V. SUMMARY AND CONCLUSION

The summary and conclusion pertaining to the study entitled “Fabrication and Enhancement of Plasma Treated Cotton, Tencel Cotton and Modal Cotton with Anti-bacterial and Mosquito Repellent Finish” are summarized.

Phase – I: Survey

The survey was conducted to elicit information from 50 shops that are care products and 100 adolescent students who use armpit pads and mosquito repellent textile for bed linen. From the survey the following information were gathered such as type of materials, durability, cost and other finishing agents in and around Coimbatore district and adequate information was also collected from market about the existing products and their demands.

From the above collected information cotton, tencel and modal yarns were selected. The regenerated cellulosic yarn can generate new features and high tech performance in the fabric. The inherent characteristics and blending concepts allow synergistic effects to meet the requirements of modern functional textiles. Hence the cotton, tencel and modal yarn (40s count) were selected for this study. The selected yarn was converted into 40s count plain weave with the combination of 50:50 tencel cotton, 50 : 50 modal cotton and 100% cotton fabric woven into 20 metres each fabric and 2 metres from each was kept aside which was used as control sample for this study.

Pre-treatment

Cellulosic fabric need some form of treatment to make them suitable for dyeing and finishing. This treatment which removes natural or added impurities is called preparatory treatments such as scouring and bleaching. This was done on all fabrics except the control samples.
Application of Value Added Finish

The textile industry is searching for innovative production techniques to improve the product quality. Plasma is one such technique to improve the study. Plasma surface treatments show distinct advantages, because they are able to modify the surface properties of inert materials, sometimes with environment friendly devices. Plasma technologies provide an environmentally-friendly and versatile way of treating textile materials in order to enhance the variety of properties such as wettability and durability.

The potential application of performance finishes in textiles is as wide as the imagination of textile manufacturers. For giving high value addition, research and development activities are required in this area to improve strength and aesthetic properties without affecting normal textile properties. The above finishes are used for the value addition of textile with improved performance properties. Oxygen plasma treatment was given to the produced fabrics before finishing as it improves the capillarity in cellulosic fabrics.

Phase – II : Pilot Study – Selection of Herbs

For selection of herbs suitable for fabric, a pilot study was carried out with few herbs namely neem, pomegranate and rhizome of turmeric, prickly chaff flower, marigold, orange peel, guava leaf, keelanalli and vetiver.

Two plants for anti-bacterial finish namely prickly chaff flower, guava leaves, two plants for mosquito repellent finish namely keelanalli and vetiver were selected for this study.

Herbal Extraction Procedure

The extraction of selected natural sources was carried out by various methods like aqueous, alkaline, acidic and alcoholic methods. As alcoholic extraction using ethanol was more effective to extract the active ingredients of the natural sources, it was used in the present study.
Phytochemical Analysis

A portion of the dry extract was subjected to the phytochemical screening using the method adopted. Phytochemical screening revealed the presence of alkaloids, phenols, flavonoids, terpenoids and tannins.

Selection of Optimization Parameters

A series of experiments were carried out for anti-bacterial and mosquito repellent finishing. The trial parameters namely pH, concentration, temperature and time were optimized to determine the parameters.

Selection of Finishing Techniques

The pad-dry-cure method gives best result and the finishing agent impregnated thoroughly during pilot study. Hence pad-dry-cure method was selected for this study.

Phase – III: Fabric Evaluation

The unfinished, finished and plasma treated finished fabric were evaluated by the standard testing procedures to measure the physical, mechanical, comfort properties and water absorbency of the fabric samples. The surface morphological features of herbal finished and plasma treated herbal finished fabric were evaluated by using scanning electron microscope.

Herbal Analysis

Phytochemical analysis of the selected herbs indicated the presence of different compounds. These were confirmed by the various colour reactions exhibited by the plant extracts when subjected with different acids and alkalis.
Antibacterial and Mosquito Repellent Compound Identification Methods

FTIR Test

The FTIR technique was used to find out the compounds present in the selected herbs. The peaks in the spectra are an indicator of the amount of components present.

Evaluation of Anti-bacterial Finishes

In the present study, the anti-bacterial effect of the fabrics was determined by Agar diffusion test and Parallel streak method. Anti-bacterial activity was confirmed by zone of inhibition and colony population.

Mosquito Repellency Test

The finished and plasma treated herbal finished fabrics were evaluated for mosquito repellency. The results were studied with standard evaluation method.

Product Development

From the plasma treated finished fabrics, two products were developed such as arm pad and cushion cover. These products were used for performance study.

Wash Durability

The arm pad and cushion cover were subjected to washing up to 25 washes. Then the washed products were evaluated for their anti-bacterial and mosquito repellent property at the intervals of 5, 10, 15 and 20 washes.

Findings of the Study

The following are the salient findings of unfinished, finished anti-bacterial and mosquito repellent and plasma treated finished fabrics when
compared with their respective control sample and within the group and between A, B and C groups.

**Fabric Weight**

The fabric weight of the anti-bacterial finished fabric samples in all groups, sample AG$_2$ had increased 4.32% and AP$_1$ had decreased by 0.04% when compared with their respective control samples A, B and C. Increase in fabric weight was significant at 1% level.

**Fabric Thickness**

Fabric thickness of the sample CP$_2$ has increased by 2.9% and AG$_2$ and AP$_2$ have decreased by 0.25%. This may be due to the adherence of the finishing material on the fabric structures. Statistical analysis also shows a significant difference at one per cent level.

**Fabric Count in Warp and Weft Direction**

Fabric count increased maximum value in both warp and weft samples CP$_1$ 20.21 per cent and AG$_1$ 1.19 per cent in all three groups of samples ABC. Statistical analysis also proved that there was a significant difference at one per cent level in all the samples except group C in weft directions. This may be due to the shrinkage and expansion during finishing treatment.

**Fabric Tensile Strength in Warp and Weft Direction**

With regard to the tensile strength, the sample AP$_2$ increased by 16.17 per cent and the sample CG$_2$ has reduced in its strength by 41.29 per cent. The comparison was made with its control groups A, B and C in both warp and weft direction. Statistical analysis also proved the level of significance at one per cent.
Fabric Elongation in Warp and Weft Directions

The fabric elongation has decreased maximum in sample BP\(_2\) in weft direction (41.95 per cent) and increased by 128.08 per cent in sample BG\(_2\) in weft direction when compared between the groups of samples in warp and weft direction.

Abrasion Resistance

Abrasion resistance value has increased maximum in sample BP\(_2\) (32.11 per cent) and in sample CP\(_2\), -90.90 per cent has decreased when comparison was made with respective their control groups of A, B and C. The statistical analysis proved that there was a significant difference at one per cent level.

Fabric Stiffness in Warp and Weft Direction

Among the stiffness of unfinished, finished and plasma treated samples, the CP\(_1\) -33.68 has decreased by 33.68 in its values and sample BG\(_2\), 32.86 per cent had increased when compared within the group and between the group of warp and weft direction. This is because of the reaction of the finishes. Statistical interpretation reveals one per cent of significant difference of all the groups of fabric.

Air Permeability of Fabrics

The fabric air permeability has increased in sample BP\(_2\) by 6.81 per cent, the sample AP\(_1\) have low by 45.80 per cent. Statistical analysis also express that there is a significant difference at one per cent level.

Fabric Drop Test

The absorbency property of the finished and plasma treated finished fabrics were increased in water absorbency. The sample BP\(_2\), CG\(_2\) increased by 61.08 per cent and sample AG\(_1\) 6.77 per cent has low absorbency when compared within the group and between the groups A, B and C. Statistically...
also it was confirmed that there exists one per cent level of significant difference among the samples.

**Fabric Sinking Test**

With regard to fabric sinking test the finished samples have taken less time to shrink by the sample CP₂ 85.62 per cent and more time taken was by the sample CG₁ (15.62 per cent). Statistical analysis proved one per cent level of significance.

**Vertical Wicking Test**

As far as the vertical wicking test is concerned the result was found to be improved in finished fabric to great extent. The sample BP₂ exhibited 65.11 per cent and AG₂ has decreased by 41.75 per cent when compare within the group and between the groups A, B and C. The statistical data proved that it was significant at one per cent level among all the groups.

**Salient Findings of the Mosquito Repellent Finished Fabrics**

**Fabric Thickness**

The thickness of the sample B₁ has increased by 14.2 per cent and C₂ has decreased by 7.69 per cent when compared within and between the groups A, B and C. The statistical data proved that it was significant at one per cent level among the group of A, B and C.

**Fabric Tensile Strength in Warp and Weft Direction**

In warp direction strength increased in sample C₂ by 46.03 per cent and the sample B₁ has decreased by 6.35 per cent over control groups of A, B and C both warp and weft. Statistically one per cent level of significance was found.
Fabric Elongation in Warp and Weft Direction

The fabric elongation within and between groups A, B and C in both warp and weft sample, C₁ has increased by 68.62 per cent and in sample B₂ 56.25 per cent has decreased. This was proved statistically at one per cent level.

Fabric Abrasion Resistance

Among all the three groups of samples, the sample C₁ and C₂ 38.46 per cent exhibited highest by 38.46 per cent and A₂ had decreased by 5.88 per cent in abrasion resistance property when compared with their control group A, B and C. The statistical analysis also proved that there was a significant difference at one per cent level between the groups.

Fabric Stiffness in Warp and Weft Directions

As for as the stiffness is concerned in warp and weft directions, the sample C₁ has decreased by 12.5 per cent in weft direction and the sample B₂ had increased by 33.5 per cent when comparisons made with their control samples and between the groups A, B and C in both warp and weft direction. This was proved statistically at one per cent level.

Fabric Air Permeability

The fabric air permeability is higher in sample C₂ by 19.11 per cent and lower in the sample A₁ by 8 per cent when comparison made within and between the groups A, B and C. This may be due to the porosity that had been created in the fabric samples, because of the finishing and plasma treatment made the fabric more porosity. The air permeability properties have one per cent level of significance in group A and C. B group has five per cent level of significance.
Drop Test

The fabric absorbency has increased in the finished fabrics. As for as the sample B₂ (66.88 per cent) and the sample A₁ (11.27 per cent) are concerned absorbency value have reduced when compared within and between group of A, B and C. The statistically data proved that it was significant at one per cent level among all the samples.

Sinking Test

As far as sinking test is concerned, the sample A₁ increased by 53.98 per cent, in sample C₂ decreased by 32.51 per cent when comparison made within and between groups A, B and C. The sinking properties exhibit one per cent level of significance between all the samples.

Vertical Wicking Test

The rate of absorbency increased in all the finished and plasma treated finished samples. The absorbency of sample B₂ has increased by 96.80 per cent and decreased by 15.14 per cent in C₁ when compared within and between group A, B and C. Statistically also it was confirmed that there exists one per cent level of significant difference among the groups.

FT-IR Analysis – Functional Groups Finding

The presence of the functional groups such as O-H, C-H is responsible for the anti-bacterial and mosquito repellency activity.

Phytochemical Findings

Phytochemical screening test shows the presence of alkaloids, flavanoids, tannins, phenols, terpenoids and saponins. This plant powder seems to have the anti-bacterial and mosquito repellent property chemical components.
Scanning Electron Microscopic Analysis

Morphology of the fabrics was analyzed using high resolution SEM suitable accelerating voltage and magnification. From the photograph, it is clear that continuous polymer film has formed on the finished fabric. This improves the durability of the anti-bacterial and mosquito repellent effect.

Agar Well Diffusion

Anti-bacterial activity imparted by the plant powders were assessed by the agar well diffusion method. This was confirmed by the zone of inhibition observed in each plant treatment.

Bacterial Reduction – AATCC 100

The anti-bacterial reduction tests were evaluated by the bacterial reduction count of colonies present in finished and plasma treatment finished fabrics. The combination of 50 : 50 tencel : cotton fabric exhibit the maximum bacterial reduction percentage.

Wash Durability

The anti-bacterial activity was assessed using *S. aureus* and *E. coli* after 15 washes. The bacterial reduction caused by herbal treatments were observed and recorded. The treatments exhibited to have a positive impact on reduction of bacterial population.

Mosquito Repellency Evaluation

The mosquito repellency results of the plasma treated finished tencel cotton fabric showed higher repellency percentage of 76 when compared with and without plasma treated fabrics.
Wear Study Findings

The plasma treated herbal finished and herbal finished fabric were constructed into arm pad and cushion covers. The selected adolescents girls were asked to wear the arm pad. After wear, the arm pads were subjected to 5, 10 and 15 washes. The plasma treated herbal finished arm pads could control bad odour even after 15 washes. The cushion covers were subjected to wash after 5, 10 and 15 uses. The respondents opine that the plasma treated herbal finished cushion covers could resist mosquito bite even after 15 washes. The respondents were satisfied with the plasma treated herbal finished products.

General summary of the study

The herbal extract application had been done successfully by exhaust and pad dry cure method on cotton, tencel cotton and modal cotton with and without plasma treated fabrics. The anti-bacterial activity of herbal finished (Pisidium guajava and Achyranthes aspera) fabric was studied qualitatively and quantitatively. Effectiveness of plasma treated herbal finished was also assessed after washing cycles. From the study following conclusions were derived.

The application of herbs such as *Pisidium guajava* and *Achyranthes aspera* on cotton, tencel cotton and modal cotton fabrics showed good anti-bacterial activity than without plasma treated fabrics. The fabrics pretreated with oxygen plasma only could further enhance the anti-bacterial property of the fabrics. The plasma gas containing reactive oxygen species which could enter the cell and eventually cause the death of the bacterial cell. The hydrophillic nature of carbonyl groups present in the oxygen plasma pre-treated fabrics also increased the anti-bacterial activity.

The present study focused on the mosquito repellency efficiency of the *Phyllanthus niruri* and *Vetiveria zizanioides* herbs. The ethanolic extracts were
finished on the cotton, tencel cotton and modal cotton fabrics and the mosquito repellency rate was tested by improved Excito chamber method.

The natural material and herbal extract treated with plasma is being capable of repelling mosquito on the fabric to a greater extent. The herbal products are eco-friendly and quite stable for prolonged period, and the above findings would be helpful for the scientific community in finding the right durable and reusable textiles for various medical applications.

The outcome of the survey showed that the awareness on the advantages of using natural herbs treated textile products to enhance lifestyle and women’s health was lacking. Therefore, the research focused on developing procedures to impart certain functionalities such as anti-bacterial and mosquito repellent characteristics to selected fibres used in the study.

It would be onerous task to consider many different type of fabrics and natural finishes. Hence the work focused on cotton and regenerated textile fibres such as tencel and modal. Likewise, four different natural products were chosen which have shown to posses anti-microbial and vector repellency characteristics. Two different sets of products were developed with one set having no pretreatment before herbal finishing and the other set having plasma pretreatment. As plasma is a surface modification technique such a treatment would enhance the reactivity of textile to subsequent chemical treatments such as natural herbs finishing treatment employed in the study. Altogether 21 different fabrics as shown in the Chapter III (Table IV) were developed for further evaluation.

Results indicated not only the type of herbal finishes influenced respective functionality, but also the nature of the fabric substrates influenced the overall property of the fabrics. For example, tencel/cotton blends treated with prickly chaff flower herbs gave the highest bacterial efficacy in the case of both \textit{E. coli} and \textit{S. aureus}. These results have been provided in Section IV.
In the case of mosquito repellency, plasma pretreated fabric after been treated with 50% vetiver and 50% keelanelli finish gave the highest repellency compared with untreated fabric.

Based on these points, It is finally concluded that the natural herbs such as; guava leaves (Psidium guajava), prickly chaff flower (Achyranthes aspera), keelanelli (Phyllanthus niruri) and vetiver roots (Vetiveria zizanioides) can be used as viable functional finishes for imparting anti-bacterial and mosquito repellency to different textile substrates like cotton, tencel cotton and modal cotton plain woven fabrics. Results from the study show that the plasma pretreatment has a positive effect on the final characteristics of fabrics. It is our understanding that plasma pretreatment will not add much cost to the overall process. Additionally, plasma treatment enhances further chemical treatments as reported similarly by many researchers for different applications that provide added advantages such as improved functionality to fabrics. Results from the research showed that natural products can serve as effective alternative materials to synthetic organic compounds, and therefore could be highly useful for the society as well as to the environment as a whole. With the necessity to reduce carbon footprint and environmental burden it is important for the textile industry to develop green processes and products for improving health and protect the environment.

The work reported in the thesis focused on natural herbs as a viable alternative to synthetics and pave the path forward for the industry to make inroads into sustainable manufacturing.

Limitation of the Study and Future Direction

This thesis based on voluminous experimental work has shown that the interaction between the type of substrates, pretreatment techniques and chemical finishes influence the overall results. Due to limitation of time, the thesis could not delve in depth on the chemical nature of fibres and its effect on the final characteristics of the fabrics. A major research programme that
would come out of the study could focus on the interaction between the chemistry of different fibres. It will be interesting and useful to gain understanding on such interactions and its effect on the functional characteristics of fabrics. While this study has shown that plasma as a pretreatment could have positive influence on functional properties such as vector repellency, as plasma is a surface treatment. Its durability over a period of time is an important aspect points that has to be seriously investigated.

As this research study predominantly focused on natural herbs, the availability and that cost aspects have to be discussed and taken into consideration towards technology translation.