.68	1.68
	Pilling (grade)		1	2	3	3	4
	Dimensional stability (%)	Warp way	2.2	2.5	2.8	4.0	4.7
		Weft way	2.0	2.2	3.0	4.0	4.0
Aesthetic properties	Fabric thickness (mm)		0.55	0.53	0.52	0.50	0.47
	Fabric stiffness or bending length (cm)	Warp way	1.7	1.6	1.6	1.4	1.4
		Weft way	2.5	2.1	2.1	2.1	1.7
	Drape Coefficient (%)		63.62	50.03	49.77	49.26	37.79
	Crease recovery (°)	Warp way	68.3	77.0	87.0	95.6	103.0
		Weft way	69.0	79.0	88.6	98.0	106.0
Comfort properties	Thermal conductivity (Tog)		2.16	2.10	2.13	1.93	2.02
	Air permeability (ft^3/ft^2/min)		4.2	4.0	3.9	4.7	7.2
	Wettability (rating)		70	50	0	0	0
	Water vapour permeability (g/m^2/day)		1707.97	1704.95	1678.22	1595.13	1644.31

4.9.1 Weave

After testing the nine different woven fabric samples collected from different hospitals, it was found that plain weave was mostly used for making protective and healthcare textiles. Therefore, the plain weave structure was kept constant for weaving the experimental fabrics. Plain weave is the simplest of all weaves having minimum repeat size of two, its appearance may be varied by differences in the closeness of the weave, by different thicknesses of the yarn, etc. and its manufacturing is relatively inexpensive **Anonymous (1974)**. **Grosicki (1988)** has asserted that in plain weave structure, each thread gives the maximum amount of support to the adjacent threads, and in proportion to the quantity of the material employed; the texture is stronger and firmer than any other ordinary cloth.

4.9.2 Fabric count

Fabric count of all pure and blended cotton-bamboo woven fabric samples were kept constant i.e. 36 X 36 (ends X picks)/inch^2 on loom. Negligible difference was observed in fabric count among all pure and blended woven fabric samples after testing, which might be due to the difference in yarn structure or due to the fabric relaxation when it was taken out of the loom after weaving also altered the fabric count. It was observed that lengthwise relaxation of fabrics was more than the widthwise relaxation of fabrics. Therefore, the picks/inch was found more than ends/inch among all pure and blended woven fabrics.

4.9.3 Fabric weight per unit area (gm/m^2)

It is evident from the Table 4.18 (Fig 4.5) that the GSM of woven fabrics made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of cotton and bamboo fiber blends were 206.1, 197.5, 196.8, 196.2 and 195.5 gm/m^2 respectively. It was observed that as bamboo content in the fabric increased, weight of the fabrics decreased. Thus it is possible to produce the light weight fabric from bamboo fibers.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabric samples except in between 50:50 and 30:70 cotton-bamboo woven fabric samples, with 0.67 CD value at 5% level of significance *(Appendix IX, a).*

4.9.4 Yarn crimp percentage

It is revealed from the Table 4.18 (Fig 4.6) that the warp yarn crimp percentage of woven fabrics made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of cotton and bamboo fiber blends were 10.80, 10.75, 10.60, 10.45 and 10.00% respectively. Significant difference was observed among the means of warp yarns taken out from pure and blended cotton-bamboo fabrics for crimp percentage

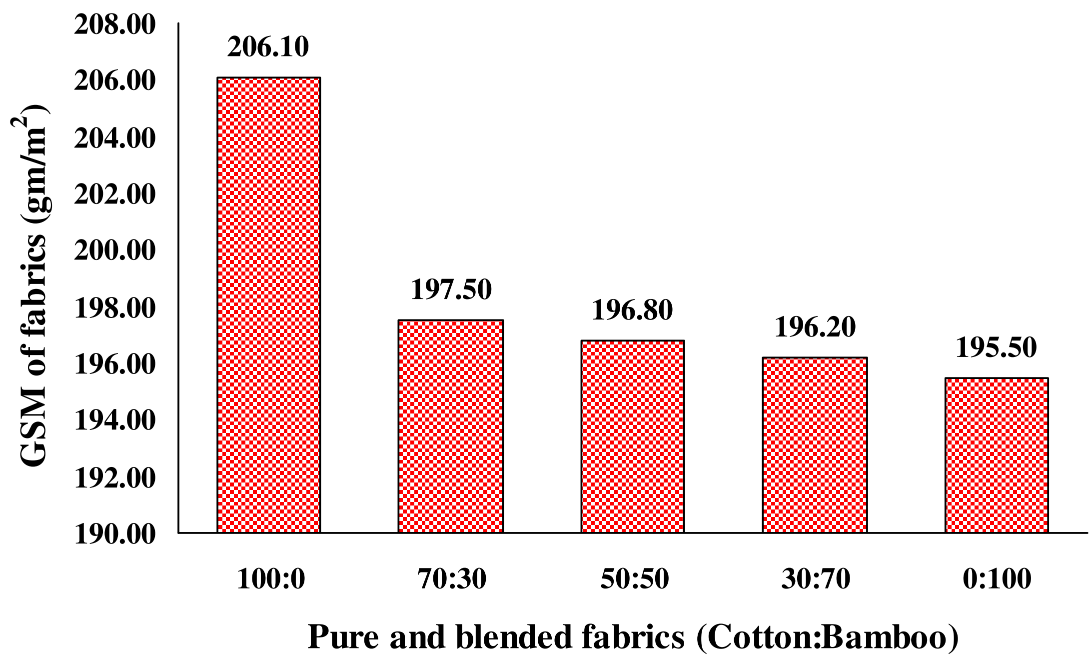


Fig. 4.5 GSM of pure and blended fabrics

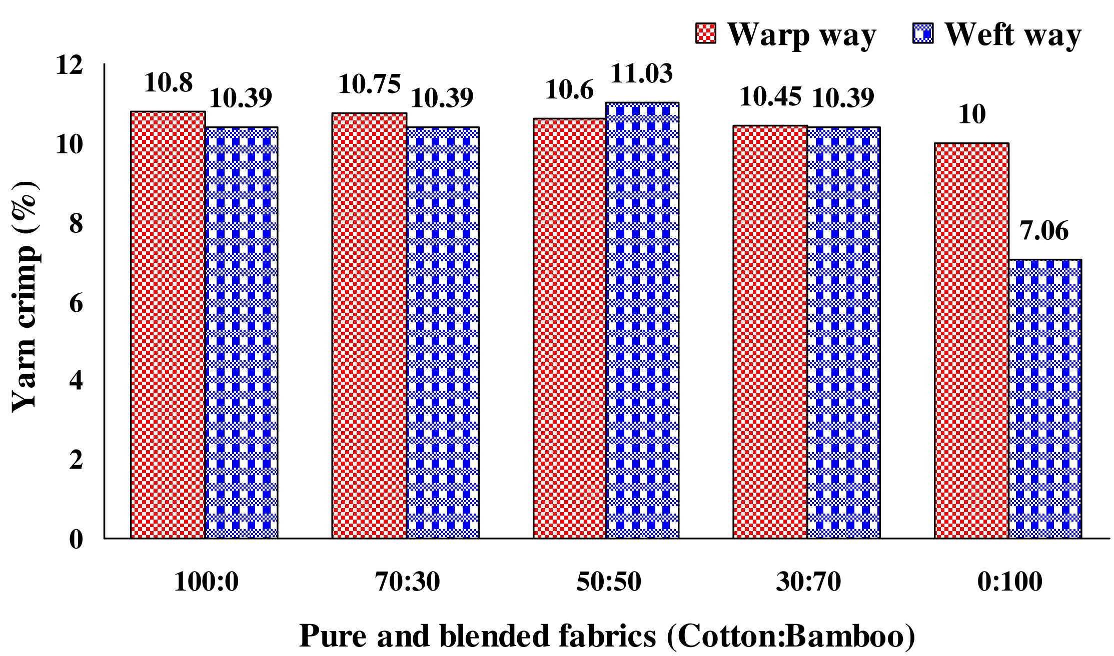


Fig. 4.6 Yarn crimp percentage of pure blended fabrics

except 100:0 and 70:30 cotton-bamboo warp yarn samples. The CD value for warp yarn crimp percentage was 0.12 at 5% level of significance *(Appendix IX, b).*

The weft yarn crimp percentage of woven fabrics made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of cotton and bamboo fiber blends were 10.39, 10.39, 11.03, 10.39 and 7.06% respectively. Significant difference was observed among the means of weft yarns taken out from pure and blended cotton-bamboo fabrics except 100:0, 70:30 and 30:70 cotton-bamboo weft yarn samples. The CD value for weft yarn crimp percentage was 0.10 at 5% level of significance *(Appendix IX, c).*

It was observed that crimp percentage was slightly higher in warp yarns than weft yarns among all pure and blended cotton-bamboo woven fabrics as warp yarns were held under high tension than weft yarns while weaving.

4.9.5 Fabric thickness

It is apparent from the Table 4.18 (Fig.4.7) that thickness of pure and blended cotton-bamboo fabric samples were ranged between 0.55 to 0.47 mm. Fabric thicknesses was recorded highest for pure cotton fabric i.e. 0.55 mm and lowest for pure bamboo fabric i.e. 0.47 mm. This might be due to the fact that cotton fiber length was shorter than bamboo fiber which in turn increased the protruding fiber ends and fuzz on the surface thus caused an

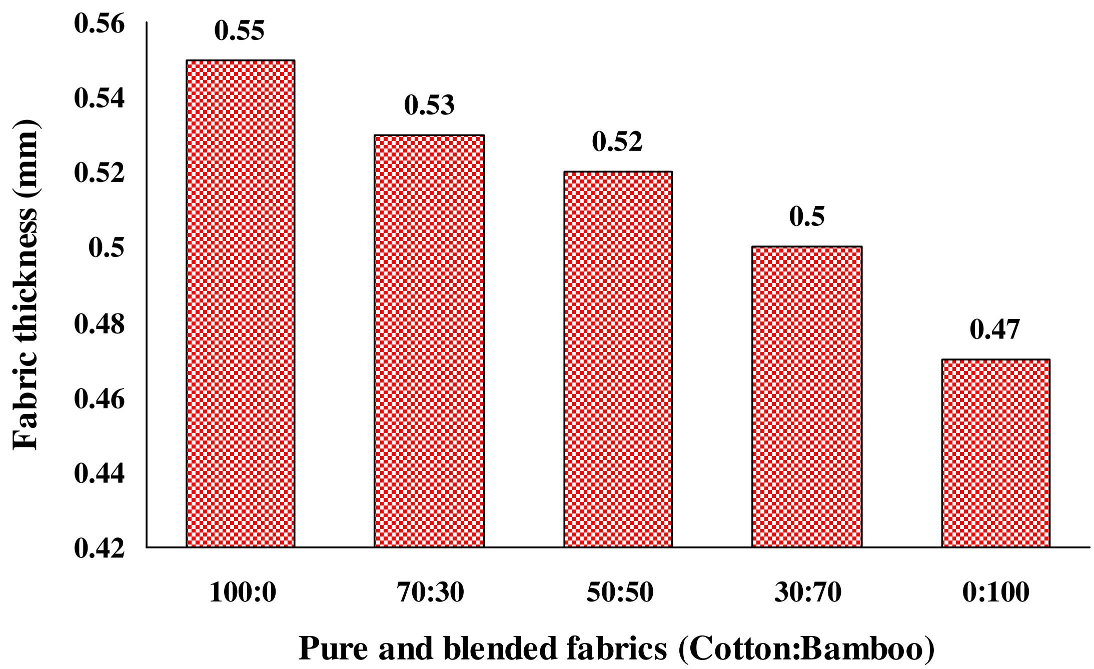


Fig. 4.7 Thickness of pure and blended fabrics

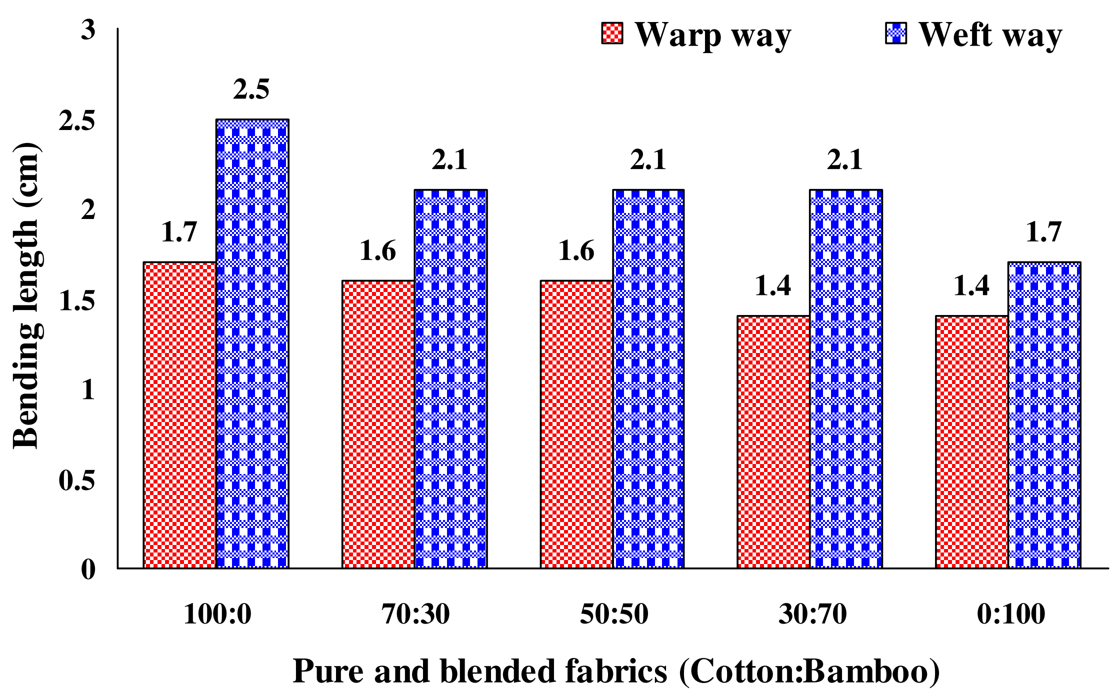


Fig. 4.8 Stiffness of pure and blended fabrics

increase in the thickness of fabric. Besides that, insignificant difference was found in thickness because the yarn count, twist/inch, weave and EPI X PPI/inch^2 were kept constant for all pure and blended woven fabrics.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabric samples except in between 70:30 and 50:50 cotton-bamboo fabrics, with 0.012 CD value at 5% level of significance for fabric thickness *(Appendix IX, d).*

4.9.6 Fabric stiffness/bending length

It is evident from the Table 4.18 (Fig 4.8) that the bending length of woven fabrics made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of cotton and bamboo blends were 1.70, 1.60, 1.60, 1.44 and 1.44 cm, respectively in warp direction and 2.48, 2.10, 2.06, 2.06 and 1.74 cm, in weft direction respectively.

Statistically, significant difference was observed among the means of all warp way cotton-bamboo fabrics. However, non-significant difference was observed among the means of 100:0, 70:30 and 50:50 warp way cotton-bamboo fabrics; similarly non-significant difference was also observed among the means of 30:70 and 0:100 warp way cotton-bamboo fabrics. The CD value for warp way stiffness was 0.11 at 5% level of significance *(Appendix IX, e)*. Significant difference was also observed among the means of all weft way cotton-bamboo fabrics. However, non-significant difference was observed among the means of 70:30, 50:50 and 30:70 weft way cotton-bamboo fabrics. The CD value for weft way stiffness was 0.08 at 5% level of significance *(Appendix IX, f)*.

It was observed that as bamboo content increased in the fabrics, it's bending length decreased; it means that stiffness of fabrics decreased. Decreasing trend of bending length of blended fabrics might be due to the softness and smoothness of the bamboo fibers. **Angappan and Gopalkrishnan (2002)** stated that stiffness is the key factor in studying the handle or drape of the fabric. The lesser the bending length, the better will be the drape of the fabric.

4.9.7 Fabric drape

It is clear from the Table 4.18 (Fig 4.9) that the drape coefficient (%) of the woven fabric samples made from the 100:0, 70:30: 50:50, 30:70 and 0:100 ratios of cotton-bamboo blends were 63.62, 50.03, 49.77, 49.26 and 37.79% respectively. It was observed that as the bamboo percentage increased in the blends, drapability increased. **Saville (2004)** also stated that the higher the drape coefficient, the stiffer is the fabric. Thus the results of the present investigation shows that fabric made from cotton-bamboo blends can be successfully used for making protective and healthcare textiles i.e. doctor's lab coat, surgical gown, patient dress, etc which requires good draping quality.

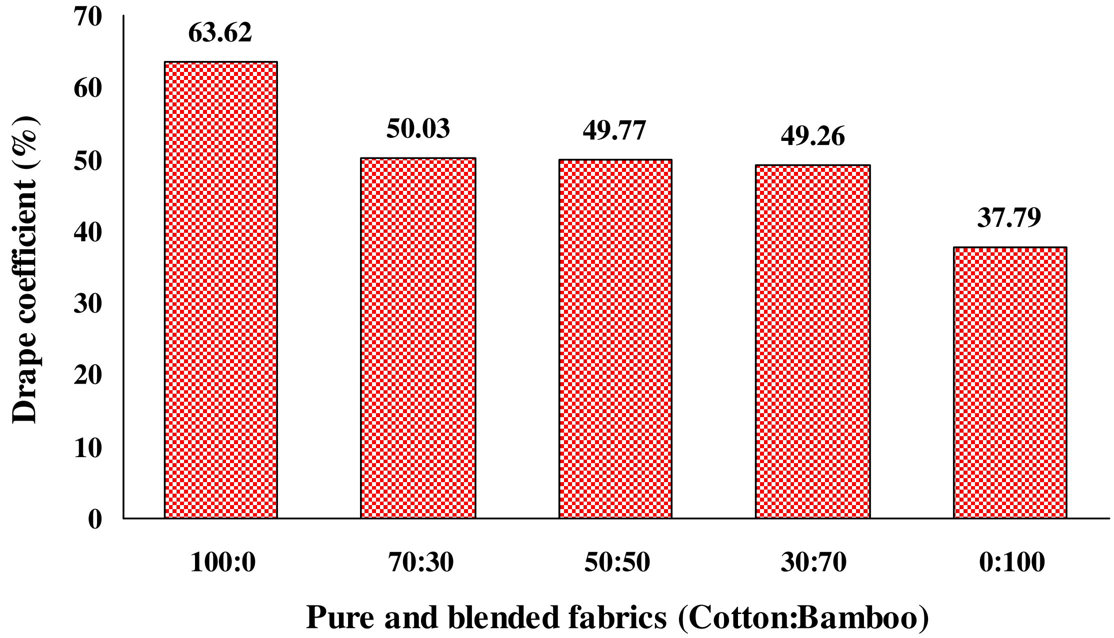


Fig. 4.9 Drape coefficient of pure and blended fabrics

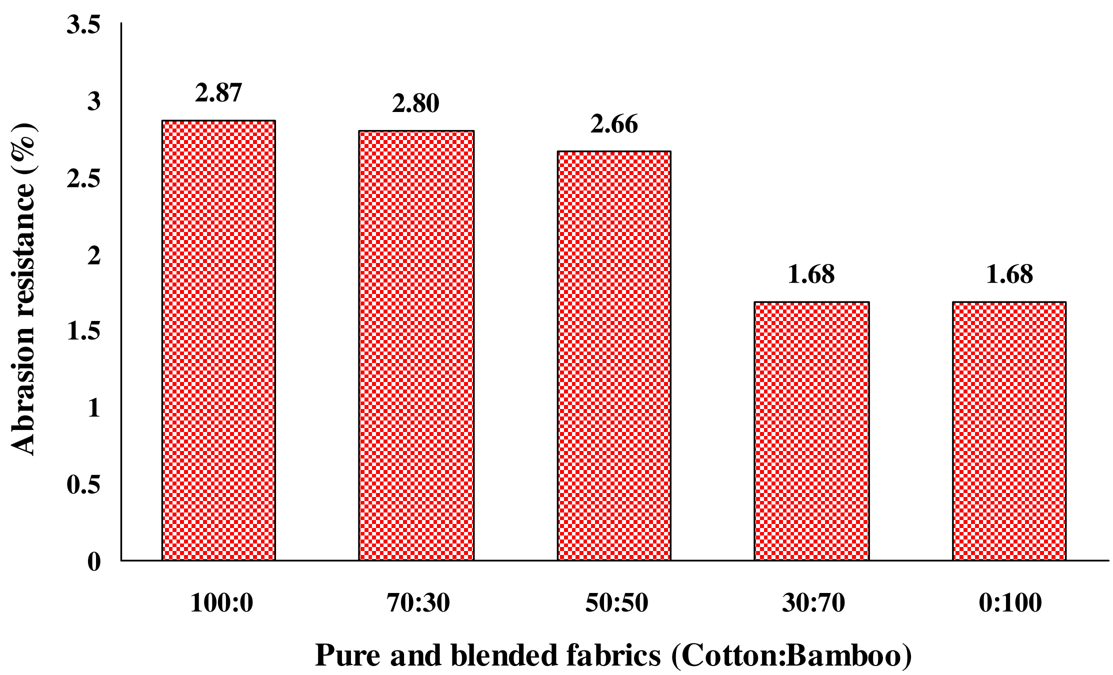


Fig. 4.10 Abrasion resistance of pure and blended fabrics

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabric samples. However, non-significant difference was observed among the means of 70:30 and 50:50; and among the means of 50:50 and 30:70 pure and blended cotton-bamboo woven fabric samples. The CD value for fabric drape was 0.60 at 5% level of significance *(Appendix IX, g).*

4.9.8 Abrasion resistance

According to **Angappan and Gopalkrishnan (2002),** abrasion resistance is the most influencing factor in deciding the serviceability of fabrics. It is apparent from the Table 4.18 (Fig 4.10) abrasion resistance for the woven fabrics prepared from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of cotton and bamboo were 2.87, 2.80, 2.66, 1.68 and 1.68% respectively. The results of present investigation clearly indicated that as the bamboo content in blend increased the abrasion resistance of the fabric also increased because percent weight was seen lowest in 30:70 and 0:100 cotton-bamboo fabrics. It means that the blended fabric having high content of bamboo i.e., 30:70, 0:100 could resist more number of abrasion cycles than pure cotton fabric. This might be due to the high elongation capacity of bamboo fiber than cotton fiber. **Saville (2004)** stated that high elongation, elastic recovery and work of rupture are considered to be the most important factors for a good degree of abrasion resistance in a fiber than its tensile strength. Yarns prepared from longer fiber incorporated into a fabric confer better abrasion resistance than short fibers because they are harder to remove from the yarn. In protective and healthcare textiles, abrasion resistance is required more in bed-sheets, pillow covers, patient dress, doctor's-nurses uniform, as these articles are passed through every kind of abrasion i.e. flat, flex and edge abrasion, which ultimately affects their serviceability. Therefore, it was found that fabrics having higher bamboo content should be used to prepare these articles.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo fabrics except in between the means of 100:0, 70:30 and 50:50; and also in between the means of 30:70 and 0:100 cotton-bamboo fabrics. The value of CD for abrasion resistance was 0.62 at 5% level of significance *(Appendix IX, h)*.

4.9.9 Pilling

Results being presented in Table 4.18 indicated that pure and blended cotton-bamboo fabrics had very severe to slight pilling (1-4), when compared with ASTM D3512/photographic standards of pilling. It was recorded as 1 for pure cotton fabric, 2 for 70:30 cotton-bamboo blend, 3 for 50:50 and 30:70 cotton-bamboo blends and 4 for pure bamboo fabric. Results thus showed that as the bamboo fiber percentage in the woven fabrics increased, pilling decreased which might be due to the fact that yarns prepared having higher percentage of bamboo were finer than cotton yarns and due to higher extensibility of bamboo fiber. It was also due to the twist variation which made fibers loose therefore they came at the surface of fabrics. **Angappan and Gopalkrishnan (2002)** stated that higher the extensibility of fiber, the less is the tendency to pill. **Vaidya (2001)** opined that very effective pilling control can be achieved by fine yarns, with high amount of twist. Because when fine yarn is used to weave fabric, the number of intersections is greater as compare to coarse yarn; this prevents the fiber migration from yarn structure and reduces pilling. The 100:0 and 70:30 cotton-bamboo blended fabrics showed very severe to severe pilling (1 & 2) which may be due to short fibers present on the surface of yarn which creates fuzziness on the surface of fabrics and after rubbing against another surface it changes into ugly looking small globules on the surface of the fabrics calls pill.

4.9.10 Thermal conductivity

It is apparent from the Table 4.18 (Fig. 4.11) that the thermal conductivity (Tog) value of 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo blended woven fabrics were found as 2.16, 2.10, 2.13, 1.93, 2.02 Tog. More or less same thermal conductivity values was observed among all pure and blended cotton-bamboo woven fabrics which showed that all pure and blended cotton-bamboo

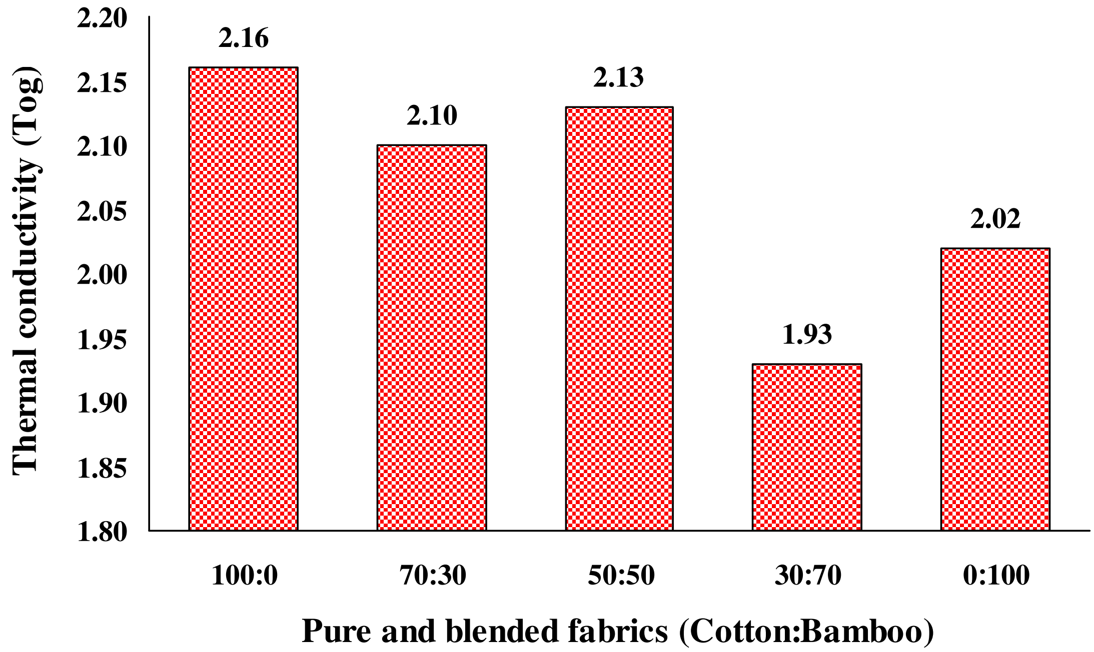


Fig. 4.11 Thermal conductivity of pure and blended fabrics

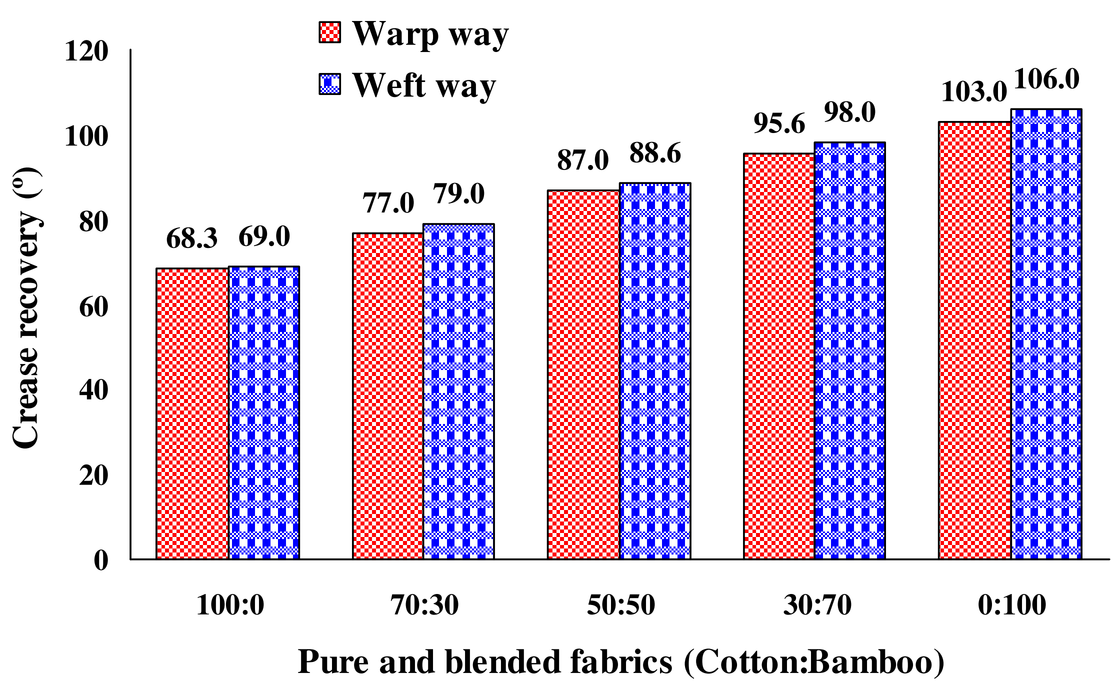


Fig. 4.12 Crease recovery of pure and blended fabrics

woven fabrics provide equal thermal protection to the wearer. Besides that, slight decrease in the thermal conductivity values was noticed as the bamboo percentage increases in the fabrics which indicated that bamboo fabrics provide cooling sensation while wearing. Tog is the frequently used value for thermal conductivity which is calculated from the clo value. Clo indicates the insulation ability of the test material. Materials having higher clo values provide wearers with more thermal protection **(Anonymous[10], 2008). Chellamani[1] (2006)** stated that due to higher moisture regain, bamboo fabrics have relatively low thermal value in comparision with viscose fabric. Hence, bamboo fabrics can be expected to provide cool sensation when they come in contact with the human body. **Cassie (2005)** stated that the heat insulation of the fabric is governed to a great extent by the air entrapped into it, because in fabrics made from whether natural and synthetic fibers, thermal insulation value of air is much higher than fiber. Hence increase in entrapped air inside the fabric by the fiber increases the thermal insulation value of the fabric.

Statistically, significant difference was found among the means of all pure and blended cotton-bamboo woven fabrics except among 70:30 and 50:50 cotton-bamboo fabrics. The CD value at 5% level of significance was 0.03 for thermal conductivity *(Appendix IX, i)*.

4.9.11 Crease recovery

The magnitude of the crease recovery angle is measured in present investigation taken as an indication of the ability of a fabric to recover from wrinkling. It is apparent from the Table 4.18 (Fig 4.12) that the crease recovery angle of pure and blended cotton-bamboo woven fabric samples were 68.3°, 77.0°, 87.0°, 95.6° and 103° in warp direction and 69.0°, 79.0°, 88.6°, 98.0° and 106.0° in weft direction respectively. The results of present investigation clearly indicated that with the increased amount of bamboo in blended fabrics, crease recovery angle increased in both warp and weft direction. This means that the ability of the fabric to resist creasing or mussing decreased. This might be due to the fact that bamboo fiber has high elongation than cotton fiber. **Encyclopedia Americana (1967)** also stated that, the recovery or resistance towards creasing is largely depends on the resiliency and elastic property of the material of the fabric itself. Thus, fabrics having good crease recovery provide aesthetic appeal and psychological comfort to the wearer.

Statistically, significant difference was found among the means of all pure and blended cotton-bamboo woven fabrics. The values of CD at 5% level of significance were 3.3 for crease recovery in warp direction and 1.8 for crease recovery in weft direction *(Appendix IX, j & k)*.

4.9.12 Breaking strength and elongation of fabrics

The breaking strength of the fabric refers to its resistance to tensile force and is used both for quality control and as a performance test (**Kothari, 1999).** The breaking strength of the fabric made from the 100:0, 70:30: 50:50, 30:70 and 0:100 ratios of cotton-bamboo blends were reported as 10.14, 9.30, 8.47, 8.72 and 8.79 kgf/cm in warp way and 13.94, 10.45, 9.26, 10.10 and 10.35 kgf/cm in weft way respectively (Fig 4.13 and Table 4.18). It is clear from the data that breaking strength was found high in weft direction as compared to warp way among all woven fabrics which might be due to less strain on weft yarns than warp yarns during weaving process. Decreasing trends in breaking strength was found among all blend ratios for both warp and weft directions respectively. It was observed that as the bamboo content was increased in the woven fabrics, the strength of the fabric decreased. Bamboo fiber has high breaking strength (dry) but subsequently its strength decreased in the yarn form which finally decreased the breaking strength of the woven fabrics. **Skinkle (1972)** stated that the quality of the fabric is dependent upon the quality of the fiber, the spinning operation, the weaving operations, etc. Therefore, the strength of fabric is the result of several variables and is rather complex and should be measured in comparison with other samples having constant fabric construction parameters.

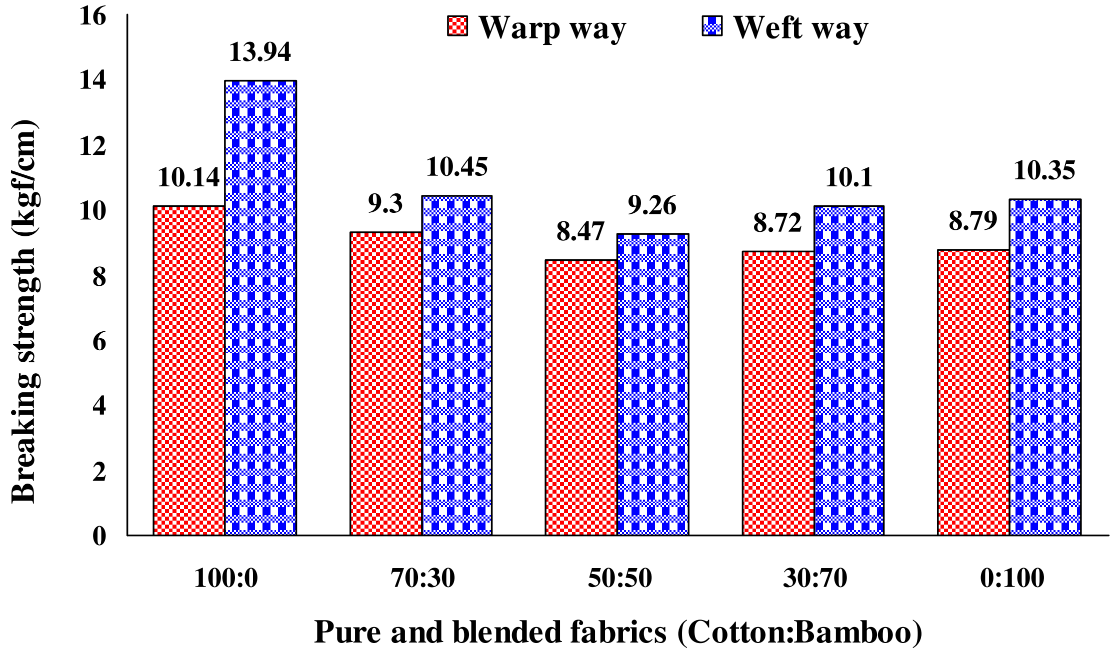


Fig. 4.13 Breaking strength of pure and blended fabrics

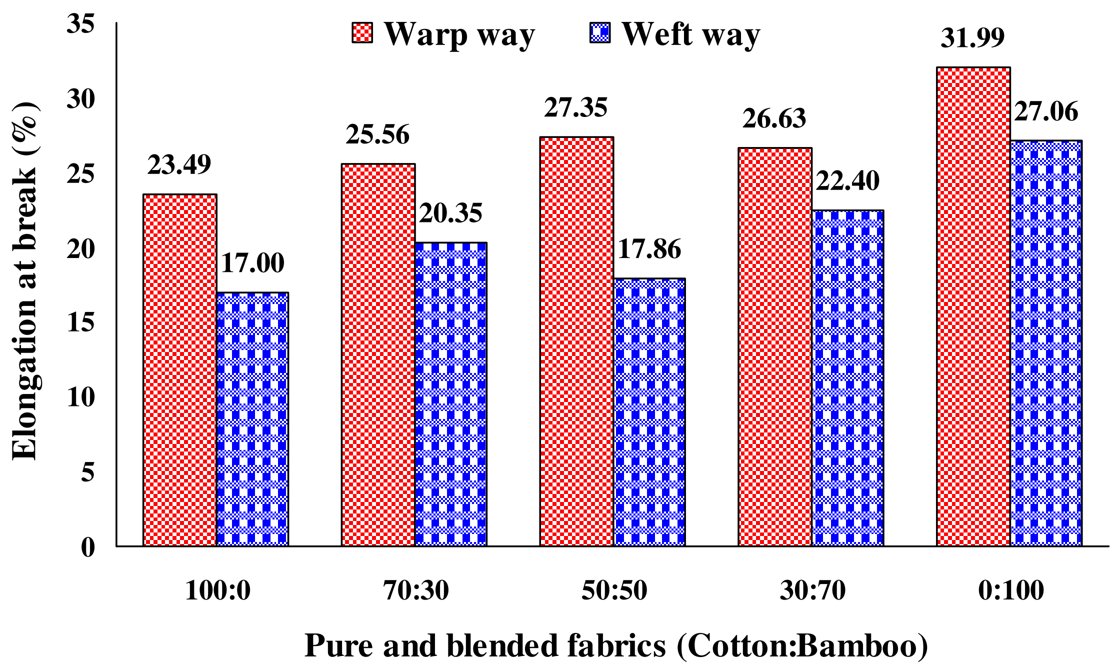


Fig. 4.14 Elongation at break of pure and blended fabrics

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics in warp direction except among 30:70 and 0:100 cotton-bamboo fabrics. However, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics in weft direction. The value of CD at 5% level of significance was 0.07 and 0.007 for warp and weft way breaking strength respectively *(Appendix IX, l and m)*.

It is apparent from the Table 4.18 (Fig 4.14) that the elongation percentage of pure and blended cotton-bamboo fabrics were 23.49, 25.56, 27.35, 26.63 and 31.99% respectively in warp direction and 17.00, 20.35, 17.86, 22.40 and 27.06% in weft direction respectively. Thus, results showed that as the proportion of bamboo in blend increases the elongation percent value of woven fabrics, also increases in both warp and weft way direction. It could be attributed to the fact that the yarn having high ratio of bamboo were elongated more because of good elongation property of bamboo fiber as compared to the cotton fiber. As a result the fabric having high percentage of bamboo showed good elongation as compared to the fabric having more cotton content.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics for fabric elongation both in warp and weft directions. The values of CD at 5% level of significance were 0.37 and 0.01 for warp and weft way fabric elongation respectively *(Appendix IX, n and o).*

4.9.13 Tearing strength

It is noticeable from the results obtained in Table 4.18 (Fig. 4.15) that tearing strength of pure and blended cotton-bamboo fabrics were 6.1, 4.1, 3.6, 3.0 and 2.8 kg respectively in warp direction and 4.3, 4.0, 3.0, 2.8 and 2.6 kg in weft direction respectively. The result of tearing strength obtained in present investigation showed a decreasing trend as the bamboo content increases in the blend. It was found maximum for pure cotton fabrics, where as it was minimum for pure bamboo fabrics. This might be due to the CV per cent of the yarn strength. **Tortora (1982)** opined that major factor in tearing strength are the strength of the yarn and strength of the fabric structure. Fiber tenacity is relatively less important because stronger yarn or fabric structure can compensated for low individual fiber tenacities. Fabric construction in which yarns are woven together such as plain weave, etc will have greater tear strength, since more yarn will group together to share the stress.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics for tearing strength both in warp and weft directions. The values of CD at 5% level of significance were 0.08 and 0.04 for warp and weft way tearing strength respectively *(Appendix IX, p & q).*

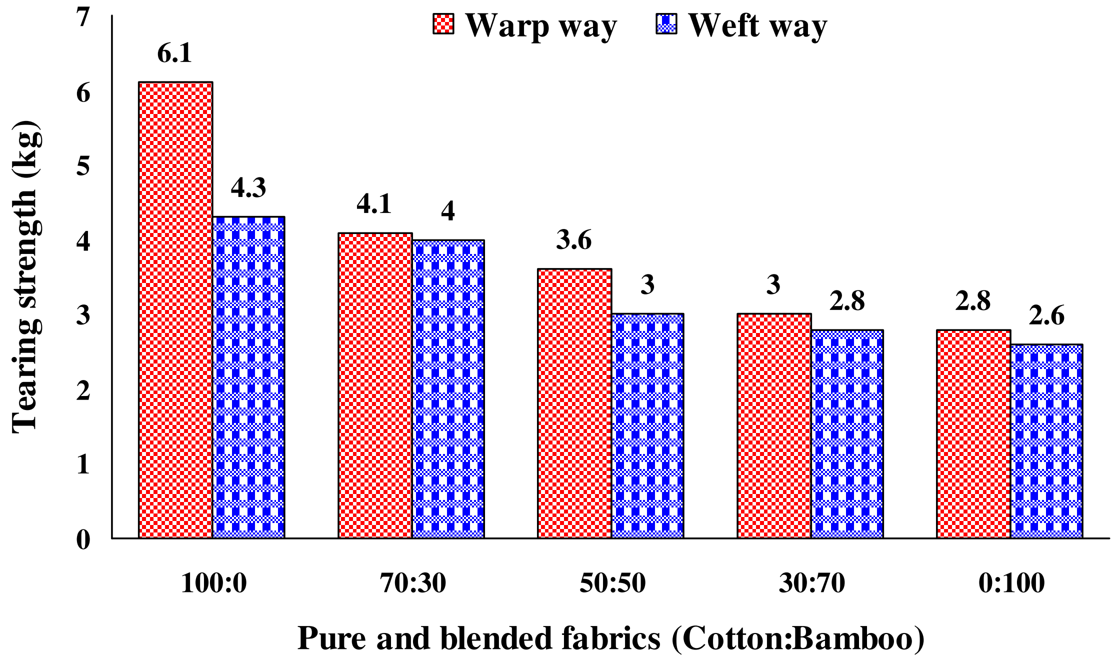


Fig. 4.15 Tearing strength of pure and blended fabrics

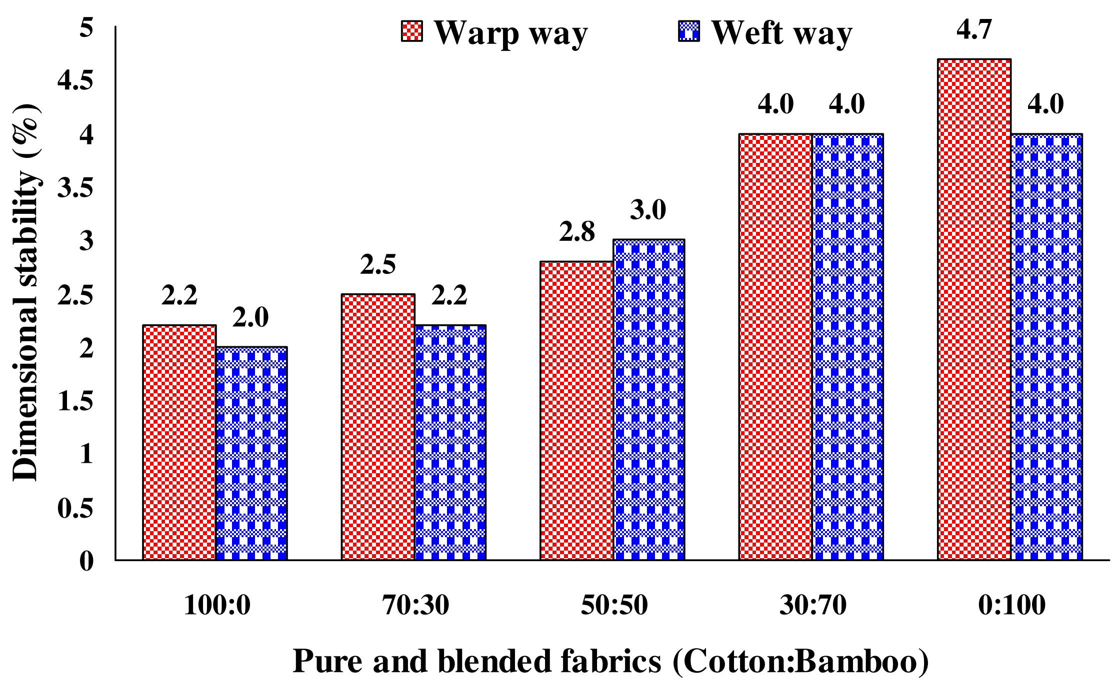


Fig. 4.16 Dimensional stability of pure and blended fabrics

4.9.14 Dimensional stability

It is noticeable from the results obtained in Table 4.18 (Fig. 4.16) that dimensional stability of pure and blended cotton-bamboo woven fabrics was 2.2, 2.5, 2.8, 4.0 and 4.7% respectively in warp direction and 2.0, 2.2, 3.0, 4.0 and 4.0% in weft direction respectively. It is observed from data that fabrics having high bamboo content were less dimensionally stable than pure cotton fabrics in both warp and weft direction respectively. **Saville (2004)** stated that dimensional stability play a very important role where laundering is a more vigorous process than pressing which usually involves mechanical agitation, hot water and detergent.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics in warp direction. However, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics in weft direction except among 30:70 and 0:100 cotton-bamboo fabrics. The value of CD at 5% level of significance was 0.18 and 0.18 for warp and weft way dimensional stability respectively *(Appendix IX, r & s).*

4.9.15 Air permeability

It is evident from Table 4.18 (Fig. 4.17) that air permeability of the fabric made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of pure and blended cotton-bamboo woven fabrics were 4.2, 4.0, 3.9,

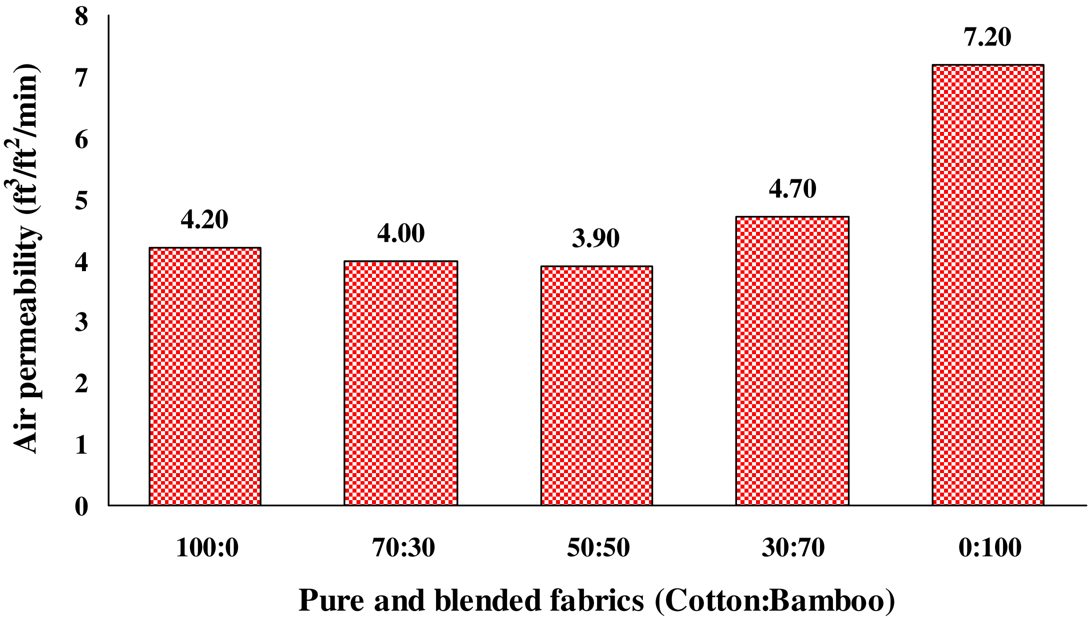


Fig. 4.17 Air permeability of pure and blended fabrics

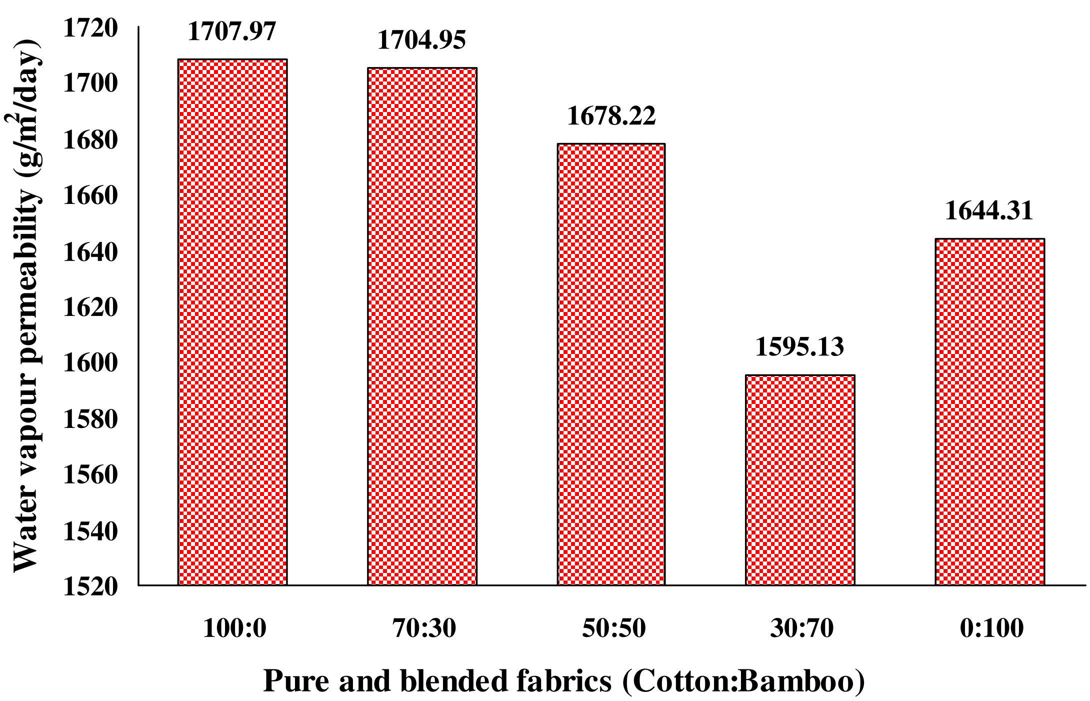


Fig. 4.18 Water vapour permeability of pure and blended fabrics

4.7, and 7.2 ft^3/ft^2/min respectively. It was found from the above presented data that pure bamboo fabric has high air permeability which might be due to the structure of bamboo fiber i.e. presence of micro holes and micro gaps which allow the air to pass easily from one side to another **(Anonymous[2], 2007)**. Negligible difference was found for air permeability in 100:0, 70:30, 50:50 and 30:70 pure and blended cotton-bamboo fabrics. **Tortora (1982)** stated that where opening between yarns or between fibers within yarns are large, a good deal of air will pass through the fabric.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics. However, non-significant difference was observed among the means of 100:0 and 70:30; and also among the means of 70:30 and 50:50 cotton-bamboo fabrics. The value of CD for air permeability at 5% level of significance was 0.2 *(Appendix IX, t).*

4.9.16 Wettability

It is noticeable from the results obtained in Table 4.18 that wettability rating of the fabric made from the 100:0, 70:30, 50:50, 30:70 and 0:100 ratios of pure and blended cotton-bamboo woven fabrics were 70, 50, 0, 0 and 0 respectively. It was observed that 50:50, 30:70 and 0:100 cotton-bamboo fabrics have highest wettability which was followed by 70:30 and 100:0 cotton-bamboo fabrics. According to **Saville (2004)**, the term wettability is related to water absorption. Textile end uses such as towels, under clothes, shirts, cleaning clothes, etc. require the material which absorbs water. Therefore, it can be concluded that fabrics having higher bamboo content showed better water absorption and can be used for making patient dress, etc., which bears direct contact with patient skin, provide comfort to the wearer by absorbing moisture.

4.9.17 Water vapour permeability

It is noticeable from the results obtained in Table 4.18 (Fig. 4.18) that water vapour permeability of pure and blended cotton-bamboo woven fabrics was 1707.97, 1704.95, 1678.22, 1595.13 and 1644.31 g/m^2/day respectively. Fabrics having higher cotton content showed better water vapour permeability in comparision with bamboo incorporated fabrics.

Saville (2004) stated that water vapour permeability is an important property related to clothing, as clothing must be able to remove the moisture in order to maintain comfort and reduces the degradation of thermal insulation caused by moisture build-up. **Tortora (1982)** stated that hydrophobic fibers may act as a shield to prevent passage of water vapour, whereas hydrophilic fibers allow water vapour to pass through the fabrics and ultimately provide comfort to the wearer.

Statistically, significant difference was observed among the means of all pure and blended cotton-bamboo woven fabrics except in between the means of 100:0 and 70:30 cotton-bamboo fabrics. The value of CD for water vapour permeability at 5% level of significance was 16.9 *(Appendix IX, u).*

4.10 Assessment of antimicrobial activity of woven fabrics

Textiles not only act as substrates for microbial growth but they may act as active agents in propagation of microbes. Therefore, in the present study, the pure and blended cotton-bamboo reusable woven fabric samples were tested for their antimicrobial properties against commonly found bacteria's i.e. *S. aureus* and *E. coli* and fungi's i.e. *A. niger* and *T. reesei* in the hospital environment.

4.10.1 Qualitative assessment of antimicrobial activity

4.10.1.1 Qualitative assessment of antibacterial activity

It is evident from the Plate 4.2 and 4.3 that no clear inhibition zone (area free from microbial growth) was noticed in all before wash and after wash pure and blended cotton-bamboo fabrics towards *S. aureus* and *E.coli* except in after wash 100% bamboo fabric which showed a clear inhibition zone of 1 mm towards *S. aureus.*

Heavy bacterial growth along the fabric specimens was noticed among all before washed and after washed pure and blended cotton-bamboo fabrics towards *S. aureus* and *E. coli.* Slight bacterial growth

Plate 4.2 Parallel streaking of *S. aureus* on woven fabrics for 24 hours

	(Before wash)		**(After wash)**	
	Along fabric	Beneath fabric	Along fabric	Beneath fabric

100:0 C:B

70:30 C:B

50:50 C:B

30:70 C:B

0:100 C:B

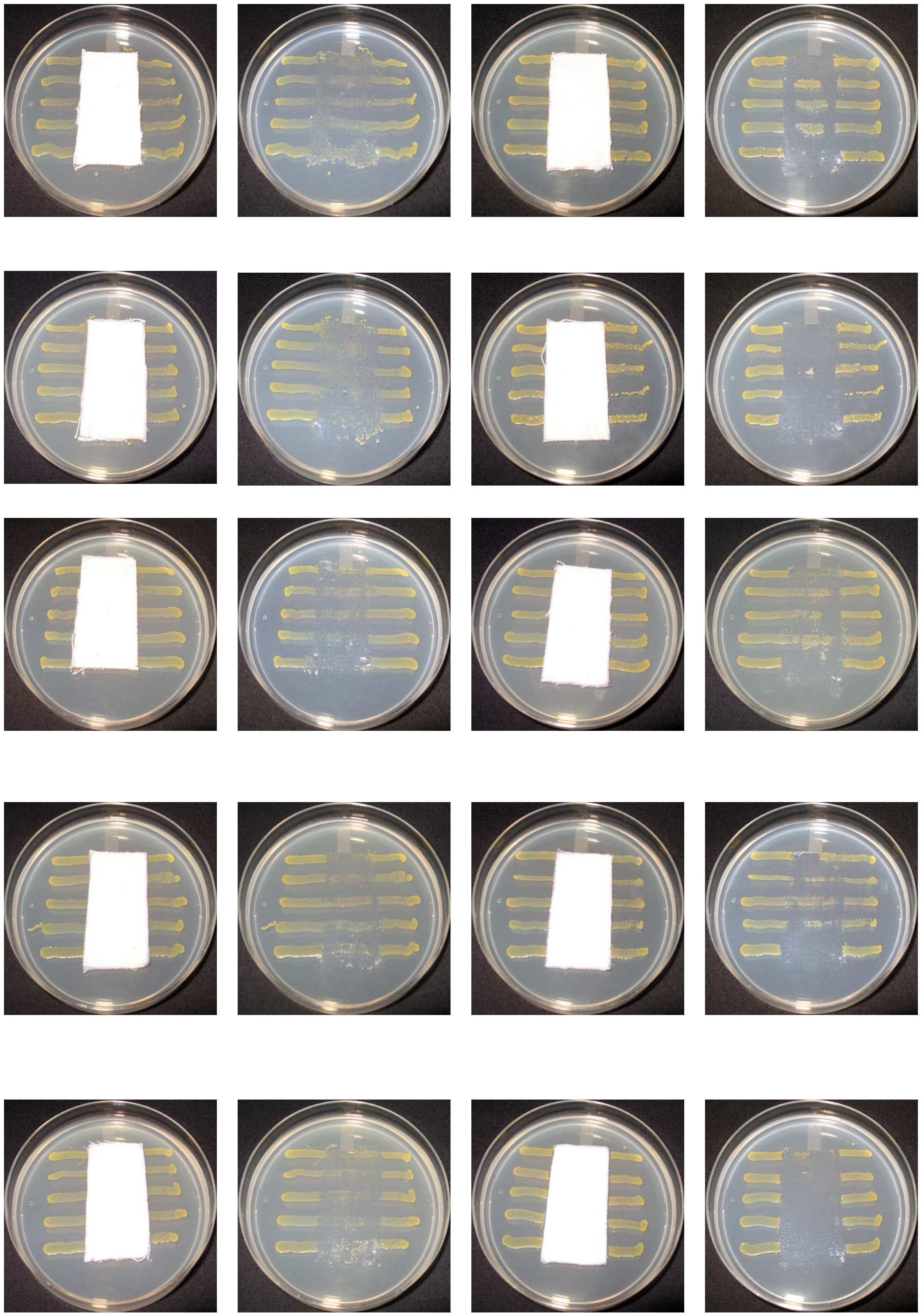
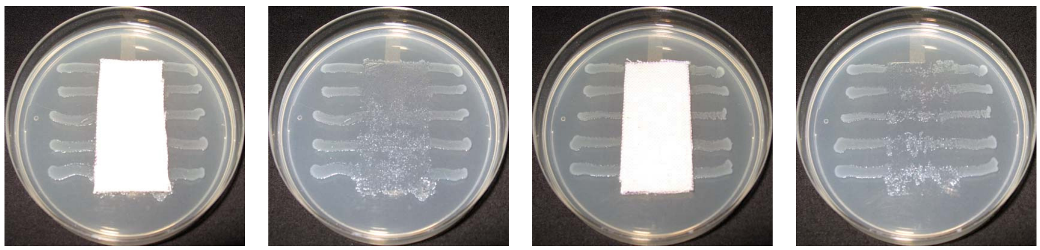


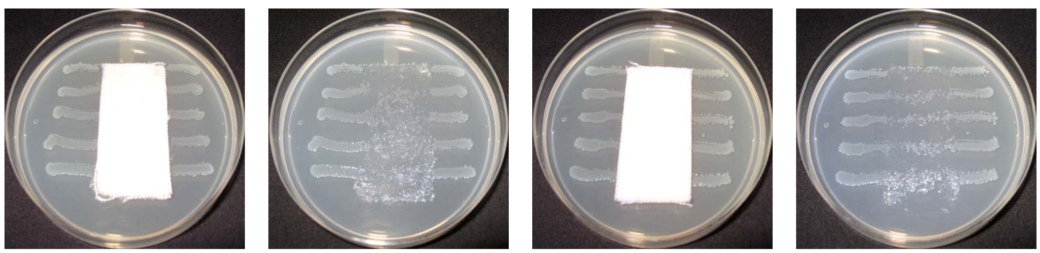
Plate 4.3 Parallel streaking of *E. coli* on woven fabrics for 24 hours

	(Before wash)		(After wash)	
	Along fabric	Beneath fabric	Along fabric	Beneath fabric

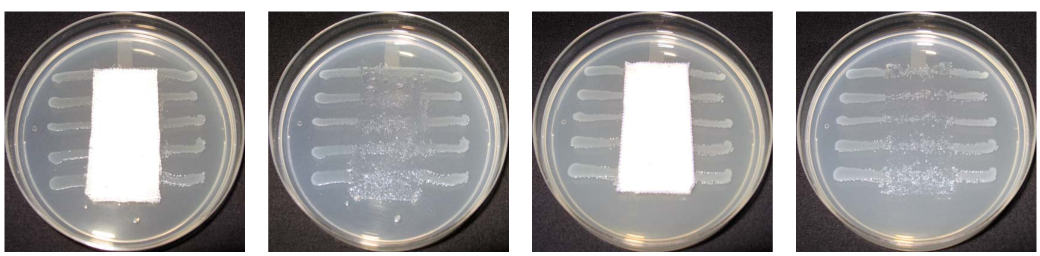
100:0
C:B



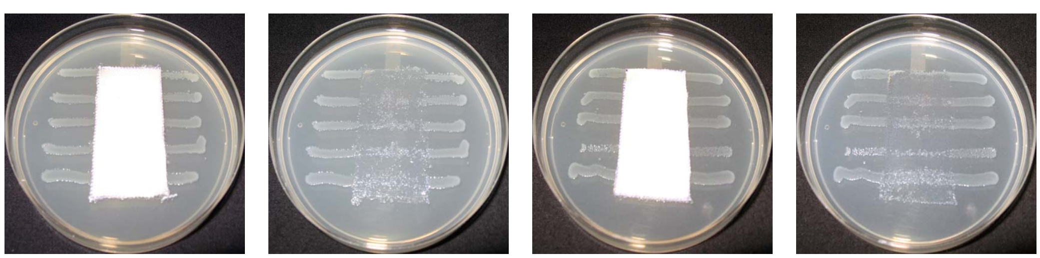
70:30
C:B



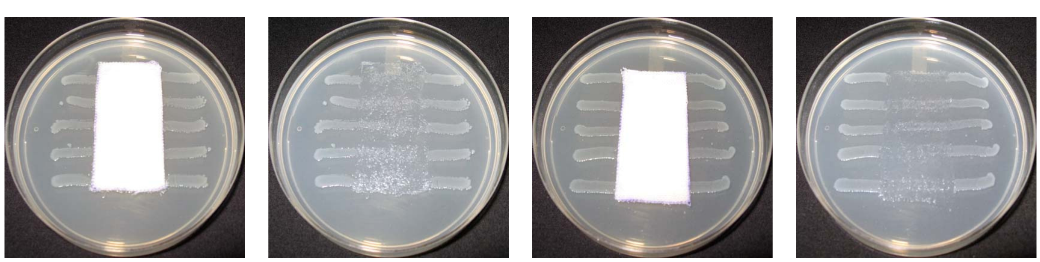
50:50
C:B



30:70
C:B



0:100
C:B



beneath the fabric specimens was noticed in all before washed and after washed pure and blended cotton-bamboo fabrics towards *S. aureus* except in after washed 70:30 cotton-bamboo fabric and 100% bamboo fabric where no bacterial growth was observed beneath the fabric specimens (Plate 4.2). It is evident from Plate 4.3 that slight bacterial growth beneath the fabric specimens was noticed in all before washed and after washed pure and blended cotton-bamboo fabrics towards *E.coli* which indicated that bamboo possesses anti-bacterial property. **Saravanan and Prakash (2007)** stated that bamboo owns a unique anti-bacteria and bacteriostasis bio-agent named "bamboo kun" which combined with bamboo cellulose molecule tightly all along during the process of being produced into bamboo fiber/fabric and does not allow the bacteria to grow. It was cited in the literature that other bamboo species like *Moso bamboo* also possess the antibacterial property.

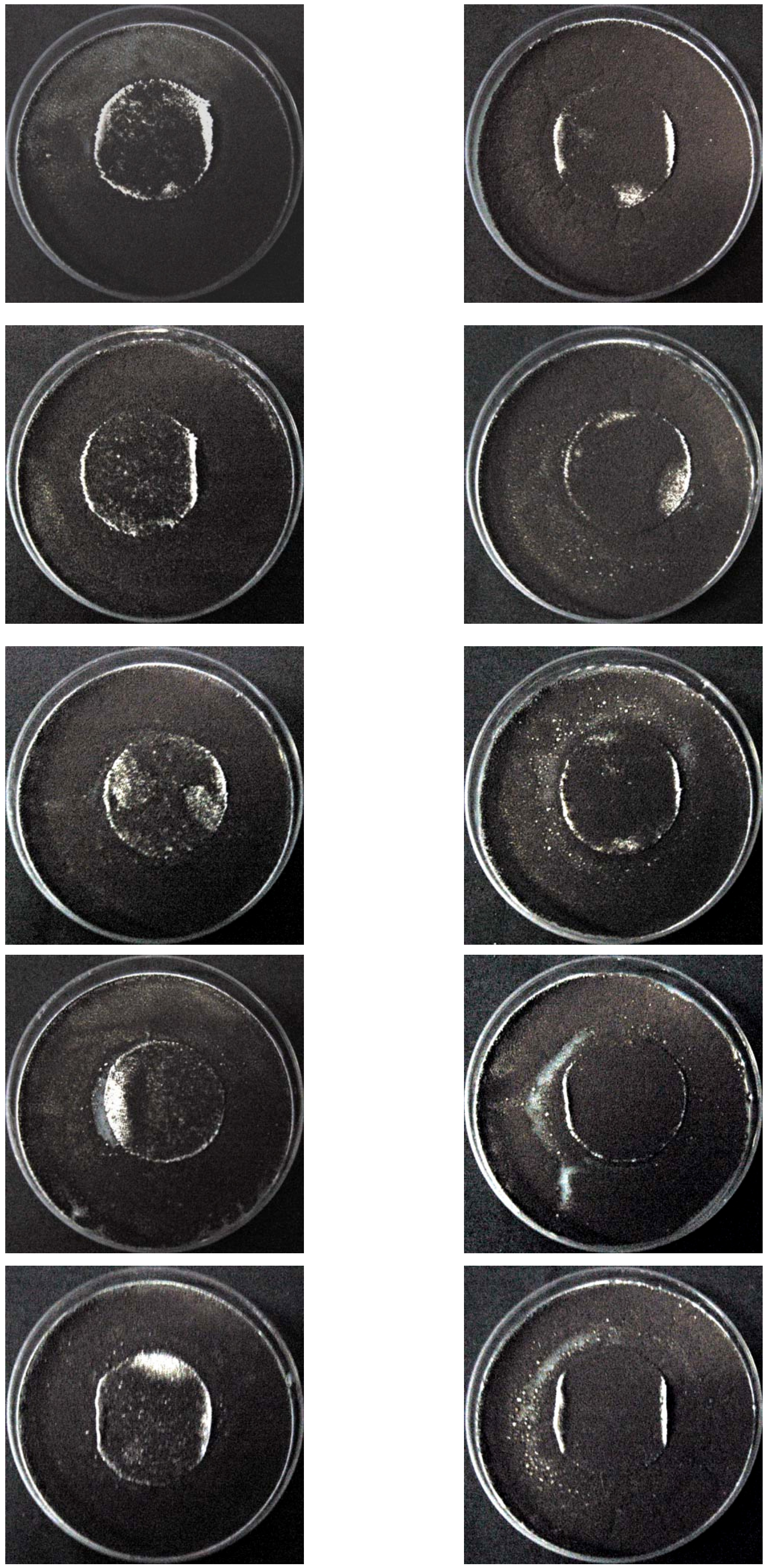
The size of the zone of inhibition is usually related to the level of antimicrobial activity present in the sample or product - a larger zone of inhibition usually means that the antimicrobial activity is more potent. Inhibition zone tests do not necessarily indicate that microorganisms have been killed by an antimicrobial product but they have been prevented from growing **(Anonymous[11], 2008)**.

4.10.1.2 Qualitative assessment of antifungal activity

It is apparent from Plate 4.4 and Plate 4.5 that 100% macroscopic growth (all the surface area of the disc was covered with

Plate 4.4 Agar Diffusion of *A. niger* on woven fabrics for 7 days

(Before wash) (After wash)



100:0 C:B

70:30 C:B

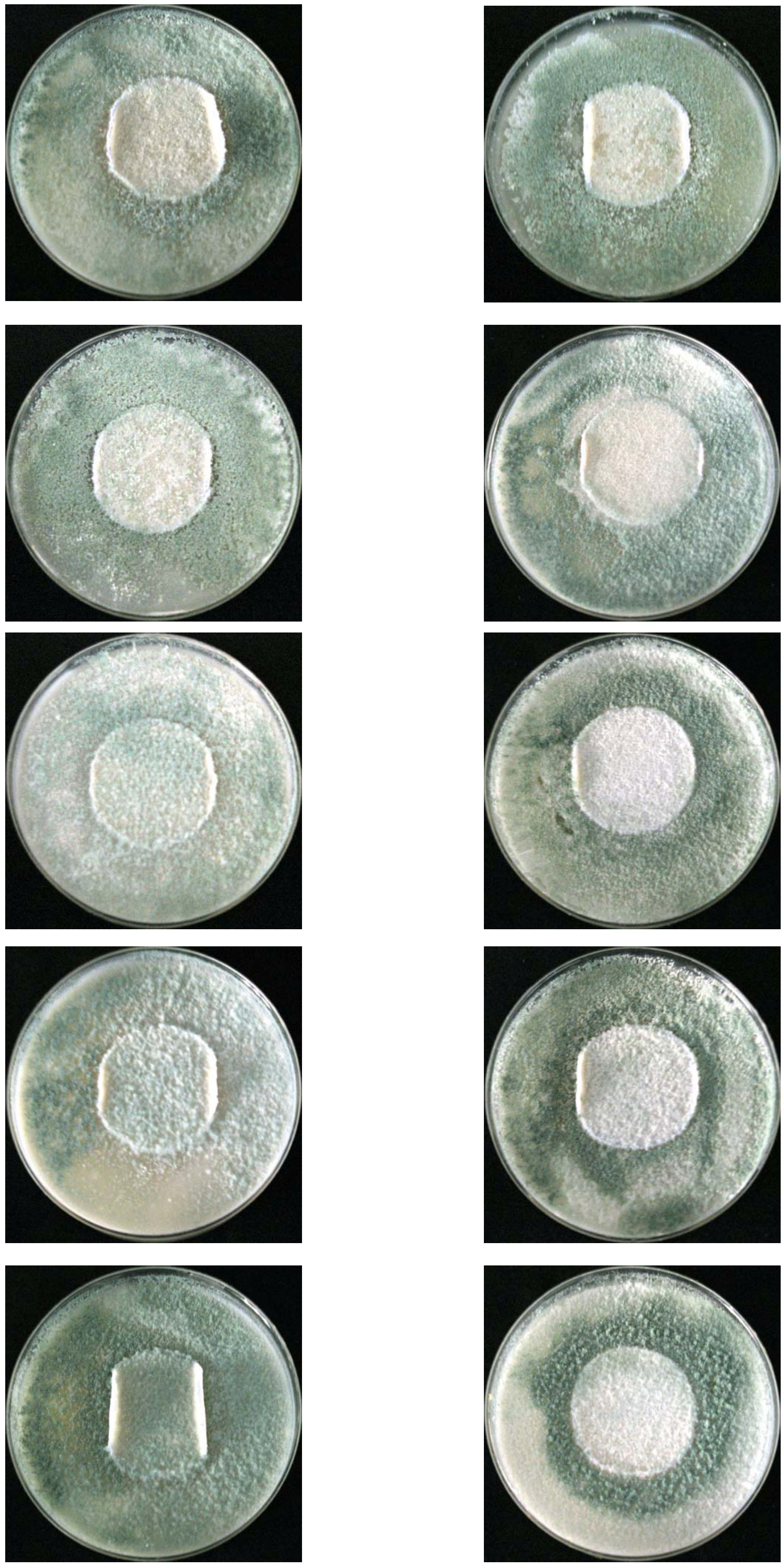
50:50 C:B

30:70 C:B

0:100 C:B

Plate 4.5 Agar Diffusion of *T. reesei* on woven fabrics for 7 days

(Before wash) (After wash)



100:0 C:B

70:30 C:B

50:50 C:B

30:70 C:B

0:100 C:B

the growth of fungi) was noticed in all before washed and after washed pure and blended cotton-bamboo fabrics towards *A. niger* and *T. reesei*, which was visible to the naked eyes.

Heavy fungal growth along the fabric specimens/discs was noticed in all before washed and after washed pure and blended cotton-bamboo fabrics towards *A. niger* and *T. reesei* (Plate 4.4 and Plate 4.5). It was noticed that characteristic black color of the *A. niger* covered the whole area of the petri dish and the surface of the specimens in all before washed and after washed pure and blended cotton-bamboo fabrics. In the case of *T. reesei*, characteristic green color of the fungi was not seen every where in the petri dish and over the fabric specimens but full growth of fungi was noticed every where in the Petri dish and over the fabric specimens among all before washed and after washed pure and blended cotton-bamboo fabrics.

4.10.2 Quantitative assessment of antimicrobial activity

It was clear from the qualitative evaluation that only 100% bamboo fabric (after washed) was very effective against *S. aureus* whereas none of the before washed and after washed fabric samples showed clear picture of their effectiveness against *S. aureus, E. coli, A. niger* and *T. reesei.* Therefore, quantitative evaluation was performed to get a clearer picture of the degree of antimicrobial activity present in the textile material under test for their possible uses. In the present study, a quantitative procedure (AATCC 100-1974) was used which clearly demonstrated the antimicrobial activity among all pure and blended cotton-bamboo woven fabric samples. Before performing the quantitative evaluation of the pure and blended fabric samples, an absorbency test of each fabric sample was performed, to know that how many circular fabric swatches of 4.8 cm ± 0.1 cm diameter from each fabric sample can absorb 1 ml inoculum, to maintain the consistency among the results.

Table 4.19 Number of swatches required to absorb 1 ml inoculum

Woven fabrics	Inoculum	Swatches required
100:0 Cotton: Bamboo	1 ml	4
70:30 Cotton:Bamboo	1 ml	3
50:50 Cotton:Bamboo	1 ml	2
30:70 Cotton:Bamboo	1 ml	2
0:100 Cotton:Bamboo	1 ml	2

It is evident from Table 4.19 that 100% cotton fabric required four swatches, 70:30 cotton-bamboo fabric required three swatches whereas 50:50, 30:70 and 0:100 cotton-bamboo fabric samples required only two swatches to absorb the 1 ml inoculum. The detailed ANOVA tables for different antimicrobial testing are given in *Appendix* X.

4.10.2.1 Quantitative assessment of antibacterial activity

Quantitative assessment of antibacterial activity against known test organisms i.e. *S. aureus* and *E. coli* was carried out to demonstrate the survivability of bacteria on five experimental fabrics after constant periods of incubation with the standard inoculum at the start of experiment. It was found at the time of survey that the changing of linens used by patient and hospital staff may vary from one day to as and when require. Therefore, the pure and blended cotton-bamboo fabric samples were assayed for such a long period to know the extent of bacterial resistance on the experimental fabrics.

It is evident from Table 4.20 (Fig 4.19) that after 24 hours contact time (Plate 4.6 a), number of *S. aureus* colonies increased by 2000%, 666.7% and 633.3% on before washed 100:0, 70:30 and 50:50 on cotton-bamboo fabrics, respectively whereas on 30:70 and 0:100 cotton-bamboo fabrics, increased by 500% over initial reading i.e. colonies grown on "0"contact time which was kept constant for all fabrics for comparative study. It was observed that more or less same number of colonies grown at "0" contact time on pure and blended cotton-bamboo fabrics, because of the least antibacterial property shown by all experimental fabrics at "0"contact time. After 48 hours contact time (Plate 4.6 a), number of *S. aureus* colonies increased by 600%, 100% and 133.3% on before washed 100:0, 70:30 and 50:50 cotton-bamboo fabrics respectively whereas on before washed 30:70

Table 4.20 Survival and percent reduction of *S. aureus* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *S. aureus* (BEFORE WASH) 10⁵ cfu/0.1 ml inocula					
	0 contact time (initial)	24 hours contact time	48 hours contact time	72 hours contact time	96 hours contact time	120 hours contact time
100:0 Cotton:Bamboo		63+ **(-2000)**	21+ **(-600)**	7+ **(-133.3)**	1+ **(66.7)**	0+ **(100)**
70:30 Cotton:Bamboo		23+ **(-666.7)**	6+ **(-100)**	3+ **(0)**	1+ **(66.7)**	0+ **(100)**
50:50 Cotton:Bamboo	3	22+ **(-633.3)**	7+ **(-133.3)**	3+ **(0)**	1+ **(66.7)**	0+ **(100)**
30:70 Cotton:Bamboo		18+ **(-500)**	5+ **(-66.7)**	2+ **(33.3)**	0+ **(100)**	0+ **(100)**
0:100 Cotton:Bamboo		18+ **(-500)**	5+ **(-66.7)**	2+ **(33.3)**	0+ **(100)**	0+ **(100)**

Table 4.21 Survival and percent reduction of *S. aureus* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *S. aureus* (AFTER WASH) 10⁵ cfu/0.1 ml inocula					
	0 contact time (initial)	24 hours contact time	48 hours contact time	72 hours contact time	96 hours contact time	120 hours contact time
100:0 Cotton:Bamboo		5+ **(-66.7)**	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
70:30 Cotton:Bamboo		0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
50:50 Cotton:Bamboo	3	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
30:70 Cotton:Bamboo		0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
0:100 Cotton:Bamboo		0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**	0+ **(100)**

NOTE:
\+ Average of 4 replications
The positive figure in parenthesis indicates the % reduction whereas a negative figure in parenthesis indicates the % increment over initial reading i.e. reading at 0 contact time

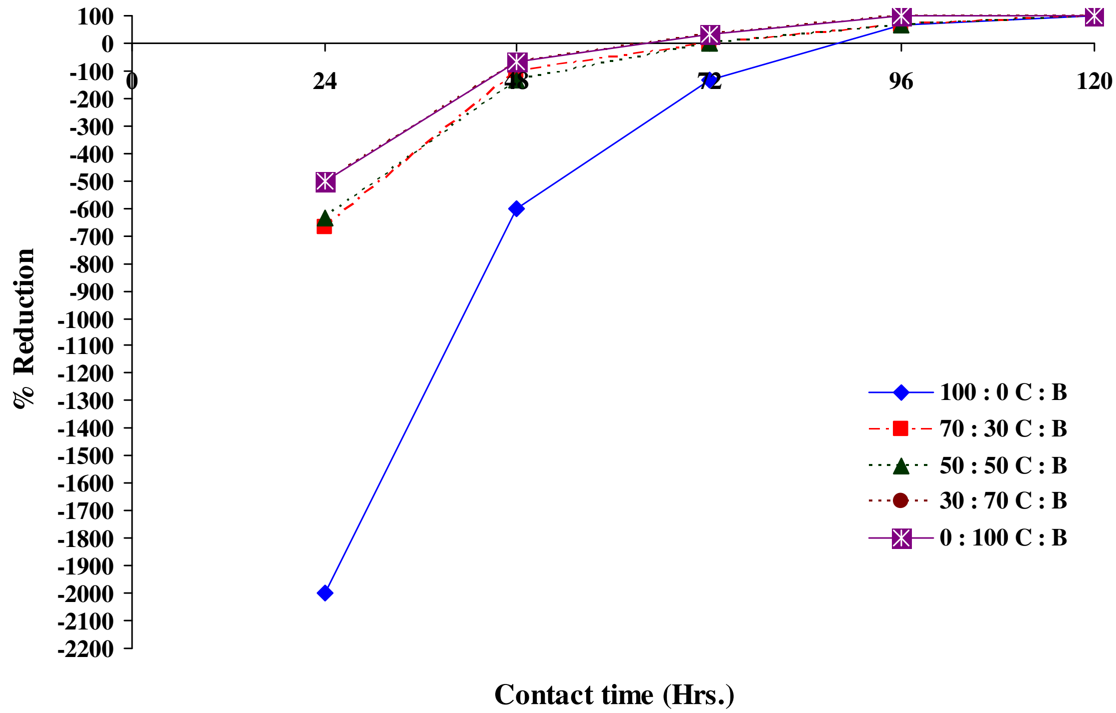


Fig. 4.19 Percent reduction of *S. aureus* over initial reading (before wash)

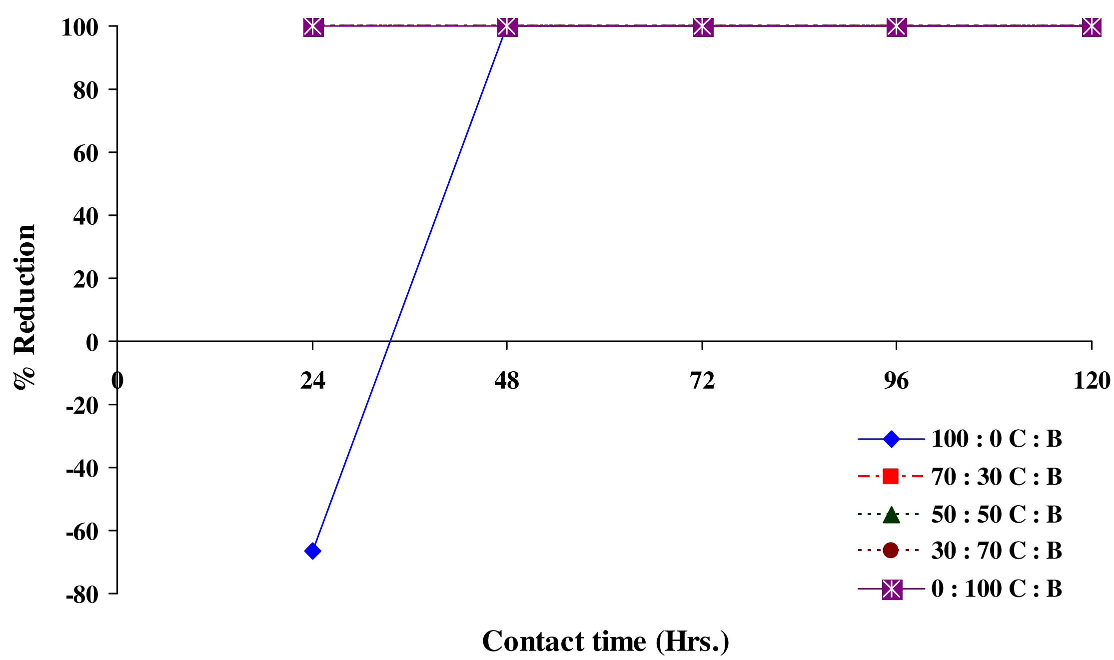
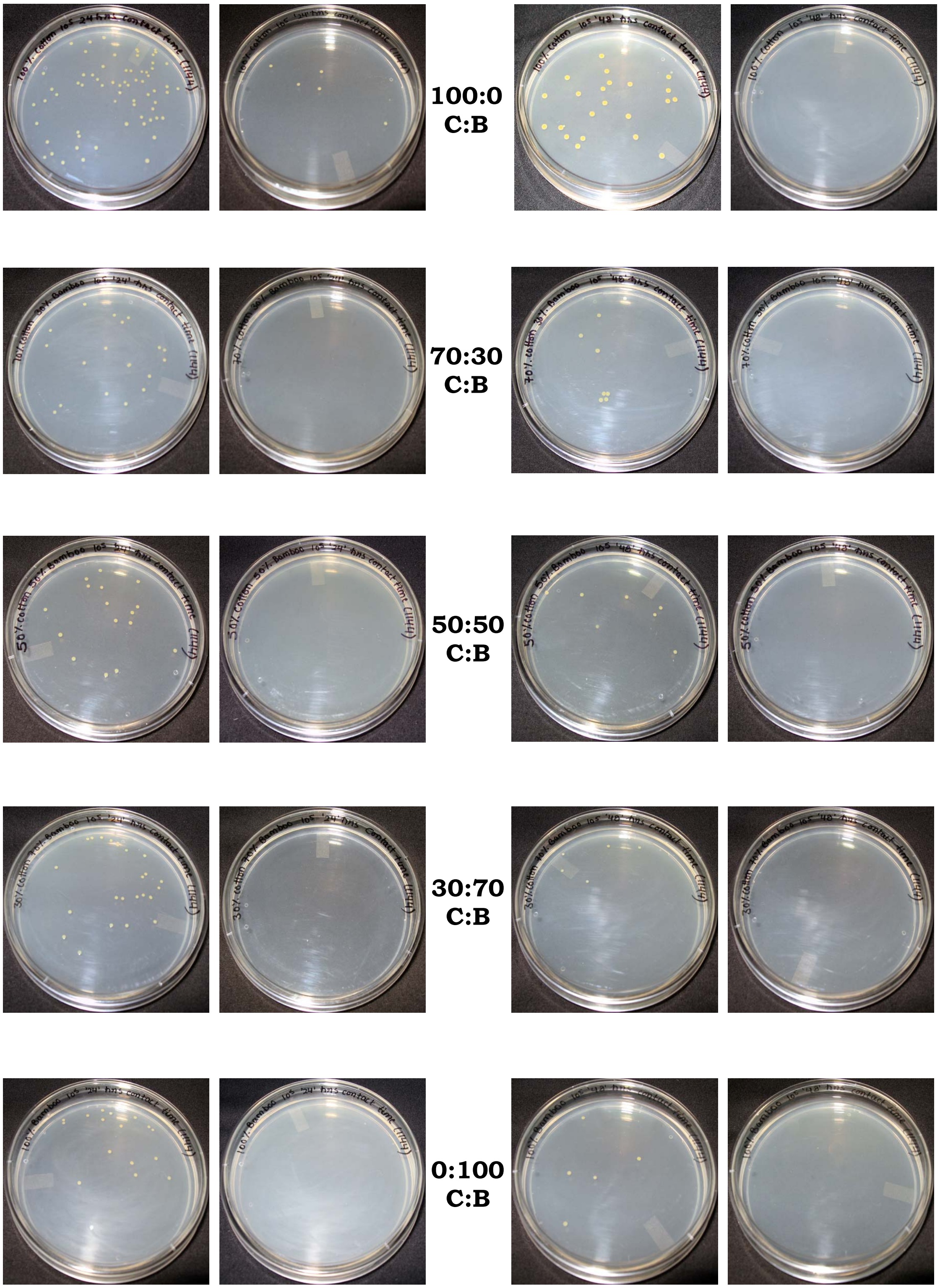


Fig. 4.20 Percent reduction of *S. aureus* over initial reading (after wash)

Plate 4.6 (a) Survival of *S. aureus* (10^5cfu/0.1ml)

24 hrs Contact Time — Before Wash | After Wash

48 hrs Contact Time — Before Wash | After Wash

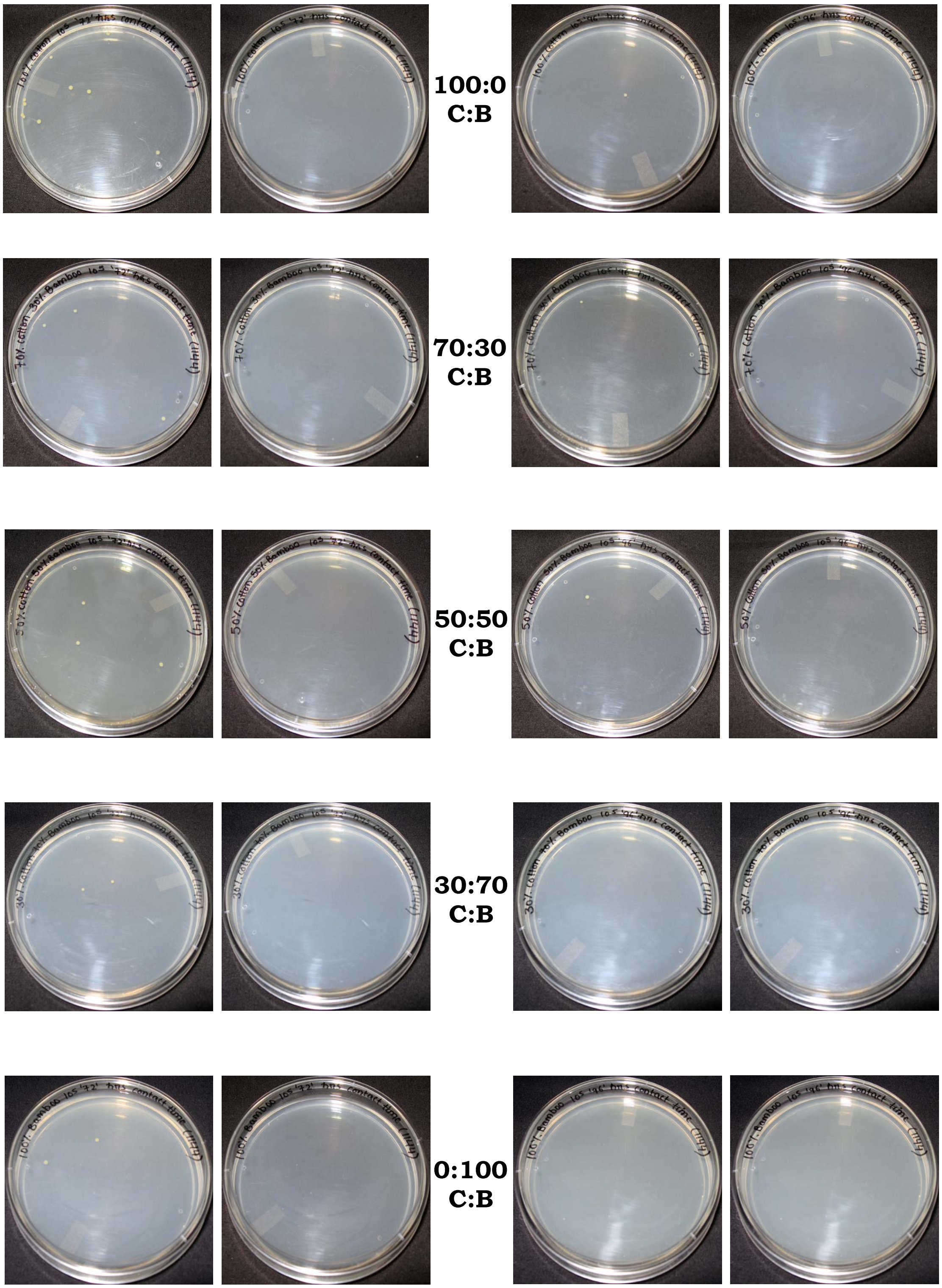


C:B = Cotton:Bamboo

Plate 4.6 (b) Survival of *S. aureus* (10^5cfu/0.1ml)

72 hrs Contact Time — Before Wash | After Wash

96 hrs Contact Time — Before Wash | After Wash

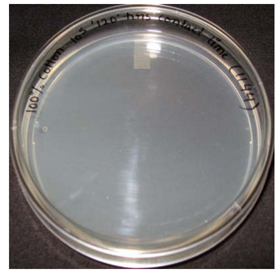


C:B = Cotton:Bamboo

Plate 4.6 (c) Survival of *S. aureus* (10^5cfu/0.1ml)

120 hrs Contact Time

Before Wash | After Wash

100:0 C:B


70:30 C:B


50:50 C:B


30:70 C:B


0:100 C:B

C:B = Cotton:Bamboo

and 0:100 cotton-bamboo fabrics, percent increment by 66.7% was noticed over initial reading. After 72 hours contact time (Plate 4.6 b), number of *S. aureus* colonies increased by 133.3% on 100% cotton fabric, reduced by 33.3% on 30:70 and 0:100 cotton-bamboo fabrics respevtively whereas 0% reduction (similar readings as initial reading) was observed on 70:30 and 50:50 cotton-bamboo fabrics respectively over initial reading. After 96 hours contact time (Plate 4.6 b), number of *S. aureus* colonies reduced by 66.7% on 100:0, 70:30 and 50:50 cotton-bamboo fabrics respectively whereas 100% reduction was observed on 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. On 120 hours contact time (Plate 4.6 c), 100% reduction in number of *S. aureus* colonies was observed among all pure and blended cotton-bamboo fabric samples respectively over initial reading.

Significant difference was observed for the survival of *S. aureus* among different cotton-bamboo woven fabrics and among different contact hours at 5% level of significance. Critical difference showed significant difference between various pairs of fabric samples and contact hours. Similarly the effect of interaction of the two factors i.e. fabric samples and contact hours was also found significant. The CD values at 5% level of significance for factor a i.e. different fabric samples, factor b i.e. different contact hours and a*b i.e. interaction between different fabric samples at different contact hours were

1.79, 1.79 and 4.00 respectively for before washed cotton-bamboo fabric samples *(Appendix X, a).*

It is evident from Table 4.21 (Fig 4.20) that after 24 hours contact time (Plate 4.6 a), number of *S. aureus* colonies increased by 66.7% only on after washed 100% cotton fabric whereas 100% reduction was observed on 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics over initial reading. Complete reduction (100%) in the number of *S. aureus* colonies was observed after 48, 72, 96 and 120 hours contact time (Plate 4.6 a, b and c) among all after washed 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics over initial reading.

Anonymous[12] (2009) stated that 100% bamboo fabric exhibits 99.8% antibacterial kill rate after the 24-hour period against *S. aureus* and also showed antibacterial efficacy (greater than) 70% after 50 industrial washings. As Methicillin resistant Staphylococcus aureus (MRSA), a form of staph bacteria is blamed for about 13 % of the nation's two million hospital infections each year. The results of the present study clearly indicate that the incorporation of least percentage of bamboo in fabrics is beneficial against *S. aureus*.

It is evident from Table 4.22 (Fig 4.21) that after 24 hours contact time (Plate 4.7 a), number of *E. coli* colonies increased by 560%, 440%, 420%, 300% and 200% on before washed 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over

Table 4.22 Survival and percent reduction of *E. coli* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *E. coli* (BEFORE WASH) 10⁵ cfu/0.1 ml inocula					
	0 contact time (initial)	24 hours contact time	48 hours contact time	72 hours contact time	96 hours contact time	120 hours contact time
100:0 Cotton:Bamboo		33+ **(-560)**	7+ **(-40)**	7+ **(-40)**	7+ **(-40)**	6+ **(-20)**
70:30 Cotton:Bamboo		27+ **(-440)**	6+ **(-20)**	3+ **(40)**	2+ **(60)**	1+ **(80)**
50:50 Cotton:Bamboo	5	26+ **(-420)**	4+ **(20)**	2+ **(60)**	2+ **(60)**	1+ **(80)**
30:70 Cotton:Bamboo		20+ **(-300)**	3+ **(40)**	1+ **(80)**	0+ **(100)**	0+ **(100)**
0:100 Cotton:Bamboo		15+ **(-200)**	2+ **(60)**	0+ **(100)**	0+ **(100)**	0+ **(100)**

Table 4.23 Survival and percent reduction of *E. coli* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *E. coli* (AFTER WASH) 10⁵ cfu/0.1 ml inocula					
	0 contact time (initial)	24 hours contact time	48 hours contact time	72 hours contact time	96 hours contact time	120 hours contact time
100:0 Cotton:Bamboo		32+ **(-700)**	5+ **(-25)**	1+ **(75)**	1+ **(75)**	0+ **(100)**
70:30 Cotton:Bamboo		21+ **(-425)**	4+ **(0)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
50:50 Cotton:Bamboo	4	19 **(-375)**	3 **(25)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
30:70 Cotton:Bamboo		15 **(-275)**	2 **(50)**	0+ **(100)**	0+ **(100)**	0+ **(100)**
0:100 Cotton:Bamboo		10 **(-150)**	1 **(75)**	0+ **(100)**	0+ **(100)**	0+ **(100)**

NOTE:
+ Average of 4 replications
The positive figure in parenthesis indicates the % reduction whereas a negative figure in parenthesis indicates the % increment over initial reading i.e. reading at 0 contact time

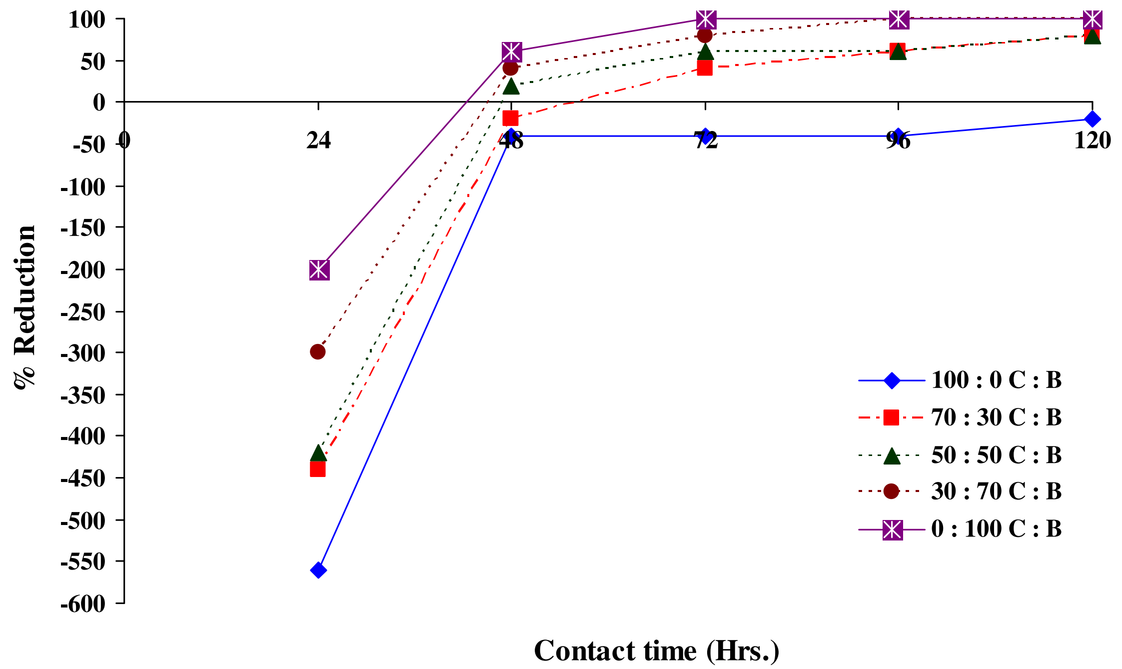


Fig. 4.21 Percent reduction of *E. coli* over initial reading (before wash)

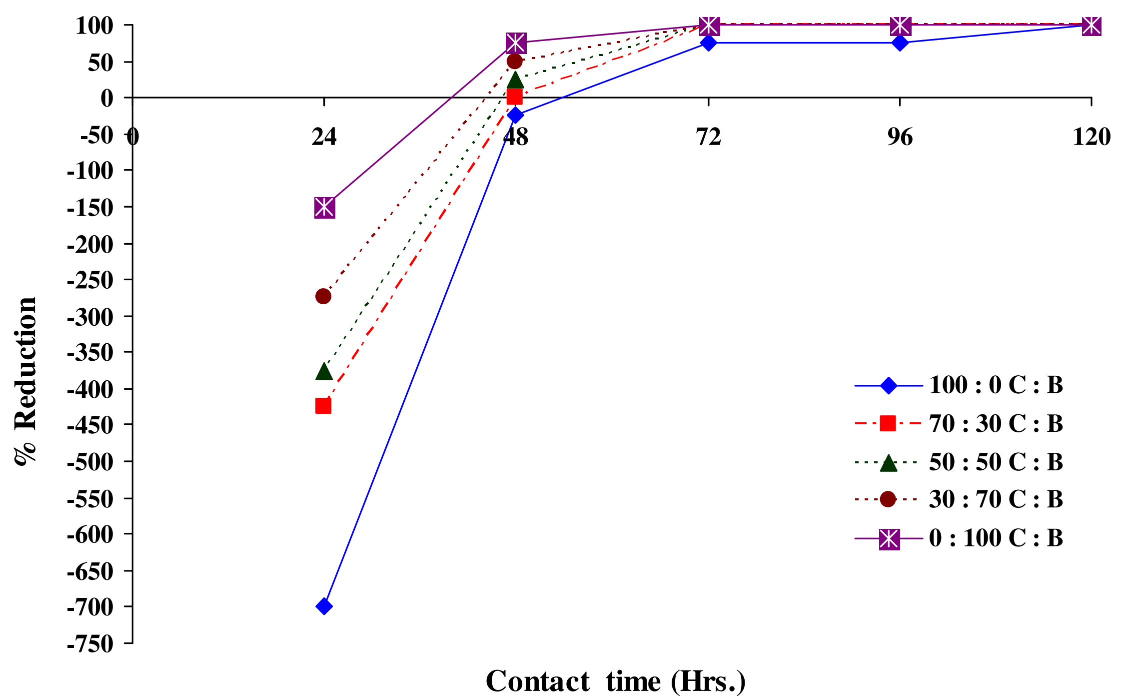
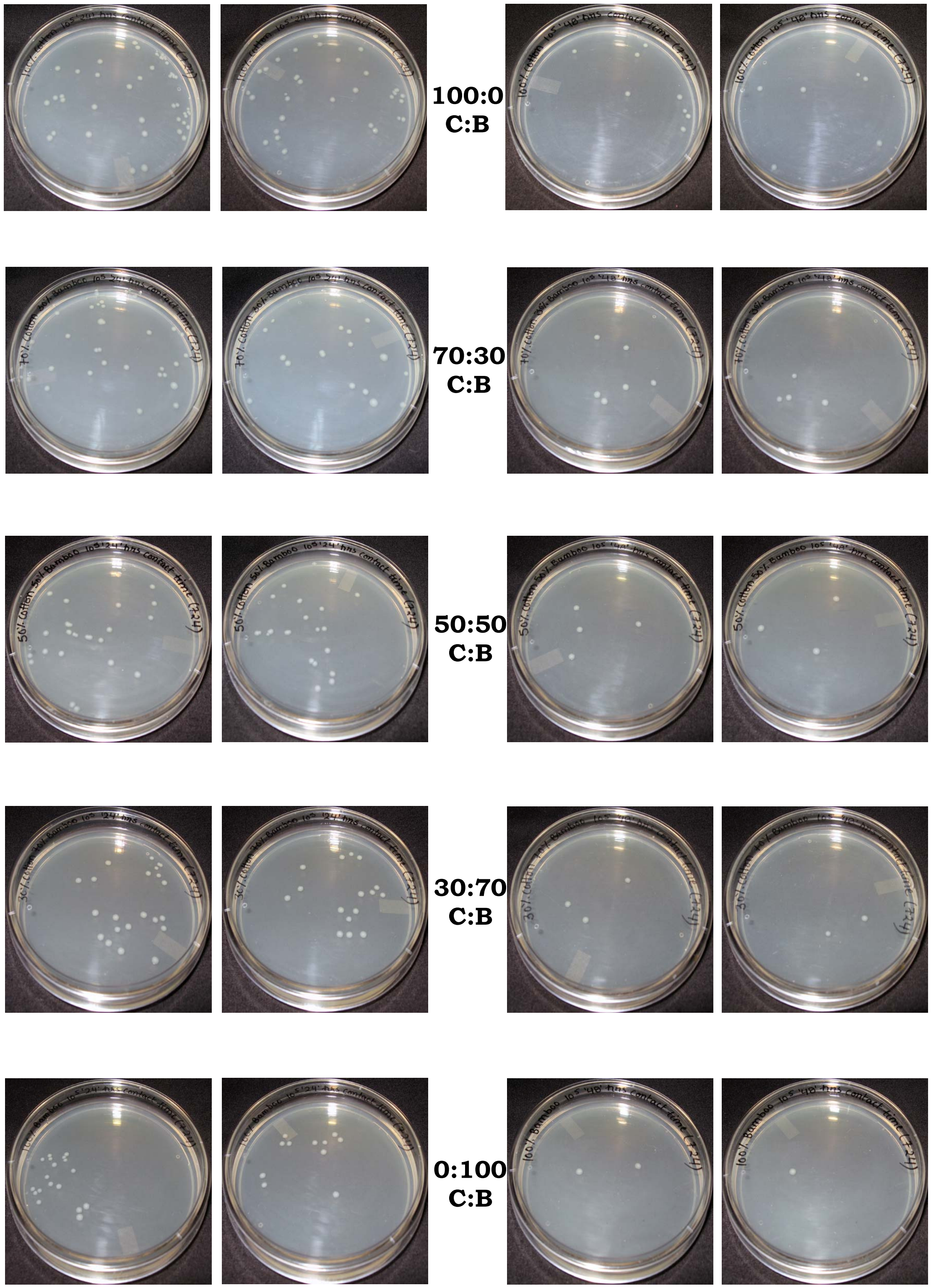


Fig. 4.22 Percent reduction of *E. coli* over initial reading (after wash)

Plate 4.7 (a) Survival of *E. coli* (10^5cfu/0.1ml)

24 hrs Contact Time | 48 hrs Contact Time

Before Wash | After Wash | Before Wash | After Wash

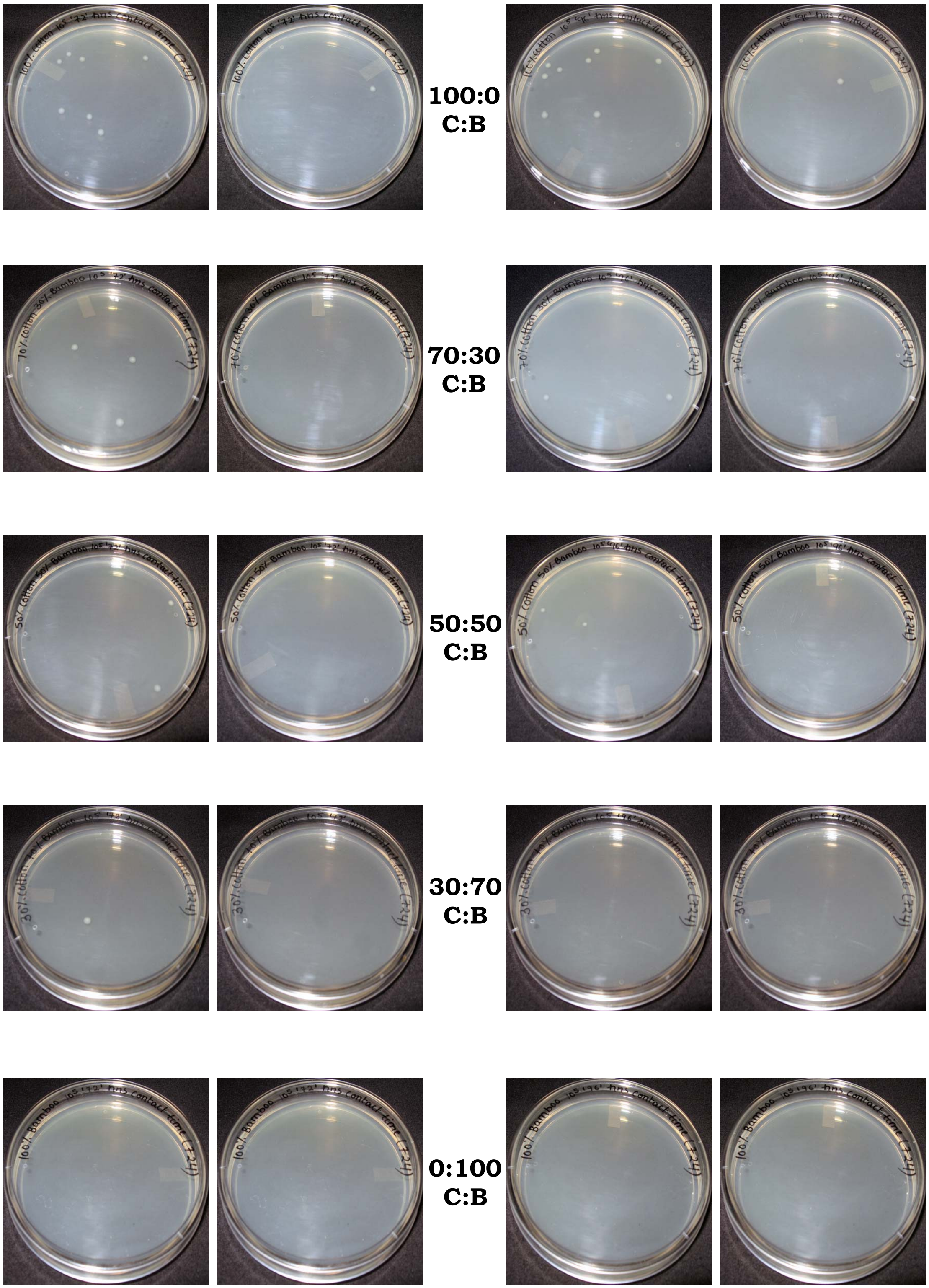


C:B = Cotton:Bamboo

Plate 4.7 (b) Survival of *E. coli* (10^5cfu/0.1ml)

72 hrs Contact Time | 96 hrs Contact Time

Before Wash | After Wash | Before Wash | After Wash

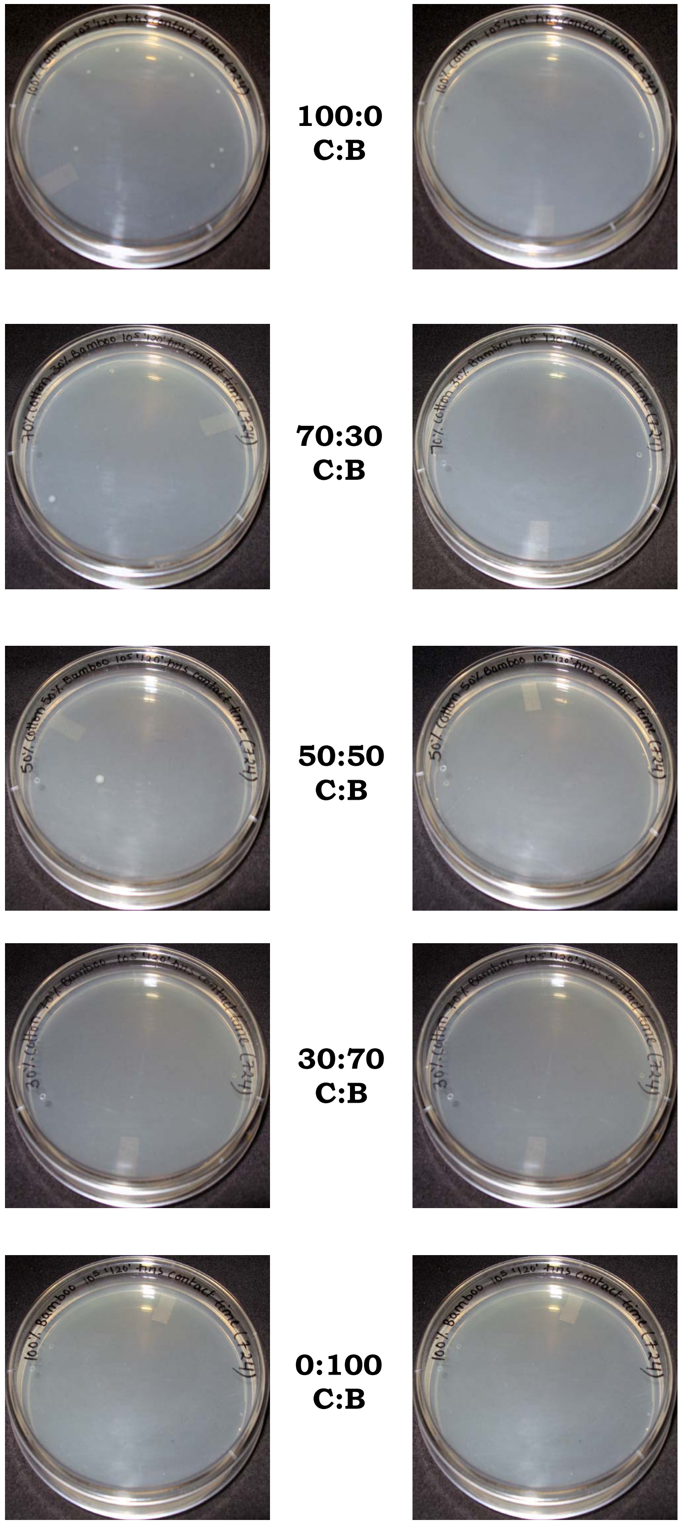


C:B = Cotton:Bamboo

Plate 4.7 (c) Survival of *E. coli* (10^5cfu/0.1ml)

120 hrs Contact Time

Before Wash | After Wash



C:B = Cotton:Bamboo

initial reading. After 48 hours contact time (Plate 4.7 a), number of *E. coli* colonies increased by 40% and 20% on before washed 100:0 and 70:30 cotton-bamboo fabric whereas reduced by 20%, 40% and 60% on 50:50, 30:70, 0:100 cotton-bamboo fabrics respectively over initial reading. After 72 hours contact time (Plate 4.7 b), number of colonies increased by 40% on 100% cotton fabric whereas number of *E. coli* colonies reduced by 40%, 60%, 80% and 100% on 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 96 hours contact time (Plate 4.7 b), *E. coli* colonies increased by 40% on 100% cotton fabric, reduced by 60% on 70:30 and 50:50 cotton-bamboo fabrics respectively whereas 100% reduction was observed on 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 120 hours contact time (Plate 4.7 c), number of *E. coli* colonies increased by 20% on 100% cotton fabric, reduced by 80% on 70:30 and 50:50 cotton-bamboo fabrics whereas 100% reduction was observed on 30:70 and 0:100 cotton-bamboo fabrics.

It is evident from Table 4.23 (Fig 4.22) that after 24 hours contact time (Plate 4.7 a), number of *E. coli* colonies increased by 700%, 425%, 375%, 275% and 150% among all after washed 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 48 hours contact time (Plate 4.7 a), *E. coli* colonies increased by 25% only on 100% cotton fabric, whereas 0%

reduction was observed on 70:30 cotton-bamboo fabric over initial reading. However, number of *E. coli* colonies reduced by 25%, 50% and 75% on 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 72 and 96 (Plate 4.7 b) hours contact time number of *E. coli* colonies reduced by 75% on 100% cotton fabric whereas 100% reduction was observed on 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 120 hours contact time, 100% reduction was observed (Plate 4.7 c) among all after washed 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading.

Significant difference was observed for the survival of *E. coli* among different cotton-bamboo woven fabrics and among different contact hours at 5% level of significance. Critical difference showed significant difference between various pairs of fabric samples and contact hours. Similarly the effect of interaction of the two factors i.e. fabric samples and contact hours was also found significant. The CD values at 5% level of significance for factor a, b and a*b were 1.38, 1.38 and 3.09 respectively for before washed and 0.64, 0.64 and 1.43 respectively for after washed cotton-bamboo fabric samples *(Appendix X, c & d).*

Subrata (2008) has asserted that bacteria will propagate rapidly in cotton and other fibers obtained from wood pulp, forming bad smell and even cause early degradation of the fiber in some cases. But it will be killed by 75% after 24 hours later in bamboo fiber. **Gupta and Bhaumik (2007)** stated that the rougher the fabric surface, the more is the retention of microbes. Therefore, the growth of bacteria was noticed more on cotton fabrics than bamboo incorporated fabric samples. *S. aureus* is responsible for pyrogenic infections (heat producing) and skin infections whereas *E.coli* is responsible for urinary infections. Besides that, both the bacteria's are responsible for causing body odors.

Erdem and Yurudu (2008) stated that 62:38% cotton-polyester fabric treated with dimethlytetradecyl (3-(trimethoxysilyl) ammonium chloride showed better antibacterial activity i.e. 98% reduction after 60 minutes contact time against *S. aureus, E. coli*, *K. pneumoniae* than untreated ones. **Basu and Balasubramaniyan (2008)** stated that bamboo fabric showed 69% reduction against *S. aureus* in comparison with cotton and rayon. **Gomathi and Manoharan (2009)** also indicated that bamboo potentially resists the colonization of bacteria i.e. *S. aureus* and *E.coli* from the second day of incubation as compared to cotton and rayon. **Devi *et al.* (2007)** stated that antibacterial property of bamboo fiber is three times more effective than cotton.

It is clear from the results that survivability of both the bacteria's i.e. *S. aureus* and *E.coli* on cotton was more lasting as compared to bamboo incorporated fabric samples. It was observed that as the percentage of bamboo increased in the fabric samples, antibacterial property also enhanced and this property was seen more on after washed fabric samples as compared to before washed fabric samples. This might be due to the removal of sizing and other materials applied on the yarns and fabrics during yarn and fabric manufacturing processes respectively or might be due the degradation of the carbon source present in the textile materials as food for microbial growth. The general survivability of the test organism *S. aureus*, was less as compared to *E. coli* on experimental fabrics. The results obtained indicated that bamboo potentially resists the colonization of both *S. aureus* from the first day of incubation and *E. coli* from the second day of incubation, which is an indication of bamboo's antibacterial resistance characteristics.

4.10.2.2 Quantitative assessment of antifungal activity

Quantitative assessment of antifungal activity against known test organisms i.e. *A. niger* and *T. reesei* was carried out to demonstrate the survivability of fungi on five experimental fabrics after constant periods of incubation with the standard inoculum at the start of experiment, to know the extent of fungal resistance on experimental fabrics as fungi's normally grow under normal storage and usage conditions.

Table 4.24 (Fig 4.23) that after 48 hours contact time (Plate 4.8 a), number of *A. niger* colonies increased by 11.1% and 44.4% on before washed 100:0 and 0:100 cotton-bamboo fabrics respectively whereas reduced by 22.2%, 55.5% and 66.7% on before washed 70:30, 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading. After 96 hours contact time (Plate 4.8 a), number of *A. niger* colonies increased by 11.1% on before washed 100:0 cotton-bamboo fabric, 0% reduction was observed on 70:30 cotton-bamboo fabric whereas reduced by 33.3%, 66.7% and 22.2% on 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 144 hours contact time (Plate 4.8 b), number of *A. niger* colonies increased by 11.1% on 100% cotton fabric, 77.7% on 30:70 and 0:100 cotton-bamboo fabric respectively, reduced by 66.7% on 70:30 cotton-bamboo fabric whereas 0% reduction was observed on 50:50 cotton-bamboo fabric over initial reading. After 192 hours contact time (Plate 4.8 b), number of *A. niger* colonies increased by 44.4%, 11.1% and 77.7% on 100:0, 30:70 and 0:100 cotton-bamboo fabrics respectively whereas 55.5% and 11.1% reduction in the number of *A. niger* colonies was observed on 70:30 and 50:50 cotton-bamboo fabrics over initial reading. After 240 hours contact time (Plate 4.8 c), 0% reduction was observed on 100% cotton fabric, number of *A. niger* colonies reduced by 77.8%, 44.4% and 66.7% on 70:30, 50:50 and 30:70 cotton-bamboo fabrics respectively whereas

Table 4.24 Survival and percent reduction of *A. niger* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *A. niger* (BEFORE WASH) 10² cfu/0.1 ml inocula							
	0 contact time (initial)	48 hours contact time	96 hours contact time	144 hours contact time	192 hours contact time	240 hours contact time	288 hours contact time	336 hours contact time
100:0 Cotton:Bamboo	9	10+ **(-11.1)**	10+ **(-11.1)**	10+ **(-11.1)**	13+ **(-44.4)**	9+ **(0)**	9+ **(0)**	13+ **(-44.4)**
70:30 Cotton:Bamboo		7+ **(22.2)**	9+ **(0)**	3+ **(66.7)**	4+ **(55.5)**	2+ **(77.8)**	8+ **(11.1)**	6+ **(33.3)**
50:50 Cotton:Bamboo		4+ **(55.5)**	6+ **(33.3)**	9+ **(0)**	8+ **(11.1)**	5+ **(44.4)**	8+ **(11.1)**	3+ **(66.7)**
30:70 Cotton:Bamboo		3+ **(66.7)**	3+ **(66.7)**	16+ **(-77.7)**	10+ **(-11.1)**	3+ **(66.7)**	3+ **(66.7)**	3+ **(66.7)**
0:100 Cotton:Bamboo		13+ **(-44.4)**	7+ **(22.2)**	16+ **(-77.7)**	16+ **(-77.7)**	14+ **(-55.6)**	12+ **(-33.3)**	20+ **(-122.2)**

Table 4.25 Survival and percent reduction of *A. niger* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *A. niger* (AFTER WASH) 10² cfu/0.1 ml inocula							
	0 contact time (initial)	48 hours contact time	96 hours contact time	144 hours contact time	192 hours contact time	240 hours contact time	288 hours contact time	336 hours contact time
100:0 Cotton:Bamboo	8	13+ **(-62.5)**	9+ **(-12.5)**	9+ **(-12.5)**	8+ **(0)**	8+ **(0)**	13+ **(-62.5)**	19+ **(-137.5)**
70:30 Cotton:Bamboo		4+ **(50)**	8+ **(0)**	9+ **(-12.5)**	1+ **(87.5)**	4+ **(50)**	7+ **(12.5)**	0+ **(100)**
50:50 Cotton:Bamboo		4+ **(50)**	3+ **(62.5)**	3+ **(62.5)**	8+ **(0)**	6+ **(25)**	5+ **(37.5)**	0+ **(100)**
30:70 Cotton:Bamboo		14+ **(-75)**	5+ **(37.5)**	4+ **(50)**	3+ **(62.5)**	2+ **(75)**	5+ **(37.5)**	0+ **(100)**
0:100 Cotton:Bamboo		14+ **(-75)**	3+ **(62.5)**	7+ **(12.5)**	4+ **(50)**	2+ **(75)**	9+ **(-12.5)**	3+ **(62.5)**

NOTE:
+ Average of 4 replications
The positive figure in parenthesis indicates the % reduction whereas a negative figure in parenthesis indicates the % increment over initial reading i.e. reading at 0 contact time

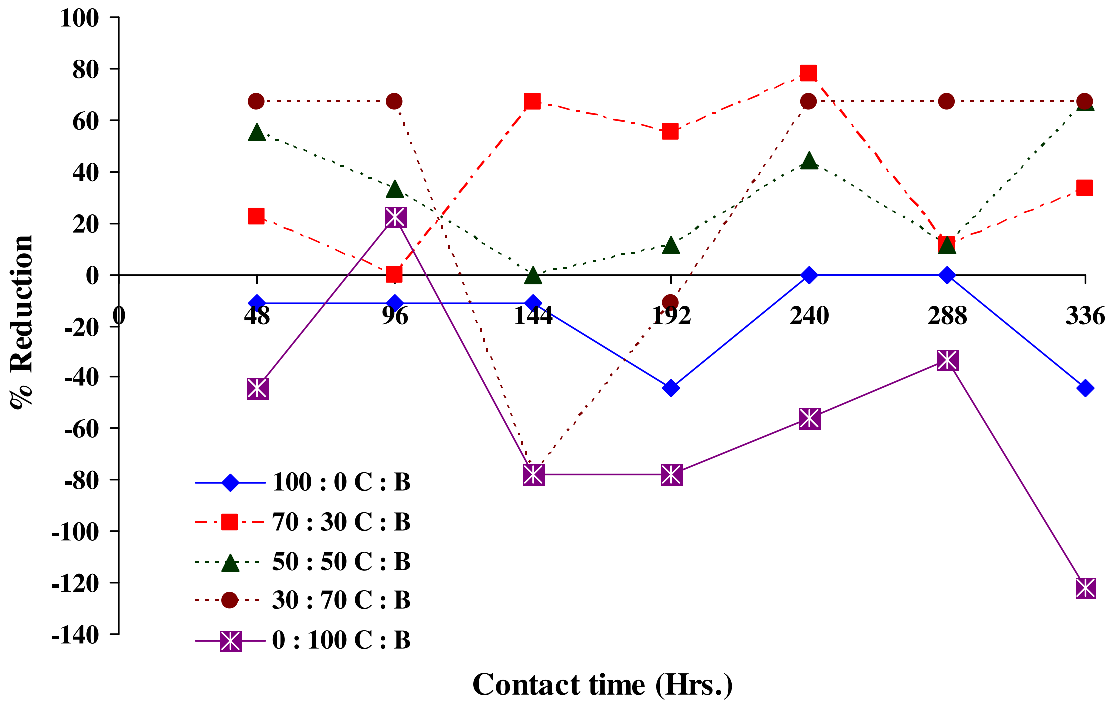


Fig. 4.23 Percent reduction of *A. niger* over initial reading (before wash)

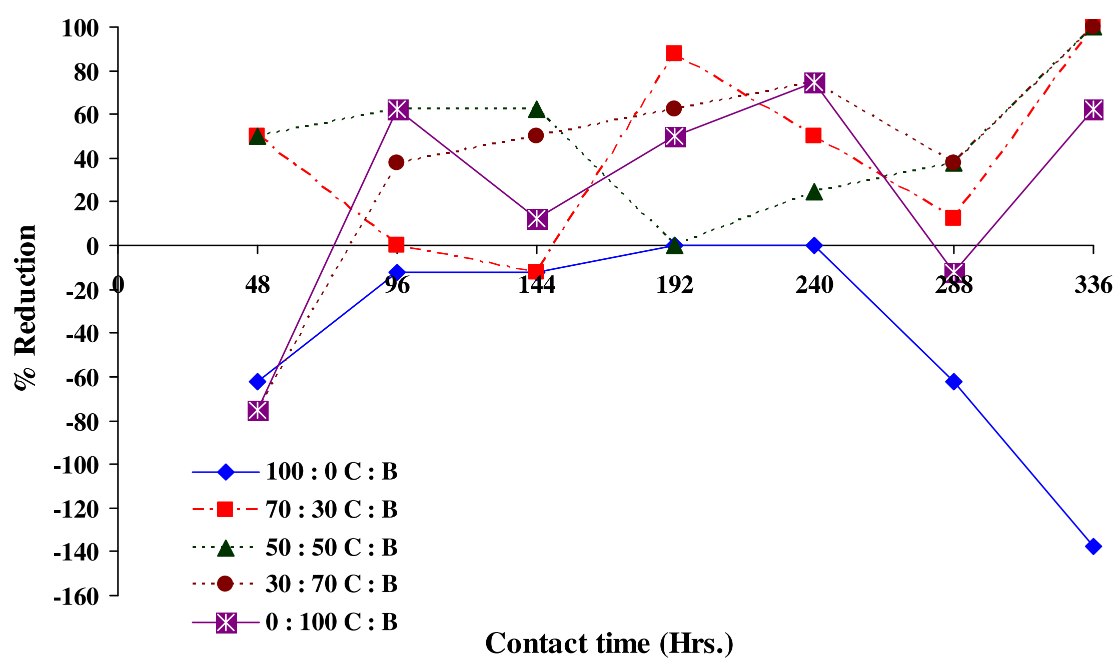
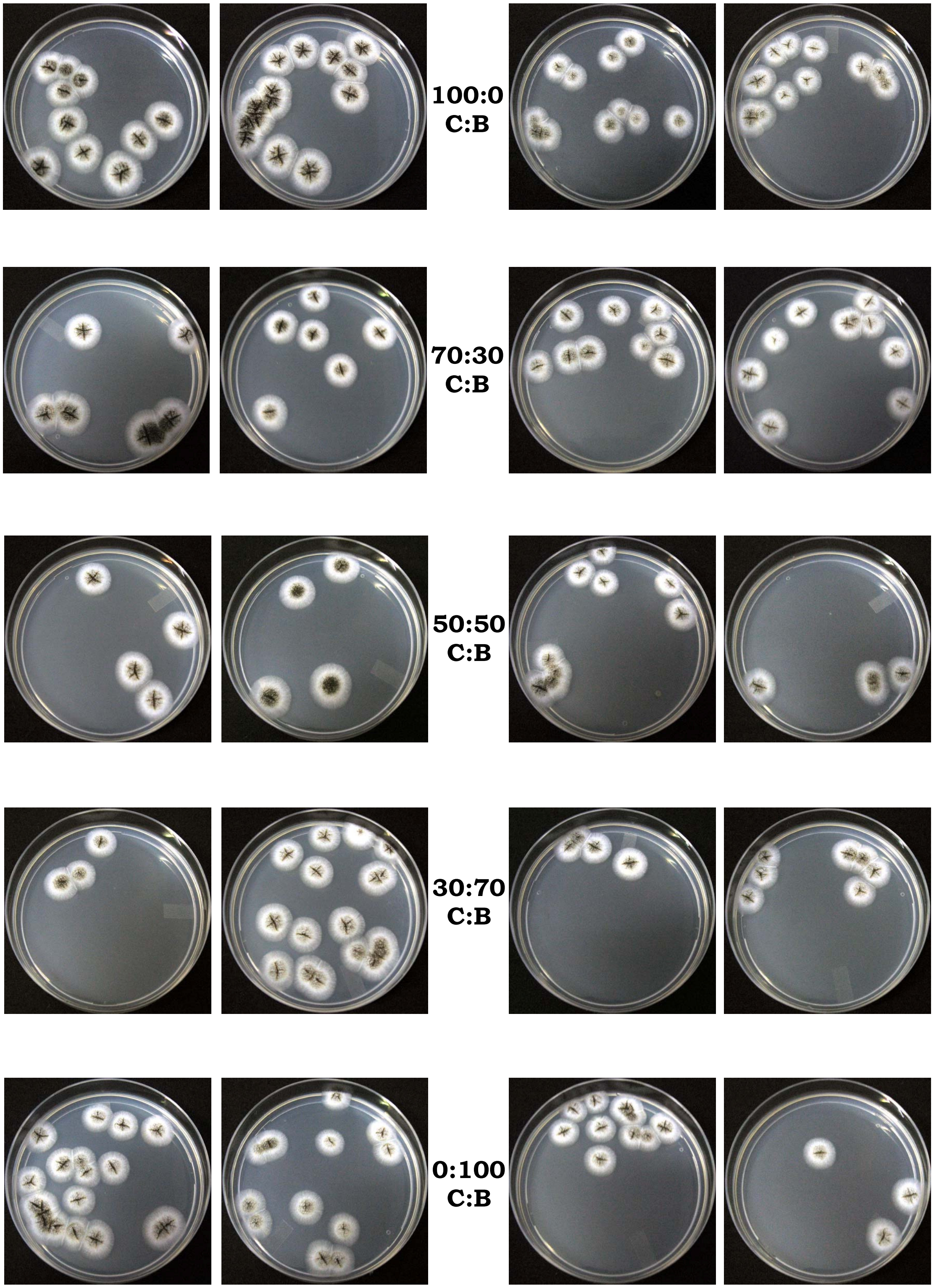


Fig. 4.24 Percent reduction of *A. niger* over initial reading (after wash)

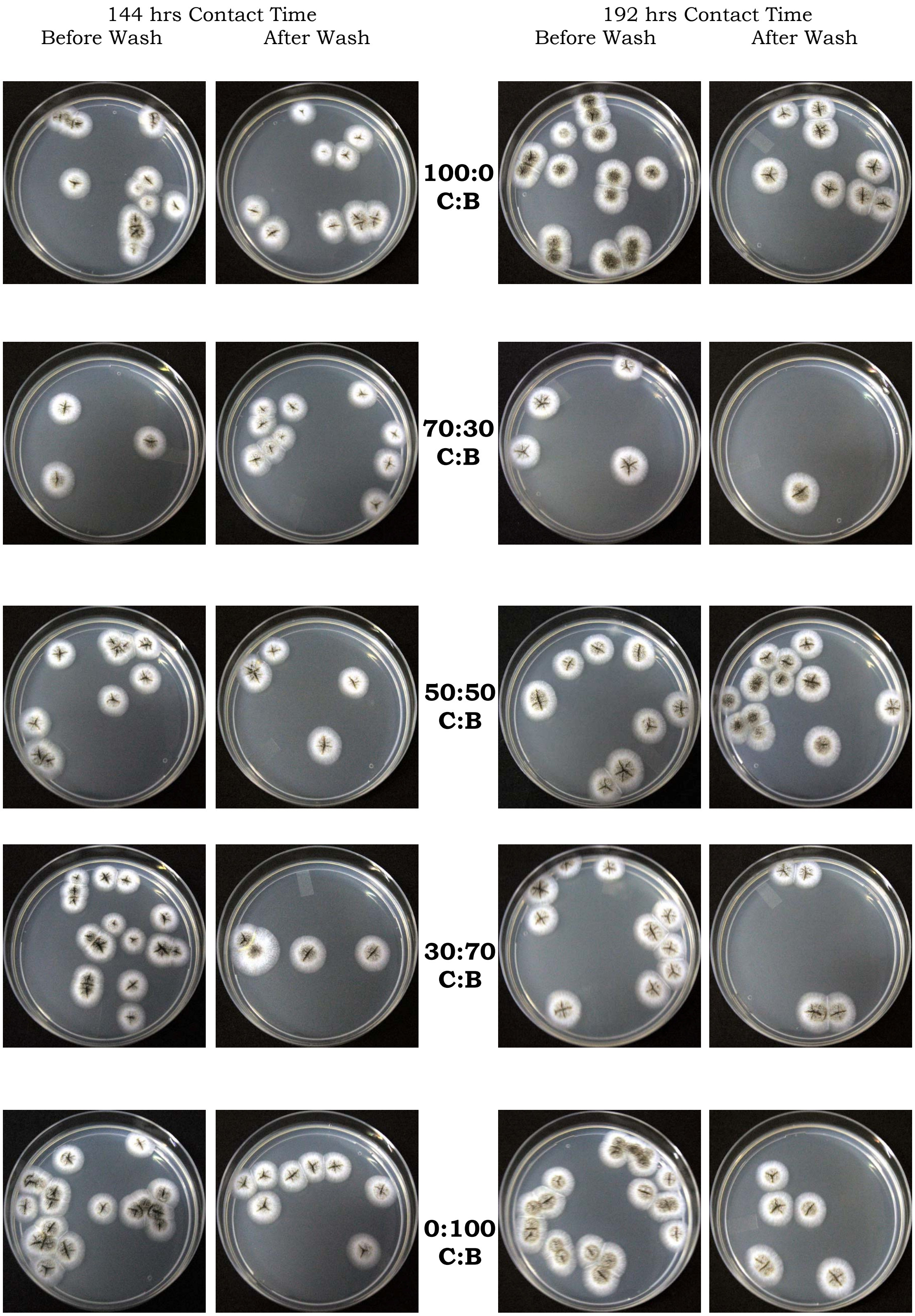
Plate 4.8 (a) Survival of *A. niger* (10^2cfu/0.1ml)

48 hrs Contact Time — Before Wash | After Wash
96 hrs Contact Time — Before Wash | After Wash



C:B = Cotton:Bamboo

Plate 4.8 (b) Survival of *A. niger* (10^2cfu/0.1ml)

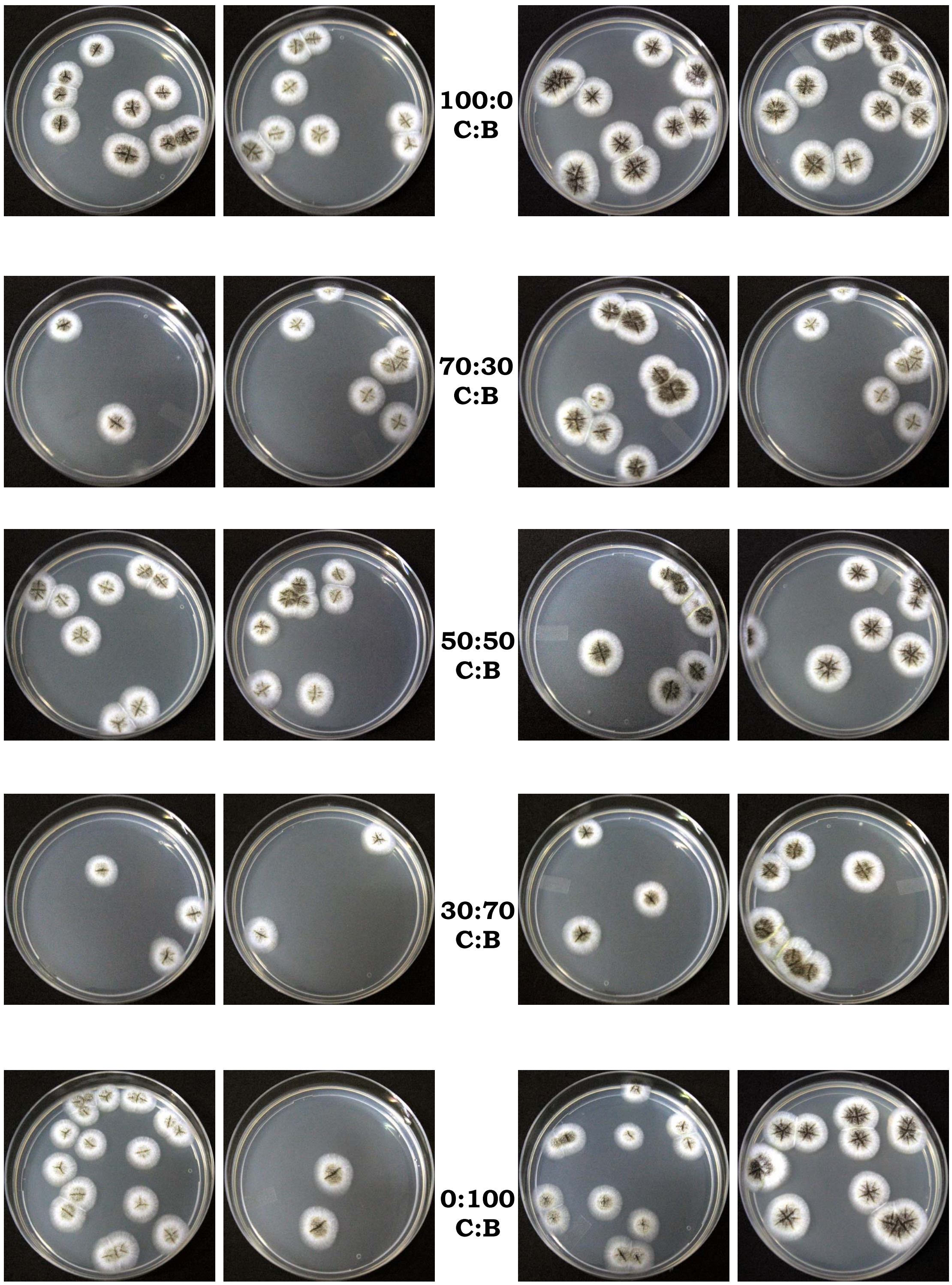


C:B = Cotton:Bamboo

Plate 4.8 (c) Survival of *A. niger* (10^2cfu/0.1ml)

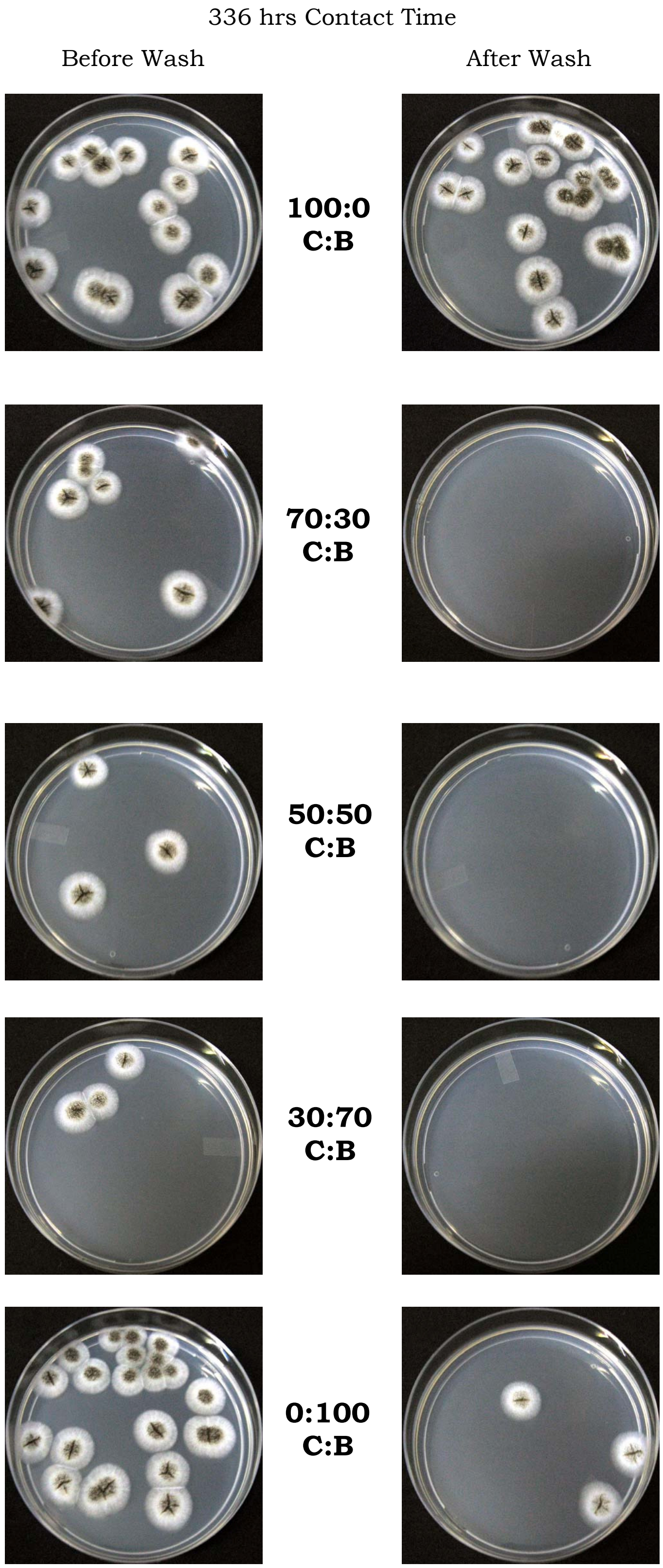
240 hrs Contact Time — Before Wash | After Wash

288 hrs Contact Time — Before Wash | After Wash



C:B = Cotton:Bamboo

Plate 4.8 (d) Survival of *A. niger* (10^2cfu/0.1ml)



C:B = Cotton:Bamboo

55.6% increment was observed on 100% bamboo fabric over initial reading. After 288 hours contact time (Plate 4.8 c), 0% reduction was observed on 100% cotton fabric, number of *A. niger* colonies reduced by 11.1% on 70:30 and 50:50 and 66.7% on 30:70 cotton-bamboo fabrics respectively whereas 33.3% increment was observed on 100% bamboo fabric over initial reading. After 336 hours contact time (Plate 4.8 d), number of *A. niger* colonies increased by 44.4% and 122.2% on before washed 100:0 and 0:100 cotton-bamboo fabrics whereas reduced by 33.3% on 70:30 and 66.7% on 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading.

It is evident from Table 4.25 (Fig 4.24) that after 48 hours contact time (Plate 4.8 a), number of *A. niger* colonies increased by 62.5% on after washed 100% cotton fabric and 75% on 30:70 and 0:100 cotton-bamboo fabric whereas 50% reduction was observed on after washed 70:30 and 50:50 cotton-bamboo fabrics respectively over initial reading. After 96 hours contact time (Plate 4.8 a), number of *A. niger* colonies increased by 12.5% on after washed 100% cotton fabric, reduced by 62.5%, 37.5% and 62.5% on 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively whereas 0% reduction was observed on 70:30 cotton-bamboo fabric over initial reading. After 144 hours contact time (Plate 4.8 b), number of *A. niger* colonies increased by 12.5% on 100:0 and 70:30 cotton-bamboo fabrics respectively, whereas 62.5%, 50% and 12.5% reduction was observed on 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 192 hours contact time (Plate 4.8 b), 0% reduction was observed on 100:0 and 50:50 cotton-bamboo fabrics respectively whereas 87.5%, 62.5% and 50% reduction in the number of *A. niger* colonies was observed on 70:30, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 240 hours contact time (Plate 4.8 c), 0% growth was observed on 100% cotton fabric, number of *A. niger* colonies reduced by 50% and 25% on 70:30 and 50:50 cotton-bamboo fabrics respectively whereas 75% reduction was observed on 30:70 and 100:0 cotton-bamboo fabrics respectively over initial reading. After 288 hours contact time (Plate 4.8 c), number of *A. niger* colonies increased by 62.5% and 12.5% on 100:0 and 0:100 cotton-bamboo fabrics respectively whereas reduced by 12.5% on 70:30 and 66.7% and 37.5% on 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading. After 336 hours contact time (Plate 4.8 d), number of *A. niger* colonies increased by 137.5% on after washed 100% cotton fabric, reduced by 62.5% on 100% bamboo fabric whereas 100% reduction was observed on 70:30, 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading.

Significant difference was observed for the survival of *A. niger* among different cotton-bamboo woven fabrics and among different contact hours at 5% level of significance. Critical difference showed significant difference between various pairs of fabric samples and contact hours. Similarly the effect of interaction of the two factors i.e. fabric samples and contact hours was also found significant. The CD values at 5% level of significance for factor a, b and a*b were 1.06, 0.90 and 2.38 respectively for before washed and 0.83, 0.70 and 1.86 respectively for after washed cotton-bamboo fabric samples *(Appendix X, d & e).*

It is evident from Table 4.26 (Fig 4.25) that after 48 hours contact time (Plate 4.9 a), number of *T. reesei* colonies increased by 16.7% on before washed 100% cotton fabric whereas reduced by 33.3%, 16.7%, 50% and 33.3% on before washed 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics respectively over initial reading. After 96 hours contact time (Plate 4.9 a), number of *T. reesei* colonies reduced by 16.7% on 100:0 and 50:50 cotton-bamboo fabrics respectively, 66.7% on 70:30 and 0:100 respectively and 50% on 30:70 cotton-bamboo fabric over initial reading. After 144 hours contact time (Plate 4.9 b), number of *T. reesei* colonies reduced by 33.3% on 100:0, 70:30, 50:50 and 30:70 on cotton-bamboo fabrics respectively whereas 50% reduction was observed on 100% bamboo fabric over initial reading. After 192 hours contact time (Plate 4.9 b), 0% reduction was observed on 100% cotton fabric whereas number of *T. reesei* colonies reduced by 66.7% on 70:30 and 0:100, 33.3% on 50:50 and 50% on 30:70 cotton-bamboo fabrics respectively over

Table 4.26 Survival and percent reduction of *T. reesei* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *T. reesei* (BEFORE WASH) 10^3 cfu/0.1 ml inocula							
	0 contact time (initial)	48 hours contact time	96 hours contact time	144 hours contact time	192 hours contact time	240 hours contact time	288 hours contact time	336 hours contact time
100:0 Cotton:Bamboo		7+ **(-16.7)**	5+ **(16.7)**	4+ **(33.3)**	6+ **(0)**	4+ **(33.3)**	5+ **(16.7)**	6+ **(0)**
70:30 Cotton:Bamboo		4+ **(33.3)**	2+ **(66.7)**	4+ **(33.3)**	2+ **(66.7)**	4+ **(33.3)**	4+ **(33.3)**	3+ **(50)**
50:50 Cotton:Bamboo	6	5+ **(16.7)**	5+ **(16.7)**	4+ **(33.3)**	4+ **(33.3)**	5+ **(16.7)**	4+ **(33.3)**	5+ **(16.7)**
30:70 Cotton:Bamboo		3+ **(50)**	3+ **(50)**	4+ **(33.3)**	3+ **(50)**	5+ **(16.7)**	1+ **(83.3)**	2+ **(66.7)**
0:100 Cotton:Bamboo		4+ **(33.3)**	2+ **(66.7)**	5+ **(50)**	2+ **(66.7)**	1+ **(83.3)**	3+ **(50)**	6+ **(0)**

Table 4.27 Survival and percent reduction of *T. reesei* on pure and blended cotton-bamboo fabrics at different contact hours

Woven fabric samples	SURVIVAL AND % REDUCTION OF *T. reesei* (AFTER WASH) 10^3 cfu/0.1 ml inocula							
	0 contact time (initial)	48 hours contact time	96 hours contact time	144 hours contact time	192 hours contact time	240 hours contact time	288 hours contact time	336 hours contact time
100:0 Cotton:Bamboo		3+ **(50)**	1+ **(83.3)**	1+ **(83.3)**	2+ **(66.7)**	1+ **(83.3)**	1+ **(83.3)**	2+ **(66.7)**
70:30 Cotton:Bamboo		1+ **(83.3)**	1+ **(83.3)**	1+ **(83.3)**	2+ **(66.7)**	1+ **(83.3)**	0+ **(100)**	1+ **(83.3)**
50:50 Cotton:Bamboo	6	5+ **(16.7)**	3+ **(50)**	3+ **(50)**	1+ **(83.3)**	1+ **(83.3)**	3+ **(50)**	1+ **(83.3)**
30:70 Cotton:Bamboo		11+ **(-83.3)**	2+ **(66.7)**	3+ **(50)**	2+ **(66.7)**	1+ **(83.3)**	1+ **(83.3)**	1+ **(83.3)**
0:100 Cotton:Bamboo		3+ **(50)**	3+ **(50)**	1+ **(83.3)**	2+ **(66.7)**	2+ **(66.7)**	2+ **(66.7)**	2+ **(66.7)**

NOTE:
+ Average of 4 replications
The positive figure in parenthesis indicates the % reduction whereas a negative figure in parenthesis indicates the % increment over initial reading i.e. reading at 0 contact time

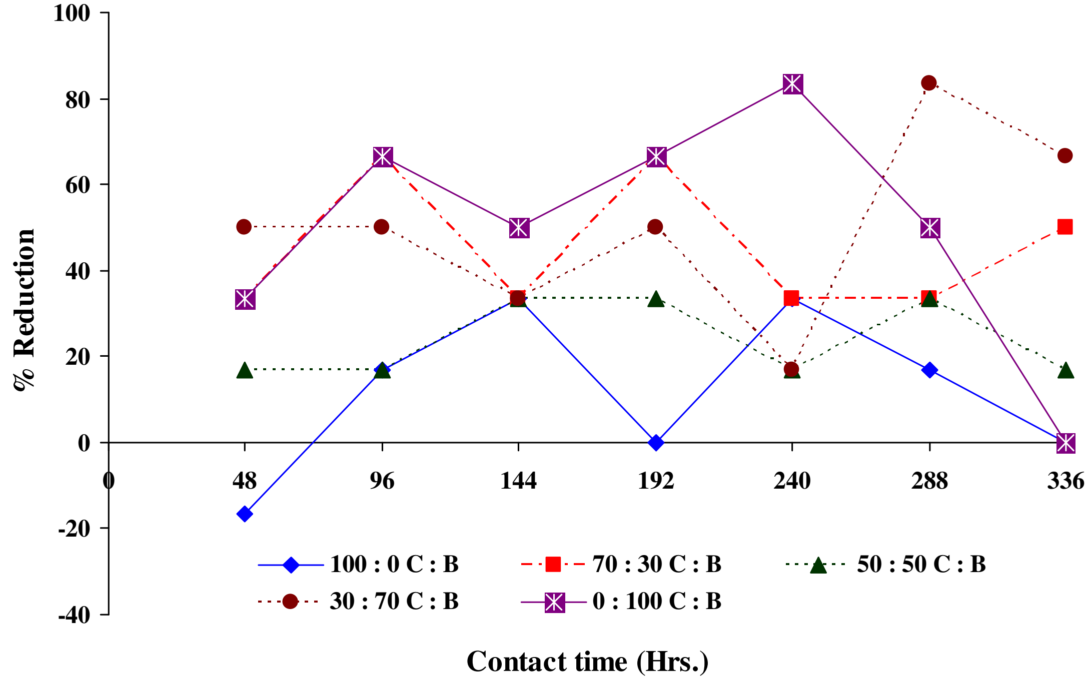


Fig. 4.25 Percent reduction of *T. reesei* over initial reading (before wash)

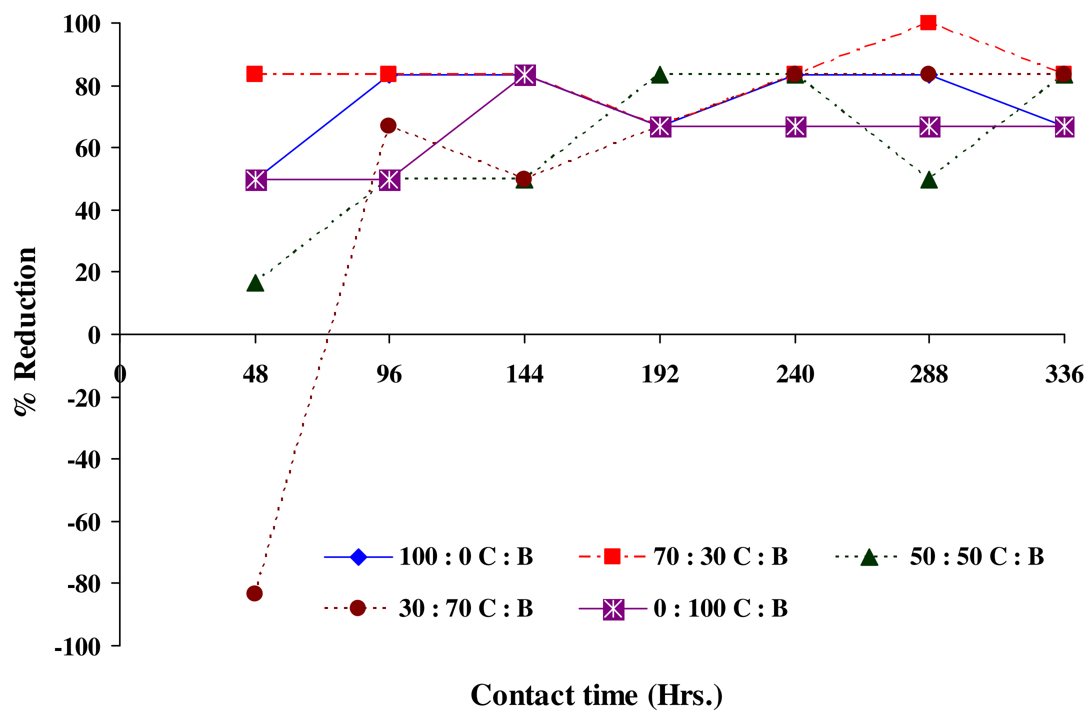
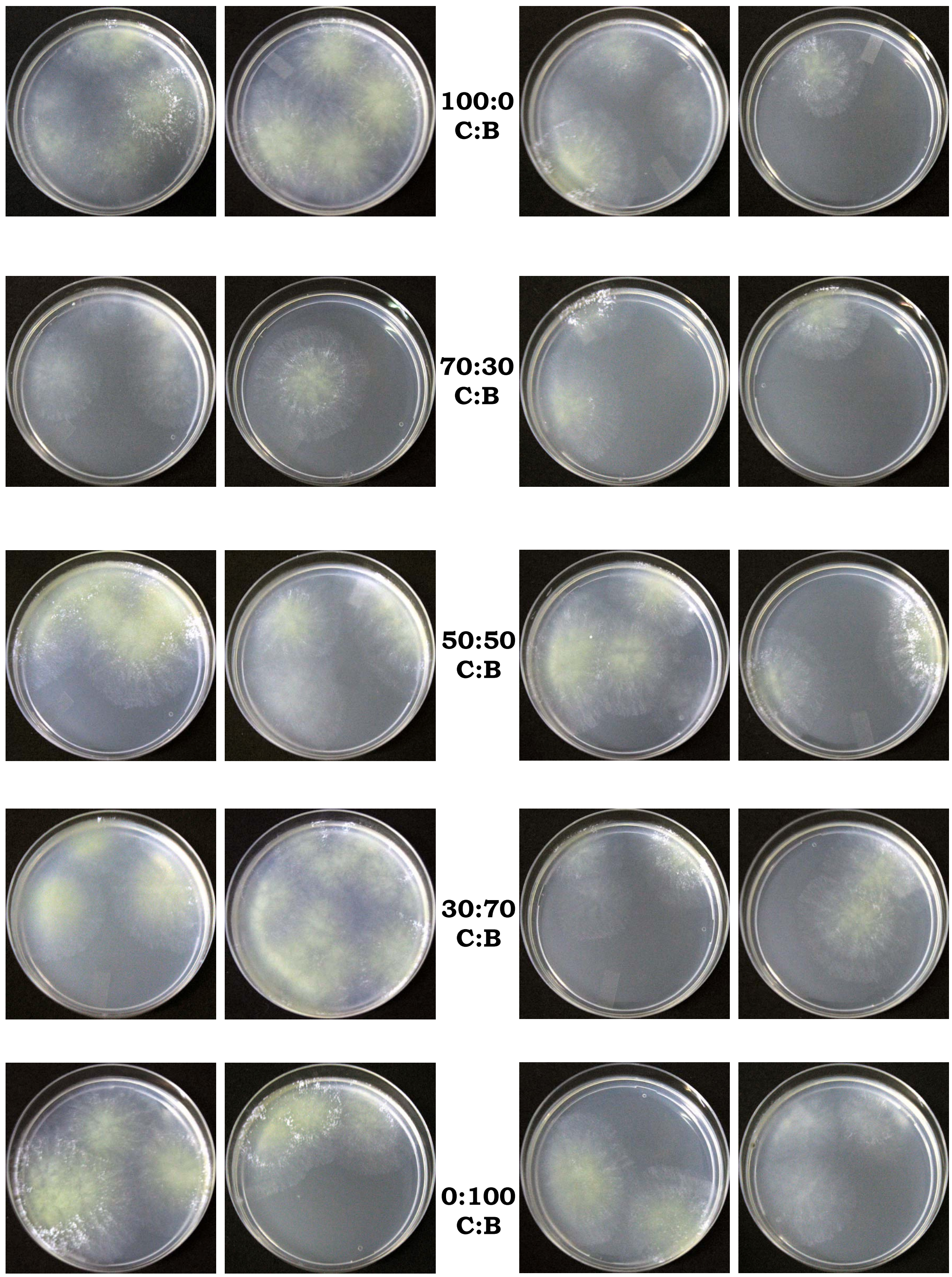


Fig. 4.26 Percent reduction of *T. reesei* over initial reading (after wash)

Plate 4.9 (a) Survival of *T. reesei* (10^3cfu/0.1ml)

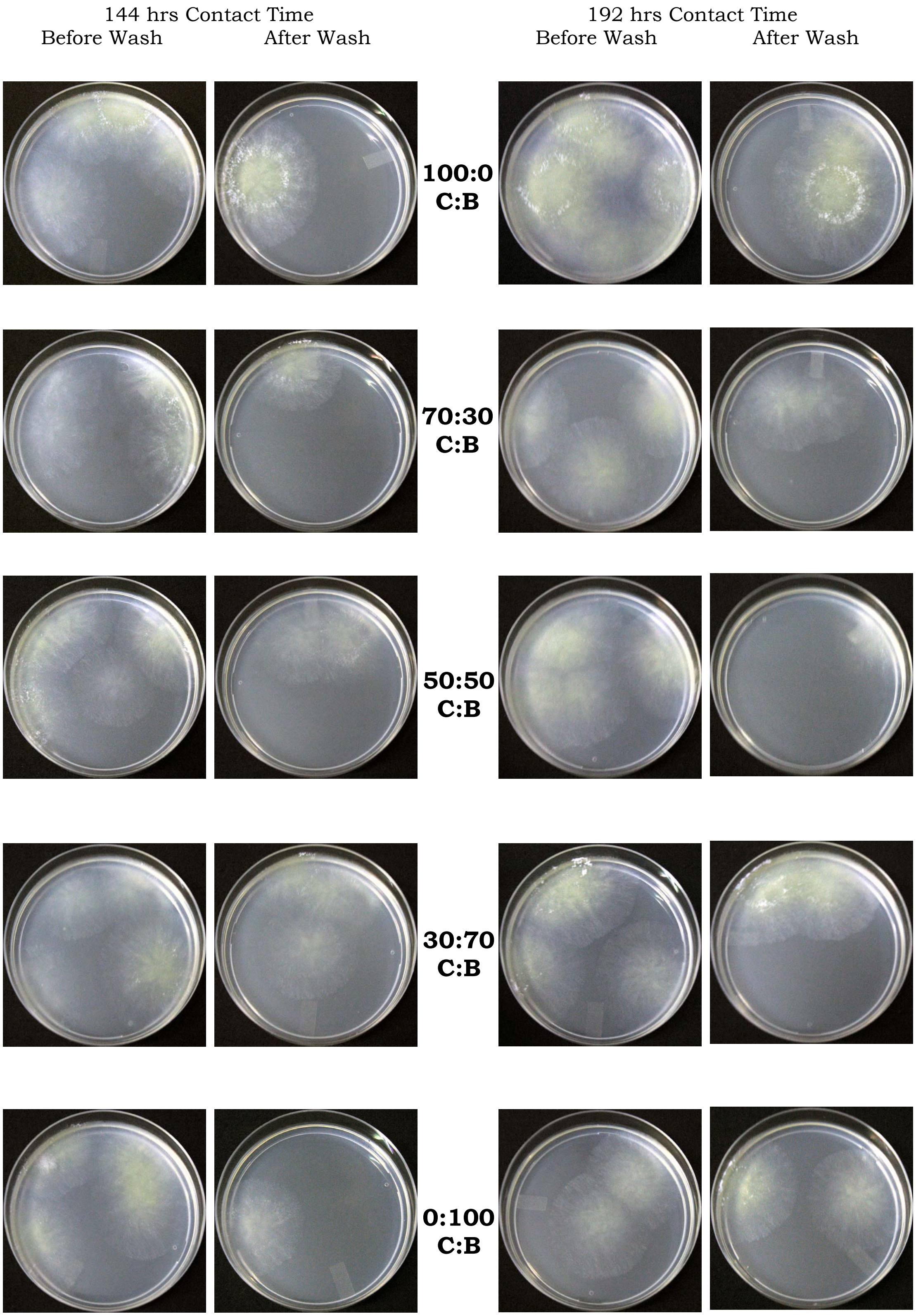
48 hrs Contact Time — Before Wash | After Wash

96 hrs Contact Time — Before Wash | After Wash



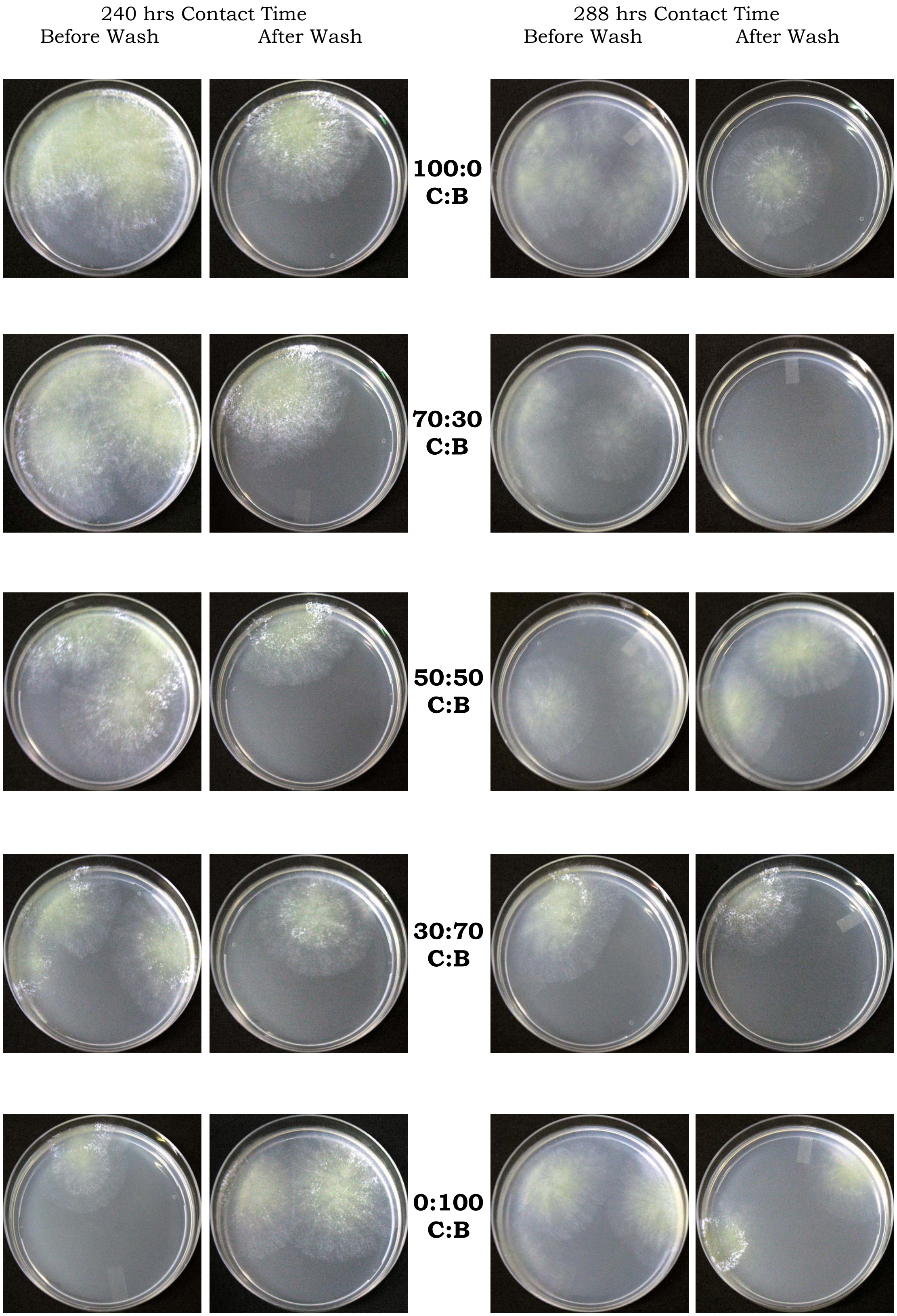
C:B = Cotton:Bamboo

Plate 4.9 (b) Survival of *T. reesei* (10^3cfu/0.1ml)



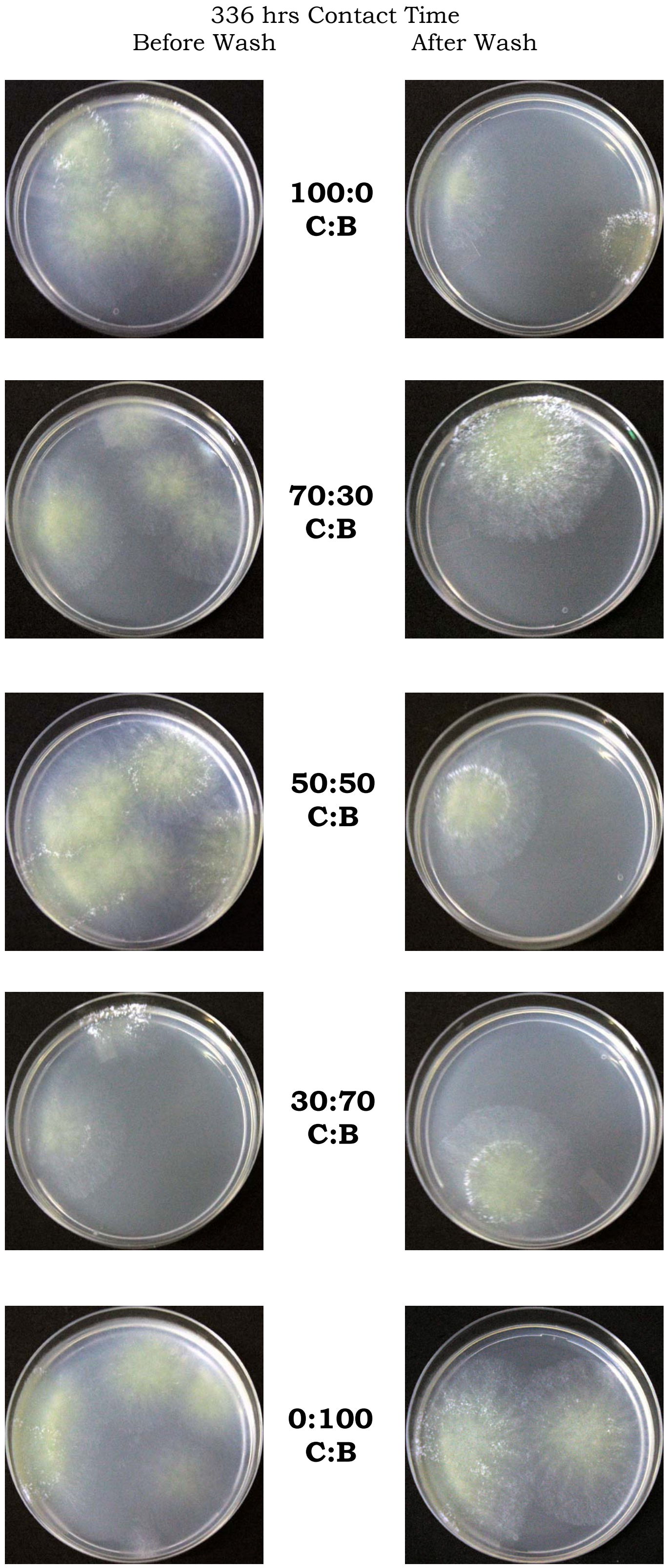
C:B = Cotton:Bamboo

Plate 4.9 (c) Survival of *T. reesei* (10^3cfu/0.1ml)



C:B = Cotton:Bamboo

Plate 4.9 (d) Survival of *T. reesei* (10^3cfu/0.1ml)



C:B = Cotton:Bamboo

initial reading. After 240 hours contact time (Plate 4.9 c), number of *T. reesei* colonies reduced by 33.3% on 100:0 and 70:30, 16.7% on 50:50 and 30:70 cotton-bamboo fabrics respectively whereas 83.3% reduction was observed on 100% bamboo fabric over initial reading. After 288 hours contact time (Plate 4.9 c), number of *T. reesei* colonies reduced by 16.7% on 100% cotton fabric, 33.3% on 70:30 and 50:50 and 83.3% on 30:70 cotton-bamboo fabrics respectively whereas 50% reduction was observed on 100% bamboo fabric over initial reading. After 336 hours contact time (Plate 4.9 d), 0% reduction was observed on 100% cotton and bamboo fabric respectively whereas number of *T. reesei* colonies reduced by 50%, 16.7% and 66.7% on 70:30, 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading.

It is evident from Table 4.27 (Fig 4.26) that after 48 hours contact time (Plate 4.9 a), number of *T. reesei* colonies reduced by 50% on 100% cotton and bamboo fabric respectively, 83.3% and 16.7% on after washed 70:30 and 50:50 cotton-bamboo fabrics respectively whereas increased by 83.3% on 30:70 cotton-bamboo fabric over initial reading. After 96 hours contact time (Plate 4.9 a), number of *T. reesei* colonies reduced by 83.3% on after washed 100:0 and 70:30 and 50% on 50:50 and 0:100 cotton-bamboo fabrics respectively whereas 66.7% reduction was observed on 30:70 cotton-bamboo fabric over initial reading. After 144 hours contact time (Plate 4.9 b), number of *T.*

reesei colonies reduced by 83.3% on after washed 100:0, 70:30 and 0:100 cotton-bamboo fabrics whereas 50% reduction was observed on 50:50 and 30:70 cotton-bamboo fabrics respectively over initial reading. After 192 hours contact time (Plate 4.9 b), reduction in the number of *T. reesei* colonies by 66.7% on 100:0, 70:30, 30:70 and 0:100 and 83.3% on 50:50 cotton-bamboo fabrics respectively was observed over initial reading. After 240 hours contact time (Plate 4.9 c), number of *T. reesei* colonies reduced by 83.3% on 100:0, 70:30 50:50 and 30:70 cotton-bamboo fabrics respectively whereas 66.7% reduction was observed on 100% bamboo fabric over initial reading. After 288 hours contact time (Plate 4.9 c), number of *T. reesei* colonies reduced by 83.3% on 100:0 and 30:70, 50% on 50:50, 66.7% on 0:100 cotton-bamboo fabrics respectively whereas 100% reduction was observed on 70:30 cotton-bamboo fabric over initial reading. After 336 hours contact time (Plate 4.9 d), number of *T. reesei* colonies reduced by 83.3% on after washed 70:30, 50:50 and 30:70 cotton-bamboo fabrics respectively whereas 66.7% reduction was observed on 100:0 and 0:100 cotton-bamboo fabrics respectively over initial reading.

Significant difference was observed for the survival of *T. reesei* among different cotton-bamboo woven fabrics and among different contact hours at 5% level of significance. Critical difference showed significant difference between various pairs of fabric samples and contact hours. Similarly the effect of interaction of the two factors i.e. fabric samples and contact hours was also found significant. The CD values at 5% level of significance for factor a, b and a*b were 0.58, 0.49 and 1.29 respectively for before washed and 0.48, 0.41 and 1.09 respectively for after washed cotton-bamboo fabric samples *(Appendix X, f & g).*

A. niger commonly found in indoor environment, responsible for deteriorating the cellulosic fabrics and also responsible for causing lung disease i.e. *Aspergillosis* when inhaled in large amounts and *Otomycosis* (ear infection) which causes pain, temporary hearing loss, damage to the ear canal and tympanic membrane **(Anonymous[13], 2009)**. **Lewin (2007)** stated that *T. reesei* is generally found in soil, degrades the cellulosic material with the help of enzymes known as cellulases.

Basu and Balasubramaniyan (2008) and **Gomathi and Manoharan (2009)** indicated that antifungal resistance of bamboo and cotton are equally efficient, when compared with rayon, but all the fabric samples under test supported the growth of *Trichoderma* and resisted the growth of *A. niger*.

It is clear from the present study that survivability of both the fungi's i.e. *A. niger* and *T. reesei* was more or less the same on all pure and blended cotton-bamboo fabric samples. This might be due to the fact that both cotton and bamboo fibers are hydrophilic in nature which allows the fungi to grow. It was observed that as the contact hours increased, bamboo incorporated fabric samples showed better antifungal property and reduction was seen more among after washed fabric samples as compared to before washed fabric samples.

Therefore, it can be concluded that the bamboo blended fabric samples showed better antifungal results in the long run, thus, can be used safely for making protective and healthcare textiles.

4.11 Assessment of bio-degradability rate of the woven fabrics

To address the growing concerns about the environment, present study was carried out to develop the reusable woven protective and healthcare textiles from biodegradable fibers, which reduced the amount of trash being disposed of in landfills. In the present study, bio-degradability assessment of all the pure and blended cotton-bamboo fabrics had been performed for twenty five days (starting from 0 day to 25 day) and differences in the bio-degradability rates of experimental fabrics after every five day interval had been observed and calculated.

It is evident from Table 4.28 (Fig 4.27) that percent reduction in weight i.e. 6.4%, 22.7% and 30.9% was observed among 100:0, 70:30 and 50:50 cotton-bamboo fabric samples respectively after 5 days interval whereas equal percentage of weight reduction i.e. 31.8% was noticed among 30:70 and 0:100 cotton-bamboo fabric

Table 4.28 Percent reduction in the weight of pure and blended cotton-bamboo fabrics at every five day interval

Woven fabric samples	Biodegradability assessment (Warp way)					
	Weight in grams and % reduction					
	0 day (initial weight)	After 5 day interval	After 10 day interval	After 15 day interval	After 20 day interval	After 25 day interval
100:0% Cotton:Bamboo	2.20	2.06+ **(6.4)**	1.86+ **(15.5)**	1.59+ **(27.7)**	1.23+ **(44.1)**	0.73+ **(66.8)**
70:30% Cotton:Bamboo		1.70+ **(22.7)**	1.10+ **(50.0)**	0.92+ **(58.2)**	0.73+ **(66.8)**	0.47+ **(78.6)**
50:50% Cotton:Bamboo		1.52+ **(30.9)**	1.03+ **(53.2)**	0.77+ **(65.0)**	0.61+ **(72.3)**	0.49+ **(77.7)**
30:70% Cotton:Bamboo		1.50+ **(31.8)**	0.71+ **(67.7)**	0.55+ **(75.0)**	0.38+ **(82.7)**	0.26+ **(88.2)**
0:100% Cotton:Bamboo		1.50+ **(31.8)**	0.99+ **(55.0)**	0.51+ **(76.8)**	0.33+ **(85.0)**	0.13+ **(94.1)**

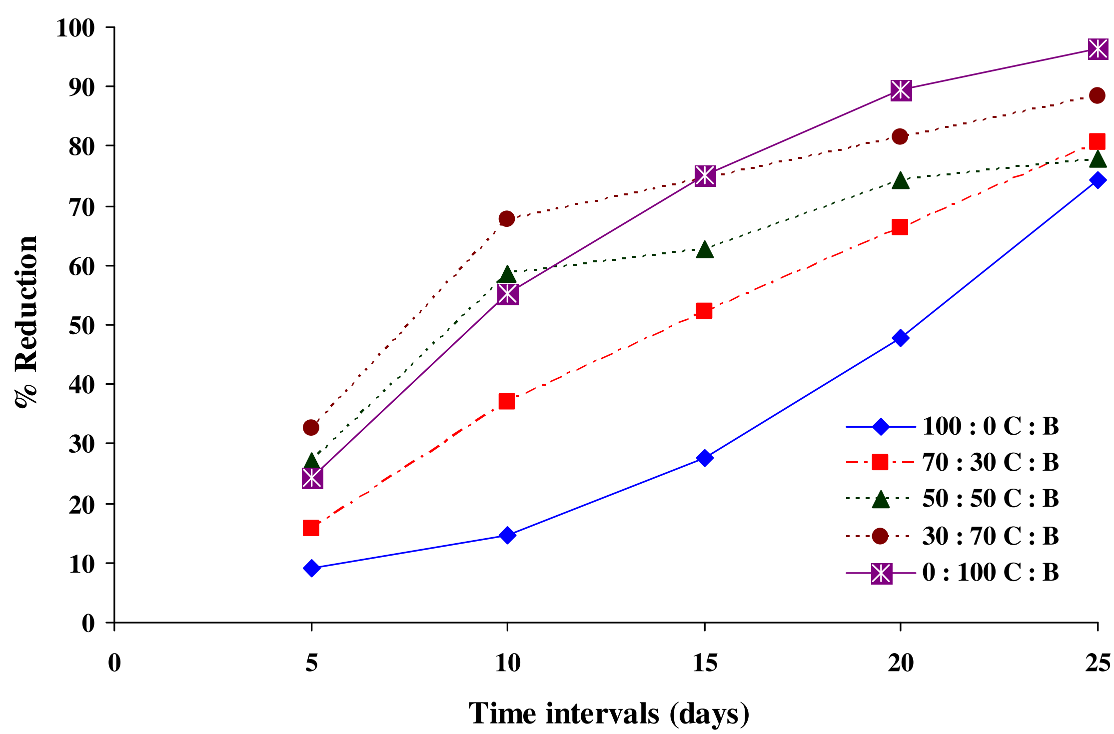
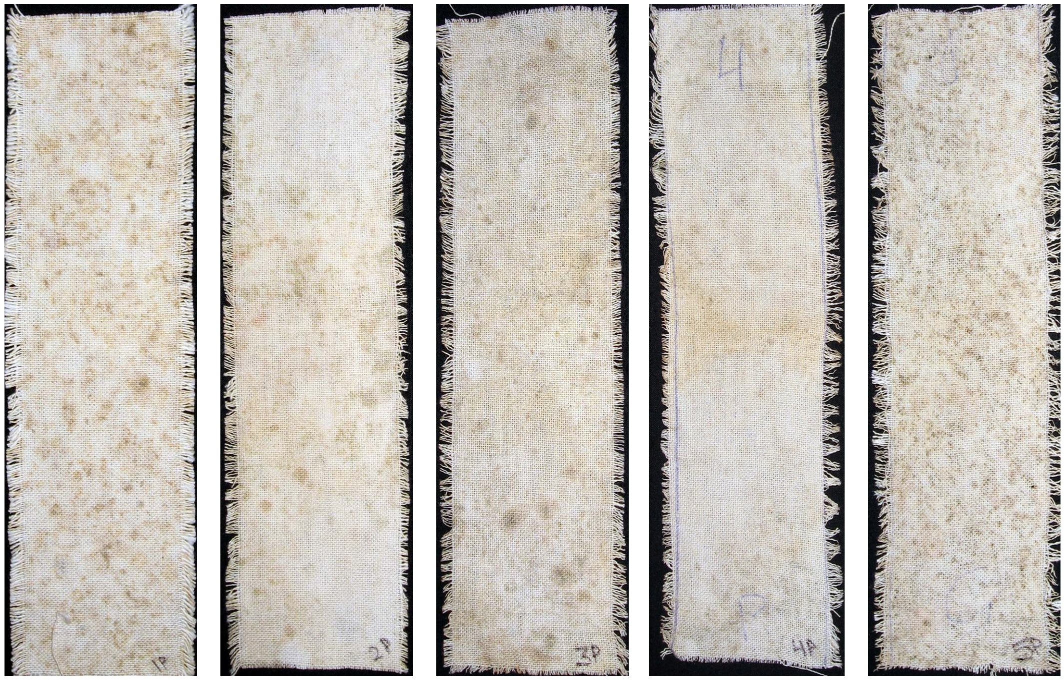


Fig. 4.27 Percent reduction in weight of fabrics over initial weight

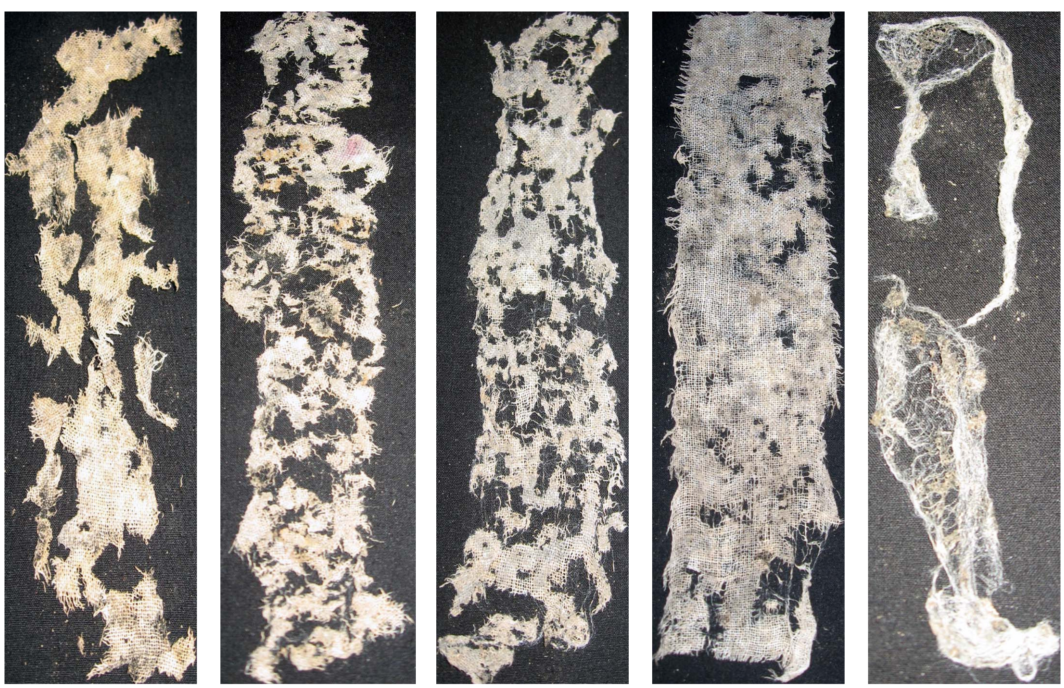
Plate 4.10 Physical nature of the woven fabric samples

(a) Fabric samples after 5 days interval



100:0 C:B **70:30 C:B** **50:50 C:B** **30:70 C:B** **0:100 C:B**

(b) Fabric samples after 25 days interval



100:0 C:B **70:30 C:B** **50:50 C:B** **30:70 C:B** **0:100 C:B**

samples respectively after 5 days interval over initial weight (Plate 4.10 a). It was observed that fabric strips from each experimental fabric was having more or less same weight initially, because of the same fabric construction parameters. After 10 days interval, weight of the fabric samples reduced by 15.5%, 50.0%, 53.3%, 67.7% and 55.0% among all 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabric samples respectively over initial weight. After 15 days interval, weight of the fabric samples reduced by 27.7%, 58.2%, 65.0%, 75.0% and 76.8% among all 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabric samples respectively over initial weight. After 20 days interval, weight of the fabric samples reduced by 44.1%, 66.8%, 72.3%, 82.7% and 85.0% among all 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabric samples respectively over initial weight. After 25 days interval (Plate 4.10 b), weight of the fabric samples reduced by 66.8%, 78.6%, 77.7%, 88.1% and 94.3% among all 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabric samples respectively over initial weight.

It is evident from the Table 4.28 (Fig 4.27) and Plates 4.10 a & b (showing the physical nature of the fabric samples at 5 days and 25 days interval) that as percentage of bamboo increased in fabric samples and as the days increased, the degradation of the fabric samples also increased which showed that degradation rate of the bamboo was much higher than cotton. **Saravanan and Prakash (2007)** also stated that bamboo as a natural cellulose fiber; it is

100% biodegradable in soil by microorganism and sunshine. The decomposition of bamboo fiber does not cause any harm to environment flora and fauna, comes from nature and completely returns to the nature in the end at a higher degradation rate than cotton.

Significant difference was observed for the degradation rate among different cotton-bamboo woven fabrics and among different days interval at 5% level of significance. Critical difference showed significant difference between various pairs of fabric samples and days interval. Similarly the effect of interaction of the two factors i.e. fabric samples and days interval was also found significant. The CD values at 5% level of significance for factor a i.e. different fabric samples, b i.e. different days interval and a*b i.e. interaction between different fabric samples at different days interval were 0.03, 0.03 and 0.07 respectively *(Appendix X h).*

In 1947, cities and towns in India generated an estimated 6 million tonnes of municipal solid waste, in 1997 it was about 48 million tones. Municipal solid waste consists of organic waste, toxic waste, recyclable and soiled which includes hospital waste such as cloth soiled with blood and other body fluids etc. Hospital waste, industrial waste and certain types of household waste are considered hazardous, could be highly toxic to humans, animals, and plants; are corrosive, highly inflammable, or explosive; and react when exposed to certain things e.g. gases. India generates around 7 million tonnes of hazardous wastes every year, most of which is concentrated in four states: Andhra Pradesh, Bihar, Uttar Pradesh, and Tamil Nadu **(Anonymous[14], 2009)**.

Gruendemann (2002) stated that hospital waste accounts for 2% of national municipal wastes. Gowns and drapes contribute approximately 2% of all hospital waste. Thus, disposable gowns and drapes constitute about 0.04% of all municipal wastes. Regarding landfill capacity and disposal of hospital waste: the number of landfills has decreased during the past 10 years but availability has increased with larger regional landfills replacing smaller sites. There is now more landfill capacity available than at any time during the past 10 years.

The results of the present study indicate that bamboo blended fabrics do not pose any harm to environmental flora and fauna as they easily degraded in the soil, thus, reducing the waste percentage of the landfills.

4.12 Assessment of visual appearance of the woven fabrics

All the pure and blended cotton-bamboo woven fabric samples were presented in front of the three respondents from different hospitals in order to select the best article to be developed from the respective fabric on the basis of their suitability to article, luster, hand feel and appearance.

Table 4.29 reveals the result of the visual assessment of the woven fabric samples. Scores of the woven fabric samples revealed that out of eight suggestive protective and healthcare textiles, bed sheets and pillow cover was ranked first with 23 marks for 100% cotton fabric sample, doctor's lab coat was ranked first with 26 marks for 70:30 cotton-bamboo fabric, surgical gown was ranked first with 27 marks for 50:50 cotton-bamboo fabric, patient dress was ranked first with 29 marks for 30:70 cotton-bamboo fabric whereas cap and mask was ranked first with 31 marks for 100% bamboo fabric. It was observed that as bamboo percentage increases in the fabric samples, luster and hand feel of the fabric samples also increases which helped the respondent to judge the fabric samples accordingly. It was found that according to respondents doctor's lab coat does not require much luster and hand feel therefore fabric with high percentage of cotton was ranked first whereas patient dress require more comfort while wearing therefore fabric with high percentage of bamboo was ranked first. All the pure and blended cotton-bamboo fabrics were appreciated by the respondents for their suitability to protective and healthcare textiles with regards to luster, hand feel and overall appearance.

4.13 Cost Calculation of woven fabrics

The cost of one meter fabric for pure and blended cotton-bamboo fabric samples are presented in Table 4.30.

Table 4.29 Score card for the visual assessment of the pure and blended woven fabrics

S. No.	Woven fabrics (C : B)	Items to be prepared	Fabric suitable for (MM 8)	Luster (MM 8)	Hand feel (MM 8)	Overall appearance (MM 8)	Total (MM 32)	Rank
1	100 : 0	Bed sheet	8	4	4	7	**23**	**I**
		Pillow cover	8	4	4	7	**23**	**I**
		Lab coat	6	4	4	5	19	II
		Patient dress	5	4	4	4	17	III
		Surgical gown	4	4	4	4	16	IV
		Nurse's uniform	3	4	4	3	14	V
		Cap	2	4	4	2	12	VI
		Mask	1	4	4	1	10	VII
2	70 : 30	Bed sheet	7	5	5	6	23	II
		Pillow cover	7	5	5	6	23	II
		Lab coat	8	5	5	8	**26**	**I**
		Patient dress	6	5	5	5	21	III
		Surgical gown	5	5	5	5	20	IV
		Nurse's uniform	5	5	5	5	20	IV
		Cap	3	5	5	5	18	V
		Mask	3	5	5	5	18	V
3	50 : 50	Bed sheet	6	6	6	5	23	IV
		Pillow cover	6	6	6	5	23	IV
		Lab coat	6	6	6	7	25	III
		Patient dress	7	6	6	7	26	II
		Surgical gown	8	6	6	7	**27**	**I**
		Nurse's uniform	7	6	6	7	26	II
		Cap	7	6	6	7	26	II
		Mask	7	6	6	7	26	II
4	30 : 70	Bed sheet	4	7	7	5	23	V
		Pillow cover	4	7	7	5	23	V
		Lab coat	6	7	7	6	26	IV
		Patient dress	8	7	7	7	**29**	**I**
		Surgical gown	6	7	7	7	27	III
		Nurse's uniform	6	7	7	7	27	III
		Cap	7	7	7	7	28	II
		Mask	7	7	7	7	28	II
5	0 : 100	Bed sheet	3	8	8	4	23	V
		Pillow cover	3	8	8	4	23	V
		Lab coat	5	8	8	5	26	IV
		Patient dress	7	8	8	7	30	II
		Surgical gown	7	8	8	7	30	II
		Nurse's uniform	6	8	8	7	29	III
		Cap	7	8	8	8	**31**	**I**
		Mask	7	8	8	8	**31**	**I**

C : B = Cotton : Bamboo
MM: Maximum marks

Table 4.30 Cost/meter of the pure and blended woven fabrics

Fabric Samples (C : B)	Yarn manufacturing charges (includes cost of raw material, fiber processing and spinning charges) in Rupees	Weaving and finishing charges in Rupees	Total cost of one meter fabric in Rupees
100 : 0	Rs. 37.10/-	Rs. 20/-	Rs. 57.10/-
70 : 30	Rs. 53.33/-	Rs. 20/-	Rs. 73.33/-
50 : 50	Rs. 64.94/-	Rs. 20/-	Rs. 84.94/-
30 : 70	Rs. 76.52/-	Rs. 20/-	Rs. 96.52/-
0 : 100	Rs. 93.84/-	Rs. 20/-	Rs. 113.84/-

C : B = Cotton : Bamboo

It is clear from the Table 4.30 that as the percentage of the bamboo increases, the cost of the fabrics also increase which might be due to higher cost of bamboo fiber in comparision to cotton fiber. Besides that, pure and blended cotton-bamboo fabrics are of reasonable prices and are in the reach of common person. However, this cost calculation is done at laboratory level work, at commercial level the cost will bring down.

4.14 Development of protective and healthcare textiles

On the basis of the results obtained from visual assessment of the woven the fabric samples by the 10 percent of the total respondent taken in 3.1. Five garments from bamboo blended fabric samples were prepared which includes doctor's lab coat (70:30 cotton-bamboo), surgical gown (50:50 cotton-bamboo), patient dress

(30:70 cotton-bamboo) and cap & masks from 0:100 cotton-bamboo fabrics respectively as per the average measurement and draftings given in *appendix V and VI*. Cost of the whole garment was also calculated which includes the cost of fabric consumed in meters, trimmings used like buttons, elastic, etc., and the labor cost. The cost of each article is shown in Table 4.31. Cost of the garments prepared from particular fabric was found comparable with the current market price.

Table 4.31 Total cost of the article

Name of the article	Cost in Rupees/ meter fabric consumed	Trimming cost in Rupees	Labour cost in Rupees	Total cost in Rupees
Doctor's lab coat	Rs. 245.7/3.35 m	Rs. 10/-	Rs. 125/-	Rs. 380.7/-
Surgical gown	Rs. 382.2/4.5 m	-	Rs. 125/-	Rs. 507.2/-
Patient dress	Rs. 415.0/4.3 m	-	Rs. 150/-	Rs. 565.0/-
Cap	Rs. 39.8/0.35 m	Rs. 5/-	Rs. 20/-	Rs.64.8/-
Mask	Rs. 22.8/0.2 m	-	Rs. 12/-	Rs. 34.8/-

Prepared articles are presented in Plates 4.11 a, b and c, were shown to doctors' and photographs were taken. Garments were highly appreciated by the doctors and they stated that it has opened new avenues for the safeguarding of patients and hospital staff in a natural way.

Plate 4.11(a) Doctor's lab coat (70:30 cotton-bamboo fabric)

FRONT VIEW

BACK VIEW

Plate 4.11(b) Doctor's surgical gown (50:50 cotton-bamboo fabric) with cap and mask (100% bamboo fabric)

FRONT VIEW **BACK VIEW**

Plate 4.11(c) Patient dress (30:70 cotton-bamboo fabric)

FRONT VIEW

BACK VIEW

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSION

Medical textiles are one of the most rapidly expanding sectors in the technical textile market. Medical Textiles are the products and constructions used for medical and biological applications and are used primarily for first aid, clinical and hygienic purposes.

The consumption of Medical Textiles worldwide was 1.5 million tons in 2000 and is growing at an annual rate of 4.6%. The Indian market size of medical textiles was estimated to be INR 23.3 billion in 2007-08 and is expected to grow at a rate of 20% per annum. The share of meditech, a part of healthcare sector in Indian technical textiles market is found to be 5%.

An important area of meditech is protective and healthcare textiles which include doctor's lab coat, surgical gowns, patient dress, cap, masks, etc. All the protective and healthcare textiles require special antimicrobial properties combined with the wearer's comfort. Antimicrobial textiles are easily finding place in medical industry and currently, the antimicrobial textiles used in medical field are disposable items and nonwovens. Some of the treatments being used to produce antimicrobial textiles are harmful to the user as the chemicals used in the treatment of textiles tend to cause skin allergy, etc. when developed into apparel and also to our environment because the treated textiles are not reusable. To address the growing concern about personal protection and environment, present study was carried out to develop reusable textiles with inherited antimicrobial and biodegradable properties which reduced the amount of chemicals and trash being disposed of in the landfills.

Therefore in order to enhance the antimicrobial and bio-degradable properties of protective and healthcare textiles, two eco friendly and biodegradable fibers i.e., cotton (cellulosic fiber) and bamboo (regenerated cellulosic fiber) were selected for the present study. Value addition of cotton with bamboo fibers was carried out by using blending technology and different protective and healthcare textiles were prepared. The summarized findings of the study and conclusions thereof are as under:

1) In-depth knowledge regarding protective and healthcare textiles was gained by surveying thirty hospitals i.e. 15 from Ghaziabad district of Uttar Pradesh and 15 from Udham Singh Nagar District of Uttarakhand. It was observed that hospitals from both the districts have almost the same standards, in keeping their doctors, nurses, staff and patients satisfied. Woven fabric samples used for making protective and healthcare textiles were collected from different hospitals at the

time of survey and evaluated to know the type of fibers used in the fabrics and their fabric construction parameters.

2) After evaluation, it was found that till today, cotton being the most used fiber for making protective and healthcare textiles because fabrics developed from cotton fiber combined durability with attractive wearing qualities and comfort. Cotton can withstand repeated washings and is ideal for garments that must be laundered often but it lacks anti-microbial properties.

3) Currently the fabrics used for making protective and healthcare textiles are based on particular fabric construction parameters. The results of physical evaluation woven fabric samples collected from different hospitals revealed that preferably S-twisted 2-ply 10s i.e. 2/20s count warp yarn and Z-twisted single ply 10s count weft yarn having approximately 10-15 twists per inch (TPI) were used for weaving plain weave fabric mostly where ends per inch (EPI) and picks per inch (PPI) were ranged in between 33 to 40, fabric weight per unit area lies nearby 200 gm/m^2 with 10% yarn crimp percentage.

4) There are number of fiber properties which influence the quality of the yarn and ultimately the fabric. Optimal conditions for processing can be applied only through the knowledge about raw material. Therefore the physico-chemical

properties were tested to find out the suitability of the fiber for manufacturing of fabric for protective and healthcare textiles. The results of physical properties of the fibers revealed that cotton and bamboo fibers were having similar fineness which helped in proper blending and mixing of fibers. Length, diameter and crimp of both the fibers were found almost same. Dry tenacity of both the fibers was found same whereas the wet tenacity of cotton fiber (3.64 gm/denier) was better than wet tenacity of bamboo fiber (2.48 gm/denier). Dry and wet elongation of bamboo fiber (24.20% and 23.34% respectively) was quite higher as compared to cotton fiber (7.40% and 9.12% respectively). Whiteness index result showed that cotton and bamboo both fibers were pure white in color i.e. 25.8 and 23.5 respectively.

5) Microscopic study of the fibers was found helpful in observing their characteristics and in understanding the fibers and fabric behavior. Micro holes present in the bamboo fiber cross-section helps in moisture absorption and ventilation. The outer surface of cotton and bamboo fibers was found smooth under microscope. Thus, it was noticed that the protective and healthcare textiles made from cotton-bamboo fiber will provide soft, smooth and comfortable feel to the skin.

6) Study of chemical constituent's of both the fibers shows that cotton had higher ash, cellulose and fat content i.e. 1.35%, 95.5% and 1.14% respectively in comparison to bamboo i.e. 0.31%, 79.55% and 0.26% respectively. Nitrogen content and crude protein was found higher in cotton as compared to bamboo. Moisture content and moisture regain was found higher in bamboo i.e. 8.33% and 9.09% respectively as compared to cotton i.e. 4.69% and 4.93% respectively, which made cotton-bamboo blended fabric comfortable to wear, because it absorbs moisture from skin and will not allow static charges to build up. pH of cotton was slightly acidic (6.79) whereas bamboo was almost neutral (7.01).

7) Detailed study of the chemical reagents on selected fibers i.e. cotton and bamboo fibers was carried out, because the resistance of a fiber to various chemical agents is important in determining processing technology and care procedure. It was seen that both the fibers were damaged by strong mineral acids like sulphuric acid, nitric acid and hydrochloric acid and degradation was more on bamboo fiber. It was noticed that both cotton and bamboo fibers were not damaged by volatile organic acids like acetic acid and formic acid whereas non-volatile organic acid like oxalic acid, only made both the fibers tender. It was found that alkalies like sodium hydroxide,

sodium carbonate and borax caused swelling of both cotton and bamboo fibers which indicate that detergents can be used safely on both the fibers. It was observed that hydrogen peroxide bleach can be safely used to bleach both cotton and bamboo fibers respectively at room temperature as well as on boiling temperature except sodium hypochlorite bleaches which can only be used at room temperature as it dissolved both the fibers on boiling.

8) Among other solvents like acetone, phenol, dimethyl formamide, spirit, carbon tetrachloride and ammonia solution were not caused much harm to both the fibers except meta-cresol which damaged both the fibers on heating. In this way study of effect of chemicals was found beneficial while recommending different chemicals for the treatment/finishing of cotton and bamboo fibers at any stage.

9) Colour reaction results showed that both the fibers respond differently to colour reagents except malachite green and methylene blue reagent, for which both the fibers obtained same colour. So, the results of colour reactions can be used to sort out the bamboo fibers from a blend of bamboo and cotton as after treatment with iodine and sulphuric acid reagent and zinc-chloride-iodine reagent, bamboo fiber turned light

turquoise green and blackish grey whereas cotton fiber acquired light yellow and yellow colour respectively.

10) Yarn acquires intermediate position in manufacturing of fabric from raw material. Ten ring spun yarn samples made up of cotton and bamboo in different ratios (100:0, 70:30, 50:50, 30:70 and 0:100) i.e. five different ratios of 2-ply warp and five different ratios of single ply weft yarns were prepared as per the yarn construction parameters obtained by evaluating the yarn samples taken out from woven fabric samples collected from different hospitals. Various yarn parameters, i.e. yarn count, twist direction, twist per inch, yarn tenacity, elongation percent, unevenness, imperfection and hairiness were tested for all pure and blended cotton-bamboo warp and weft yarns. Yarn count, twist direction and twist per inch were kept constant for all warp and weft yarns but negligible difference was found in yarn count and twist per inch after testing among all pure and blended warp and weft yarns. Unevenness was found more or less same for all pure and blended cotton-bamboo 2-ply warp yarns and single ply weft yarns. Besides that, yarn imperfections and hairiness decreased significantly with the increased percentage of bamboo in the blends. Yarn imperfections and hairiness in warp and weft yarns respectively were found maximum in 100:0 cotton-bamboo

followed by 70:30, 50:50, 30:70 and 0:100. Yarn strength decreased and elongation percent at break increased with the increased percent of bamboo in blends.

11) Five woven fabric samples of cotton-bamboo fiber (pure and blended) i.e. 100:0, 70:30, 50:50, 30:70, 0:100 were made on power loom as per the fabric construction parameters obtained by evaluating the woven fabric samples collected from different hospitals. These power loom woven fabrics were tested to evaluate the quality of fabric with respect to performance and aesthetic appeal. Selection of fabrics for making protective and healthcare textiles was done on the basis of their resultant properties. Various properties tested were weave, GSM of the fabric, yarn crimp percentage, fabric thickness, fabric count, drape coefficient, fabric stiffness or bending length, crease recovery angle, abrasion loss, pilling resistance, breaking strength, elongation, tearing strength, thermal conductivity, dimensional stability, air permeability, water absorption and water vapor permeability.

12) Plain weave was kept constant for all pure and blended cotton-bamboo fabrics. The fabric count of all woven fabric samples made from pure and blended cotton-bamboo fibers was kept constant i.e. 36 X 36 ends X picks/inch^2 on loom. But after testing negligible difference was observed in fabric count

among all pure and blended woven fabric samples. It was found that as the bamboo content in the fabrics was increased, weight of the fabrics decreased. It was observed that crimp percentage was higher in warp yarns than weft yarns among all pure and blended cotton-bamboo woven fabric samples as warp yarns were held under high tension than weft yarns while weaving.

13) Fabric thickness was recorded highest for pure cotton fabric i.e. 0.55 mm and lowest for pure bamboo fabric i.e. 0.47 mm. This might be due to the fact that cotton fiber length was shorter than bamboo fiber which in turn increased the protruding fiber ends and fuzz on the surface thus caused an increase in the thickness of fabric. It was observed that as bamboo content of fabrics was increased its bending length and drape coefficient decreased, it means that stiffness of fabrics decreased. But very little difference in bending length and drape coefficient was observed among all blends. Decreasing trend of bending length and drape coefficient of blended fabrics might be due to the softness and smoothness of the bamboo fibers.

14) The result of present investigation clearly indicated that as the bamboo content in blend increased the abrasion resistance of the fabrics also increased because percent weight loss was

seen lowest in 30:70 and 0:100 cotton-bamboo fabrics. It means that the blended fabric having high content of bamboo i.e., 30:70, 0:100 could resist more number of abrasion cycles than pure cotton fabric.

15) Pill formation in all fabric samples prepared from pure and blended cotton-bamboo yarns ranged from 1-4 (very severe to slight pilling) when compared with ASTM pilling standards. It was found that as the bamboo fiber percentage in the woven fabrics increased, pilling decreased which might be due to the reason that yarns prepared having higher percentage of bamboo were finer than cotton yarns and due to higher extensibility of bamboo fibers.

16) Thermal conductivity values were found more or less same for pure and blended cotton-bamboo woven fabrics which showed that all pure and blended cotton-bamboo woven fabrics provide equal thermal protection to the wearer.

17) The results of present investigation clearly indicated that with the increased amount of bamboo in blended fabrics, crease recovery angle increased in both warp and weft direction. This means that the ability of the fabric to resist creasing or mussing decreases as proportion of bamboo in blends increases. This might be due to the fact that bamboo fiber has high elongation than cotton fiber.

18) The breaking strength of the fabric made from the 100:0, 70:30: 50:50, 30:70 and 0:100 ratios of cotton-bamboo blends were reported as 10.14, 9.30, 8.47, 8.72 and 8.79 kgf/cm in warp way and 13.94, 10.45, 9.26, 10.10 and 10.35 kgf/cm in weft way respectively. The result obtained in present investigation shows that the breaking strength was found high in weft direction for all blend ratios as compared to warp way in all woven fabrics which might be due to less strain on weft yarns than warp yarns during weaving process. It was observed that as the bamboo content increased in the woven fabrics, the strength of the fabric also decreased. Bamboo fiber has high breaking strength but subsequently its strength decreased in the yarn form which finally decreased the breaking strength of the woven fabrics. It was found that as the proportion of bamboo in blend increased the elongation percent value of woven fabrics, also increased in both warp and weft way direction.

19) The results of tearing strength obtained in present investigation showed a decreasing trend as the bamboo content increased in the blend. It was found maximum for pure cotton fabrics i.e. 6.1 kg for warp way and 4.3 kg for weft way respectively, where as it was minimum for pure bamboo fabrics i.e. 2.8 kg for warp way and 2.6 kg for weft way respectively.

20) It was observed that fabrics having high bamboo content were less dimensionally stable than pure cotton fabrics in both warp and weft direction.

21) It was found that pure bamboo fabric has high air permeability i.e. 7.2 $ft^3/ft^2/min$ which might be due to the morphological structure of bamboo fiber i.e. presence of micro holes and micro gaps which allow the air to pass easily from one side to another whereas negligible difference was found for air permeability in 100:0, 70:30, 50:50 and 30:70 pure and blended cotton-bamboo fabrics.

22) It was observed that 50:50, 30:70 and 0:100 cotton-bamboo fabrics have higher wettability which was followed by 70:30 and 100:0 cotton-bamboo fabrics. Therefore, it can be concluded that fabrics having higher bamboo content showed better water absorption and can be used for making patient dress, etc. which bears direct contact with patient skin, provide comfort to the wearer by absorbing moisture.

23) Significant difference was found for water vapour permeability among all pure and blended cotton-bamboo woven fabric samples. Fabrics having higher cotton content showed better water vapour permeability. It is an important property related to clothing, as clothing must be able to remove the moisture in order to maintain comfort.

24) It was observed from the results obtained that survivability of both the bacteria's i.e. *S. aureus* and *E. coli* on cotton was more lasting as compared to bamboo blended fabric samples. It was observed that as the percentage of bamboo increased in the fabric samples, antibacterial property also enhanced and this property was seen more on after washed fabric samples as compared to before washed fabric samples. This might be due to the removal of sizing and other materials applied on the yarns and fabrics during yarn and fabric manufacturing processes respectively or might be due the degradation of the carbon source present in the textile materials which act as a food for microbial growth. The general survivability of the test organism *S. aureus*, was less as compared to *E. coli*. The results obtained indicated that bamboo potentially resists the colonization of *S. aureus* from the first day of incubation and *E. coli* from the second day of incubation. This might be due to that bamboo owns a unique anti-bacterial bio-agent "bamboo kun" which combined with bamboo cellulose molecules tightly all along during the process of being produced into bamboo fiber/fabric.

25) It was observed from the results obtained that survivability of both the fungi's i.e. *A. niger* and *T. reesei* was more or less the same on all pure and blended cotton-bamboo fabric samples

but reduction was seen among after washed fabric samples as compared to before washed fabric samples. This might be due to the fact that both cotton and bamboo fibers are hydrophilic in nature which allows the fungi to grow. It was observed that as the contact hours increased, bamboo blended fabrics showed better antifungal property and reduction was seen more among after washed fabric samples as compared to before washed fabric samples. Therefore, it can be concluded that the bamboo blended fabrics showed better antifungal results in the long run, thus, can be used safely for making protective and healthcare textiles.

26) It was found that as percentage of bamboo increased in fabric samples and as the days increased the degradation of the fabric samples also increased which showed that degradation rate of the bamboo is much higher than cotton.

27) Visual evaluation of all pure and blended cotton-bamboo fabrics was done by ten percent of total respondents. Scores of the woven fabric samples revealed that out of eight suggestive protective and healthcare textiles, bed sheet and pillow cover was ranked first with 23 marks for 100% cotton fabric sample, doctor's lab coat was ranked first with 26 marks for 70:30 cotton-bamboo fabric, surgical gown was ranked first with 27 marks for 50:50 cotton-bamboo fabric, patient dress was

ranked first with 29 marks for 30:70 cotton-bamboo fabric whereas cap and mask were ranked first with 31 marks for 100% bamboo fabric.

28) Cost of one meter fabric was calculated for all pure and blended cotton-bamboo fabrics and it was found that cost of all fabrics was very reasonable and it can easily be purchased by anyone. The cost of 100:0, 70:30, 50:50, 30:70 and 0:100 cotton-bamboo fabrics was Rs. 57.10/- sq meter, Rs. 73.33/- sq meter, Rs. 83.94/- sq meter, Rs. 96.52/- sq meter and Rs. 113.84/-sq meter respectively. Higher cost of bamboo blended fabrics was due to the higher cost of bamboo fiber (Rs. 210/kg) in comparison with cotton fiber (Rs. 60/kg).

29) Five garments from bamboo blended fabric samples were prepared which includes doctor's lab coat (70:30 cotton-bamboo), surgical gown (50:50 cotton-bamboo), patient dress (30:70 cotton-bamboo) and cap and masks from 0:100 cotton-bamboo fabrics respectively and cost of the whole garment was found comparable with the current market price. Prepared articles were shown to doctors' and photographs were taken.

Majority of the respondents appreciated the study and stated that it had opened new avenues for the safeguarding of patients and hospital staff in a natural way. The findings of the present study showed that pure and blended cotton-bamboo protective and healthcare textiles will have wide target market and can fetch good premium price in global market.

Thus it can be concluded from the results of fabric testing including physical properties of fabrics, antimicrobial and biodegradability assessment that blending of bamboo with cotton produce fabrics with good strength, lusture, hand, abrasion resistance with low pilling problem. Hand of all bamboo blended fabrics was soft and smooth with good luster and light weight, so these fabrics were found suitable for making protective and healthcare textiles. Apart from improving the structural and mechanical properties of blended fabric, use of bamboo fiber was found very useful in improving the antimicrobial and biodegradable properties of fabrics.

It is recommended that the bamboo blended fabrics not only beneficial to both hospital staff and patients but also to the general public. Even the fabric having lowest percentage of bamboo showed excellent antimicrobial and biodegradable properties with good hand feeling in comparison to pure cotton fabric.

Bamboo fiber is easily damaged by acids and other chemicals and pure bamboo fabric showed less strength in comparison with pure cotton and cotton-bamboo fabrics. Therefore, it is better to use bamboo-cotton blends as they are more durable for the long run, possesses excellent antimicrobial and biodegradable properties at reasonable prices.

Recommendations

- Similar studies can also carry out by taking other cellulosic fibers to be blend with bamboo fibers.
- Range of different yarn counts can also explored for producing a variety of fabrics for different end uses.
- Different weaves structures can also explored with the same fibers for fashion apparels.
- Effect of different bacteria's and fungi's can also be assessed and compared for other epidemic diseases like swine flu.
- Intervention can also be given by using the protective and health care textiles in different hospital and their feedback can be analyzed.

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Appendices

INTERVIEW SCHEDULE

GENERAL INFORMATION

1. Name of the Hospital. ---
2. Type of Administration.

a) Public b) Private

3. Is your hospital registered?

a) Yes b) No

If yes then

a) When ---
b) Where ---

4. Date of establishment of the hospital. ---------------------------------
5. What type of specialties/health problems your hospital deals with?

a) General problem
b) ENT problem
c) Heart problem
d) Gynecology problem
e) Eye problem surgeon
f) Neuro problem
g) Pathology problem
h) Dental problem
i) Skin problem
j) Pediatrics problem
k) Nephrology problem
l) Radiology problem
m) Orthopedic problem
n) Any other

6. What type of room facilities you have?

a) General
b) Private
c) Both
d) Any other
e) Any other

7. Is there any separate department in your hospital who is responsible for the care and maintenance (related to hygiene) of the hospital?

f) Yes g) No

SPECIFIC INFORMATION'S

1. What are the protective, health care and hygiene products used by the hospital?

a) Doctors' lab coat
b) Doctors' – nurses surgical gown
c) Patient dress
d) Bed sheet - pillow cover
e) Blankets
f) Towels
g) Cap and mask
h) Gloves
i) Any other

2. From where do you procure the protective, health care and hygiene products used in the hospital?

a) You produce of your own
b) Directly from factory
c) From whole sale market
d) From retailers
e) Import
f) Any other

3. Mention the name/address of place form where you procure the protective, health care and hygiene products used by the hospital.

Name --

Address ---

4. In which form do you get these products?

a) Readymade
b) Fabric form

If in fabric form, then where from do you get the finished products? Specify --

5. What qualities do you prefer in protective, health care and hygiene products?

a) Softness
b) Air permeability
c) Absorbency
d) Comfort
e) Easy to handle
f) Drape ability
g) Any other

6. What is the cost/product?

Name of the items	Cost in rupees
a) Doctors' lab coat	
b) Doctors' – nurses surgical gown	
c) Patient dress	
d) Bed sheet – pillow cover	
e) Blankets	
f) Towels	
g) Cap and mask	
h) Gloves	
i) Any other	

7. Which fibers do you prefer for protective, health care and hygiene products?

a) Cotton
b) Wool
c) Silk
d) Synthetic
e) Any other like blends

8. Which types of weaves do you prefer for protective, health care and hygiene products?

a) Plain weave
b) Twill weave
c) Satin weave
d) Fancy weave
e) Any other

9. Do you have any idea what pre-treatments/finishing are given to the products at the time of manufacturing?

a) Scouring
b) Bleaching
c) Degumming
d) Anti-microbial
e) Flame retardant
f) Deodorant
g) Any other

10. Do you procure the products in dyed from?

a) Yes
b) No

If yes then what type of dye is it?

a) Natural
b) Synthetic
c) Any other

11. Do you have separate department for the care and storage of these products?

a) Yes
b) No

12. How many personnel's are working in care and storage department?

----

13. How often the linens of the patients and other items used by doctors/nurses are changed?

Name of the items	Daily	After 2 days	After 4 days	After a week	As and when required	Any other interval
a) Doctors' lab coat						
b) Doctors'–nurses surgical gown						
c) Patient dress						
d) Bed sheet–pillow cover						
e) Blankets						
f) Towels						
g) Cap and mask						
h) Gloves						
i) Any other						

14. (A) Do you give any after treatment to the products?

a) Yes b) No

(B) If yes, why? --

(C) Please specify the method ---

15. What kinds of practices are followed for maintaining the care and hygiene of the products?

a) Washing
b) Sterilization
c) Drying
d) Ironing
e) Any other

16. Do you apply any kind of insect repellent at the time of product storage?

a) Naphthalene balls
b) Sprays
c) Any other

17. What are the sources from where do you get information about new and improved protective, health care and hygiene products?

a) Newspaper
b) Books/magazines/journal s
c) Fairs and exhibitions
d) Company sales personnel's
e) Any other

18. (A) Are you ready to adopt new products?

a) Yes b) No

(B) If yes, why?

a) Economic
b) Better services
c) Any other

(C) If no, why? ---

19. What colors do you prefer for the following products?

Name of the items	White	Light green	Light blue	Yellow	Pink	Any other
a) Doctors' lab coat						
b) Doctors'–nurses surgical gown						
c) Patient dress						
d) Bed sheet –pillow cover						
e) Blankets						
f) Towels						
g) Cap and mask						
h) Gloves						
i) Any other						

20. What are the sizes/dimensions of the following products?

Name of the items	Sizes/Dimensions
j) Doctors' lab coat	
k) Doctors' – nurses surgical gown	
l) Patient dress	
m) Bed sheet –pillow cover	
n) Blankets	
o) Towels	
p) Cap and mask	
q) Gloves	
r) Any other	

21. What are the fasteners used for these products?

a) Buttons
b) Zippers
c) Strings
d) Velcro
e) Any other

22. How often do you purchase the following products?

Name of the items	Weekly	Monthly	Quarterly	half yearly	Annually	Any other
s) Doctors' lab coat						
t) Doctors' – nurses surgical gown						
u) Patient dress						
v) Bed sheet – pillow cover						
w) Blankets						
x) Towels						
y) Cap and mask						
z) Gloves						
aa) Any other						

23. Are you satisfied with the performance of the products you use?

a) Yes. Reason --

b) No. Reason --

24. Please suggest measures to improve the quality of the protective, health care and hygiene products?

----

25. Are doctors/patients satisfied with the products you are using or purchasing for the hospitals?

a) Yes. Reason --

b) No. Reason --

26. How do you collect the used products?

a) All together b) Separately

a. Infectious

b. others

27. Who ensures the quality of the protective, health care and hygiene products in your hospital?

----

28. Do you and your staff needs any training regarding hygiene practices?

a) Yes b) No

Options for training-

a) Care and maintenance

b) Properties of products

c) Sterilization process

d) Any other

List of Machines/Instruments used *vis-à-vis* their manufacturer and purpose used for fiber, yarn and fabric testing

Sl	Name of Machine & Instrument	Manufacturer	Purpose
1	Air permeability tester	Eureka Industrial Equipment Pvt. Ltd., India	Air permeability testing of fabrics
2	Beesley balance	Eureka Precision Inst. Company, Coimbatore, India	Count testing of yarns
3	Blowroom machine	NSE (National Standard Engineering), India	Opening, cleaning of fibers & recycling of waste
4.	Carding machine	Lakshmi – LC 300A, India	Carding of fibers
5	Crease recovery tester	Eureka Precision Inst. Company, Coimbatore, India	Crease recovery testing of fabrics
6	Creel machine	Nota Machinery, Ludhiana, India	Preparation of warp beam
7	Crimp parameter laser	Shirely Development Ltd., England	Crimp testing of fibers
8	Digital electronic balance	Roy Electronics, Varanasi	Weighing of different materials
9	Doubling machine	Jeetsten – JD – 2, India	Doubling of yarns
10	Drape meter	Paramount Instrument Pvt. Ltd. New Delhi	Drape testing of fabrics
11	Draw frame machine	Lakshmi – LMW – RSB51, India	Drawing of slivers
12	DUSTEX machine	Lakshmi Reiter-DJ15, India	Dedusting of fibers during fiber processing
13	Electronic tensile tester (yarn and fabric) no. 3095	Kamal Metal Industries, Ahemdabad	Tensile testing of yarns and fabrics
14	Fafegraph-M, Vibromat-M	Harbert stein gmph and co., Monchenglabah, Germany	DTE testing of fibers
15	Hot air oven	M/S Innovative Engitech (P) Ltd, New Delhi	Drying of fibers and glasswares
16	Hunter colour lab	Hunter Association Laboratory Inc., 11491 Sunset hills road, Reston, VA	Whiteness index testing of fibers
17	Incubator	Remi Instruments, India	Growing of microbes
18	Laminar air flow	Basil, India	Microbial testing of fabrics

19	Launderometer	Metrex Scientific Inst. (P) Ltd., New Delhi	Washing of fabrics
20	Martindale abrasion tester	Prolific Engineers, Noida	Abrasion resistance and pilling of fabrics
21	Micrometer	American Optical Company, New York	Diameter measurement of fibers
22	Muffle furnace	Narang Scientific Works Pvt. Ltd. New Delhi	Ashing of fibres
23	Orbital shaker	Toshiba, India	Shaking of inoculum
24	Paramount Digi count	Paramount Instrument Pvt. Ltd., New Delhi	GSM testing of fabrics
25	pH-meter-324	Electronics Corporation of India Ltd. Hyderabad	pH measurement of fibers
26	Pickglass	Shirely Development Ltd., England	Fabric count testing
27	Powerloom	Nota Machinery, Ludhiana, India	Weaving of fabrics
28	Premier tQ Qualicenter Ver M 3. 0.2	Premier, India	Unevenness, imperfection and hairiness testing of yarn
38	Projection microscope (Nikon Eclipse E1000)	UNILVX-II, Tokyo, Japan	Microscopic structure testing of fibers
29	Ring frame machine	Lakshmi – LMW – LR/6, India	Ring spinning of yarns
30	Simplex frame machine	Lakshmi – LF1400, India	Attenuation, twisting of drafted strand and winding of twisted roving on a bobbin
31	Soxhlet apparatus	Unilab, India	Cellulose content of fibers
32	Spray tester	SASMIRA, Worli Mumbai	Wettability testing of fabrics
34	Stiffness tester	Eureka Precision Instrument Co. Coimbatore	Stiffness testing of fabrics
33	Tearing strength tester	Innolab Tensile Strength Tester TS-06, India	Tearing strength testing of fabrics
35	Thermal conductivity apparatus	SASMIRA, Worli Mumbai	Thermal conductivity testing of fabrics
36	Thickness gauge	Shirely Development Ltd., England	Thickness testing of fabric
37	Winding machine	Tentool – RT 95	Winding of yarns
39	Yarn twist tester	Kamal Metal Industries, Ahemdabad	Twist testing of yarns

List of chemicals/reagents used along with their sources

Sl. No.	Reagents	Sources
1	Acetic acid	Central drug house (P) Ltd., New Delhi
2	Acetone	Qualigens Fine Chemicals, Navi Mumbai
3	Agar-Agar (Bacteriological grade)	Qualigens Fine Chemicals, Navi Mumbai
4	Ammonia solution	Merck Limited, Worli, Mumbai
5	Beef extract powder (Type-I) Bacteriological grade	Titan Biotech Limited, Bhiwadi, Rajasthan
6	Benzene	Qualigens Fine Chemicals, Navi Mumbai
7	Borax	Central drug house (P) Ltd., New Delhi
8	Boric acid	Loba Chemie, Thane, Mumbai
9	Bromocresol green	Loba Chemie, Thane, Mumbai
10	Carbon tetrachloride	Loba Chemie, Thane, Mumbai
11	Chloroform	Loba Chemie, Thane, Mumbai
12	Copper sulphate	Thomas Baker(chemicals)Pvt. Ltd. Marine Drive Mumbai
13	D-glucose	Qualigens Fine Chemicals, Navi Mumbai
14	Dimethyl formamide	s. d. fine-chem Ltd., Boisar
15	Ethyl alchohal	Thomas Baker(chemicals)Pvt. Ltd. Marine Drive Mumbai
16	Formic Acid	Thomas Baker (chemicals) Pvt. Ltd. Marine Drive Mumbai
17	Glycerine	Loba Chemie, Thane, Mumbai
18	Hydrochloric acid	Loba Chemie, Thane, Mumbai
19	Hydrogen peroxide	Thomas Baker(chemicals)Pvt. Ltd. Marine Drive Mumbai
20	Iodine	Loba Chemie, Thane, Mumbai

21	Malachite Green	Loba Chemie, Thane, Mumbai
22	Meta cresol	s. d. fine-chem Ltd., Boisar
23	Methyl red	Thomas Baker(chemicals)Pvt. Ltd. Marine Drive Mumbai
24	Methylene blue	Loba Chemie, Thane, Mumbai
25	Monoethanol amine	Loba Chemie, Thane, Mumbai
26	Nitric Acid	Thomas Baker (chemicals) Pvt. Ltd. Marine Drive Mumbai
27	Oxalic acid	Loba Chemie, Thane, Mumbai
28	Peptone-R (Bacto-Grade)	Titan Biotech Limited, Bhiwadi, Rajasthan
29	Phenol	Thomas Baker (chemicals) Pvt. Ltd. Marine Drive Mumbai
30	Potassium Dichromate	Loba Chemie, Thane, Mumbai
31	Potassium hydroxide	Loba Chemie, Thane, Mumbai
32	Potassium Iodide	Loba Chemie, Thane, Mumbai
33	Potassium sulphate	Loba Chemie, Thane, Mumbai
34	Sodium carbonate	Sisco Research Laboratories Pvt. Ltd., Mumbai
35	Sodium chloride	Loba Chemie, Thane, Mumbai
36	Sodium Hydroxide	Thomas Baker(chemicals)Pvt. Ltd. Marine Drive Mumbai
37	Sodium hypochlorite	Qualigens Fine Chemicals, Navi Mumbai
38	Sucrose	Loba Chemie, Thane, Mumbai
39	Sulphuric Acid	Loba Chemie, Thane, Mumbai
40	Surf excel	Hindustan Unilever Ltd. India
41	Zinc chloride	Loba chemie, Thane, Mumbai

Appendix IV

Performa for the visual assessment of the pure and blended cotton-bamboo fabrics for protective and healthcare textiles

Name of the Doctor:
Name of the Hospital:

* Please give marks to the specimens given to you on the basis of following criteria and their suitability for the items given in the table. Marks were given out of 8 for each criterion.

S. No.	Woven fabrics	Items to be prepared	Fabric suitable for	Luster	Hand feel	Overall appearance	Total	Rank
1	100:0 C:B	Bed sheet						
		Pillow cover						
		Lab coat						
		Patient dress						
		Surgical gown						
		Nurse's uniform						
		Cap						
		Mask						
2	70:30 C:B	Bed sheet						
		Pillow cover						
		Lab coat						
		Patient dress						
		Surgical gown						
		Nurse's uniform						
		Cap						
		Mask						
3	50:50 C:B	Bed sheet						
		Pillow cover						
		Lab coat						
		Patient dress						
		Surgical gown						
		Nurse's uniform						
		Cap						
		Mask						
4	30:70 C:B	Bed sheet						
		Pillow cover						
		Lab coat						
		Patient dress						
		Surgical gown						
		Nurse's uniform						
		Cap						
		Mask						
5	0:100 C:B	Bed sheet						
		Pillow cover						
		Lab coat						
		Patient dress						
		Surgical gown						
		Nurse's uniform						
		Cap						
		Mask						

C:B = Cotton:Bamboo

Average body measurement chart

S. No.	Body Measurements	
1	Round chest	100 cm
2	Round waist	90 cm
3	Across shoulder	48 cm
4	Neck girth	42 cm
5	Round hip	104 cm
6	Sleeve length (full)	64 cm
7	Sleeve length (half)	25 cm
8	Outside leg	102 cm

DRAFTING'S OF PREPARED ARTICLES

Drafting of Doctors' Lab Coat

LAB COAT

Measurements required

Round chest: 100 cm

Across shoulder: 48 cm

Length: 97 cm

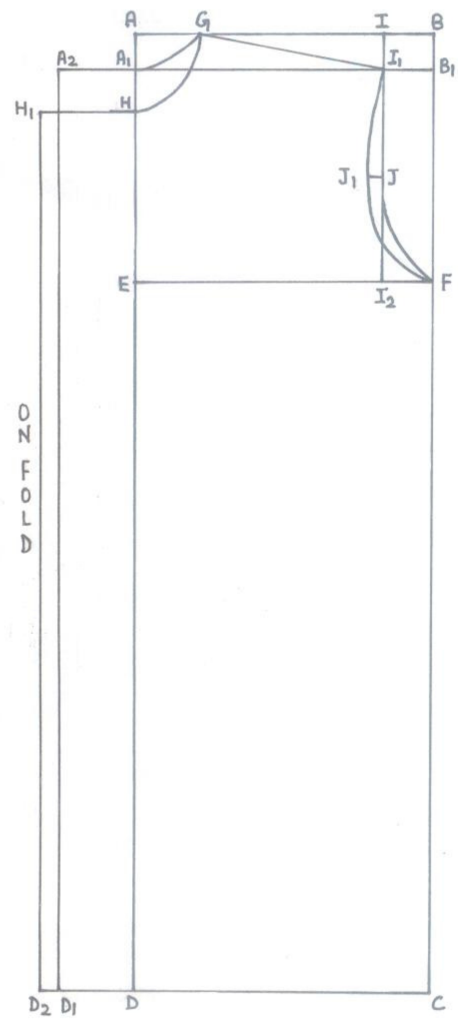
Size of the paper

Length: Top length = 93 cm (15.5 cm)

Width: ½ of round chest + 10.16 cm = 60.16 cm (10.03 cm)

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.



- $AA_1 = BB_1$ = 3.81 cm for back side

Join A_1 and B_1 with a line

- AE = BF = ¼th of the round chest (for arm hole = 25 cm

Join E and F with a line

- AG = 1⁄12th of round chest - 1.27 cm (for neck width) = 7.06 cm
- AH = 1⁄12th of round chest - 0.635 cm = 7.7 cm
- HH_1 = 8.5 cm for neck depth of front side

Join G and A_1 with a curve for back neckline

Join G and H_1 with a curve for front neckline

- AI = ½ of across shoulder + 1.27 cm = 25.27 cm
- Drop a perpendicular from I on EF line and mark the intersect points as I_1 and I_2

Join G with I_1 for the shoulder slope

Join I_1 and F with a curve for the back arm hole

- Take center point of I_1 and I_2 and mark as J
- $JJ_1 = 1.27$ cm

Join F, J_1 and I_1 with a curve for the front armhole

- $A_1A_2 = DD_1 = 8$ cm

Join A_1A_2, DD_1 and A_2D_1 (for slit opening at back)

- $HH_1 = DD_2 = 10$ cm

Join HH_1, DD_2 and H_1D_2 (for front opening)

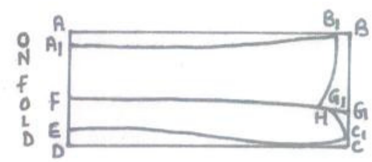
Cutting

- Cut along F, J, I, G, A_1, A_2, D_1 and C for back side, and
- Cut along F, J, I, G, H, H_1, D_2 and C for front side

Seam allowances

- Keep 1.27 cm for curves and shoulder slope, and
- Keep 2.54 cm for the side seam and 3.81 cm at the bottom for fold

LAB COAT COLLAR



Measurement required

Round neckline: 42 cm

Size of paper

Length: Round neckline + 5.08 cm = 47.08 cm

Width: 8.87 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.

- DE = 1.27 cm
- $CC_1 = 0.635$ cm

Join E and C_1 with a curve touching DC line

- EF = 3.175 cm
- $C_1G = 2.54$ cm
- $GG_1 = 0.635$ cm

Join G_1 and C_1 with a line or curve and FG_1 with an upward curve

- $G_1H = 1.27$ cm
- $BB_1 = 1.27$ cm

Join G_1B_1 with a line

- $AA = 0.85$ cm

Join A_1B_1 with a curve

Cutting

Cut along E, C_1, G_1 and F for band, and F, G_1, B_1 and A_1 for the collar

Seam allowances

Keep 1.27 cm at all lines

LAB COAT SLEEVE

Measurement required

Round chest: 100 cm

Sleeve length: 64 cm

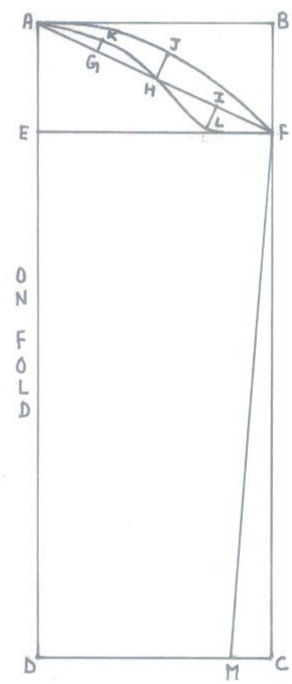
Size of paper

Length: 64 cm

Width: ½ of round chest – 2.54 cm = 47.46 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.



- AE = BF = $\frac{1}{12}^{th}$ of round chest +2.54 cm = 10.87 cm

Join A and F with a line. Divide it into four equal parts and mark it as G, H and I.

- HJ = 2.54 cm
- GK = 1.27 cm
- IL = 2.54 cm

Join A, J and F with a curve for the back side, and

Join A, K, H, L and F with a curve for the front side

- CM = 3.81 cm

Join FM with a line

Cutting

Cut along M, F, J and A for back side. Unfold the paper and cut along F, L, H, K and A for the front side.

Seam allowances

- Keep 1.27 cm on the curves, and
- Keep 2.54 cm for the side seam and at the bottom for fold

DRAFTING OF SURGICAL GOWN

SURGICAL GOWN

Measurements required

Round chest: 100 cm

Across shoulder: 48 cm

Length: 150 cm

Size of the paper

Length: Top length = 150 cm

Width: ½ of round chest + 10.16 cm = 60.16 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.

- $AA_1 = BB_1$ = 3.81 cm for back side

Join A_1 and B_1 with a line

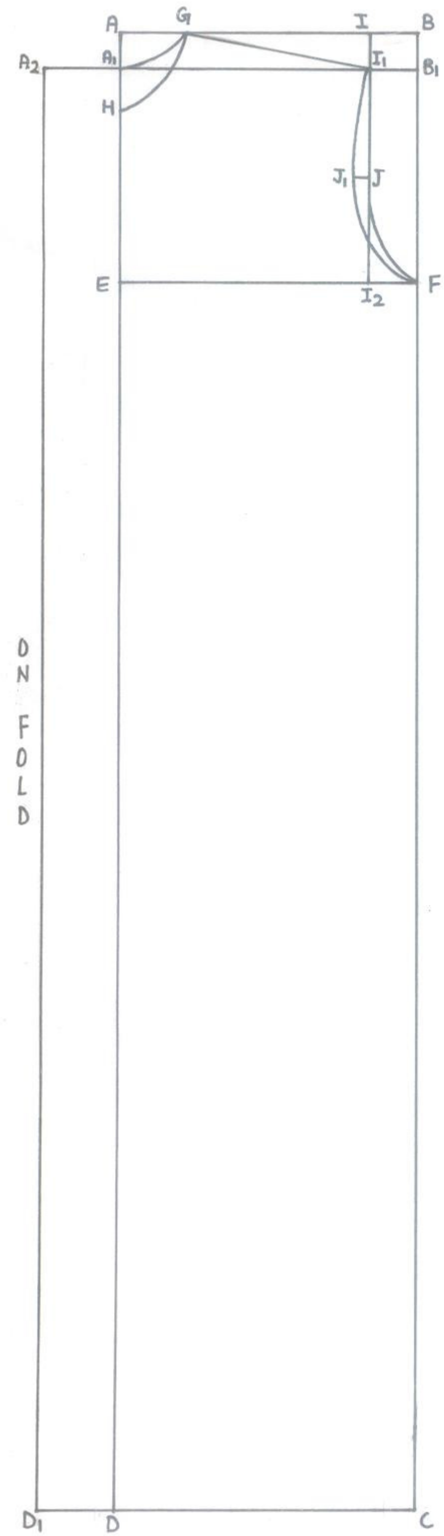
- AE = BF =¼th of the round chest (for arm hole = 25 cm

Join E and F with a line

- AG = 1⁄12th of round chest - 1.27 cm (for neck width) = 7.06 cm
- AH = 1⁄12th of round chest - 0.635 cm = 7.7 cm
- HH_1 = 8.5 cm for neck depth of front side

Join G and A_1 with a curve for back neckline

Join G and H_1 with a curve for front neckline



- AI = ½ of across shoulder + 1.27 cm = 25.27 cm
- Drop a perpendicular from I on EF line and mark the intersect points as I_1 and I_2

Join G with I_1 for the shoulder slope

Join I_1 and F with a curve for the back arm hole

- Take center point of I_1 and I_2 and mark as J
- JJ_1 = 1.27 cm

Join F, J_1 and I_1 with a curve for the front armhole

- $A_1 A_2$ = DD_1 = 8 cm

Join $A_1 A_2$, DD_1 and A_2D_1

Cutting

- Cut along F, J, I_1, G, A_1, A_2, D_1 and C for back side, and
- Cut along F, J_1, I_1, G, H, D and C for front side

Seam allowances

- Keep 1.27 cm for curves and shoulder slope, and
- Keep 2.54 cm for the side seam and 3.81 cm at the bottom for fold

SLEEVE

Measurement required

Round chest: 100 cm

Sleeve length: 64 cm

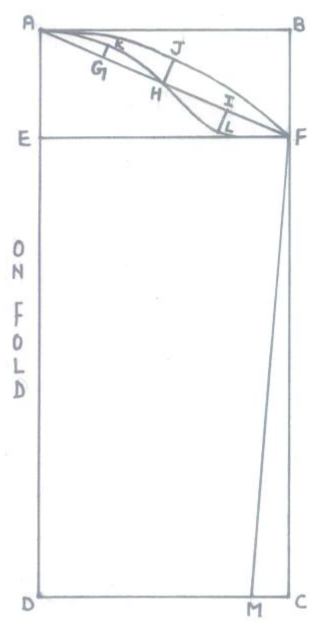
Size of paper

Length: Sleeve length – cuff width = 57.65 cm

Width: ½ of round chest = 50 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.



- AE = BF = $\frac{1}{12}$th of round chest +2.54 cm = 10.87 cm

Join A and F with a line. Divide it into four equal parts and mark it as G, H and I.

- HJ = 2.54 cm
- GK = 1.27 cm
- IL = 2.54 cm

Join A, J and F with a curve for the back side, and

Join A, K, H, L and F with a curve for the front side

- CM = 3.81 cm

Join FM with a line

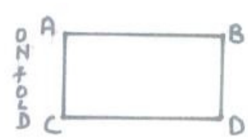
Cutting

Cut along M, F, J and A for back side. Unfold the paper and cut along F, L, H, K and A for the front side.

Seam allowances

- Keep 1.27 cm on the curves, and
- Keep 2.54 cm for the side seam

Cuff



Size of the paper

Length: ¼th of round chest = 25 cm

Width: 6.35 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.

AB = CD = 12.5 cm

AC = BD = 6.35 cm

Seam allowances

Keep 1.27 cm at all lines

DRAFTING OF PATIENT DRESS

PATIENTS' TOP

Measurements required

Round chest: 100 cm

Across shoulder: 48 cm

Length: 71 cm

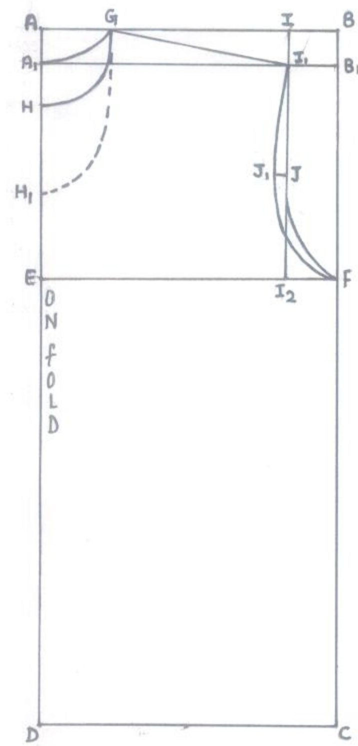
Size of the paper

Length: Top length = 71 cm

Width: ½ of round chest + 10.16 cm = 60.16 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure.



- $AA_1 = BB_1$ = 3.81 cm for back side

Join A_1 and B_1 with a line

- AE = BF = $\frac{1}{4}^{th}$ of the round chest (for arm hole = 25 cm

Join E and F with a line

- AG = $\frac{1}{12}^{th}$ of round chest - 1.27 cm (for neck width) = 7.06 cm
- AH = $\frac{1}{12}^{th}$ of round chest - 0.635 cm = 7.7 cm
- HH_1 = 8.5 cm for neck depth of front side

Join G and A_1 with a curve for back neckline

Join G and H_1 with a curve for front neckline

- AI = ½ of across shoulder + 1.27 cm = 25.27 cm
- Drop a perpendicular from I on EF line and mark the intersect points as I_1 and I_2

Join G with I_1 for the shoulder slope

Join I_1 and F with a curve for the back arm hole

- Take center point of I_1 and I_2 and mark as J
- JJ_1 = 1.27 cm

Join F, J_1 and I_1 with a curve for the front armhole

Cutting

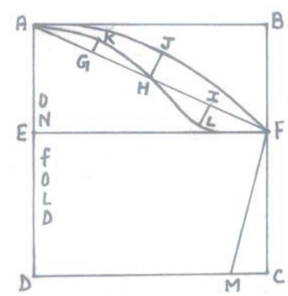
- Cut along F, J, I_1, G and A_1 for back side, and
- Cut along F, J_1, I_1, G and H_1 for front side

Seam allowances

- Keep 1.27 cm for curves and shoulder slope, and
- Keep 2.54 cm for the side seam and 3.81 cm at the bottom for fold

PATIENTS' TOP SLEEVE

Measurements required



Round chest: 100 cm

Sleeve length: 25 cm

Size of paper

Length: 25 cm

Width: ½ of round chest – 2.54 cm = 47.96 cm

Method

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure

- AE = BF = $\frac{1}{12}^{th}$ of round chest + 2.54 cm = 10.87 cm

Join A and F with a line. Divide it into four equal parts and mark it as G, H and I

- HJ = 2.54 cm
- GK = 1.27 cm
- IL = 2.54 cm

Join A, J and F with a curve for the back side, and

Join A, K, H, L and F with a curve for the front side

- CM = 3.81 cm

Join FM with a line

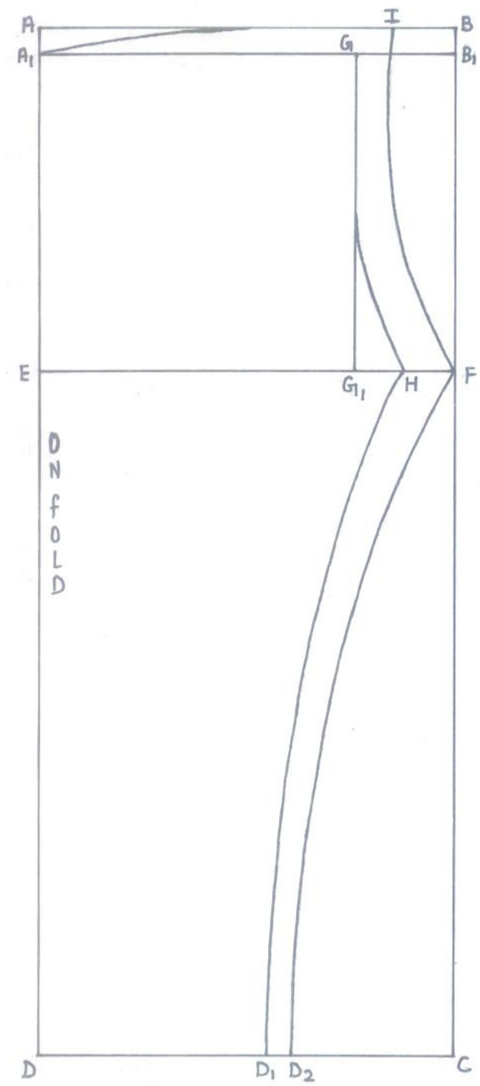
Cutting

Cut along M, F, J and A for back side. Unfold and cut along F, L, H, K and A for the front side

Seam allowances

- Keep 1.27 cm on the curves, and
- Keep 2.54 cm for the side seam and at the bottom for fold

PATIENTS' TROUSER



Measurements required

Trouser length: 102 cm

Round hip: 104 cm

Size of paper

Length: Trouser length + 2.54 cm = 104.54 cm

Width: ⅔rd of round hip + 15.24 cm = 84.54 cm

Method:

Take the calculated size of the paper and fold it widthwise. Keep the fold on left side. Mark the corners A, B, C and D as shown in figure

$AA_1 = BB_1 = 2.54$ cm

Front side

- $A_1E = B_1F$ = ⅓rd of round hip – 2.54 cm (for crotch length) = 32.1 cm
- A_1G = ⅓rd of round hip – 2.54 cm = 32.1 cm
- Draw a perpendicular from G on EF line and mark the intersect point as G_1
- EH = ⅓rd of round hip + 2.54 cm = 37.2 cm

Join H and G with a curve for crotch

- DD_1 = ¼th of round hip – 2.54 cm = 23.46 cm

Join D_1 with a curve

Back side

- AI = ⅓rd of round hip + 1.27 cm = 35.9 cm

Join F and I with a curve for crotch

Join A_1 and I with an outward curve

- DD_2 = ¼th of round hip = 26 cm

Join D_2 and F with a curve

Cutting

Cut along A_1, I, F and D_2 for back side. Unfold the paper and cut along A_1, G, H and D_1 for front side.

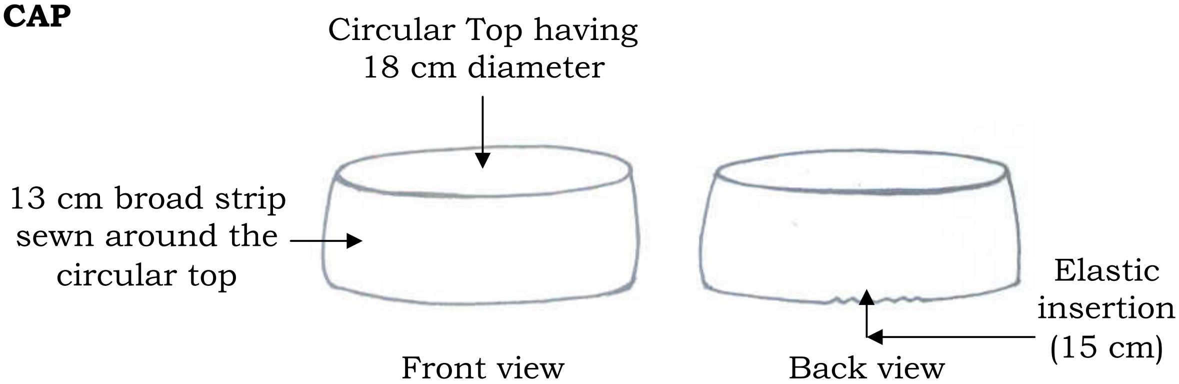
Seam allowances

- Keep 2.54 cm at crotch and inner lines, and
- Keep 3.81 cm at the bottom and for nepha.

DRAFTING OF CAP AND MASK

Cap and mask were prepared on the basis of the standard sizes available in the market.

CAP



Seam allowances

Keep 1.27 cm at all lines and 3.81 cm at the bottom for fold

MASK

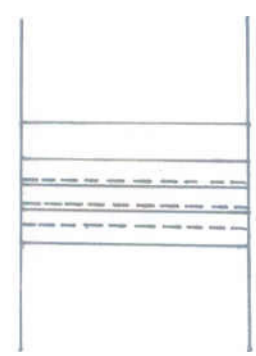
Size of the mask: 18 x 17.5 (without pleats)

: 10 x 17.5 (with pleats)

Three pleats was made horizontally

- Upper and lower pleats were of 2.5 cm
- Middle pleat was of 3 cm

90 cm long and 1 cm broad strings were attached on both sides of the mask



Seam allowances

Keep 1.27 cm at all lines

NAMES OF THE HOSPITALS SURVEYED

S. No.	Name of the hospitals	
	Ghaziabad district of Uttar Pradesh	**U. S. Nagar district of Uttarakhand**
1.	Sarvodaya Hospital, Modinagar	Sri Ram Hospital, Haldwani
2.	Ginni Modi Medical Research Centre, Modinagar	S. K. Nursing Home, Haldwani
3.	Pyarelal Hospital, Modinagar	Krishna Hospital & Research Centre, Haldwani
4.	Jeevan Hospital & Stone Centre, Modinagar	Jawahar Lal Nehru District Hospital, Rudrapur
5.	Lok Priya Hospital, Modinagar	Futela Hospital, Rudrapur
6.	Priyadarshini Hospital, Modinagar	Atul Hospital, Rudrapur
7.	ESI Hospital, Modinagar	Parisa Positive Health Retreat, Rudrapur
8.	Samudayak Swasthaya Kendra, Modinagar	Jeevan Deep Hospital & Diagnostic Centre, Rudrapur
9.	Sarvodaya Hospital, Ghaziabad	Anupam Hospital, Rudrapur
10.	Ganesh Hospital, Ghaziabad	Asha Nursing Home, Rudrapur
11.	Yashoda Hospital & Research Centre Ltd., Ghaziabad	Charvi Surgical Hospital, Rudrapur
12.	Shivom Hospital, Ghaziabad	Kumauon Pathology, Rudrapur
13.	A Unit of Nidhi Medical & Research Centre Private Ltd., Ghaziabad	Maharaja Agrasen Hospital, Rudrapur
14.	Pannalal Shayamlal Hospital, Ghaziabad	Surbhi Nursing Home, Rudrapur
15.	Narendra Mohan Hospital, Ghaziabad	University Hospital, Pantnagar

Analysis of variance (ANOVA) for different yarn testing properties

(a) Analysis of variance for total number of imperfections in 2-ply warp yarns

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	69696.00	17424.00	7290.000	**
Error	20.0	44.00000	2.200000		
Total	24.0	69740.00			

gm = 303.6000   sem = .6633250
cd at 1% = 2.668968   cd at 5% = 1.956765
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(b) Analysis of variance for total number of imperfections in single ply weft yarns

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	121162.2	30290.55	14155.50	**
Error	20.0	42.79688	2.139844		
Total	24.0	121205.0			

gm = 307.0400   sem = .6541932
cd at 1% = 2.632226   cd at 5% = 1.929826
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(c) Analysis of variance for hairiness in 2-ply warp yarns

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	3.838184	.9595459	2827.574	**
Error	20.0	.006787062	.0003393531		
Total	24.0	3.844971			

gm = 10.15400   sem = .008238362
cd at 1% = .03314805   cd at 5% = .02430262
Comparision at 5%

1	2 ns	3 *	4 *	5 *
2	3 ns	4*	5 *	
3	4 *	5 *		
4	5 *			

(d) Analysis of variance for hairiness in single ply weft yarns

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	5.801440	1.450360	281.3480	**
Error	20.0	.1031008	.005155039		
Total	24.0	5.904541			

gm = 6.578000 sem = .03210931
cd at 1% = .1291957 cd at 5% = .09472033
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 ns	4 *	5 *	
3	4 *	5 *		
4	5 ns			

(e) Analysis of variance for strength in 2-ply warp yarns

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	2.025673	.5064182	221257.5 **
Error	45.0	.0001029968	.000002288818	
Total	49.0	2.025776		

gm = 1.016600 sem = .0004784160
cd at 1% = .001819830 cd at 5% = .001362728
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(f) Analysis of variance for elongation percent at break in 2-ply warp yarns

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	490.3135	122.5784	2218.598	**
Error	45.0	2.486267	.05525038		
Total	49.0	492.7998			

gm = 8.119998 sem = .07433060
cd at 1% = .2827436 cd at 5% = .2117245
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 ns	4 *	5 *	
3	4 *	5 *		
4	5 *			

(g) Analysis of variance for strength in single ply weft yarns

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	1.191382	.2978455	16161.12 **
Error	45.0	.0008293390	.00001842976	
Total	49.0	1.192211		

gm = .8203999 sem = .001357562
cd at 1% = .005163985 cd at 5% = .003866903
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(h) Analysis of variance for elongation percent at break in single ply weft yarns

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	629.3695	157.3424	1234100 **
Error	45.0	.005737305	.0001274957	
Total	49.0	629.3752		

gm = 7.972000 sem = .003570653
cd at 1% = .01358228 cd at 5% = .01017071
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

Analysis of variance (ANOVA) for different fabric testing properties

(a) Analysis of variance for GSM of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	758.1750	189.5437	341.8623	**
Error	45.0	24.95001	.5544447		
Total	49.0	783.1250			

gm = 198.4200 sem = .2354665
cd at 1% = .8956829 cd at 5% = .6707066
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4*	5*	
3	4 ns	5 *		
4	5 *			

(b) Analysis of variance for yarn crimp percentage of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	4.128516	1.032129	56.25799	**
Error	45.0	.8255858	.01834635		
Total	49.0	4.954102			

gm = 10.52000 sem = .04283264
cd at 1% = .1629296 cd at 5% = .1220052
Comparision at 5%

1	2ns	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(c) Analysis of variance for yarn crimp percentage of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	100.5127	25.12817	1845.269	**
Error	45.0	.6127930	.01361762		
Total	49.0	101.1255			

gm = 9.851999 sem = .03690206
cd at 1% = .1403705 cd at 5% = .1051124
Comparision at 5%

1	2ns	3 *	4ns	5 *
2	3 *	4ns	5 *	
3	4 *	5 *		
4	5 *			

(d) Analysis of variance for thickness of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	.03530369	.008825922	47.55513 **
Error	45.0	.008351706	.0001855935	
Total	49.0	.04365540		

gm = .5129999 sem = .004308056
cd at 1% = .01638727 cd at 5% = .01227114
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3ns	4 *	5 *	
3	4 *	5 *		
4	5 *			

(e) Analysis of variance for stiffness of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	.2575851	.06439628	8.944672 **
Error	20.0	.1439880	.007199402	
Total	24.0	.4015732		

gm = 1.556000 sem = .03794575
cd at 1% = .1526794 cd at 5% = .1119375
Comparision at 5%

1	2ns	3ns	4 *	5 *
2	3ns	4 *	5 *	
3	4 *	5 *		
4	5ns			

(f) Analysis of variance for stiffness of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	1.382417	.3456043	82.31105 **
Error	20.0	.08397520	.004198760	
Total	24.0	1.466393		

gm = 2.088000 sem = .02897847
cd at 1% = .1165984 cd at 5% = .08548457
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3ns	4ns	5 *	
3	4ns	5 *		
4	5 *			

(g) Analysis of variance for drape of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	3351.392	837.8480	1839.310	**
Error	45.0	20.49854	.4555230		
Total	49.0	3371.891			

gm = 50.09401 sem = .2134299
cd at 1% = .8118584 cd at 5% = .6079370
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3ns	4 *	5 *	
3	4ns	5 *		
4	5 *			

(h) Analysis of variance for abrasion resistance of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	5.829849	1.457462	8.372644	**
Error	15.0	2.611115	.1740743		
Total	19.0	8.440964			

gm = 2.339000 sem = .2086111
cd at 1% = .8691091 cd at 5% = .6287732
Comparision at 5%

1	2ns	3ns	4 *	5 *
2	3ns	4 *	5 *	
3	4 *	5 *		
4	5ns			

(i) Analysis of variance for thermal conductivity of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	.1734131	.04335327	81.79644	**
Error	20.0	.01060028	.0005300142		
Total	24.0	.1840134			

gm = 2.068000 sem = .01029577
cd at 1% = .04142627 cd at 5% = .03037183
Comparision at 5%

1	2 *	3ns	4 *	5 *
2	3ns	4 *	5 *	
3	4 *	5 *		
4	5 *			

(j) Analysis of variance for crease recovery of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	3881.453	970.3633	149.4124	**
Error	20.0	129.8906	6.494531		
Total	24.0	4011.344			

gm = 86.18000 sem = 1.139696
cd at 1% = 4.585704 cd at 5% = 3.362026
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(k) Analysis of variance for crease recovery of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	4331.440	1082.860	532.1154	**
Error	20.0	40.70020	2035010		
Total	24.0	4372.141			

gm = 88.12000 sem = .6379671
cd at 1% = 2.566938 cd at 5% = 1.881960
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(l) Analysis of variance for breaking strength of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	17.57744	4.394361	596.9711	**
Error	45.0	.3312492	.007361094		
Total	49.0	17.90869			

gm = 9.084000 sem = .02713134
cd at 1% = .1032039 cd at 5% = .07728133
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5ns			

(m) Analysis of variance for breaking strength of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	130.4440	32.61101	455799.9 **
Error	45.0	.003219604	.00007154677	
Total	49.0	130.4473		

gm = 10.82000 sem = .002674823
cd at 1% = .01017467 cd at 5% = .007619008
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(n) Analysis of variance for elongation percent at break of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	394.7430	98.68575	560.3616 **
Error	45.0	7.924988	.1761108	
Total	49.0	402.6680		

gm = 27.00240 sem = .1327068
cd at 1% = .5047986 cd at 5% = .3780040
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(o) Analysis of variance for elongation percent at break of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	649.4426	162.3606	848973.4 **
Error	45.0	.008605957	.0001912435	
Total	49.0	649.4512		

gm = 20.93400 sem = .004373140
cd at 1% = .01663483 cd at 5% = .01245652
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(p) Analysis of variance for tearing strength of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	69.88048	17.47012	1966.694	**
Error	45.0	.3997345	.008882989		
Total	49.0	70.28021			

gm = 3.919999 sem = .02980434
cd at 1% = .1133717 cd at 5% = .08489518
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(q) Analysis of variance for tearing strength of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	23.12000	5.779999	361.2340	**
Error	45.0	.7200317	.01600070		
Total	49.0	23.84003			

gm = 3.340000 sem = .04000088
cd at 1% = .1521580 cd at 5% = .1139392
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(r) Analysis of variance for dimensional stability of pure and blended fabrics (warp way)

Source of variation	d.f.	s.s.	m.s.	fvalue	
Treatment	4.0	13.59599	3.398998	339.8791	**
Error	10.0	.1000061	.01000061		
Total	14.0	13.69600			

gm = 3.240000 sem = .05773679
cd at 1% = .2585138 cd at 5% = .1818785
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

(s) Analysis of variance for dimensional stability of pure and blended fabrics (weft way)

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	10.89601	2.724002	272.3705 **
Error	10.0	.1000109	.01000109	
Total	14.0	10.99602		

gm = 3.040000 sem = .05773817
cd at 1% = .2585200 cd at 5% = .1818829
Comparision at 5%

1	2 *	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5ns			

(t) Analysis of variance for air permeability of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	37.90000	9.475000	220.3467 **
Error	20.0	.8600082	.04300041	
Total	24.0	38.76001		

gm = 4.800000 sem = .09273663
cd at 1% = .3731371 cd at 5% = .2735669
Comparision at 5%

1	2ns	3 *	4 *	5 *
2	3ns	4 *	5 *	
3	4 *	5 *		
4	5 *			

(u) Analysis of variance for water vapour permeability of pure and blended fabrics

Source of variation	d.f.	s.s.	m.s.	fvalue
Treatment	4.0	44600.00	11150.00	67.65777 **
Error	20.0	3296.000	164.8000	
Total	24.0	47896.00		

gm = 1666.116 sem = 5.741080
cd at 1% = 23.09993 cd at 5% = 16.93580
Comparision at 5%

1	2ns	3 *	4 *	5 *
2	3 *	4 *	5 *	
3	4 *	5 *		
4	5 *			

Analysis of variance (ANOVA) for antimicrobial and bio-degradable testing of fabrics

(a) Analysis of variance for survivability of *S.aureus* on pure and blended fabrics (before washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	4.0	11453.76	2863.440	354.3861	**
b	4.0	2591.360	647.8400	80.17822	**
a*b	16.0	4168.640	260.5400	32.24505	**
error	75.0	606.0000	8.080000		
total	99.0	18819.76			

sem1=	.6356099	sem2=	.6356099	sem3=	1.421267
cd1 at 1%	2.375903	cd2 at 1%	2.375903	cd3 at 1%	5.312682
cd1 at 5%	1.790709	cd2 at 5%	1.790709	cd3 at 5%	4.004148

(b) Analysis of variance for survivability of *E.coli* on pure and blended fabrics (before washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	4.0	7483.200	1870.800	387.5967	**
b	4.0	868.8000	217.2000	45.00000	**
a*b	16.0	311.9998	19.49999	4.040053	**
error	75.0	362.0000	4.826667		
total	99.0	9026.000			

sem1=	.4912569	sem2=	.4912569	sem3=	1.098484
cd1 at 1%	1.836313	cd2 at 1%	1.836313	cd3 at 1%	4.106122

(c) Analysis of variance for survivability of *E. coli* on pure and blended fabrics (after washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	4.0	5629.440	1407.360	1353.235	**
b	4.0	352.6399	88.15997	84.76947	**
a*b	16.0	770.5601	48.16000	46.30784	**
error	75.0	77.99976	1.039997		
total	99.0	6830.640			

sem1=	.2280347	sem2=	.2280347	sem3=	.5099012
cd1 at 1%	.8523915	cd2 at 1%	.8523915	cd3 at 1%	1.906005
cd1 at 5%	.6424443	cd2 at 5%	.6424443	cd3 at 5%	1.436549

(d) Analysis of variance for survivability of *A.niger* on pure and blended fabrics (before washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	6.0	312.1004	52.01674	17.92209	**
b	4.0	1540.829	385.2072	132.7211	**
a*b	24.0	1100.971	45.87379	15.80557	**
error	105.0	304.7501	2.902381		
total	139.0	3258.650			

sem1=	.3809450	sem2=	.3219573	sem3=	.8518189
cd1 at 1%	1.413454	cd2 at 1%	1.194587	cd3 at 1%	3.160580
cd1 at 5%	1.068237	cd2 at 5%	.9028248	cd3 at 5%	2.388650

(e) Analysis of variance for survivability of *A.niger* on pure and blended fabrics (after washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	6.0	487.0858	81.18096	45.82795	**
b	4.0	967.3143	241.8286	136.5161	**
a*b	24.0	1269.486	52.89523	29.86020	**
error	105.0	186.0001	1.771429		
total	139.0	2909.886			

sem1=	.2976096	sem2=	.2515260	sem3=	.6654752
cd1 at 1%	1.104248	cd2 at 1%	.9332596	cd3 at 1%	2.469173
cd1 at 5%	.8345497	cd2 at 5%	.7053232	cd3 at 5%	1.866110

(f) Analysis of variance for survivability of *T. reesei* on pure and blended fabrics (before washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	6.0	31.77139	5.295231	6.177769	**
b	4.0	110.1714	27.54285	32.13332	**
a*b	24.0	144.2286	6.009525	7.011112	**
error	105.0	90.00001	.8571429		
total	139.0	376.1714			

sem1=	.2070197	sem2=	.1749636	sem3=	.4629101
cd1 at 1%	.7681237	cd2 at 1%	.6491830	cd3 at 1%	1.717577
cd1 at 5%	.5805196	cd2 at 5%	.4906286	cd3 at 5%	1.298081

(g) Analysis of variance for survivability of *T. reesei* on pure and blended fabrics (after washed) at different contact hours

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	6.0	163.8857	27.31429	44.81250	**
b	4.0	66.74288	16.68572	27.37501	**
a*b	24.0	237.2571	9.885713	16.21874	**
error	105.0	64.00001	.6095239		
total	139.0	531.8857			

sem1= .1745743 sem2= .1475422 sem3= .3903601
cd1 at 1% .6477388 cd2 at 1% .5474392 cd3 at 1% 1.448388
cd1 at 5% .4895371 cd2 at 5% .4137344 cd3 at 5% 1.094638

Analysis of variance (ANOVA) for bio-degradability rate of fabrics

(h) Analysis of variance for bio-degradability of pure and blended fabrics at different days interval

Source of variation	d.f.	s.s.	m.s.	fvalue	
a	4.0	18.24090	4.560225	1729.307	**
b	4.0	8.817198	2.204299	835.9042	**
a*b	16.0	1.052088	.06575549	24.93549	**
error	75.0	.1977768	.002637024		
total	99.0	28.30796			

sem1= .01148265 sem2= .01148265 sem3= .02567598
cd1 at 1% .04292202 cd2 at 1% .04292202 cd3 at 1% .09597655
cd1 at 5% .03235016 cd2 at 5% .03235016 cd3 at 5% .07233717

VITA

The authoress was born on 22nd September, 1983 at Aligarh in U.P. She passed her High School in 1998 and Intermediate Examination in 2000 with first division from Central Board of Secondary Education.

Thereafter, for under graduate programme she joined Ginni Devi Modi Girls (P. G.) College, Modinagar in the year 2000 and secured the B.Sc. (Home Science) degree in 2003 with first division. Subsequently, in 2003 she joined Post Graduate Programme in Textile & Clothing in the same college and in 2005 she completed M. Sc. (Textile & Clothing) with first division.

Subsequently, in 2006 she joined College of Post Graduate studies in G. B. Pant University of Agriculture and Technology, Pantnagar for her Ph.D Degree with major in Clothing & Textiles and minor in Social Sciences. Authoress was reciepient of University Ph.D. fellowship till February 2008. She was also the recipient of ICAR Senior Research Fellowship from February 2008 onwards. She completed her Ph.D course work with C.G.P.A 8.037/10.00.

Permanent Address

Vandana Sharma
D/o Shri. R. C. Sharma
H. No. 18, Vinay Park, Modinagar
Distt. Ghaziabad (U. P.)
Pin 201201
E-mail: texsep_22@yahoo.co.in

ABSTRACT

Name	:	Vandana Sharma	**Id. No.**	:	34021
Sem. & Year of admission	:	Ist Semester, 2006-07	**Degree**	:	Ph.D.
Major	:	Clothing & Textiles	**Deptt.**	:	Clothing & Textiles
Minor	:	Social Sciences			

Thesis Title : **Utilization of Eco-Friendly Bamboo-Cotton Fiber Blends for Protective and Healthcare Textiles**

Advisor : **Dr. (Mrs.) Alka Goel**

Medical textiles are one of the most rapidly expanding sectors in the technical textile market. Medical Textiles are the products and constructions used for medical and biological applications and are used primarily for first aid, clinical and hygienic purposes. An important area of meditech is protective and healthcare textiles which include doctor's lab coat, surgical gowns, patient dress, cap, masks, etc. All the protective and healthcare textiles require special antimicrobial properties combined with the wearer's comfort. Antimicrobial textiles are easily finding place in medical industry and mostly disposable and nonwoven antimicrobial textiles are used in medical field. Some of the treatments being used to produce antimicrobial textiles are harmful to the user as the chemicals used in the treatment of textiles tend to cause skin allergy, etc. when developed into apparel and also to our environment because the chemically treated textiles are not reusable. To address the growing concern about personal protection and environment, present study was carried out to develop reusable textiles with inherited antimicrobial and biodegradable properties which will help in reducing the amount of chemicals and trash being disposed off in the landfills. Therefore in order to enhance the antimicrobial and bio-degradable properties of protective and healthcare textiles, two eco friendly fibers i.e., cotton (cellulosic fiber) and bamboo (regenerated cellulosic fiber) were selected for the present study.

Till today, cotton being the most used fiber for making protective and healthcare textiles because fabrics developed from cotton fiber combined durability with attractive wearing qualities and comfort. Cotton can withstand repeated washings and is ideal for garments that must be laundered often but it lacks anti-microbial properties. Cotton fiber is easily available in India whereas bamboo fiber is imported from China which made it slightly costlier than cotton. Thus in view of the above stated points, value addition of cotton with bamboo fibers was carried out by using blending technology in order to prepare eco friendly fabrics with inherited antimicrobial properties. Bamboo fiber owns a unique anti-bacterial bio-agent named "bamboo Kun" which combined with bamboo cellulose molecules tightly all along during the process of being produced into bamboo fiber. Bamboo fiber's natural anti-bacterial function differs greatly from that of chemical antimicrobial treatments. The later often tend to cause skin allergy when added to apparels. Fiber properties were evaluated on the basis of end use of products. Ten ring spun yarn samples made up of cotton and bamboo in different ratios (100:0, 70:30, 50:50, 30:70 and 0:100) i.e. five different ratios of 2-ply warp and five different ratios of single ply weft yarns were prepared. Pure and blended warp and weft yarn samples were tested for estimating the quality of raw material and for controlling the quality of fabric produced. It was found that it is possible to produce good quality, strong and regular yarn with less hairiness through blending of cotton with bamboo. In order to ensure that the product being manufactured will meet the desired quality level and confirm to the laid down specifications for their intended purpose, pure and blended cotton-bamboo woven fabric samples were prepared and tested for various structural, mechanical, aesthetic and comfort properties. All the pure and blended fabrics were found suitable for preparation of different types of protective and healthcare textiles.

Assessment of antimicrobial property of pure and blended woven fabrics against commonly found bacteria's i.e. *S. aureus, E. coli* and fungi's i.e. *A. niger, T. reesei* were also carried out. It was observed that as the contact hours increased, bamboo-cotton blended fabric samples showed better antibacterial and antifungal properties as compared to pure cotton fabric sample. Reduction in the number of bacterial and fungal counts was seen higher among after washed fabric samples than the before washed fabrics. Biodegradability assessment of pure and blended fabrics were also carried out which indicated that as percentage of bamboo increased in fabric samples and as the days increased, the degradation of the fabric samples also increased. Visual assessment of all fabrics was done and the article which secured highest rank for the particular fabric was prepared. Cost of one meter fabric and the articles cost on the basis of the fabric consumed, trimmings used and labour cost were also calculated. Textile customers all over the world are demanding eco-friendly textiles; hence manufacturers and exporters are becoming more aware of the fascination and commercial value of eco textiles. The only way to produce the eco textile product is to turn towards the nature.

Thus the findings of the present research study **concluded** that pure and blended cotton and bamboo protective and healthcare textiles will have a great potential to finds its own place in today's competitive global market and can fetch good premium price in both domestic and global market as now a days customers are giving more importance to health and hygiene.

(Alka Goel)	(Vandana Sharma)
Advisor	Authoress