Original Research Article **Bio-material science**

International Journal of Pharma and Bio Sciences

ISSN 0975-6299

ECO-FRIENDLY AND ANTIBACTERIAL FINISHES OF ORGANIC FABRICS USING HERBAL COMPOSITE MICROENCAPSULES

SUMATHI.S*[1], ANCY THOMAS[2]

[1]*Research Scholar, Research and Development Centre, Bharathiar University, Coimbatore, India*
[2]*Principal, Angels School of Fashion & Apparel Manufacturing, Thiruvalla, Pathanamthitta, Kerala, India*

ABSTRACT

Due to great demand for antimicrobial textiles based on eco-friendly natural agents, herbal microcapsules were prepared using *Curcuma aromatica*, *Camellia sinensis* and *Azadirachta indica* at optimized conditions and finished onto bamboo and organic cotton fabrics. Optimization of microencapsulation process was carried out after determining the antibacterial activity of fabrics finished with three different concentrations of herbal capsules and three different shell materials by EN ISO 20645 and AATCC 100. Optimized microencapsulation was prepared using 3X herbal concentration and neem gum as shell materials. The optimized microcapsule finished fabrics showed increased bacterial reduction percentage ($p<0.05$). Maximum bacterial reduction percentage was observed for organic cotton fabrics against *Escherichia coli* (93%) and *Staphylococcus aureus* (96%). Topographical FESEM analysis of microcapsules finished fabrics revealed that the surfaces were very smooth and uniform. Microencapsulation method implied in this research was a unique method for imparting the pharmacological compounds of the herbal composite onto fabric materials permanently.

KEYWORDS: Shell materials, AATCC 100, *Curcuma aromatica*, *Camellia sinensis* and *Azadirachta indica*

SUMATHI.S

Research Scholar, Research and Development Centre, Bharathiar University, Coimbatore, Indi.a

Received on: 25-04-2017
Revised and Accepted on: 01-07-2017
DOI: http://dx.doi.org/10.22376/ijpbs.2017.8.3.b310-321

INTRODUCTION

There is an increasing awareness for hygienic lifestyle and effects of global warming are raising necessity and expectation in consumers for a wide range of finished textile products with antimicrobial properties and UV protection factor[1]. In the field of medical industry one of the great challenge faced is the negative effects of the microorganisms. Plant materials have exhibited antimicrobial activities against various pathogenic organisms which in turn it is clear that consumption of green tea reduces risk of major diseases[2]. Bacterial infections are offering extensive challenge to health care and a major cause of morbidity and mortality. Due to bacterial resistance to antibiotics over the past decade, treatment of these infections has become even more challenging[3]. Cotton garments are an excellent medium for its adherence, transfer and propagation of infectious microbes in hospitals, clinics and hygiene industry. This may cause health disorders, odour and finally deterioration of fabric[4]. In recent years, there is a growing awareness in cleaner surroundings and healthy lifestyle. A range of textile products based on synthetic antimicrobial agents such as triclosan, metal and their salts, organometallics are currently used by the consumers. Even though the antimicrobial agents are found to be efficient and have durability in textile products they are major reason in causing side effects, toxicity, non biodegradability action on non target organism[5]. In contrast, these herbal finishing of antimicrobial agents are eco-friendly. Non allergic and do not cause any adverse effects to fabrics[6]. One of the important identified global problem is the treatment of infections by antibiotic resistance by pathogenic microorganisms[7]. In order to treat such infections there is an urgent and constant production and discovery of new antimicrobial products with novel mechanisms for new emerging diseases that is being caused by infections[8]. Plant extracts provide unlimited opportunities for the development and production of new drugs as pure compounds as well as it possess enormous therapeutic potential to treat many infectious diseases[9]. Tannins, alkaloids, flavonoids, triterpenoids, sesquiterpenes phenolic compounds, Carotenoids, steroids and ketones, present in the medicinal herbs have been suggested to be involved in antibacterial activities[10]. The antibacterial effect of essential oil against *Staphylococcus aureus* and *Escherichia coli* in nutrient broth medium was studied by Mohsenzadeh[11]. In the present study, three medicinal herbs, *Curcuma aromatica* (Kasthuri manjal), *Camellia sinensis* (Green tea) and *Azadirachta indica* (Ne0em) used for antibacterial finishing in bamboo and organic cotton materials were selected based on their numerous therapeutic value and different antibacterial phytochemical constituents. Bouhadjera *et* al.,[12] stated that the addition of essential oil leaves in broth culture inoculated with *S. aureus* and *E. coli* inhibited the growth of these organisms. Crude extracts of *Curcuma aromatica* exhibit antimicrobial activity against gram-positive and gram-negative bacteria due to the presence of mono-, di-, and sesquiterpenes[13, 14]. *Azadirachta indica* (neem) is naturalized in most of tropical and subtropical countries. The active antibacterial compound, Azadirachtin is responsible for its antibacterial properties[15]. Gul *et al.,*[16] stated that aloe vera consists of active ingredients like curcumin which have been reported to exert antimicrobial, anti inflammatory and antioxidant properties. Common green tea is rich source of dietary flavonoids which are classified as catechins (C) and epigallocatechin-3-gallate (EGCG). One of the potent polyphenol (EGCG) with the abundant potentialities with antimicrobial properties against resistant to microorganisms which acts by either disrupting the cell membrane which in turn inhibits the biosynthesis of the cell[17]. The need of antimicrobial textiles has increased abundantly with respect to the particular active agents and fibre type developed or under the development to confer antimicrobial activity to textiles. The usage of conventional exhaust pad-dry-cure processes, microencapsulation methods have been used for finishing both natural and synthetic fibres for the biocides like herbal extracts, triclosan and PHMB[18]. The process of microencapsulation is best compared to the conventional method in the aspects of economy, energy saving, eco friendliness and controlled release of substance, since the colloidal suspension is within the amorphous zone of the binder so that the reservoir of the agent is present in the solid solution within the polymer matrix which are found to be durable even after several washes[19, 20]. This process also separates a core material from the environment and also protects the unstable core thereby extends the core's shelf life which in turn improves the sustainability and controlled release[21].Considering the significant characteristics of this technique, in the present research, microcapsules of herbal extracts were prepared after optimizing its effective concentration and effective shell material. The optimized microcapsules were functionally finished on to the organic textile materials. To find out the efficiency of microencapsulated finished materials, the antibacterial and functional properties were investigated using standard test methods.

MATERIALS AND METHODS

Fabrics used in the study

Bamboo 100% and Organic cotton 100% fabrics were selected based on their significance in the environment. All the selected fabrics were considered to be eco-friendly in nature. The specification of the fabric materials were presented in Table 1. All the materials were scoured, bleached and dyed with reactive dye to attain basic preparatory process.

Table 1
Test fabrics and its parameters

Fabric parameter	Bamboo 100%	Organic cotton100%
Courses per cm	22.71	22.04
Wales per cm	17.20	17.99
GSM	127	114
Tightness factor	16.01	16.01
Loop shape	1.320	1.225

All parameters were selected based on the textile standards

Herbs and shell materials

Curcuma aromatica (Kasthuri manjal), *Camellia sinensis* (Green tea) and *Azadirachta indica* (Neem) herbal powders and three shell materials like sodium alginate (Hi Media), gum acacia (Hi Media) and neem gum was commercially procured from a local supplier at Coimbatore, Tamil Nadu, India.

Bacterial cultures used

Two bacterial cultures, *Escherichia coli* and *Staphylococcus aureus* which have the ability to cause hospital-acquired infections were commercially procured from a diagnostic laboratory at Coimbatore, Tamil Nadu, India.

Herbal composite preparation[18]

Commercial powders of neem leaves, green tea leaves and rhizome of *Curcuma aromatica* were weighed, air-dried and reduced to coarse powder. Using 100s siever the powders were finely sieved and packed separately before the extraction procedure. About 40g of each fine sieved powder was extracted overnight with distilled water. The distillates were freeze-dried to get dried plant extracts. Certain concentration of the plant extract was prepared by dissolving it with sterile distilled water, and filtrated through a 0.2 µm membrane filter. The neem leaf extracts were taken in a beaker and kept under magnetic stirring conditions at room temperature. During the stirring conditions, the green tea leaf extracts were slowly added at the rate of 1ml/min using a burette. Using similar conditions finally the rhizome powder extracts of *Curcuma aromatica* was added to get a final herbal composite. The herbal composite solution was then separated as three different concentrations (1X, 2X and 3X) and each concentrates were used for the microencapsulation process.

Optimization of herbal concentration and shell material for the preparation of microencapsulation solution[18]

Microcapsules were prepared by orifice-ionic gelation method. To optimize the conditions for preparing microencapsulation solution, two different herbal concentrations and two different shell materials were used separately. Briefly, sodium alginate was dissolved in sterile distilled water to form a homogenous solution. Different herbal concentration (1X, 2X and 3X) was added separately to the alginate solution and mixed thoroughly with a stirrer to form a viscous dispersion. The resulting dispersion was then sprayed into 0.5 ml calcium chloride (1%) solution by means of a sprayer under controlled aseptic conditions. Microcapsule droplets obtained in the calcium chloride solution were allowed to retain for 15 minutes. The obtained microcapsules were decanted and washed repeatedly with isopropyl alcohol. Finally, the microcapsules were dried at 45 °C for 12 hours. The microcapsules were then viewed under bright field microscope to determine its uniform size and structures. Similar procedure was carried out separately for the other shell material (gum acacia and neem gum). All the three microcapsule solutions (1X, 2X and 3X herbal concentration, sodium alginate, gum acacia and neem gum shell materials) were used for finishing 100% bamboo and 100% organic cotton separately (Table 2). Briefly, one litre solution containing 700 grams of capsules was used to finish one meter of fabric (Joshi et al)[17]. The fabric was immersed in the solution with 8% citric acid as a binder for 30 min under 50 ºC in oven. After exhaust finishing the fabric was removed from the oven and air dried at room temperature aseptically. All the test fabric finished separately with different microcapsules were subjected to qualitative antibacterial activity (ENISO 20645 test method) and one best herbal concentration and one best shell material was finally selected.

Table 2
Optimization of herbal microcapsule preparation and finishing onto test fabrics

Fabrics	Herbal concentration/ Shell material (1X)*			Herbal concentration/ Shell material (2X)#			Herbal concentration/ Shell material (3X)@		
100% Bamboo	1X/ sodium alginate	1X/ gum acacia	3X/ neem gum	2X/ sodium alginate	2X/ gum acacia	3X/ neem gum	2X/ sodium alginate	2X/ gum acacia	3X/ neem gum
100% Organic cotton	1X/ sodium alginate	1X/ gum acacia	3X/ neem gum	2X/ sodium alginate	2X/ gum acacia	3X/ neem gum	2X/ sodium alginate	2X/ gum acacia	3X/ neem gum

****10mg/10ml, # 20mg/10ml, @30mg/10ml***

***Finishing the fabric with optimized herbal microcapsules*[17]**

The fabric material (100% bamboo and 100% organic cotton) was finished separately in the optimized herbal microcapsule solution prepared with selected herbal concentration (3X) and selected shell material (neem gum). After exhaust finishing, the fabrics were subjected to determine its antibacterial activity, UV protection factor and mosquito repellent properties.

***Assay for qualitative antibacterial properties of samples (ENISO 20645)*[22]**

The antibacterial activities of microcapsules finished fabrics were tested according to ENISO 20645 test methods against *Escherichia coli* and *Staphylococcus aureus*. Nutrient agar plates were prepared by pouring 15 ml of media into sterile Petri dishes. The plates were allowed to solidify for 5 min and 0.1% inoculum was swabbed uniformly and allowed to dry for 5 min. The finished fabric with the diameter of 2.0 ± 0.1cm was placed on the surface of medium and the plates were kept for incubation at 37ºC for 24 hour. At the end of incubation, the zone of inhibition formed around the fabric was measured in millimetres and recorded.

***Assay for quantitative antibacterial properties of samples (AATCC 100-2004)*[23]**

The antibacterial properties of materials can be studied by quantitative (AATCC-100) test methods. Quantitative test is the proper indicator of degree of antibacterial activity when the antibacterial agents are fixed on to the textile material or are unable to leach out. The different tests carried out in this study were based on such consideration. All the treated fabrics and untreated fabrics by microencapsulation method were subjected to antibacterial assay. The assay used for measuring antibacterial properties was based on the AATCC Test Method 100-2004. Briefly, 1.0 ml of 12 hours challenge bacterial inoculum was dispersed as droplets over the test swatches (fabrics) using a micropipette. The swatches were inoculated in pre-sterilized 250 ml Erlenmeyer flasks. After all the samples were inoculated, the flasks were incubated at 37 ± 2 °C for 18 hour before being assayed for bacterial population density. The bacterial population density was determined by extracting the bacteria from the fabric by adding 100 ml of distilled water to each flask and shaken using an orbital shaker for 1 min. Then aliquots were serially diluted and pour plated to determine the bacterial density. The difference in number of viable bacteria was evaluated on the basis of the percentage reduction. Percentage reduction was calculated using the following formula.

$$R = (A-B) / A \times 100$$

Where, R is percentage reduction; A is the number of bacteria in the broth inoculated with treated test fabric sample immediately after inoculation i.e., at zero contact time and B is the number of bacteria recovered from the broth inoculated with treated test fabric sample after the desired contact period of 18 hours.

Statistical analysis of total viable bacteria on herbal microcapsule finished fabrics

Chi-square non parametric test using SPSS-9 for Windows 7 was used as a statistical tool to determine the effect of herbal microcapsules on bacterial reduction. The hypothesis selected (H_0) was that there is significant quantitative antibacterial activity of herbal microcapsules on the test organisms. The difference in the bacterial reduction percentage between the microcapsule finished and unfinished fabrics were statistically calculated with $p < 0.05$ considered significant.

***Characterization of finished fabrics*[17]**

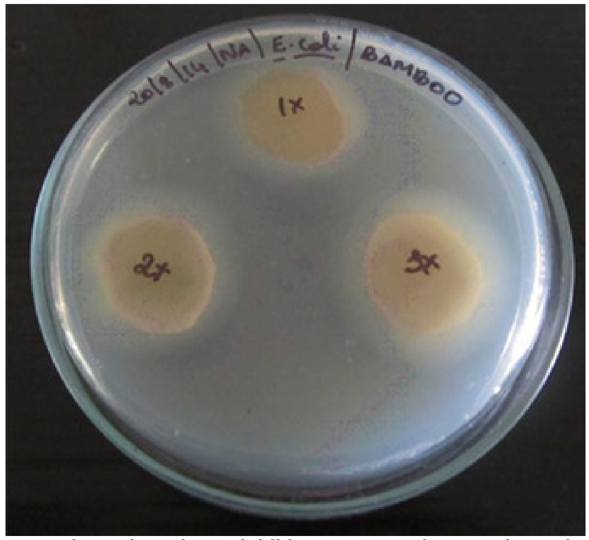
The surface morphology of microcapsules finished fabric samples were established by using Field Emission Scanning Electron Microscopy (FESEM). FESEM evaluation was used to know the uniformity of finishing microcapsules over the specimen. The topographic analysis of untreated and treated fabrics was prepared for SEM using a suitable accelerating voltage (0.2 to 30 kV), vacuum (between 2-133 Pa) and resolution at 1 kV/ 15 kV: 2.8 nm/1.5 nm.

RESULTS

Qualitative antibacterial activity of the herbal microcapsule finished fabrics - Selection of herbal microcapsule concentration

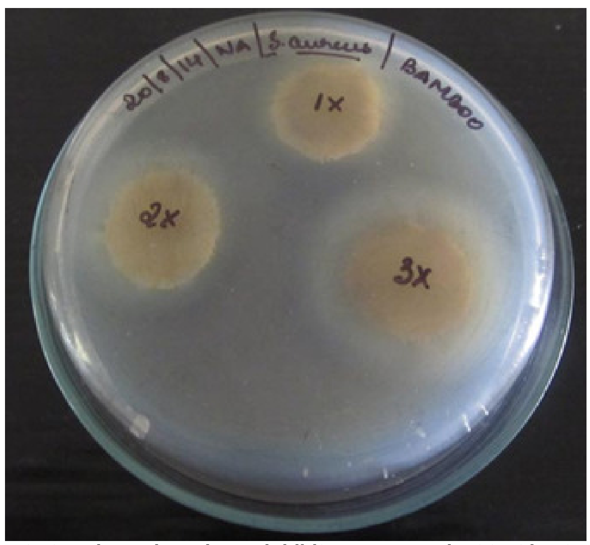
Qualitative antibacterial activity was determined based on the zone of inhibition around the finished fabrics against the test organisms. Maximum zone of inhibition was influenced by the greater action of finished herbal microcapsules. Three herbal concentrations (1X, 2X and 3X) extracted for the synthesis of microcapsules showed antibacterial activity under *in vitro* conditions. Among the three different concentrations, bamboo finished with 3X herbal capsules produced maximum inhibitory zones when tested against bacterial cultures. Inhibitory zones of 32.6 mm and 34.3 mm against *Escherichia coli* and *Staphylococcus aureus* were observed in Fig. 1a & b. Organic cotton finished with similar herbal microcapsule concentration produced inhibitory zones of 37.3 mm and 39.6 mm (Fig. 2a & b) against their respective test cultures (Table 3a). The zones around the test fabrics clearly indicate the leaching capacity of the capsules thus inhibiting the growth of the bacteria.

Qualitative antibacterial activity of the herbal microcapsule finished fabrics



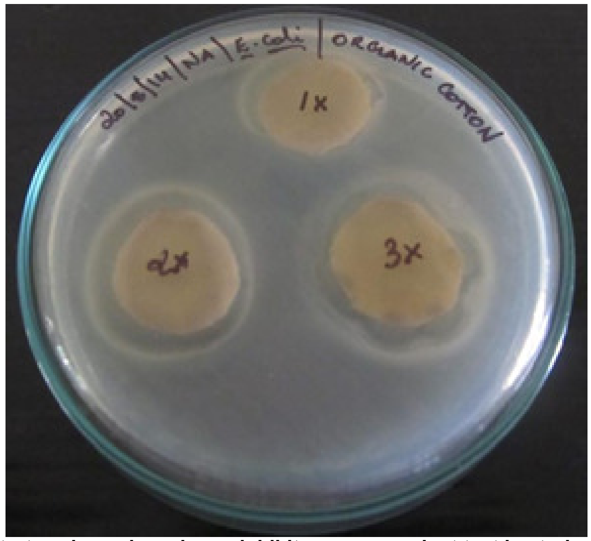
3X concentrates showed maximum inhibitory zone against test bacterium (32.6mm)

Figure 1a
Antibacterial activity of herbal concentrations finished in Bamboo against Escherichia coli



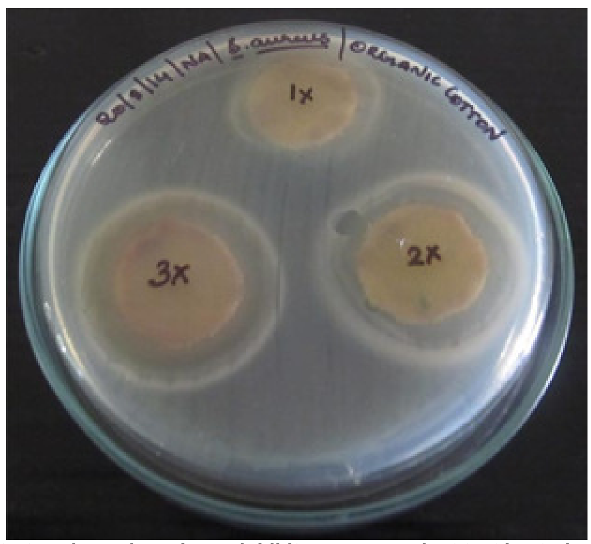
3X concentrates showed maximum inhibitory zone against test bacterium (34.3mm)

Figure 1b
Antibacterial activity of herbal concentrations finished in Bamboo against *Staphylococcus aureus*



3X concentrates showed maximum inhibitory zone against test bacterium (37.3mm)

Figure 2a
Antibacterial activity of herbal concentrations finished in Organic cotton against Escherichia coli



3X concentrates showed maximum inhibitory zone against test bacterium (39.6mm)

Figure 2b
Antibacterial activity of herbal concentrations finished in Organic cotton against Staphylococcus aureus

Table 3a
Qualitative antibacterial activity of herbal microcapsule finished fabrics
Selection of herbal microcapsule concentration

Fabric sample	Herbal concentration	Zone of inhibition (mm)	
		Escherichia coli	*Staphylococcus aureus*
Bamboo	Untreated (Control)	0	0
	1X	26.3	27.6
	2X	28.3	29.9
	3X*	32.6	34.3
Organic cotton	Untreated (Control)	0	0
	1X	30.9	26.3
	2X	34.6	36.6
	3X*	37.3	39.6

***Maximum inhibitory zones**

Selection of shell material

As expected all the fabric samples finished individually with three different shell materials (sodium alginate, gum Arabic and neem gum) showed significant inhibitory zones against the test organisms. Very interestingly the herbal microcapsules treated with neem gum showed maximum inhibitory zones against *Escherichia coli* and *Staphylococcus aureus* for both bamboo and organic cotton fabric materials. Bamboo finished with neem gum as shell materials showed inhibitory zones of 35.6 mm against *Escherichia coli* and 37.3 mm against *Staphylococcus aureus*. Comparatively, organic cotton finished with similar shell material showed slightly more inhibitory zones of 40.6 mm and 42.3 mm against the same test organisms (Table 3b). This may be due to difference in leaching action of the fabric materials on the surface of agar media. In Fig. 1 and 2 the microbicidal action of the herbal capsule leaching out from the finished fabrics, bamboo and organic cotton illustrating the inhibitory zones were presented.

Table 3b
Qualitative antibacterial activity of herbal microcapsule finished fabrics Selection of shell material

Fabric sample	Shell materials	Zone of inhibition (mm)	
		Escherichia coli	*Staphylococcus aureus*
Bamboo	Untreated (Control)	0	0
	Sodium alginate	30.3	31.6
	Gum acacia	32.3	34.3
	Neem gum*	35.6	37.3
Organic cotton	Untreated (Control)	0	0
	Sodium alginate	31.6	36.3
	Gum acacia	37.9	39.6
	Neem gum*	40.6	42.3

***Maximum inhibitory zones observed for Neem gum as shell material finished fabric**

Quantitative antibacterial activity of the optimized herbal microcapsule finished fabrics

The fabric samples treated with optimized herbal microcapsules (3X herbal concentration and neem gum as shell material) were quantitatively tested by AATCC-100 (bacterial reduction) test method. This quantitative test was performed to evaluate the effect of optimized herbal microcapsules finished onto bamboo and organic cotton separately. The anti-adherent activity of finished fabrics against the test organisms, *Escherichia coli* and *Staphylococcus aureus* was concentration dependent as the reductive effect of herbal microcapsules was in the range of 80% to 96% (Table 4). Bacterial reduction percentage was calculated from the CFU of the herbal microcapsule finished fabrics after exposing 0^{th} hour and 18^{th} hour. Maximum bacterial reduction percentage was observed for organic cotton fabrics against *Escherichia coli* (93%) and *Staphylococcus aureus* (96%). Interestingly, maximum antibacterial activity was also observed for similar fabric during the qualitative assay. It was clearly evident that by optimizing the conditions for preparation of microcapsules, the bacterial reduction percentage was progressively increased.

Table 4
Quantitative antibacterial activity of the optimized herbal microcapsule finished fabrics

Fabric samples		Bacterial reduction (%)	
		Escherichia coli	*Staphylococcus aureus*
Bamboo	Unfinished (Control)	0	0
	Finished*	80	83
Organic cotton	Unfinished (Control)	0	0
	Finished*	93	96

***fabric finished with optimized herbal microcapsules (3X herbal concentration and neem gum shell material)**

Statistical analysis of total viable bacteria on coated materials

Using chi-square statistical analysis, the effect of herbal microcapsules on bacterial adherence was determined. The difference in bacterial reduction percentage of finished and unfinished fabrics were taken as the experimental design. The hypothesis selected (H_0) was that there is significant quantitative antibacterial activity of herbal microcapsules on the test organisms. The difference in the bacterial reduction percentage between the microcapsule finished and unfinished fabrics were statistically calculated with $p < 0.05$ considered significant. For all the data, the calculated value was less than the table value (Table 5). In Table 5, the calculated value of each finished fabrics tested against the test organisms was presented. Since the calculated value was less than the table value, the assigned hypothesis is accepted. The statistical survey of the research proved the quantitative antibacterial activity of the optimized herbal microcapsule finished fabrics.

Table 5
Statistical analysis of anti-adherent activity of herbal microcapsule finished fabrics

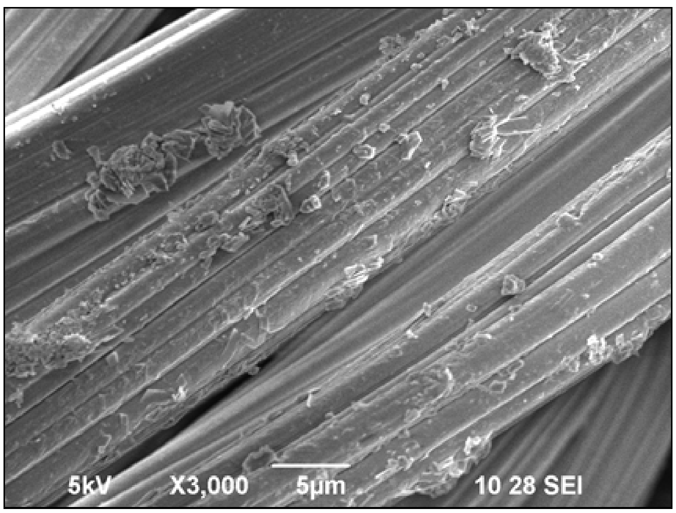
Fabrics	Test organisms	Significant comparison	Calculated value	Table value	Chi square test
Bamboo	*Escherichia coli*	Finished vs Unfinished Bamboo	3.56*	14.06	p<0.05
	Staphylococcus aureus	Finished vs Unfinished Bamboo	3.87*	14.06	p<0.05
Organic cotton	*Escherichia coli*	Finished vs Unfinished Organic cotton	4.25*	14.06	p<0.05
	Staphylococcus aureus	Finished vs Unfinished Organic cotton	4.31*	14.06	p<0.05

*** Calculated value is less than the table value, so the assigned hypothesis is accepted**

Characterization of finished fabrics

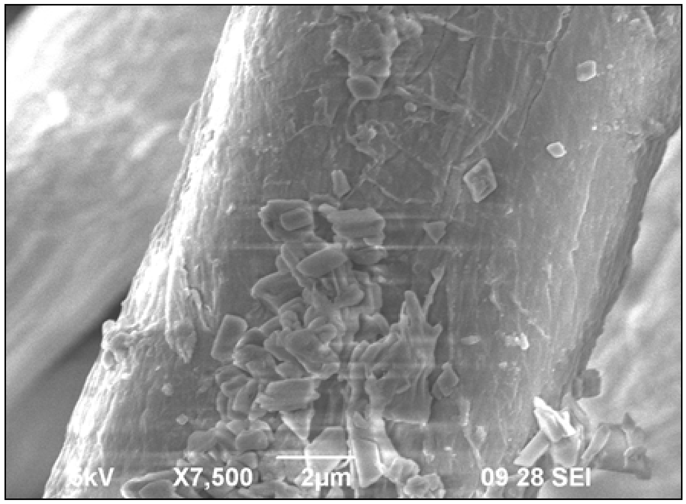
FESEM was used to examine if the treatment finishes were applied successfully on the test fabrics. It was also used to project an image of each specimen (microencapsulated finished and unfinished fabrics) to examine visually any differences in the specimen surface, across the test fabrics. If the finishes were evenly applied on the fabric surface through treatment, the fabric surface of specimens with treatment was expected to be smoother and more uniform than the untreated fabric surface. FESEM images of encapsulated herbal finished fabric samples were shown in Fig. 3a and b separately for bamboo and organic cotton respectively. The surfaces of specimens treated with microcapsules looked very smooth and uniform. The encapsulated particles were well dispersed on the fibre surface with homogeneous distribution in the coating layer, thus making the finished fabrics to have uniform antimicrobial property.

FESEM analysis of Microcapsule finished fabrics



At lower magnification, the herbal composite binding onto the surface of the fabric is evident but the structure of the compounds are not clear and not observed to be uniform

Figure 3a
FESEM analysis of bamboo finished with microencapsulated herbal particles.



At higher magnification, the herbal composite binding onto the surface of the fabric is evident very clearly and the structure of the compounds appears to be in the form of crystals

Figure 3b
FESEM analysis of organic cotton finished with microencapsulated herbal particles.

DISCUSSION

A wide range of textile products for medical, technical, industrial, home furnishing and apparel sectors with the application of antimicrobial properties have gained special interests to protect human being against harmful microbes. Commercially available antimicrobial agents and their compliance to the regulations imposed by international bodies like EPU is still unclear. Recent developments on herbal and its oil extracts for functional finishing onto textile fabrics raised a novel avenue in the biomedical textile research. In the present study two different fabrics finished with three different herbal concentrations (1X, 2X and 3X) individually showed good qualitative antibacterial activity. Qualitative antibacterial activity revealed the antimicrobial effectiveness against standard test cultures *Staphylococcus aureus* (gram positive) and *Escherichia coli* (gram negative) organisms. The zone of bacterial inhibition was indicated by a halo around the fabric samples. It was apparent that the activity of microcapsule finished fabrics was excellent for 3X herbal concentration. According to Ghannam[24], bacterial inhibition was due to the slow release of active substances from the fabric surface. Amino groups of the herbal extract were responsible for its excellent antimicrobial activity. Hecht[25], reported that in presence of slight acidity the amino groups will be converted to positive amino group ions. Thus converted ions will react with the negatively charged protoplasm of microorganisms and breaks the cell wall to destroy the microorganisms. After optimizing the conditions for microencapsulation process, the herbal composite finished fabrics also showed good bacterial reduction percentage during the quantitative antibacterial assay. Quantitative antibacterial activity tested by AATCC 100 test method revealed that antibacterial agent gets attached to the substrate through bond formation on the surface. According to Sarkar *et al*.,[26] the finished antibacterial compounds in the fabric samples disrupts the cell membrane of the microbes through the physical and ionic phenomenon. The finishing agent inhibited growth of test organisms by using an electrochemical mode of action to penetrate and disrupt their cell walls. When the cell walls are penetrated, leakage of metabolites occurs and other cell functions are disabled, thereby preventing the organism from duplication. EGCG of green tea extracts in the prepared herbal composite was found to have an interesting antibacterial action on methicillin resistant *Staphylococcus aureus*. The biological activity of EGCG and the *in vitro* study suggested that binding of negatively charged EGCG to positively charged lipids of the cell membrane, damages the membrane structure or fragments the lipid bilayer causing intramembranous leakage. EGCG can lead to bacterial cell death by inhibiting bacterial DNA gyrase, thus preventing DNA supercoiling. EGCG against clinical isolates revealed that the primary target of their anti-bacterial activity is phospholipids of the bacterial membrane, hence kills the cell by membrane disruption. Another biologically active compound in the prepared herbal composite namely, Azadirachtin of *Azadirachta indica* is actually a mixture of seven isomeric compounds labelled as azadirachtin A-G and azadirachtin E. Kazeem *et* al.,[27] evaluate the in vitro inhibitory effect of *Azadirachita indica* leaf extract on the activity of alpha-amylase and alpha-glucosidase as a means of alleviating hyperglycemia and managing diabetes mellitus. The compound is more effective and its antibacterial activity was influenced with the other active ingredients like salannin, volatile oils, meliantriol and nimbin[28]. The visual examination of the FESEM micrographs indicated that the antibacterial treatments were applied successfully to each test fabric. Similar observations were obtained by Chellamani and Panneerselvam[29] for the nano-scaled silver and fluorocarbon particles on cotton and polyester/cotton fabric samples. They observed that the nanoparticles were well dispersed on the fibre surface in both the cases, thus making the coated fabrics to have uniform antimicrobial and liquid repellent property. Rajendran *et al*.,[30] also observed similar coating patterns on the cotton fabric; the uniform coating of neem chitosan nano-composites on the fibers of the cotton fabric with a particle size ranging 30 nm provided enhanced antibacterial activity. Another significant characteristic that would influence the coating of particles on the material surface was determining the particle size. According to Castanon *et al.,*[31] the particle size plays a major role in determining their adhesion to the fibre molecules. They also specified that, generally agglomeration of large particles will get easily removed from the fibre surface, while the small particles will penetrate deeper and adhere strongly into fabric matrix. In the present research, smaller sized microcapsules were treated to fix firmly on the fibre assembly of the cotton fabric to enhance their durability. According to Sathianarayanan *et al*.,[32] the microcapsules were capable of binding in the interstices of the fibre assembly of cotton fabric. They reported that the microencapsulated cotton fabric treated with thulasi plant extract showed greater activity and durability even after 15 washings. In their research they reported that the microcapsules are firmly fixed on the fibre assembly due to the small spherical shape with a fairly uniform sized distribution. In support of this analysis, in our present research, the microcapsules were sized approximately on an average of 2.0 μm over the surface of treated fabrics. Due to the smaller size, the microcapsules facilitate the antibacterial activity and durability of drugs after adhering onto the fabric matrix firmly. Parthasarathi and Thilagavathi,[33] analysed the presence and sizes of antibacterial nano particles of zinc on the fabric surface using SEM. In their report they suggested that the nano particles were well dispersed on the fibre surface, although some aggregated nano particles were still visible. Thus the present finding from FESEM analysis was found supportive in accordance to the surface coatings of microcapsules on bamboo and organic cotton fabric samples. Microencapsulation method imparted in the present study was proved to be more significant due to its influence on durable antibacterial property. These particles were found more resistant to withstand repeated washes than any other methods like dip-dry and reactive exhaust due to many following reasons. According to Nelson[34], the microcapsules are small particles, size of between one and several hundred micrometers composed of liquid, solid or gas core and a coat, which protects the core material from external conditions. Microencapsulation is more advantageous to conventional processes in terms of economy, energy saving, ecofriendliness and controlled release of substance. The agents reside in colloidal suspension within the amorphous zone of the binder so that a reservoir of agent is present in solid solution within the polymer matrix. Such treated fabrics were reported to be durable to a few number of wash cycles. According to Sathianarayanan *et al*.,[32] microencapsulation is one of the novel methods of getting functional finishes on textiles. It is a process by which very tiny droplets of liquid or solid particles were covered with a continuous film of polymeric material. The agents reside in colloidal suspension within the amorphous zone of the binder so that a reservoir of agent is present in solid solution with in the polymer matrix. Such treated fabrics were reported to be durable to more number of wash cycles. The prolonged bioactivity of the fabric was due to slow diffusion of the antimicrobial agent out of the polymer reservoir. Wash fastness test proved that microencapsulated fabrics showed more percentage reduction of test organisms than the reactive drug bound fabrics.

CONCLUSION

All the fabric materials finished with optimized herbal microcapsules showed excellent antibacterial activity against *Escherichia coli* and *Staphylococcus aureus* due to the active biological compounds in the prepared herbal composite. Mode of action of these compounds on the cell membrane and peptidoglycan layer of bacteria thus proved its antibacterial activity. This indicated that the herbal composites could act as bactericidal and bacteriostatic. The fabrics with these finishing conditions shall be used for garments like bed linen sheet in hospital, surgical gowns, patient uniforms and other healthcare dress materials. Since these herbs and shell materials are abundantly available in tropical and sub-tropical countries, the scopes of imparting antibacterial finish in different fabrics are high. Since the raw materials used in this study are 100% natural, the antibacterial finished fabrics are considered to be eco-friendly possessing economic, social and health benefits to the human beings.

ACKNOWLEDGEMENT

The authors wish to express their gratitude to the Doctoral committee members of Research and Development Centre, Bharathiar University, Coimbatore, Tamil Nadu, India, for their input, valuable discussions and accessibility.

CONFLICT OF INTEREST

Conflict of interest declared none.

REFERENCES

1. Purwar R and Joshi M. Recent Developments in Antimicrobial Finishing of Textiles- A Review, AATCC Review. 2004;4(3): 22-26.
2. Jazani NH, Sahahabi S and Abdi Ali A. Antibacterial effects of water soluble green tea extracts on multi-antibiotic resistant isolates of *Pseudomonas aeruginosa*. Pak J Biol Sci. 2007;10(9): 1544 - 1546 .
3. Das S, Tanwar J, Hameed S and Fatima A. Antimicrobial potential of epigallocatechin-3-gallate (EGCG): A green tea polyphenol. J Biochem Pharmacol Res. 2014; 2(3): 167-174.
4. Deepti G. Antimicrobial treatment of textiles. Ind J Fibre Text Res. 2007;32: 254-263.
5. Sun G and Worley SD. Chemistry of durable and regenerable biocidal textiles. J Chem Educ. 2005;82(1): 60-64.
6. Akhtar Khan, N, Noor S, Abdus S and Ali-Abbas Q. Incidence and antibiogram patterns of *Escherichia coli* isolated from various clinical samples from patients at N.I.H. Islamabad. Pak J Biol Sci. 2002;5: 111-113.
7. Barbosa LN, Rall VL, Fernandes AA, Ushimaru PI, da Silva Probst I and Fernandes A. Essential oils against foodborne pathogens and spoilage bacteria in minced meat. Foodborne Pathog. Dis. 2009;6: 725-728.
8. Kozlowski R and Walentowska J. Role of biocides from plant origin in protection of natural fibers against biodeterioration. Proceedings of the International Conference on Flax and Other Bast Fibers, July 20th-23rd, Saskatoon, Canada. 2008; 326-331.
9. Enzo AP. Traditional plants and herbal remedies used in the treatment of diarrheal disease: Mode of action, quality, efficacy and safety considerations. In: Ahmad I, F. Aqil and M. Owais. (Eds). Modern Phytomedicine Turning Medicinal Plants in to Drugs. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim. 2007; 248-260.
10. Mohsenzadeh M. Evaluation of antibacterial activity of selected Iranian essential oils against *Staphylococcus aureus* and *Escherichia coli* in nutrient broth medium. Pak J Biol Sci. 2007;10: 3693-97.
11. Bouhadjera K, Bendahou ZM and Tabti B. Anti-microbial activity of extracts from Algerian Aristida pungens *L*. Pak J Biol Sci. 2005;8: 206-210.
12. Sharma S, Mukesh CS and Dharm VK. Formulation and antimicrobial activity of 95% ethanolic-benzene-chloroform extract of *Curcuma aromatica* Salisb. Ann Biol Res. 2010;1: 153-156.
13. Sharmin AS, Mohammad JA, Mominul IS, Rashed Z, Muhammad K, Sanjoy CM, Mohammad AH. Micropropagation and antimicrobial activity of *Curcuma aromatica*, a threatened aromatic medicinal plant. Turk J Biol 2013;37: 698-708.
14. Mukherjee PK and Wahile A. Integrated approaches towards drug development from Ayurveda and other Indian system of medicines. J Ethnopharmacol. 2006;103: 25-35.
15. Gul N, Mujahid TY, Jehan N and Samia A. Studies on the antibacterial effect of different fractions of *Curcuma longa* against urinary tract infection isolates. Pak J Biol Sci. 2004;7: 2055-2060.
16. Mehrotra S, Ashwani K, Srivastava and Shoma Paul Nandi. Comparative antimicrobial activities of Neem, Amla, Aloe, Assam Tea and Clove extracts against *Vibrio cholerae*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*. J. Med. Plants Res. 2008; 4(18): 2473-2478.
17. Joshi M, Wazed Ali S, Purwar R and Rajendran S. Ecofriendly antimicrobial finishing of textiles using bioactive agents based on natural products. Ind J Fibre Text Res. 2009;34: 295-304.
18. Thilagavathi G, Krishnabala and Kannaian T. Microencapsulation of herbal extracts for microbial resistance in healthcare textiles. Ind J Fibre Text Res. 2007;32: 351-354.
19. Monllor P, Capablanca L, Gisbert J, Díaz P, Montava I and Bonet A. Improvement of microcapsule adhesion to fabrics. Text Res J. 2010;80(7): 631-635.
20. Jalil R and Nixon JR. Biodegradable poly (lactic acid) and poly (lactide-co-glycolide) microcapsules: Problems associated with preparative techniques and release properties. J Microencap. 1990;7(3): 297-325.
21. EN ISO 20645: 2004. Determination of antibacterial activity - Agar diffusion plate test. Technical Committee CEN/TC 248. 2004; 1-3.
22. AATCC Test Method 100. Antibacterial Activity Assessment of Textile Materials: Percentage Reduction Method, American Association of Textile Chemist and Colorist, AATCC technical Manual. 2012; 149-150.
23. Ghannam N and Davidson PRK. The antidiabetic activity of aloes: Preliminary clinical and experimental observations. Horm Res. 1986;24: 288-294.
24. Hecht A. The overselling of aloe vera. FDA Consum. 1981;15(6): 26-29.
25. Sarkar RK, Purushottam DE and Chauhan PD. Bacteria-resist finish on cotton fabrics using natural herbal extracts. Indian J Fib Text Res. 2003;28: 322-331.
26. Kazeem MI, Dansu TV and Adeola SA. Inhibitory effect of *Azadirachta indica A*. juss leaf extract on the activities of alpha-amylase and alpha-glucosidase. Pak J Biol Sci. 2013;16(21): 1358-1362.
27. Vinoth BR, Manivasagaperumal R and Rajaravindran M. Phytochemical analysis and antibacterial activity of *Azadirachta indica* a juss. Int J Res Plan Sci. 2012;2(3): 50-55.
28. Chellamani, KP and Panneerselvam G. Breathability of Woven Surgical Gowns Treated With Nano Finishes. South India Textile Research Association, SITRA. 2010.
29. Rajendran R, Radhai R, Balakumar C, Ahammed HAM, Vigneswaran C and Vaideki K. Synthesis and characterization of neem chitosan nano-composites for development of antimicrobial

cotton textiles. J Eng Fiber Fab. 2012;7(1): 136-142.
30. Castanon MGA, Nino-Martinez N, Martinez-Gutierrez F, Martinez-Mendoza JR and Ruiz F. Synthesis and antibacterial activity of silver nanoparticles with different sizes. J Nanopart Res. 2008;10: 1343-1348.
31. Sathianarayanan MP, Bhata NV, Kokate SS and Walunj VE. Antibacterial finish for cotton fabric from herbal products. Indian J Fibre Text Res. 2010;35: 50-58.
32. Parthasarathi V and Thilagavathi G. Synthesis and characterization of zinc oxide nanoparticle and its application on fabrics for microbe resistant defence clothing. Int J Pharm Pharm Sci. 2011;3(4): 392-398.
33. Nelson G. Microencapsulates in textile coloration and finishing. Review of Progress in Coloration. 1991;21: 72-85.

Reviewers of this article

Dr M.Shabana Begum, M.Sc., M.Phil., Ph.D.

Associate Professor and Head,
Department of Biochemistry,
Muthayammal College of Arts and Science,
Rasipuram, Namakkal Dt.-637 408

Prof.Dr. M.Ranga Priya, M.Pharm., Ph.D., R.Ph.

Professor, Dept of Pharmaceutics,Sun Institute Of Pharmaceutical Education & Research, Kakupall, Nellore Rural, Nellore, Andhra Pradesh 524346

Prof.Dr.K.Suriaprabha

Asst. Editor , International Journal of Pharma and Bio sciences.

Prof.P.Muthuprasanna

Managing Editor , International Journal of Pharma and Bio sciences.

We sincerely thank the above reviewers for peer reviewing the manuscript