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Antimicrobial Property of Plasma Treated Bamboo Fabric Imparted with Combinatorial Herbal Extract

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ABSTRACT

The present study focused on DC air plasma exposed on bamboo fabric finished with antimicrobial agents. The knitted bamboo fabrics were exposed to plasma treatment at optimized conditions to increase the hydrophilicity. The changes in the hydrophilic properties, chemical and physical modification of the plasma treated fabric were studied using the AATCC 79, FTIR and FESEM respectively. The combinatorial herbal powder was subjected to different solvent extracts and their antimicrobial activities against test pathogens were studied. The ethanolic herbal extract showed higher activity against E. coli (12 mm), S. aureus (14 mm), A .niger (4mm), C. albicans (16mm), P. varians (9mm) and T. viride (7mm). The antimicrobial efficiency of the ethanolic herbal extract finished on plasma pre-treated bamboo fabric was evaluated using AATCC methods. The treated fabric showed a better antimicrobial activity against the test pathogens. Effectiveness of the antimicrobial finished fabrics was assessed using wash durability analysis which proved that the antimicrobial activity was retained till 25 washes. The results confirmed that the plasma treated antimicrobial coated fabrics showed the higher hydrophilicity as well as the combinatorial herbal extract could act against the test pathogens.

Key words: *AATCC methods, Antimicrobial, Bamboo fabric, Combinatorial extract, Plasma.*

INTRODUCTION

In recent years, all over the world consumers are demanding for high performance from the textiles industries. A purchasing decision is often based as much on the functional aspects of a fabric as on colour and texture[1]. The textiles are not only the carrier but also a good media for the growth of microorganisms. Whereas, the obnoxious smell, degradation and staining of the inner garments are mostly due to effect of microbes[2].For this reason, textile industry are playing a central role in protective aspects of textiles with the innovative antimicrobial finishes.

The antimicrobial finishes can offer an added value to textiles. This kind of antimicrobial finishes prevents the growth of bacteria, unpleasant odour and preventing diseases. There are numerous natural and synthetic antimicrobial compounds[3].

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The synthetic antimicrobial agents and metal oxides are very effective against a range of microbes but it also associated with side effects and hence cannot used for medical application[4]. Hence, there is a great demand for eco-friendly antimicrobial finishes on textiles. The antimicrobial components from the plant origin have therapeutic potential as they are effective against numerous infectious diseases. The herbal extract finished fabrics were considered as significant for the textile application. The finishing of natural compounds would be a best alternative for the synthetic antimicrobial agents and heavy metals on the hygienic health care textiles[4].

On the other, the moisture transmission through the textiles has got a great impact on the comfort property of the human. Whereas the body heat in the human body, makes the wearer to become tired when the cloth worn next to the skin fails to release moisture quickly to the atmosphere[5]. Wettability can be controlled by using surface modification techniques such as exposure to plasma, flame, chemicals, enzymes, etc. Plasma technology is a clean and dry process which offers numerous advantages over the conventional chemical processes. It is considered as more economical and ecological process and it does not require water or chemicals[6]. The surface of the fabric is treated in such a way that it improves the properties such as wettability, dyeability, hydrophilicity, adhesion and other finishing processes without affecting the bulk property of the fabric[7, 8]. Hence due to the plasma pre-treatment there is an increase in hydrophilicity rate in the fabric which leads to high rate absorbability of the herbal extract[5].

The present investigation aims to develop the natural antimicrobial finishes for textile application. In this study, different solvent extraction of the *Aloe barbendensis miller* and *Rosa damascene* were screened for the antimicrobial activity. The best combinatorial solvent extract proved to have the maximum antimicrobial activity were used for further study. The knitted bamboo fabric was pre-treated with plasma to increase the rate of hydrophilicity. The combinatorial herbal extract was coated on the plasma pre-treated and untreated knitted bamboo fabric and their efficacy was checked using standard AATCC methods and the findings were discussed in this paper.

MATERIALS AND METHODS

The fabric used in the present study was a knitted bamboo fabric procured from Sevvel International, Tirupur, India. The medicinal herbs *Aloe barbadensis miller* (leaves) and *Rosa damascene* (flowers) were collected from in and around Coimbatore, India. The bacteria and fungi were obtained from PSG IMSR, Coimbatore.

Plasma treatment

The treatment was carried out in a 12" DC plasma chamber. The samples (40X40 cm) were placed on the lower electrode. The chamber was initially evacuated to a base pressure of 10^{-3} mbar using a rotary pump (Hindhivac, India). Atmospheric air was used as working gas was admitted into the chamber by means of a needle valve. The optimized process parameters used in the study for the fabric samples to attain maximum hydrophilicity are as follows: pressure 0.07 mbar, inter electrode distance 5 cm, exposure time 6 sec and Current 0.8 mA.

Assessment of hydrophilicity

The hydrophilicity of the treated and untreated fabrics was analyzed using the wicking test (AATCC 79). In this test, a fabric strip (2 cm × 17 cm) was suspended above the distilled water surface in a glass beaker such that the horizontal bottom edge touches the surface of the water. A spontaneous wicking was observed due to capillary force. The rise in the height of the water was measured for a period of 60 seconds. The height of the liquid rise boundary was recorded for every 5 seconds up to 60 seconds were made for three trials for each sample and the average values are calculated.

Percentage weight loss

The bamboo fabrics before treatment are reported to have impurities like natural waxes, pectins, fats and other dust particles on the fabric surfaces. However, plasma treatment etches the surface of fabric and induces a chemical change in it by removing the surface contaminants[8]. The weight loss of the fabrics was calculated by measuring the dry weight of a fabric before and after the treatments using the formula.

$$\%\mathbf{Weight\ loss} = [(\mathbf{W1} - \mathbf{W2})/\mathbf{W1}] \times \mathbf{100} \quad (1)$$

Where, W1 is the weight of the fabric before treatment, W2 is the weight of the fabric after treatment.

Fourier Transform Infra-Red spectroscopy (FT-IR)

The chemical changes that occurred during the DC air plasma treatments and untreated fabrics were analyzed by FTIR. The ATR-FTIR spectra were recorded using a Thermo Nicolet Avatar 330 instrument in the range of 450-4500 cm^{-1} with a resolution of 4 cm^{-1} and % Transmittance. All samples were run in triplicate and the data presented are the average of the three measurements. The basic principle that governs is that the bonds and groups of bonds vibrate at characteristic frequencies. A molecule that is exposed to infrared rays absorbs infrared energy at frequencies which are characteristic of that molecule, is then analyzed and matched with known signatures of identifying materials in the FTIR library.

High Resolution Scanning Electron Microscopy (HR SEM analysis)

HR SEM analysis was done to study the surface morphology of the fabrics. The surface morphology of the untreated and the treated bamboo fabrics were studied using HR SEM. Platinum coating was used as the conducting material to analyze the sample. Platinum was sputtered onto the fabric samples, as a conducting material to analyze the samples.

Collection, processing and extraction of *Aloe barbadensis miller* and *Rosa damascene*

The collected leaves and flowers were shade dried at room temperature to reduce the moisture content. The dried leaves and flowers were then powdered and sieved separately. About 10 grams of grounded *Aloe barbadensis miller* (leaves) powder and *Rosa damascene* (flowers) was suspended in 100 ml of solvents separately, such as water, ethanol, chloroform and petroleum ether incubated in a rotary shaker at room temperature for 48 hrs at 120rpm. The supernatant was filtered twice using Whatman No. 1 filter paper and the filtrate was mixed with DMSO (0.1 g/1ml).

Assessment of antimicrobial activity of combinatorial herbal extracts

Assessment of antibacterial activity

The antibacterial assay was carried out by the well diffusion method. Test organisms were first revived in nutrient broth at 37° C for 1-2 hours and were adjusted to McFarland's standards before it was swabbed onto Muller Hinton agar.The inoculum was spread on the sterile Muller Hinton agar; about 60µl of the different solvent combinatorial extracts were loaded on to the wells and the plates were then incubated at 37° C for 24 hours. And finally, the zone of inhibition around the well was measured. Tetracycline and DMSO were used as reference to evaluate the susceptibility of test organisms[9].

Assessment of antifungal activity

The combinatorial extracts that showed better antibacterial activity were subjected to antifungal assessment by the agar plug method. A fungal plug was placed on the center of the plate. A sterile disc was immersed in the plant extracts were also placed on the plates. Ketoconazole was used as positive control. The antifungal effect was seen as crescent shaped zone of inhibition.

Finishing the bamboo fabric with the combinatorial herbal extract

The plasma treated and untreated bamboo fabrics were coated with the combinatorial herbal extract. This fabric was used for disc diffusion assay and quantitative bacterial reduction studies. The plasma treated fabric was primarily coated with citric acid to ensure better binding of the prepared formulation using pad-dry-cure method[10]. For 1 gm of the fabric 20 ml of the plant extract and about 1.6 gm of citric acid was used as a binder, the fabric was kept immersed in the treatment solution for 20 minutes. The fabric was then passed through a padding mangle (R. B. Electronics and Engineering, Mumbai), running at a speed of 15m/min with a pressure of 2 kgf/cm^2 to remove excess solution. A 100% wet pick-up was maintained for all of the treatments. After padding, the fabric was air-dried and then cured for 3 min at 140 ˚ C and immersed for 5 min in 2 g/l of sodium lauryl sulfate to remove unbound solutions and rinsed to remove the soap solution followed by air-drying.

Assessment of antimicrobial activity

Antimicrobial activity was evaluated by both qualitative and quantitative test methods. The following are the descriptions of test methods employed in this study.

Antibacterial assessment of the treated fabrics

The treated fabrics (Combinatorial extract coated on control, Plasma treated, Combinatorial extract coated on plasma pre-treated bamboo fabric) were tested for the antibacterial activity using AATCC standards – Parallel streak test was performed using AATCC test method 147-1988.The test specimen was gently pressed transversely, across the five inoculums of streaks to ensure intimate contact with agar surface. The plates were incubated at 37^{o}C for 18 to 24 hours. After incubation, a streak of interrupted growth underneath and along the side of the test material indicates the antibacterial effectiveness of the fabric[11]. The inoculated plates were examined for the interruption of growth along the streaks of inoculum beneath the fabric and for a clear zone of inhibition beyond the fabric edge. The average width of the zone of inhibition around the test specimen was calculated in mm using the formula

$$\textbf{Zone of inhibition (mm)} = (\mathbf{T} - \mathbf{I})/2 \quad \text{...(1)}$$

Where, **T** referred to the width of the zone of inhibition and **I** referred to the width of the specimen.

Quantitative assessment - Percentage Reduction method (AATCC 100-2004)

Test specimens were taken and were cut into circular swatches of 4.8 × 0.1 cm diameter, the recommended standard. The swatches to be tested were placed in sterile petri dish and 0.1 ml of the test inocula were loaded using a micro pipette. The treated and untreated swatches were then transferred to the respectively labeled sterile AATCC Bacteriostasis broth. The flasks were then incubated in a shaker at room temperature for 24 hours. About 0.1 ml of sample of each dilution was transferred to the sterile AATCC Bacteriostasis agar plates and spread plated[12]. The inoculated plates were incubated at 37 (C for 24 hours. The inoculated plates were examined for the presence of bacterial colonies. The percentage reduction of bacteria of the treatment can be calculated by the formula

$$\mathbf{R} = \mathbf{100}\,(\mathbf{B} - \mathbf{A})/\mathbf{B} \quad \text{..........(2)}$$

R = % reduction

A = the number of bacteria recovered from the inoculated treated swatch.

B =the number of bacteria recovered from the inoculated untreated swatch.

Assessment of antifungal activity of the treated fabric

The antifungal activity was assessed using the agar diffusion method (AATCC 30 – Test method III) for the treated and untreated fabrics[13]. The test fabrics were checked for the activity against *A. niger* (ATCC 6275). The plates were incubated at 27^{0}C for 5 days. At the end of the incubation period the antifungal activity was reported by measuring the zone of mycostasis underneath and alongside of the fabric.

Wash durability test

The treated and untreated fabrics were tested for their wash fastness using wash durability testing. Washing was carried out as per test no: 1 of IS: 687-1979 using a neutral soap (5gpl) at 40°C + 2°C for 30 minutes, keeping the material: liquor ratio at 1:50, followed by rinsing, washing and drying[14]. After drying, the test samples were assessed for antimicrobial activity using AATCC 100 procedure. Washing was carried up to 50 laundering cycles and results were evaluated by after counting the bacterial colonies upon incubation and calculated for the bacterial reduction using the formula as in (AATCC 100).

RESULTS AND DISCUSSION

Assessment of hydrophilicity for the plasma pre-treated fabric

The changes in the hydrophilic properties of the fabric untreated and plasma treated were studied using the standard wicking test (AATCC 79). The results revealed that the samples treated with DC air plasma show a higher wicking height when compared with untreated fabrics as shown in Fig 1. These effects can be attributed by the physical changes through plasma etching on the fabric surface[15] and chemical changes through the formation of polar group's free radicals on the bamboo fabric surface[16]. Thus, the plasma pre-treated bamboo fabric showed enhanced rate of hydrophilicity.

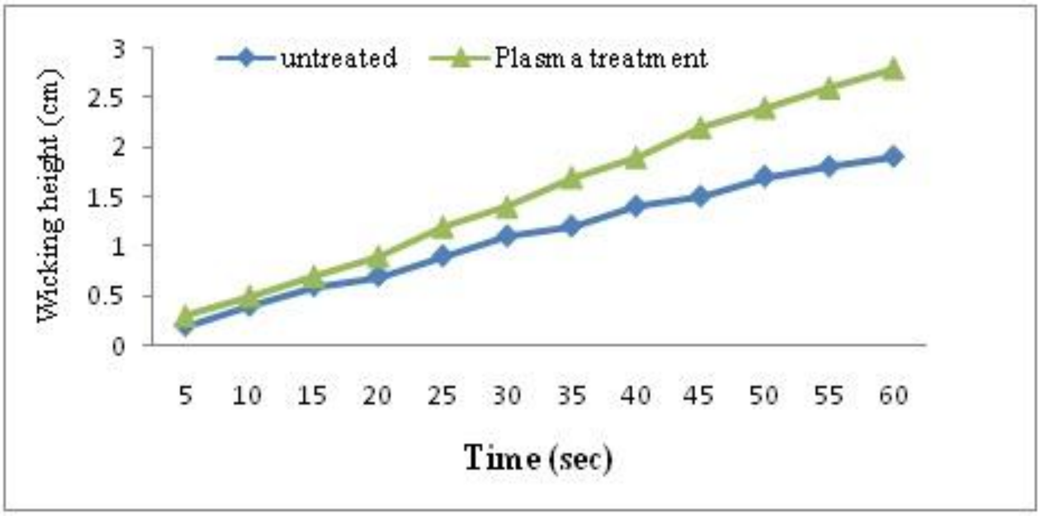

Fig. 1: Wicking rate of the untreated and plasma treated bamboo fabrics

Percentage weight loss

The plasma pre-treated bamboo fabric weight was compared to the weight of the fabric before pre-treatment. Whereas the plasma pre-treatment resulted in the low percentage weight loss of the bamboo fabric it is due to the interaction between different plasma particles and the fabric surface. Another study has also reported that plasma treatment prior to untreated showed highest weight loss percentage[15].The weight loss of the plasma pre-treated bamboo fabric could be attributed to the introduction of cracks and holes as well as more reactive ends of molecular chain on the fabric surface.

Assessment of physical parameters of the fabrics

FT-IR analysis of treated and untreated fabrics

The ATR-FTIR spectra were recorded using a Thermo Nicolet Avatar 330 instrument in the range of 450-4500 cm^{-1} with a resolution of 4 cm^{-1}. The chemical changes on the fabric surface due to plasma pre treatment were analyzed using ATR-FTIR spectra. This has been compared with the FTIR spectrum of untreated bamboo fabric available in the standard literature to identify the reaction mechanism that has modified the chemical structure of cellulose units in the pre treated bamboo fabrics. The FTIR spectra of the untreated and plasma treated bamboo fabrics were represented in Figure 2. The characteristic peaks in the spectra were compared with the literature[17] and reported in table 1. The spectra revealed the presence of all the peaks corresponding to various functional groups in the treated fabrics. The concentration of the functional groups was proportional to the intensity of the corresponding absorption peaks.

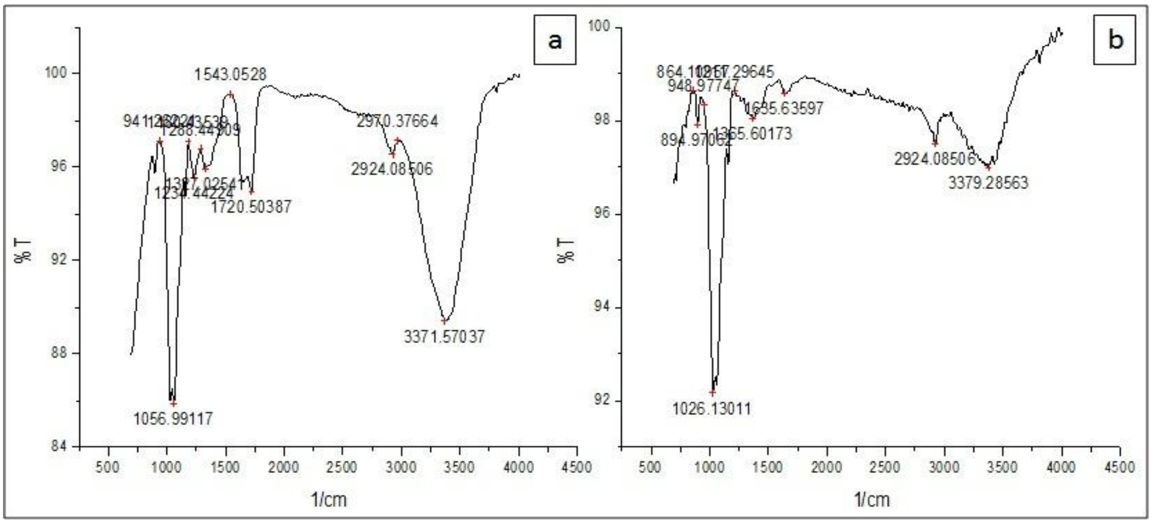

Figure 2: **FT-IR Spectrum of untreated bamboo fabric (a), DC air plasma treated bamboo fabric (b)**

In the DC air plasma treated fabric it is evident from the figure that, the spectra 1226, 1056 and 1026 cm^{-1} of the untreated fabric corresponds to the C–N stretch was shifted to 2924, 2893 and 1365 cm^{-1} after plasma treatment belonged to C-H stretch. The shift of C-H from the C–N stretch of the plasma treated fabric confers hydrophilicity to the fabric. The peak at 3371 cm^{-1} of the untreated fabric indicated the N–H stretch. The 3371 cm^{-1} was shifted to the followed by the spectra 3201, 3440 and 3116 cm^{-1} of the DC air plasma treated fabric which belonged to the O-H stretch. Hence the O-H peak was found after plasma treatment, this indicates the plasma treatment of the fabric under optimized conditions has introduced a new group which has the capacity to accept water molecules, thereby conferring hydrophilicity. During the exposure to plasma the surface of the fabric would have undergone a series of changes, as the fabrics showed a maximum hydrophilicity when exposed for 6 Sec and when the electrodes were placed closer, which implied that the air molecules would have etched the surface of the fabric leaving space for some other molecule to attach. These results indicated that the plasma treatment has added hydrogen and alcohol groups to the knitted bamboo fabric surface which has resulted in the increased hydrophilicity of the fabric.

Table 1: Peak Characteristics of the untreated and plasma treated fabrics

Literature cm^{-1}	Untreated fabric cm^{-1}	Plasma treated fabric cm^{-1}	Peak Characteristics
3500-3200	-	3440	O-H stretch, H-bonded
3400-3250	3371	3379	N–H stretch
3300–2500	-	3201,3116	O–H stretch
3000-2850	2924	2924,2893	C–H stretch
1730-1715	1720	-	C=O stretch
1680-1640	1651	-	–C=C– stretch
1650–1580	-	1635	N–H bend
1550-1475	-	-	N–O asymmetric stretch
1370-1350	-	1365	C–H rock
1335-1250	1319		C–N stretch
1320-1000	-	1157	C–O stretch
1300-1150	1157	-	C–H wag (–CH_2X)
1250-1020	1226,1056, 1026	1056,1026	C–N stretch
900-675	894	894	C–H "oop"
850-550	-	794,709	C–Cl stretch

High Resonance Scanning Electron Microscopy (HR SEM analysis)

The surface morphology of the control (untreated) and DC air plasma treated bamboo fabrics were studied using FESEM. Figure 3 A and B showed the FESEM micrographs of untreated and DC air plasma treated bamboo fabric respectively. FESEM micrographs confirmed that the proturdation and the interstitial pore size increased for the treated samples when compared to untreated samples. SEM results confirmed that the DC air plasma treatment has indeed etched the hair like projections which were present on the surface of the fabric. The mean diameter of the pores present in the fabric matrix was also increased[18]. This improved the hydrophilicity of the fabric.

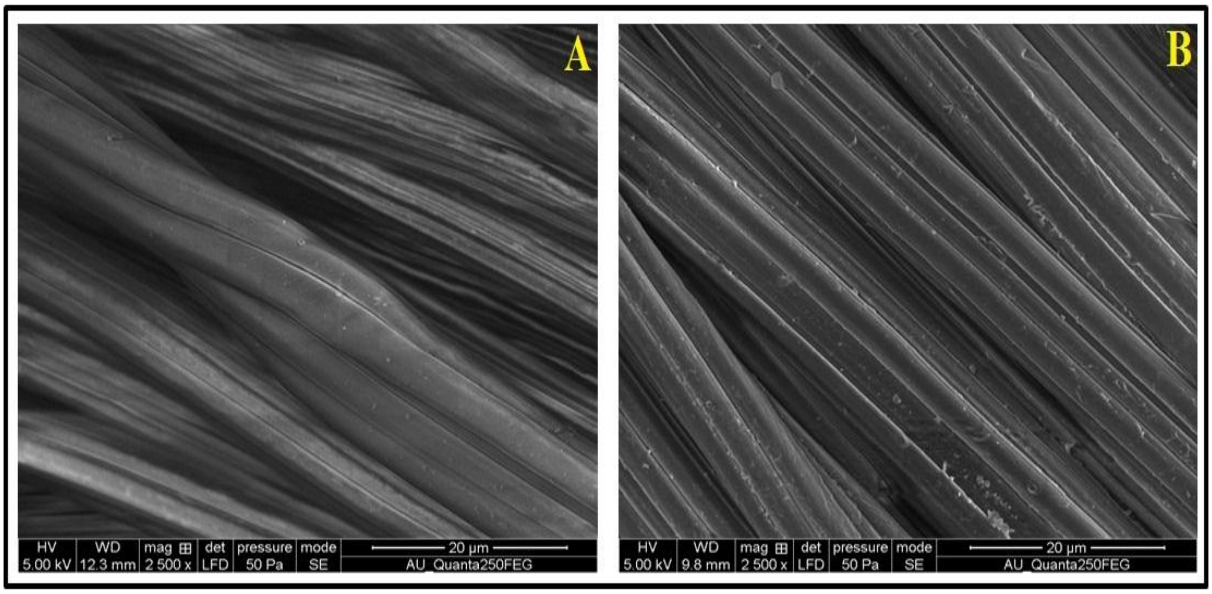

Fig. 3: HR SEM images A) Untreated bamboo fabric B) DC air plasma treated fabric

Assessment of antimicrobial activity of combinatorial herbal extracts

Assessment of antibacterial activity

Combinatorial herbal extract prepared from water, ethanol, chloroform and petroleum ether solvent was screened for their antibacterial activity using the well diffusion method. The zone of inhibition around the well represented the antibacterial activity was qualitatively evaluated for the above mentioned solvent extracts and zone was measured and tabulated in table 2. The maximum zone of inhibition against two test organisms was observed in the ethanolic extract than the other three extracts. The ethanolic combinatorial herbal extract showed a higher level of activity against *E. coli* (12 mm) and *S. aureus* (14 mm). Another study also proved that among different solvents ethanol extract was found to be quite impressive as compared to other solvents[19]. The previous study has revealed that *Aloe vera* gel extract possesses compounds with antimicrobial properties[20]. In another study, the phytoconstituents and antimicrobial activity of aqueous, ethanol and acetone extracts of the *A.vera* gel against some human and plant pathogens by disc diffusion method[21]. Among the three extracts, ethanolic extracts recorded significant antimicrobial activity against test pathogens.

Table 2: Antimicrobial activity of the combinatorial herbal extract in different solvents

S.No	Test Organisms	Antimicrobial activity (zone of inhibition in mm) Test Solvents (1mg/ml)					
		Water	**Ethanol**	**Chloroform**	**Petroleum ether**	**Tetracycline/ ketaconazole**	**DMSO**
	Bacteria						
1	*E. coli*	8	12	10	8	10	-
2	*S. aureus*	10	14	12	10	15	-
	Fungi						
3	*A. niger*	-	4	-	-	-	-
4	*C. albicans*	-	16	10	4	4	-
5	*P. varians*	-	9	3	-	2	-
6	*T. viridae*	-	7	3	2	6	-

The ethanolic aloe leaf extract was also reported to be more effective on Gram-positive than on Gram negative bacteria[22] and reported that *Aloe vera* gel exerted strong bactericidal activity. Whereas, the other tests solvent and aqueous extract also showed better resistance to test organisms used. Thus, the study showed that the average relative antibacterial activity was found higher in the alcoholic extract as compared to aqueous extract and petroleum ether[23]. The *in vitro* antibacterial activities of *R. damascena* showed antimicrobial activity against *S. aureus*, *E. coli* and *P. aeruginosa*[24, 25, 26]. Antibacterial properties of rose absolute could be attributed to its high phenylethyl alcohol content. The antimicrobial properties of alcohols have been known for a long time[27]. The standard antibiotic disc, such as Tetracycline (positive control) was used for effective comparison that showed inhibition in *E. coli* (10 mm) and *S. aureus* (15 mm). The DMSO was used as negative control which does not show any zone of inhibition against the test organisms.

Assessment of antifungal activity for the combinatorial herbal extract

The combinatorial extract was screened for antifungal activity by Agar plug method against *A. niger, C. albicans, P. varians* and *T. viride*. The potential sensitivity of the extract was observed against all the fungi tested. The antifungal activity was evaluated by measuring the zone of inhibition of fungal growth surrounding the disc in mm. The standard antifungal antibiotic ketaconazole was used for the comparative study. The zone obtained for each fungal organism was recorded in table 2. The ethanolic combinatorial herbal extract showed maximum activity against *A.niger* (4mm), *C. albicans* (16mm), *P.varians* (9mm) and *T.viride* (7mm). Thus, the maximum zone of inhibition was observed at *C. albicans*. Lisin *et al*., 1999 reported the maximum anti-fungal activity of the tested rose oil and petal extracts against *C.albicans* than the *P. notatum* and *A. niger*. In another study, for the *Aloe vera* extract *P. varians* and *C. albicans* showed highest activity against all other fungal species[28]. The results clearly demonstrated that *Aloe vera* and *Rosa damascene* extract possessed higher and boarder spectrum of antimicrobial activity. It could be theorized that presence of greater amount of the anthraquinones and phenolic antioxidants in the extract could be responsible for the high and broad spectrum antimicrobial activity[26, 29]. It showed that the herbs are potential sources of novel antimicrobial compounds especially against fungal pathogens. *In vitro* studies in this work showed that the combinatorial herbal extracts inhibited both bacterial and fungal growth. The combinatorial herbal extracts would therefore provide a microbicidal property without conferring resistance as the conventional antibiotics.

Assessment of antibacterial activity of the fabrics

The antimicrobial efficacy of the treated and untreated bamboo fabric was determined by parallel streak method (AATCC 147). The extent of antimicrobial activity was measured and recorded, the zone of inhibition of antimicrobial activity of the treated and untreated fabric against two pathogens were shown in figure 4.

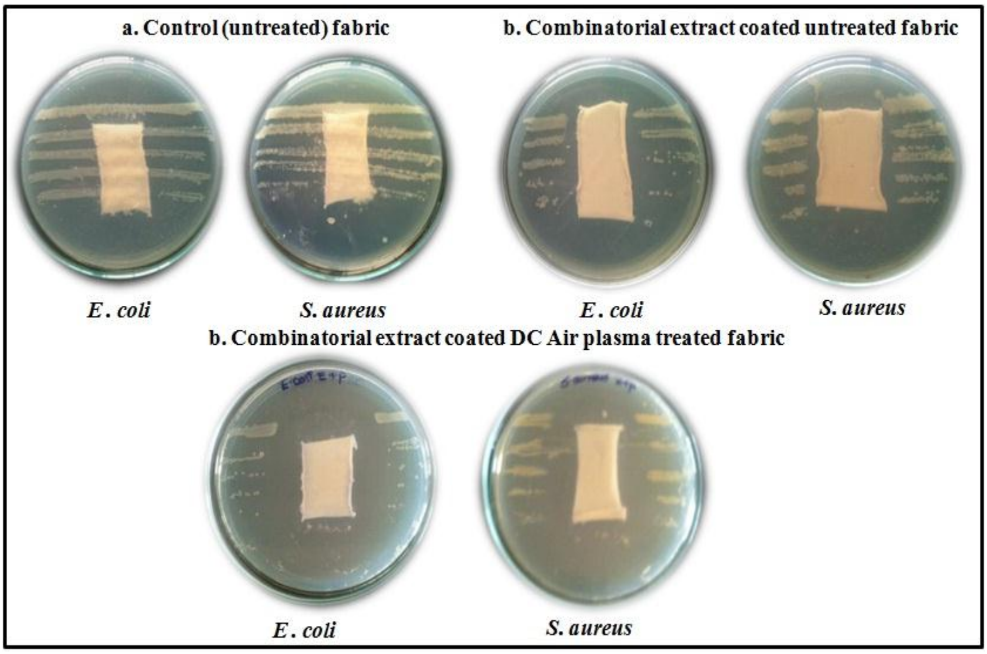

Fig. 4: Assessment of Antibacterial activity of the treated and untreated fabrics

The untreated fabric coated with combinatorial herbal extract showed the least zone of inhibition against the test organisms *E. coli* (7 mm) and *S. aureus* (6 mm). Whereas, untreated fabrics did not show any zone of inhibition. Measuring the inhibition zone method is dependent upon two factors: the ability of the antimicrobial agent to diffuse into the agar, and the antimicrobial activity of the agent against the microorganism. The plasma pre-treated fabrics coated with combinatorial herbal extract showed a better antibacterial activity against *E. coli* (17 mm) and *S. aureus* (15 mm) than the untreated fabric coated with combinatorial herbal extract. It was because the plasma pre-treated fabric had a positive effect on moisture absorption[30], which leads to the uptake of high amount of combinatorial herbal extract. In another study, it was proved that herbal encapsulated nanoparticles treated fabrics inhibited microorganisms[31].

Assessment of antifungal activity of the fabrics

Antifungal activities of the untreated fabric and treated fabric (plasma pre-treated and untreated fabric finished with combinatorial herbal extract) were determined using AATCC 30 method. There is no zone of mycostasis for the untreated fabric where, the *A. niger* was grown under and over the untreated fabric. Also, there is no zone of mycostasis produced by the fabric finished with the combinatorial herbal but *A. niger* was grown few numbers on those fabrics. The plasma pre treated fabric finished with and combinatorial herbal extract showed the zone of mycostasis of about 2mm. whereas the maximum mycostasis was observed against *A. niger* for the fabric pre treated with plasma finished with combinatorial herbal extract. Thus, the plasma pre treated fabric finished with and combinatorial herbal extract fabric could be attributed to increases in hydrophilicity which in turn increases the absorbency of the herbal extract due to the etching and removing fuzz fibrils effect when compared to the other treated and untreated fabric samples.

Quantitative Assessment - Percentage Reduction method (AATCC 100-2004)

The percentage in reduction of the test bacteria were confirmed using AATCC 100 method. The quantitative assessment was studied by bacterial reduction method. The percentage of reduction was calculated and represented in figure 5

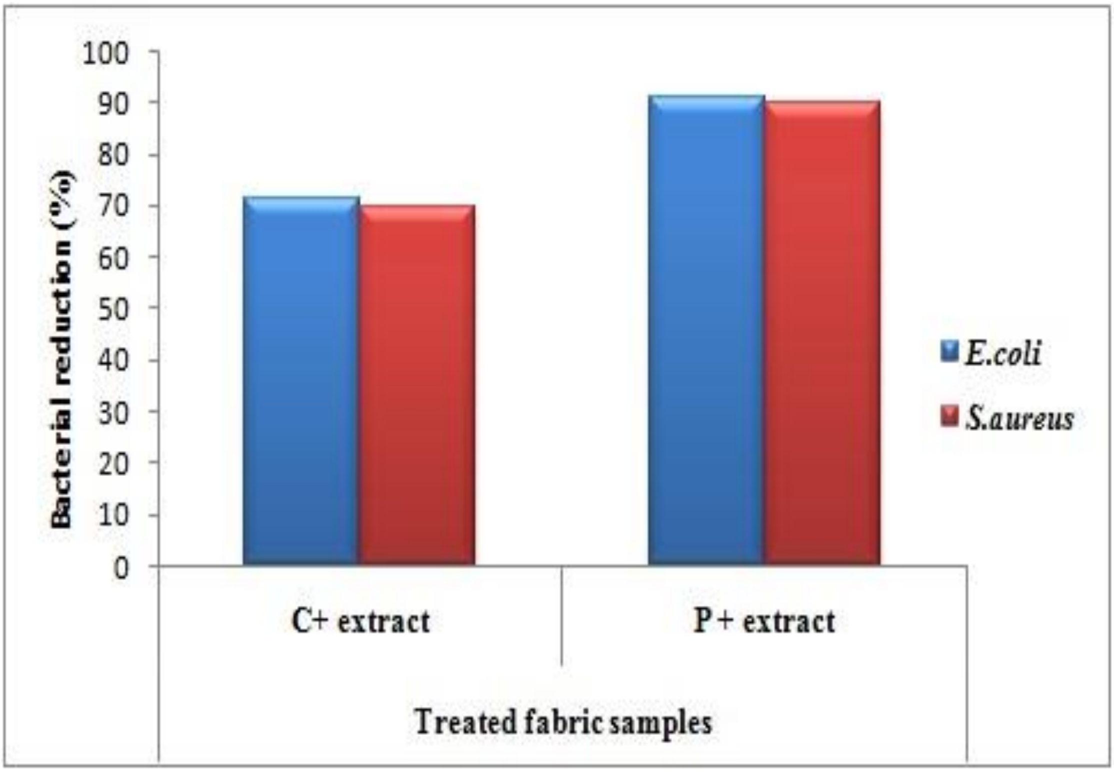

Fig. 5: Percentage reduction of the treated fabrics (AATCC 100)

The results were similar to the parallel streak results. The test bacteria used for the percentage reduction method were *E. coli and S. aureus*. The fabric, pre-treated with plasma finished with combinatorial herbal extract showed the 90.93 % and 89.76 % bacterial reduction against *E. coli* and *S. aureus* respectively. The bacterial reduction of the untreated fabric coated with combinatorial herbal extract against *E. coli* (71.02%) and *S. aureus* (69.78%) were found to be minimum than the other treated fabric (Figure 5). As a result of etching of the fabric by plasma pre treatment, the uptake of the herbal extract would have also increased. The increase in pore radius of the same sample would have increased the retention of extract by the fabric. These might be the reasons for the increased antibacterial activity of the fabric treated with plasma[15]. The result of the quantitative reduction could be further substantiated by the results of qualitative assessment of antibacterial activity.

Wash durability test

The bacterial reduction percentage until 30 laundering cycles were determined in untreated fabric and treated fabric (plasma pre-treated and untreated fabric finished with combinatorial herbal extract) using laundry test. The fabrics were then tested for the percentage reduction of bacterial growth after every 5 cycles. The difference in the durable properties between the different treatments of fabrics was analyzed by repeated washing. The results were calculated and tabulated in table3.

Table 3: Wash durability of the treated bamboo fabrics

S.No	Test samples	Number of laundering cycles	Percentage of Bacterial reduction (%)	
			E.coli	***S.aureus***
1	Untreated fabric coated with combinatorial herbal extract	5	75.56	75.78
		10	61.70	63.25
		15	55.00	58.78
		20	48.62	49.79
		25	31.37	33.58
		30	14.69	15.62
2	Plasma pretreated fabric coated with combinatorial herbal extract	5	87.72	85.00
		10	76.59	73.80
		15	64.31	66.65
		20	59.77	62.47
		25	47.50	50.41
		30	36.36	29.30

The untreated fabric coated with the combinatorial herbal extract loaded nanoparticles showed bacterial reduction. Whereas, the fabric pre-treated with plasma finished with combinatorial herbal extract showed the bactericidal activity against the test bacteria until 15 washes effectively due to the hydrophilic nature of the fabric after the plasma treatment compared to the untreated fabric coated with the combinatorial herbal extract. The increase in the wash durability of the plasma treated fabric attributed to the increase in average pore radius of the fabric which in turn increased the herbal extract retention capabilities of the fabric. The results obtained were correlated with Vaideki *et al.*, who also discussed that plasma treatment enhanced the retention rate of the fabric[16]. The plasma treatment attributed to the increase in average pore radius of the fabrics and improved the water absorbent property and cleaner surface with less fuzz. The fabric possessed higher antibacterial activity against *E. coli* and *S. aureus* due to the uniform coating of combinatorial herbal extract. Hence it could be inferred that the fabric treated with plasma and finished with combinatorial herbal extract was durable to 15 washes with a detergent in the provided process conditions of the test. As expected, that the untreated fabrics did not show any antibacterial activity.

CONCLUSION

The plants resources are the natural antimicrobial agents, which can be attributed to the use of antimicrobial property to the fabric. Although there are many cited literature about the natural antimicrobial agents coated fabrics, but there are very few studies which have carried out in the combinatorial herbal extract coated on the plasma pre-treated fabric. Plasma surface treatments without altering the bulk property it shows distinct advantages, because they are able to modify the surface properties of inert materials, sometimes with environment friendly devices. It is the best pre-treatment to enhance the textile wet processing right from pre-treatment to finishing. The combinatorial herbal extract (*Aloe vera* and *Rosa damascene*) exhibit its potential antimicrobial activity. Hence the plasma pre-treated fabric showed better antimicrobial activity than the untreated fabric coated with combinatorial herbal extract due to the highest absorbency of the pre-treated knitted bamboo fabric. The durability was quite less than the other synthetic agents, which need to be looked into. However, because of their ecofriendly nature and non-toxic properties, they are still promising candidates for textile applications such as medical and health care textiles.

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