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Assessment of Antibacterial Activity of Herbal Finished Surface Modified Polypropylene Nonwoven Fabric Against Bacterial Pathogens of Wound

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ABSTRACT: The field of medical textiles, an antimicrobial textile in particular is interdisciplinary. Antimicrobial textiles are mainly used in medical and healthcare environments to control the proliferation of microorganisms. The present work is aimed to study the antimicrobial activity of the air plasma treated (PT) nonwoven polypropylene fabric coated with herbs, which can be used as wound dressing. Surface modification of the nonwoven polypropylene fabric was performed using air plasma. The air PT fabric was finished with the methanolic extracts of 11 medicinal herbs. Their antibacterial activities were analyzed against *Staphylococcus aureus* and *Escherichia coli*. Of these, three herbs namely *Ficus bengalensis*, *Cleome viscosa*, and *Areca catechu* showed good activity against *S. aureus* and *Escherichia coli*. The antibacterial activity of the air PT polypropylene fabric coated with 1 : 1 : 1 combination of the abovementioned herbs was also assessed as per AATCC 100 method and it was found to be 99%. The herbal finished fabric was tested against the predominant wound isolates by agar diffusion method. The results showed excellent antibacterial activity against *Staphylococcus* sp., good antibacterial activity against *Bacillus* sp., *Escherichia* sp., *Klebsiella* sp., *Pseudomonas* sp., *Serratia* sp., and *Proteus* sp. thus proving its potential as wound dressing. © 2012 Wiley Periodicals, Inc. J. Appl. Polym. Sci. 129: 672–681, 2013

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INTRODUCTION

Postoperative wound infection leads to longer hospitalization, and therefore, a costlier process for patients. However, it is still a common surgical complication despite the advances in modern medicine.[1] Postoperative wound infection occurs after surgeries. They can originate during the operation as a primary wound infection, or may occur after the operation from sources in the ward as a secondary wound infection. There are multiple reasons for postoperative wound infection which have been validated and documented as risk factors. A risk factor is any recognized contribution to an increase in postoperative wound infection.[2] The physiological state of the tissue in the wound and immunological integrity of the host seem to be of equal importance in determining the occurrence of infection.[3,4] Wound infection after operations is usually caused by the bacteria normally resident in the open, viscous or on the incised mucus membrane, that is, opportunistic or nosocomial pathogens.[5,6] Bacteriological studies have shown that postoperative wound infection is universal and that the bacterial types present vary with their geographical location[7–9] suggesting that different bacterial species colonize at the site of wound. *Escherichia coli*, *Bacilli*, *Enterococci*, Beta-hemolytic *Streptococci*, and *Staphylococcus aureus* are the important causes of postsurgical infection.

The use of textiles for wound dressings in medicine has a long tradition. Starting from a simple swab, cotton was used in medical textiles from ages past. Woven textiles are mostly used. The most important application of textiles in the medical field is the prevention of postoperative wound infection.[10]

Antimicrobial textile products find their applications in medical, technical, industrial, home furnishing, and apparel sectors. In general, there is a good demand for fabrics having functional/specialty finishes and antimicrobial finishes in particular, protecting humans against microbes. Currently, polypropylene is widely used in medical textiles in the form of disposable

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surgical gowns, shoe covers, facemasks, drapes, head covers, and so forth. Through this research work, an attempt has been made to impart antimicrobial property to the nonwoven polypropylene fabric that could be used for wound care. Though the inherent hydrophobicity of polypropylene is a bottleneck to use in wound care applications, this is overcome by imparting hydrophilicity on to the surface of polypropylene through surface modification by air plasma treatment.[11]

Antimicrobial finishes can be imparted to fabrics either using natural herbs or using chemical agents. Though a number of commercial antimicrobial agents have been introduced in the market, their compliance to the regulations imposed by international bodies, is still unclear.[12] According to WHO, medicinal plants would be the best source for obtaining a variety of drugs. These evidences contribute to support and quantify the importance of screening of natural products. Herbal molecules are safe, will overcome the resistance offered by the pathogens, since they are in a combined or pooled form of more than one molecule in the protoplasm of the plant cell. Some herbs have antibacterial as well as antifungal properties, which are clinically useful.[13] The results of some *in vitro* studies concluded that herbal oral liquids can be given to clinical drug resistant strains and different serotype strains of infection.[14]

Plasma technology in recent years, has emerged as a novel technique for the manufacture of newer and better materials.[15] The word Plasma is used to describe the activities of a wide variety of free electrons, ionized atoms or molecules and neutral particles.[16] Plasma is an ionized gas. When a solid is heated sufficiently that the thermal motion of the atoms break the crystal lattice structure apart, and therefore a liquid is formed. When a liquid is heated enough, the atoms vaporize off the surface, a gas is formed. Similarly, when a gas is heated enough, the atoms collide with each other and knock the electrons off, due to which plasma, the so-called "fourth state of matter" is formed.[17] Such knocked off electrons in the excited state, dissociate the ions of the gas present in the electric field. These dissociated ions of the gas and free electrons in the excited state, impinge or etch the topical surface of the polymer substrate kept in the electric field resulting in the surface modification of polymer surface through the introduction of polar groups.[18] Surface modification of polymeric surfaces is an emerging field due to its versatility in forming polar groups that result in the modification of the polymeric surface without affecting the bulk properties of the polymer.[19]

Based on the above information, this study is designed to assess the antibacterial activity of herbal extract finished air plasma treated (PT) nonwoven polypropylene fabric against postoperative wound causing pathogens. For this purpose, different herbal plant sources were collected, identified, dried, powdered, and extracted using methanol. The herbal extracts were finished onto the air PT polypropylene fabric by pad-dry-cure method and the antibacterial activity of the finished fabric was assessed qualitatively by the agar diffusion method. The combinatorial antibacterial activity of the best selected herbal extracts was studied quantitatively according to AATCC 100 test method for the finished fabric. To determine the antibacterial activity of the finished fabric against the predominant wound causing pathogens, wound swab samples were collected and the predominant bacterial isolates from the wound samples were identified morphologically and biochemically. The antibacterial activity of the herbal extract finished fabric was tested against these predominant pathogens by disc diffusion method. Such *in vitro* analysis of the antibacterial activity of the air PT polypropylene fabric finished with the herbal extract could establish its use in curtailing the postoperative wound infection.

EXPERIMENTAL

Fabric Selection and Air Plasma Treatment

The fabric used in this research work was a spun bonded nonwoven polypropylene fabric, having an aerial density of 50 gm^{-2}. Plasma treatment[20] was performed to the nonwoven polypropylene fabric using air as the working gas, to convert the hydrophobic fabric surface into hydrophilic surface. The plasma reactor (supplied by M/s Hydro pneoVac, Bangalore) was working on the principle of atmospheric pressure glow discharge plasma system. The airflow rate was 10 c^3/min and the distance between the electrodes was set as 2 mm. The pressure inside the plasma reactor was maintained at 200 mTorr and the time of treatment was 20 s. A fabric sample of 20×20 cm^2 was placed between the two electrodes and was subjected to atmospheric glow discharge plasma. The wettability of the PT fabric was estimated by Capillary rise method, by measuring the wicking height of the PT fabric. The wicking height was determined by the method based on INDA Standard test method 10.3.70. Five samples were tested along the machine direction (MD), and five samples along the cross MD, and the mean values were estimated. Then, the air PT nonwoven polypropylene fabric was subjected to herbal finishing.

Collection of Herbal Sources

Live and healthy herbal plant parts, such as leaves of *Ficus bengalensis* (Banyan), whole plant of *Tridax procumbens* (Coatbuttons), leaves of *Pongamia pinnata* (Indian beech), leaves of *Vinca rosea* (Periwinkl), gel of *Aloe vera* (Indian aloe), leaves and barks of *Morinda pubescens* (Great Morinda), nuts of *Areca catechu* (Betel nut palm), whole plant of *Cleome viscosa* (Spider flower) and flower of *Ixora coccinea* (Idly flower), were collected from different regions in and around Coimbatore, India. Both the commercially available (dyed) and the undyed raw betel nuts (*Areca catechu)* were selected for the analysis. These herbal sources were authenticated by the Botanical Survey of India, Coimbatore. The plant parts were washed twice in distilled water to remove the epiphytes and other extraneous matter from the plants. These herbal materials were dried under shade and powdered using an electrical grinder. The herbal powders were stored in dry containers for further studies.

Extraction of Medicinal Herbs

Methanolic extract of the herbs[21] were prepared by mixing 7 g of herbal powder to 100 mL of 80% methanol in an airtight conical flask and was kept at room temperature overnight. After 12 h of extraction, the solution was filtered using cheesecloth and the filtrate was kept at room temperature for evaporation of methanol. The solution was then filtered and used for finishing onto the PT fabric.

Finishing of PT Fabric Using Herbal Extract

The air PT polypropylene fabric was finished with the herbal extract by pad-dry-cure method.[22] The fabric was immersed in a bath containing herbal extract for 10 min at room temperature, with a liquor ratio set at 20 : 1. The fabric was then padded with a pressure of 20 kgf/cm^2 at a speed of 15 m/min. The padded fabric was air-dried and then cured at 120°C for 3 min.

Qualitative Assessment of Antibacterial Activity—Agar Diffusion Method

An *in vitro* antibacterial activity of the herbal extract finished fabric, was tested against *S. aureus* (ATCC 6538), a Gram-positive organism, and *Escherichia coli* (ATCC 8739), a Gram-negative organism, using nutrient agar (obtained from Himedia, Mumbai).[23] Nutrient agar plates were prepared by pouring 15 mL of media into sterile petri plates. The plates were allowed to solidify for 5 min. 0.1% inoculum suspension of the wound predominants was swabbed uniformly and the inoculum was allowed to dry for 5 min. The herbal extract-finished air PT polypropylene fabric of 2.0 ± 0.1 cm diameter was placed on the surface of the medium and the plates were incubated at 37°C for 24 h. At the end of incubation, the zone of inhibition formed around the fabric was measured in millimeters and recorded. Three herbs with higher antibacterial activity were selected. The powders of three selected herbs of higher antibacterial activity were combined in equal proportion. The extract was prepared for such herbal combination and finished onto the air PT nonwoven polypropylene fabric, by pad-dry-cure technique. The fabric finished with herbal combination was tested for its antibacterial activity against *S. aureus* and *Escherichia coli* using agar diffusion method.

Quantitative Assessment of Antibacterial Activity-AATCC 100-Test Method

The antibacterial activity of the nonwoven polypropylene fabric finished with herbal combination was assessed quantitatively against *S. aureus* and *Escherichia coli* in accordance with AATCC 100 test method.[24] The control fabric, that is, air PT polypropylene fabric and herbal extract finished air PT polypropylene fabric samples of 4.8 ± 0.1 cm diameter, were placed in a 50-mL conical flask with 0.5 mL of bacterial inoculums. After incubation over a contact period of 24 h at 37°C, the broth solution was serially diluted. The diluted solution was plated on nutrient agar and incubated for 24 h at 37 ± 2°C. Colonies of bacteria recovered on the agar plate were counted and the percent reduction of bacteria (R) was calculated using the following equation:

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

where A is the number of bacteria colonies from treated specimen after inoculation over a 24 h contact period, and B is the number of bacteria colonies from untreated (UT) control specimen after inoculation over a 24 h contact period.

Collection and Processing of Postoperative Wound Samples

Sterile cotton swabs were prepared for collection of post-operative wound samples. The pus samples were collected from different infected sites of patients' wounds. The collected swabs were stored in airtight sterile containers and then processed to isolate the wound pathogens. These samples were inoculated aerobically on sterile Glucose broth, Nutrient agar, Blood agar, Eosin Methylene Blue agar, Mannitol salt agar, MacConkey agar, and Chocolate agar and the plates were incubated at 37°C for 24–48 h to obtain the bacterial predominants, based on their nutritional requirements and biochemical characteristics.

Isolation, Purification, Identification of Bacterial Predominants, and Assessment of Antibacterial Activity Against the Isolated Pathogens

The colonies of each representative isolate were then characterized by standard bacteriological methods (morphologically and biochemically), subcultured and maintained in sterile nutrient agar slants. The isolates were subjected to microscopic analysis by staining techniques, and the colony morphology of the isolate was studied by growing the cultures on various agar media. The biochemical characteristics of the isolates were studied by performing indole production, methyl-red, Voges-Proskauer, citrate utilization, catalase production, oxidase production, starch hydrolysis, carbohydrate fermentation, and urease production tests. The identified bacterial isolates were then used for assessing the antibacterial activity of the air PT nonwoven polypropylene fabric finished with the best herbal extract combination by disc diffusion method.

Surface Morphology Analysis

The surface morphology of the UT, PT, and herbal finished (HF) polypropylene nonwoven fabric samples were analyzed using a scanning electron microscope (SEM). The fabric samples were mounted on a specimen stub and examined with a SEM, Jeol Model JSM-6360.

PHYSICAL TESTING

Tensile Strength Testing. The tensile strength of the polypropylene nonwoven fabric of both UT and treated samples were estimated as per ASTM D 5035:2006.

Air Permeability Testing. Air permeability of the UT, PT, and the HF polypropylene nonwoven fabric samples were measured using the standard testing procedure (ASTM D 737:2008).

Thermal Resistance Testing (ISO11092). The fabric sample was placed over a measuring plate, which was maintained at a standard temperature (35°C). Continuous exposure of the fabric over the heated surface facilitates the absorption of heat by the fabric. The heat was absorbed due to the property of the fabric and temperature of the measuring unit decreases thus increasing the watts. The experiment was repeated for every 15 min up to 120 min and the mean value was estimated.

All the above physical and functional tests were performed after conditioning the test specimens at 65% relative humidity and 27 ± 2°C for 24 h by placing them in an appropriate moisture equilibrium in the standard atmosphere for preconditioning textiles as directed in Practice D 1776 (ASTM 2008).

RESULTS AND DISCUSSIONS

India is endowed with a rich wealth of medicinal plants. Herbs have always been the principal form of medicine in India, and presently, they are gaining popularity throughout the developing countries as people strive to stay healthy and to treat illness

Table I. Antibacterial Activity of Herbal Finished Fabric by Agar Diffusion Method

S. no.	Name of the herbs	Antibacterial activity—zone of bacteriostasis (mm)	
		Staphylococcus aureus	*Escherichia coli*
1.	***Areca catechu***	**36**	**25**
2.	***Pongamia pinnata***	24	0
3.	*Ficus bengalensis*	**31**	**24**
4.	***Vinca rosea***	0	0
5.	***Cleome viscosa***	**27**	**25**
6.	*Ixora coccinea*	22	0
7.	*Tridax procumbens*	0	0
8.	*Aleo vera*	0	0
9.	*Morinda pubescens (Leaf)*	0	0
10.	*Morinda pubescens (Bark)*	26	0
11.	*Areca catechu dyed*	23	0

with medicines that work in concert with the body's own defense. India recognizes more than 2500 plant species which have medicinal values. However, such vast natural resources of flora are still to be investigated for their medicinal properties.[25]

The wound samples collected from the patients were processed for the predominant bacterial flora and were identified based on biochemical and morphological characteristics. The identified bacterial isolates were used to test the antibacterial activity of the finished fabric and the diameter for zone of inhibition was compared to obtain the efficient herbal remedies against postoperative wound infection.[26]

Air Plasma Treatment of Nonwoven Polypropylene Fabric

The fabric used for this study was a nonwoven polypropylene fabric, which was subjected to plasma treatment using air as working gas.

Surface modification of polymeric surfaces is an emerging field due to its versatility in forming polar groups that result in the modification of the polymeric surface without affecting the bulk properties of the polymer.[19] The atmospheric conditions that were prevailing inside the plasma reactor, which were mentioned earlier, have made the atoms in the electric field, to knock off the electrons. The knocked off electrons in the excited state, dissociated the ions of the air present in the plasma chamber, as the working gas. These dissociated ions of the air and the free electrons in the excited state, impinged or etched the topical surface of the polymer substrate kept in the electric field resulting in the surface modification of nonwoven polypropylene through the formation of polar groups.[18] These polar groups formed, were responsible for the conversion of the inherent hydrophobic polymer surface into a hydrophilic one. The scanning electron micrographs are given in Figure 3(a–c). The etching of the polymer surface due to plasma surface activation can be observed in Figure 3(b). Atmospheric pressure plasma surface activation of polypropylene using air as the reactive gas, modifies the hydrophobic surface into hydrophilic surface.[27]

Air plasma treatment modifies the hydrophobic surface of the nonwoven polypropylene fabric into hydrophilic surface. The hydrophilicity of air PT polypropylene fabric was determined by calculating the absorbency time in seconds, based on INDA Standard test method of 10.1.70. The time of absorbency was noted in 10 different places of the fabric, and their mean value was estimated to be 7.01 s. The UT polypropylene fabric did not absorb any water droplets even for more than 60 min, which implies that it is a total hydrophobic fabric. The wickability of the PT fabric was estimated by Capillary rise method, by measuring the wicking height of the PT fabric. The wicking height was determined by the method based on INDA Standard test method 10.3.70. The mean wicking height was calculated as 6.6 cm along the MD and 6.1 cm across the cross MD.

The above investigation reveals that the hydrophilicity was obtained for 100 W radiofrequency (RF) power,[28] at an air pressure of 200 mTorr, with an electrode gap of 2 mm and for an exposure of 20 s. This may be the reason that a high concentration of hydrophilic groups have been formed due to the plasma treatment by the aforementioned process parameters.[29] The gas-phase radicals have sufficient energy to disrupt the chemical bonds in the polymer surface on exposure, which results in the formation of a new chemical species. Modification of textile surfaces by plasma technology can be used to obtain nano-porous structures.[30]

Antibacterial Activity of the Herbal Extract Finished Polypropylene Fabric by Agar Diffusion Method (ENISO 20645)

Herbal extracts of all the 11 herbs were extracted using 80% methanol. The antibacterial activity of the herbal extracts was tested by agar diffusion method against *S. aureus* and *Escherichia coli* as per the standard. From the results as in Table I, it was concluded that 3 (*Areca catechu*, *F. bengalensis*, and *C. viscosa*) of the 11 herbal extract-finished air PT polypropylene fabric samples showed maximum antibacterial activity against both *S. aureus* and *Escherichia coli*. The antibacterial activity of *Areca catechu*, *F. bengalensis*, and *C. viscosa* against *S. aureus*/*Escherichia coli* was measured in terms of zone of bacteriostasis (mm) which were found to be 36/25 mm, 31/24 mm, and 27/25 mm, respectively. The air PT nonwoven polypropylene fabric, coated with combination of herbs exhibited better activity

Table II. Antibacterial Activity of Best Herbal Combination Finished Air Plasma Treated Nonwoven Polypropylene Fabric

Test organism	Zone of bacteriostasis (mm) according to ENISO 20645	Bacterial reduction according to AATCC 100 (%)
Staphylococcus aureus	38	99.00
Escherichia coli	27	99.00

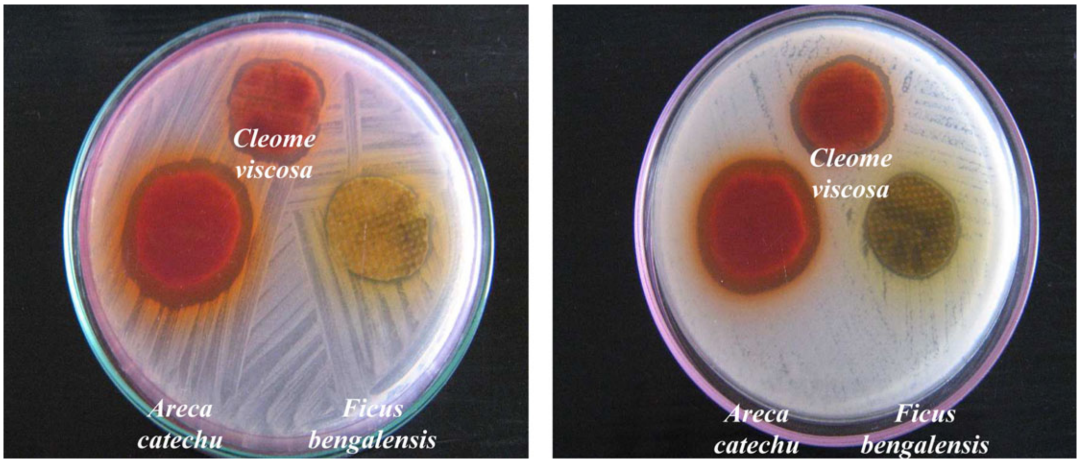
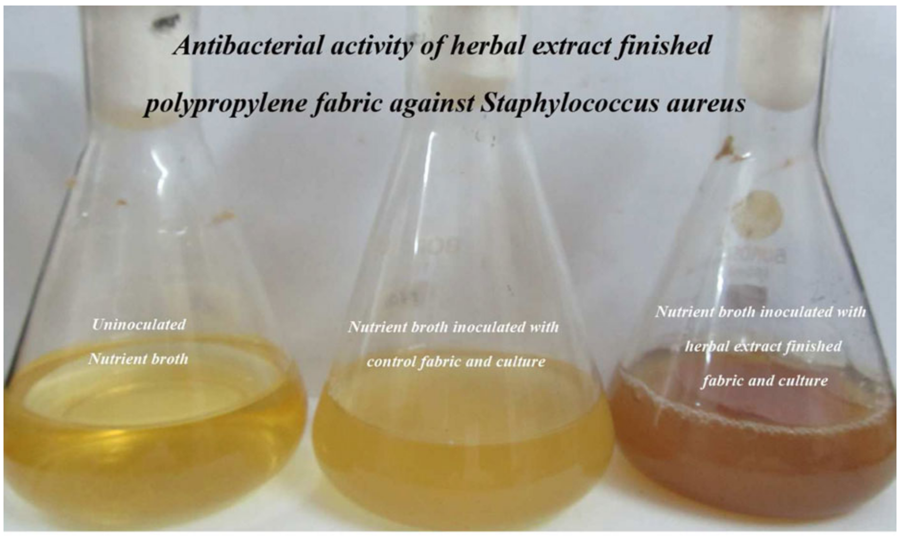


Figure 1. Assessment of antimicrobial activity for methanolic extracts against wound causing organisms. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]



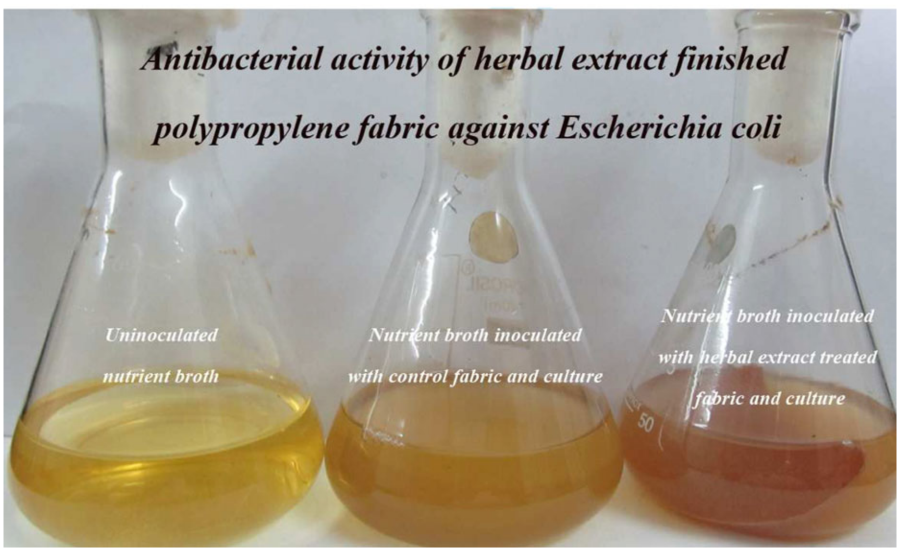


Figure 2. Assessment of antibacterial activity by AATCC 100-test method. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Table III. Morphological Identification of Wound Causing Bacterial Isolates

Isolate no.	Morphological identification: Colony morphology	Microscopic observations: Gram staining	Microscopic observations: Motility
1.	Colonies are circular, convex with entire margin	Positive, cocci	–
2.	Medium sized colony with regular margin and convex elevation	Negative, short rods	+
3.	Slightly gummy circular, convex with entire margin	Negative, short rods	–
4.	Red in appearance, circular with entire margin	Negative, short rods	+
5.	Circular convex with entire margin	Negative, rods	+
6.	Colonies are large, undulated, circular with flat elevation	Positive, rods	+
7.	Medium to large sized colony, shiny cream color colony, warming growth on agar surface	Negative, rods	+
8.	Colonies are circular, convex with entire margin	Positive, cocci	–
9.	Medium sized colony with regular margin and convex elevation	Negative, short rods	+
10.	Slightly gummy circular, convex with entire margin	Negative, short rods	–
11.	Colonies are circular, convex with entire margin	Positive, cocci	–
12.	Slightly gummy circular, convex with entire margin	Negative, short rods	–
13.	Circular convex with entire margin	Negative, rods	+
14.	Colonies are circular, convex with entire margin	Positive, cocci	–
15.	Colonies are circular, convex with entire margin	Positive, cocci	–

against *S. aureus* than that against *Escherichia coli*. However, from the results of the earlier work,[31] it is apparent that the measured values of the zone of inhibition showed good sensitivity against *Escherichia coli* than that of *S. aureus*.

Assessment of Antibacterial Activity of the Combinational Herbal Extract Finished Fabric

The antibacterial activity of the air PT herbal extract-finished nonwoven polypropylene fabric was compared with that of the unfinished polypropylene fabric against *S. aureus* and *Escherichia coli*. The three selected herbal extracts mixed in the ratio 1 : 1 : 1 was finished on the air PT polypropylene fabric and the antibacterial activity was tested according to ENISO 20645 and AATCC 100 test methods. The antibacterial activity of the herbal extract combination finished polypropylene fabric was found to be 38 mm against *S. aureus* and 27 mm against *Escherichia coli* according to ENISO 20645 test method (Table II). The herbal extract-finished fabric showed maximum antibacterial activity of 99% against both the test organisms according to AATCC 100 test method (Figure 2). This result closely relates to

Table IV. Biochemical Identifications of Wound Causing Bacterial Predominants

Isolate no.	I	MR	VP	Citrate	Catalase	Oxidase	Starch	Glucose	Lactose	Urease
1	–	+	+	–	+	–	–	A+/G+	A+/G+	+
2	+	+	–	–	+	–	–	A+/G+	A+/G+	–
3	–	–	+	+	–	+	–	A+/G+	A+/G+	+
4	–	–	+	+	+	–	–	A+/G+	A–/G–	–
5	–	–	–	+	+	+	–	A–/G–	A–/G–	+
6	–	–	–	–	+	–	+	A–/G	A–/G–	–
7	–	+	–	–	+	–	–	A–/G–	A–/G–	+
8	–	+	+	–	+	–	–	A+/G+	A+/G+	+
9	+	+	–	–	+	–	–	A+/G+	A+/G+	–
10	–	–	+	+	–	+	–	A+/G+	A+/G+	+
11	–	+	+	–	+	–	–	A+/G+	A+/G+	+
12	–	–	+	+	–	+	–	A+/G+	A+/G+	+
13	–	–	–	+	+	+	–	A–/G–	A–/G–	+
14	–	+	+	–	+	–	–	A+/G+	A+/G+	+
15	–	+	+	–	+	–	–	A+/G+	A+/G+	+

Table V. Identification of Bacterial Flora from Postoperative Wound Samples

Isolate no.	Genus identified
1, 8, 11, 14, 15	*Staphylococcus*
2, 9	*Escherichia*
3, 10, 12	*Klebsiella*
4	*Serratia*
5, 13	*Pseudomonas*
6	*Bacillus*
7	*Proteus*

that of Vaideki et al.,[29] in which it was stated that the air PT sample, because of its increased hydrophilicity, was able to absorb more neem extract when compared to the UT sample, thus improving the antimicrobial efficacy of fabric.

Predominant bacterial flora in postoperative wound samples

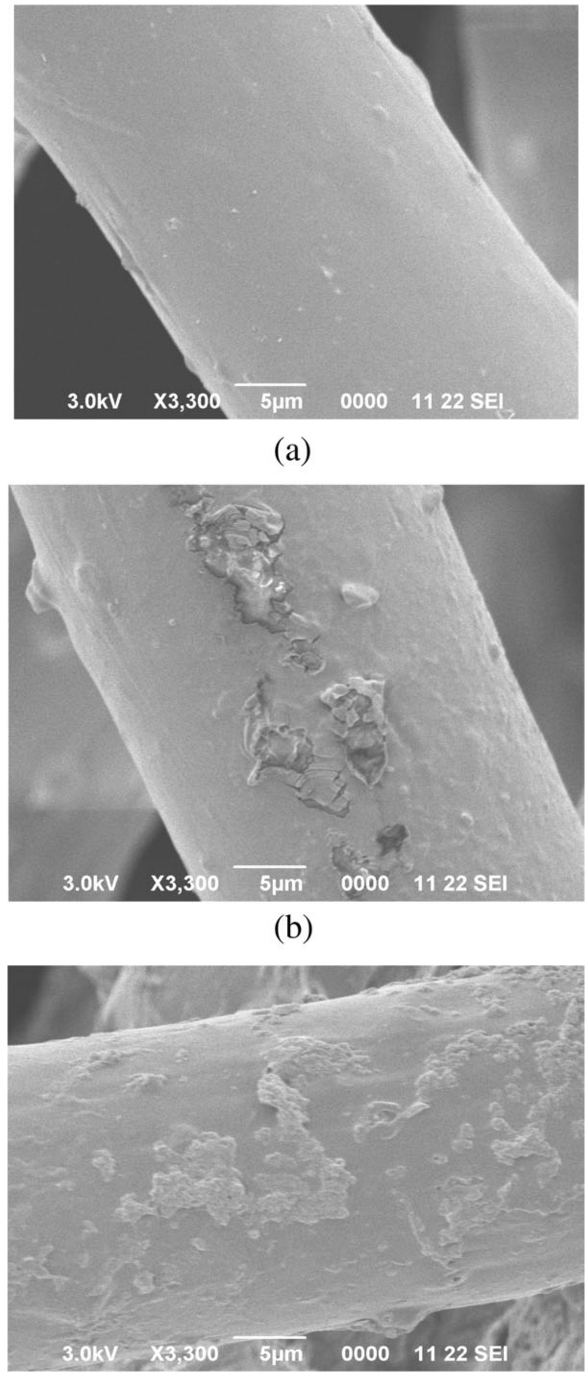
The swabs collected from the wound infected sites were used for the isolation of bacterial predominants by plating them on nutrient agar plates. The plates were incubated for 24 h at 37°C. After incubation, 15 predominant bacterial wound isolates were obtained, which were then subcultured and purified in separate nutrient agar slants for further identification studies. These bacterial isolates were identified by microscopic and biochemical studies, and the results were presented in Tables III and IV. The biochemical characteristics of the isolates were tested by performing Indole, Methyl Red, Voges-Proskauer, Citrate utilization, Catalase production, Oxidase production, Starch hydrolysis, Carbohydrate fermentation, and Urease production. From the results of morphological and biochemical identifications, the isolated bacterial predominants were found to belong to the following genus as given in Table V. The results of this work showed that the predominant bacterial isolates belonged to *Staphylococcus*, *Escherichia*, *Klebsiella*, *Serratia*, *Pseudomonas*, *Bacillus*, and *Proteus* genus. According to the reports,[32] the frequently isolated wound aerobes were *E. coli* (57 isolates), alpha-hemolytic *Streptococci*, gamma-hemolytic *Streptococcus*, Group D *Streptococcus*, and *Pseudomonas aeruginosa*.

The isolates could be classified into two major groups - the intestinal bacteria represented by *Escherichia coli*, and a large variety of other bacteria, which includes *Staphylococcus* sp.[20] *Staphylococcus* sp. remains the most important microorganism responsible for postoperative wound infection. A previous work[33] reported that a total of 183 organisms were identified by gram staining. Of these, 57 were gram positive (31.15%) and 126 were gram negative (68.85%). Predominant organisms isolated were: *S. aureus* 48 (26.23%), *Klebsiella pneumoniae* 38 (20.77%), *P. aeruginosa* 38 (20.76%), and *Escherichia coli* 29 (15.85%).

Table VI. Antibacterial Activity of Herbal Extract Finished Fabric Against Wound Causing Bacterial Isolates

S. no.	Wound isolate	Zone of bacteriostasis (mm)
1.	*Staphylococcus*	34
2.	*Escherichia*	25
3.	*Klebsiella*	25
4.	*Serratia*	24
5.	*Pseudomonas*	25
6.	*Bacillus*	26
7.	*Proteus*	22

: Please provide the significance for bold entries in Table 1.



(c)

Figure 3. (a) SEM micrograph of UT polypropylene nonwoven fabric. (b) SEM micrograph of PT polypropylene nonwoven fabric. (c) SEM micrograph of HF polypropylene nonwoven fabric.

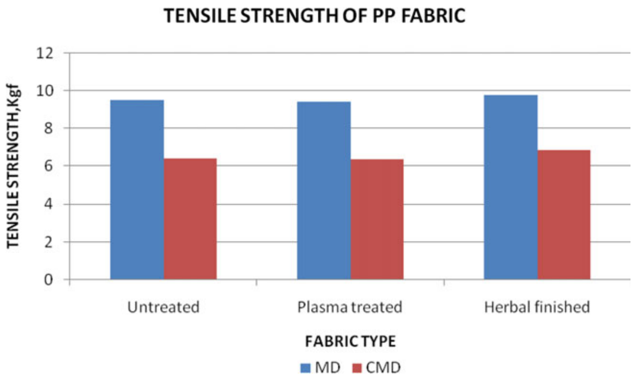


Figure 4. Tensile strength of UT, PT and HF fabrics. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

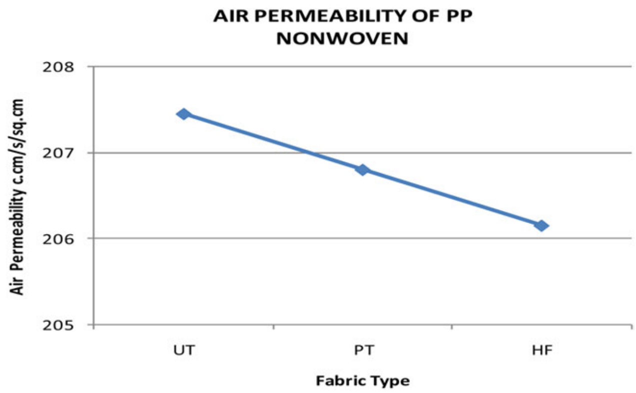


Figure 5. Air permeability of UT, PT and HF fabrics. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Assessment of Antibacterial Activity Against the Isolated Wound Pathogens

The antibacterial activity of air PT herbal extract finished nonwoven polypropylene fabric under study was tested against the wound causing bacterial species. The level of antibacterial activity was measured in terms of zone of bacteriostasis and is tabulated in Table VI. Figure 1 shows the zone of bacteriostasis of the fabric finished with the herbal extracts of *F. bengalensis*, *C. viscosa*, and *Areca catechu*. The air PT polypropylene fabric finished with the combination of herbal extracts was tested for its antibacterial activity against the wound isolates by the agar diffusion method. The results showed that the finished fabric had maximum antibacterial activity against *Staphylococcus* with a zone of bacteriostasis of 34 mm. The same fabric showed antibacterial activity against all the other wound isolated pathogens, namely *Bacillus*, *Pseudomonas*, *Klebsiella*, *Serratia*, *Escherichia*, and *Proteus* as shown in Table V.

Surface Morphology Analysis

The SEM Micrographs of the UT, PT, and HF fabric were presented as Figure 3(a–c). It can be seen in Figure 3(a), that the surface of the UT fabric was smooth and almost uniform. The etching of the polymer surface due to plasma surface activation was clear in Figure 3(b). The deposition of herbal particles onto the PT polypropylene nonwoven fabric surface was obvious in Figure 3(c).

Physical and Functional Testing

Tensile Strength Testing. The Tensile Strength test results of the UT, PT, and HF fabric samples were presented in Figure 4. The tensile strength (measured in kgf) of the UT, PT, and HF fabric samples were estimated with their standard error as 9.506 ± 1.01, 9.44 ± 1.25, and 9.8 ± 1.11 Kgf, respectively, along the MD. The tensile strength values of the UT, PT, and HF fabric samples along the cross MD were found to be 6.42 ± 1.12, 6.38 ± 1.02, and 6.88 ± 1.04

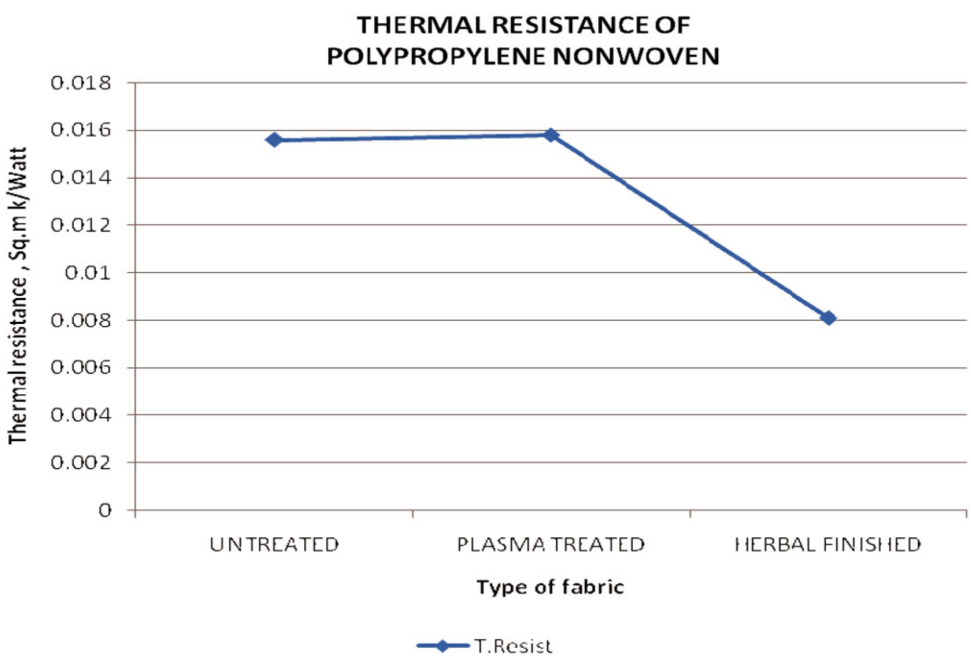


Figure 6. Air permeability of UT, PT and HF fabrics. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Kgf, respectively. From these results, it is clear that the air plasma treatment has decreased the tensile Strength of the fabric which is not significant as per the student's *t*-test. This decrease in the tensile strength of the PT fabric is due to the plasma etching, which would have resulted in the changes in the crystalline lattice on the topical surface of the fabric. These results are in agreement with that of Virk et al.,[34] and also that of Shishoo.[35] At the same time, the herbal treatment given to the fabric has increased the tensile strength of the polypropylene fabric. This increase in the tensile strength, though insignificant, is due to the coating of the herbal extract on to the PT polypropylene substrate.

Air permeability Testing. The results of the Air permeability Tests were given in Figure 5. Air permeability values of the UT, PT and the HF fabrics were 207.45 ± 0.98, 206.8 ± 1.17, 206.15 ± 1.25, respectively. These results were statistically analyzed using Turkey's studentized tests. From the analysis, it can be inferred that the plasma treatment reduced the air permeability, but not to a significant level (t value = 2.04 which is less than that of 1% confidence level). Similarly, the reduction in the Air permeability due to herbal finishing was also insignificant, *t*-value being 1.97.[28] The decrease in the air permeability, though insignificant, of the PT fabric is due to the structural changes that take place on the topical surface which might alter the pores of the fabric. Also, the reduction in the air permeability though not significant, is obviously due to the coating of the herbal extract.

Thermal Resistance Testing. The thermal Resistance tests were performed according to the procedure Prescribed by ISO 11092. Lower the thermal resistance higher the coolness. The thermal resistance of UT fabric is 0.0156 ± 0.35 Sq m k/watt as shown in Figure 6. The thermal resistance of the PT fabric and that of the HF fabric is 0.0158 ± 0.58 and 0.0081 ± 0.27 Sq m k/watt, respectively. From these results, it can be concluded that the thermal resistance of the PT fabric has increased, but not significantly. However, the HF fabric showed a significant decrease in the thermal resistance values implying that the HF fabric possesses higher coolness when compared to the UT and PT fabric.[36]

CONCLUSION

Functional finishing for different applications is the modern area of interest in textile research today. In line with this application, the current work is focused on imparting hydrophilicity to nonwoven polypropylene fabric with air plasma and improving the antibacterial property using herbal extract. From this study, it can be concluded that Plasma treatment can be safely used for the surface modification of nonwoven polypropylene, without affecting the bulk properties of the fabric. Also, plasma technology is an environmental friendly process, which can be suggested as a solution for many pollution problems that arise during the processing of textile materials.

Among the 11 different herbal extracts, the antibacterial activity of *Areca catechu*, *F. bengalensis*, and *C. viscosa* were found to be maximum, both against *S. aureus* and *Escherichia coli*. The herbal extract in the combination of 1 : 1 : 1 was used and tested against the standard strains. The herbal-coated fabric showed 99% bacterial reduction when tested according to AATCC 100 test method. The antibacterial activity of the herbal extract-finished polypropylene fabric was effective against all the common wound pathogens isolated, with maximum activity against *Staphylococcus* and minimum activity against *Proteus*. The ecofriendly and nontoxic properties of these herbs are promising candidates for medical and health care textile applications. The herbal extract-finished air PT polypropylene fabric strongly supports its use as a wound care product.

REFERENCES

1. Hoe, N. Y.; Nambiar, R. *Ann. Acad. Med. Singapore* **1985**, *14*, 700.
2. Mousa, H. J. *Hosp. Infect.* **1997**, *37*, 317.
3. Heinzelmann, M.; Scott, M.; Lam, T. Am. J. *Surg.* **2002**, *183*, 17990.
4. Ayliffe, G. A. J., Babb, J. R.; Taylor, L. J. In Hospital-Acquired Infection. Principles and prevention, 3rd ed.; Butterworth-Heinemann: Oxford, **1999**; pp 109–121, ISBN: 0750621052.
5. Andenaes, K.; Lingaas, E.; Amland, P. F.; Giercksky, K. E.; Abyholn, F. J. *Hosp. Infect.* **1996**, *34*, 291.
6. Zerahn, B.; Storgaad, M.; Arendrup, M. *Ugeskr Laagr* **1997**, *160*, 53.
7. Anupurba, S.; Bhattacharjee, A.; Garg, A.; Sen, M. R. Indian J. *Dermatol.* **2006**, *51*, 286.
8. Trilla, A. Intensive Care Med. **1994**, *20*, 1.
9. Mehta, G.; Khanna, S.; Trehan, B.; Gupta, V. J. *Hosp. Infect.* **1990**, *15*, 353.
10. Alsaimary, I. E.; Mezaal, T. *Adv Biores* **2010**, *1*, 51.
11. Inbakumar, S.; Anukaliani, A. Surface modification of polyester fabrics by non-thermal plasma for improving hydrophilic properties. Eleventh International Conference on Electrostatic Precipitation, Coimbatore, India. 718.
12. Jothi, D. Af. J. Microbiol. *Res.* **2009**, *3*, 228.
13. Sengupta, A.; Ghosh, S.; Bhattacharjee, S. Pac. J. Cancer Prev. **2004**, *5*, 237.
14. Kalemba, D.; Kunicka, A. *Curr. Med. Chem.* **2003**, *10*, 813.
15. Venkatramani, N. *Curr. Sci.* **2002**, *83*, 254.
16. Bittencourt, J. A., Eds. Fundamentals of Plasma Physics, 3rd ed.; Springer: Verlag-Newyork, USA, **2004**; p 1.
17. Goldston, R. J.; Rutherford, H. Introduction to Plasma Physics; Institute of Physics Publishing: Bristol and Philadelphia, **2007**; p 1.
18. Chapman, B. Glow Discharge Processes: Sputtering and Plasma Etching; Wiley: Newyork, USA, **1980**; p 21.
19. Sharma, C. P.; Thomas, C.; Sunny, M. C. J. Biomater. *Appl.* **1986**, *1*, 533.
20. Karahan, H. A.; Ozdogan, E.; Demir, A.; Ayhan, H.; Seventekin, N. Fibres Text. *Eastern Eur.* **2009**,*17*, 19.
20. Natarajan, V.; Venugopal, P. V.; Menon, T. Indian J. *Med. Microbiol.* **2003**, *21*, 98.
21. Yadav, A.; Prasad, V.; Kathe, A. A.; Raj, S.; Yadav, D.; Sundaramoorthy, C.; Vigneshwaran, N. *Bull. Mater. Sci.* **2006**, *29*, 641.
22. Mucha, H.; Hotes, D.; Swerev, M. Melliand Int. **2002**, *8*, 148.

23. AATCC Test Method 100-2004, Antibacterial Activity Assessment of Textile Materials: Percentage Reduction Method, AATCC technical Manual, 149.
24. AATCC Test Method 100-2004, Antibacterial Activity ssessment of Textile Materials: Percentage Reduction Method, AATCC Technical Manual, **2007**, *82*, 145.
25. Davidson, A. I. G.; Clark, C.; Smith, G.; Br. J. *Surg.* **1971**, *58*, 333.
26. Samantha, K.; Manjeet J.; Ashwini, K. Indian J. Fibers Text. *Res.* **2006**, *31*, 83.
27. Karahan, H. A.; Ozdogan, E.; Demir, A.; Ayhan, H.; Seventekin, N. Fibres Text. *Eastern Eur.* **2009**, *17*, 19.
28. Vaideki, K.; Jayakumar, S.; Thilagavathi, G. J. Instrum. *Soc. India* **2005**, *37*, 258.
29. Raslan, W. M.; Rashed, U. S.; Sayad, H. E.; Halwagy, A. A. E. Mater. *Sci. Appl.* **2011**, *2*, 1432.
30. Lalitha, P.; Arathi, K. A.; Sripathi, S. K.; Hemalatha, S.; Jayanthi, P.; Alfa Univ. **2010**, *1*, 63.
31. Brook, I. Bacterial studies of peritoneal cavity and postoperative surgical wound drainage following perforated appendix in children, Infectious disease and clinical Microbiology Laboratory, Children's Hospital, National Medical Center, **1980**, 208–212.
32. Brook, I. Bacterial studies of peritoneal cavity and postoperative surgical wound drainage following perforated appendix in children, *Ann. Surg.* **1980**, *192*, 208.
33. Virk, R. K.; Ramaswamy, G. N.; Bourham, M.; Bures, B. L. *Text. Res. J.* **2004**, *74*, 1073.
34. Shishoo, R. Plasma Technology for Textiles, Woodhead Publishing Limited: Cambridge, 79, **2007**.
35. Krishnaveni; Amsamani. *J. Text. Apparel Technol. Manage.* **2012**, *7*, 1.