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ORIGINAL ARTICLE

Antimicrobial study on surface-coated *Hibiscus sabdariffa* L. fiber reinforcement

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Abstract

The majority of the advancement in cellulose-based materials over the past few years has unquestionably been made through the extraction of micro-sized fibers from plant sources. One of the most noticeable fiber crops with exceptional cellulose content among the best fibers is *Hibiscus sabdariffa* L. In this study, a novel attempt was made to produce the eco-friendly nonwoven fabric using *H. sabdariffa* L. fiber through spun lacing technology. Subsequently, the spun-laced nonwoven has been coated with *Vitex negundo* L. extract to enhance the anti-microbial, anti-fungal, and moisture management properties through pad–dry–cure method. *H. sabdariffa* L. fiber extraction was accomplished with the use of bacterial retting. The extracted fibers were de-lignified to reduce the stiffness and increase the softness and flexibility of the nonwoven fabric. Fourier–transform infrared spectroscopy (FTIR) analysis was carried out between the raw *H. sabdariffa* L. and *V. negundo* L. treated fiber. The antibacterial and antifungal efficacies of the nonwoven fabric were analyzed. The overall moisture management capability (OMMC) of the non-woven fabric was reported as 0.63. It was also discovered that *V. negundo* L.–treated *H. sabdariffa* L. nonwoven has potent antibacterial and antifungal properties against the pathogens tested.

Keywords Antimicrobial · Cellulose · Delignification · Kraft Pulping · Nonwoven · Spun lacing · *Vitex negundo* L

1 Introduction

Due to the increasing demand for textiles around the world at the end of the 1800s, cellulose-based regenerated fiber was employed to replace cotton in textiles. However, its use was limited due to deforestation, high production costs, and low wet strength, prompting both manufacturers and users to look for more environmentally responsible substitutes. Plants derived from field crops and agricultural waste have recently received increased interest as a potential source of woody cellulose fiber. Agro-residues such as banana stems, maize husk, rice straw, sugarcane bagasse, pineapple leaves, and so on were instances of fibre production as a result of increased concerns about public health, the viability of waste management, and environmental conscience [1–3]. Nonwood lingo cellulosic fiber materials are viable options for the development of a wide range of industrial products, including textiles, packaging, pulp and paper, building, and bio-composites. Furthermore, nonwood plants are lighter, non-toxic, biodegradable, and compostable than wood plants, and they contain less lignin [4, 5]. Further, these fibers are easily renewable through high cellulose yields, shorter growing cycles, and less watering. The *Hibiscus sabdariffa* L. plant, which belongs to the kenaf and jute families, produces more leaves, flowers, and stems for sale. It is a tall, simple-to-grow shrub that is easily recognized by its vivid red stem. For generations, *H. sabdariffa* L. has been utilized as a medicine plant. Conjunctivitis, wounds,

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urinary tract infections, ulcers, and other conditions are all traditionally treated with *H. sabdariffa* L.–based extract [6, 7]. It is primarily grown for the production of bast fiber, which is removed from the stem and utilized as a substitute for already-existing natural fibers. These fibers' main ingredients include waxes, lignin, hemicelluloses, and cellulose [8, 9]. Numerous industrial applications have found these natural fibers to be particularly appealing due to their availability, abundance, and inexpensive cost [10, 11]. To maximize this contact, the surface of the fiber must be altered using chemical and physical techniques. These natural fibers with specialized bio-molecules exhibit specific qualities, such as antibacterial, anti-inflammatory, anti-oxidative, etc., and have shown enhanced performance in the medical textile industry for nonwoven fabrics used in specific hygiene material applications [12]. Nonwoven fabric is a type of web made of fibers that are entangled by water jets or other forms of pressure, or bonded by the filaments' ability to solidify after being heated, or glued together with adhesive [13]. Due to their strength, texture, disposability, flexibility, and low-cost production method, these are well-established for their application. It has a wide range of applications in areas like civil engineering, automotive, agriculture, apparel, and medicine. For medical textile products, the spun-lace (hydro-entangling) procedure is extensively employed in addition to other production methods. Dry-laid carded webs could be used as a pioneer for hydro-entanglement. For their high strength, flexibility, water insolubility, hydrophilic characteristic, and chemical stability, cellulosic fibers are frequently chosen. The high concentration of hydroxyl groups in cellulosic fiber enhances the fiber's ability to form bonds and significantly draws water molecules. Medical applications for spunlace fabrics include wipes, wound dressings, surgical materials, diapers, and incontinence pads [14, 15].

There has been a lot of research done on the manufacturing of sanitary fabrics utilizing natural fibers. Karthirvel and Ramachandran created feminine sanitary diapers out of aloe vera and regenerated bamboo fiber and discovered that it had a good antibacterial effect against bacteria like *E. coli* and *Staphylococcus aureus* [16]. Rajesh Kumar and others manufactured sanitary napkins with cotton blended with milkweed fiber and observed that increasing the milkweed fiber blend percentage improved the moisture-holding properties of the sanitary napkins [17]. Similarly, Bhanu Rekh et al. fabricated the core absorbent product of sanitary napkins using cellulose-based waste fiber like banana, bagasse, and sisal. It was discovered that utilizing the water-laid method, preforms created from extracted pulp with the use of binders enhanced the water-retaining capacity [18]. Shbhasmita et al. produced an absorbent textile for female hygiene applications using chitosan-dispersed organic modified cotton fabric. It was demonstrated that the absorbency, as well as the antimicrobial activity of the product, was greatly improved [19]. Murugeshbabu et al. have developed an eco-friendly medical fabric for diaper application by utilizing cotton and bamboo fiber coated with silk fibroin and a mixture of neem extract, clove, and eucalyptus with a ratio of 10:1. The finished product has a good moisture retention capacity and antibacterial activity [20]. *Vitex negundo* L. is a deciduous shrub that has been naturalized throughout much of the world and is valued highly in Ayurveda as a medicinal plant. It has been used as medicine from the dawn of time, administered both internally and externally to cure various disorders in a variety of methods. Alkaloids, flavonoids, saponins, amino acids, and aromatic amines are all found in *V. negundo* L. leaves [21]. It has numerous uses in India, including dyeing, basketry, food, fuel, insecticides, manure, and medicinal. Due to its antifungal, antibacterial, and anti-androgenic properties, several researchers have suggested this plant for the treatment of acne. The effectiveness of this extract finish on cotton fabric against Gram-positive and Gram-negative bacteria has already been tested and reported [22, 23]. In this research work, renewable eco-friendly *H. sabdariffa* L. stem fiber is undergone surface modification through various processes, fabricated as a nonwoven spunlace substance, finished with *V. negundo* L. herbal extract, and analyzed for the application of hydrophilic, antimicrobial layer in a medical textile product.

2 Materials and methods

2.1 Materials

Materials utilized in this study included fresh, disease-free leaves of *V. negundo* L. (1 kg), which were taken from a field in Erode, TN, India, and *H. sabdariffa* L. (10 kg), which was grown on cultivation land in Guntur, Ap, India. The chemicals used were 96% ethanol, 3–4% sodium hydroxide, and sodium sulfide, all of which were purchased from Samy & Co. in India. The Soxhlet apparatus, grinding machine (Philips HR2116), stainless steel sieves 50 mesh (0.355mm), tabletop spun lacing machine (Advantech), moisture management tester (STLATAS M290), FTIR (Jasco FT/IR-6300), SEM (SIGMAHV), and Labman UV-Visible spectrophotometer were used to create hygiene textile products.

2.2 Selection of fiber

Among the plant (bast) fibers *H. sabdariffa* L. fiber is selected for its exceptional qualities, like luster, flexibility, strength, microbial resistance, hygiene, biodegradability, and recyclability to serve as nonwoven fabric in the medical textile industry [8]. The *H. sabdariffa* L. plant is a small annual shrub that belongs to the Malvaceae family and is part of the Hibiscus genus. Fiber will get matured in 90–120 days. The fiber quality is based on cultivation area, extracting method, and agro-climatic conditions. Matured and harvested disease-free *H. sabdariffa* L. plants were sourced for this investigation [9]. The leaves and other plant parts were removed and the isolated stems were collected. *Negundo* L. belongs to Verbenaceae woody substance with aromatic medicinal value which grows up to 2–5 m in height. Most plant parts like leaves, roots, bark, seed, and flowers are considered useful medicine. More specifically, the trifoliated leaves of this plant hold superior biological qualities. In wastelands in humid areas, these plants were very common. Figures 1 and 2 show the image of the *H. sabdariffa* L. and *Vitex negundo* plants.

3 Methods

3.1 Extraction of fiber

The *H. Sabdariffa* L. plant was sourced from the cultivation land of Guntur, India. Since enzymatic retting is claimed to give more environmentally friendly effluent products, a shorter retting period, and a regulated fiber extraction procedure, the collected *H. sabdariffa* L. stems were exposed to bacterial retting [24]. This procedure involved extracting the fibers by submerging them in water for 15 to 20 days. The temperature of retting water was maintained at 27°C ± 2°C. After that, the retted fiber was estranged from the decomposed skin by washing through running water, combed, and dried under the sunlight for obtaining long finer fibers. The extracted fiber is shown in Fig. 3a.

Fig. 1 *H. sabdariffa* L.

Fig. 2 *V. negundo* L. plant

3.2 Pulping and carding

The extracted fiber was de-lignified by the kraft pulping process. For which the *H. sabdariffa* L. fibers were cut into pieces of length 1.5 cm and weighed for the pulping process. This pulping procedure was chosen for de-lignifying fiber since it does not alter the fundamental properties of cellulosic fibers. In the kraft process, *H. sabdariffa* L. fiber is treated with a solution of sodium hydroxide and sodium sulfide at relatively high temperatures (423–453°K) for 2 h to remove lignin from the cellulose [25]. During the treatment, the lignin polymer is solubilized by removing the ether linkages. During this process, alkali pH (9–10) condition was maintained and this was executed through a batch digester system. Once this fiber was taken away from the digester, then the necessary quantity of water was added to this system. After treatment, the pulp was disintegrated to separate the fiber pulp bundles and then washed thoroughly, drained, and dried. Figure 3b indicated the chopped and pulped *H. sabdariffa* L. fiber

The *H. sabdariffa* L. pulp was dried and fluffed (Fig. 3c) using a mixer grinder fitted with a blunt blade to beat the fiber to separate it as single strands at 17,000 to 20,000 RPM. The fluffed pulp is then carded using a tabletop carding system to make the fiber parallel to form uniformity for lap formation. Figure 3D and E indicates the fluffed fiber and carded fiber respectively.

Fig. 3 **a** *H. sabdariffa* L. fiber, **b** chopped fiber, **C** *H. sabdariffa* L. after pulping, **D** fluffed *H. sabdariffa* L. pulp fiber, **E** carded *H. sabdariffa* L. fiber

3.3 Non-woven fabric production through spun lacing

The integration of the fiber structure was achieved using this spun lacing method. The process of spunlacing is entangling a web of loose fibers on a porous belt of moving perforated screen to form a sheet structure by subjecting the fibers to multiple rows of fine high-pressure air jets. The fiber interaction was achieved by the dual advantage of jet force. The final specifications of *H. sabdariffa* L. fiber nonwoven are as follows, density was 15.22 g/sq.m, the thickness of the fabric was 0.50 mm, and the tearing strength of the fabric was 5.78 kg.f.

3.4 *Vitex negundo* L. herb extraction

Fresh disease-free leaves of *V. negundo* L. were collected from the field of Erode, India. These leaves were cleaned and shadow dried for 15–20 days within a temperature range of 37–40°C, grounded, and sieved to remove the coarse particles. The dried leaves were subjected to grinding in a mixer grinder to obtain fine particles after sieving. Figure 4 depicted the image of dried and powered leaves of *V. negundo* L.

V. negundo L. leaf powder 20g (5% w/v of the nonwoven fabric) was taken in a Soxhlet apparatus containing 200ml of ethanol over the heating unit and kept boiled for 30 min. The final mass of extract after vaporization of solvent concentrated extracts was filtered and then collected in a sterile glass bottle. This cycle was repeated for 2 h to the crude extracts [26]. Figure 5 shows the *V. negudo* L. extraction setup.

3.5 Treatment on non-woven spunlace fabric

Nonwoven spunlace fabric samples were treated with 5% w/v extract of *V. negudo* L. (extracted through Soxhlet) extract using 8% citric acid as a cross-linking agent by the pad–dry–cure method in a padding mangle machine [27]. The fabric sample was padded at a pressure of 3 lb/in^2, then taken and dried at 100°C for 5 min and cured at 120°C for 3min.

4 Characterization

4.1 Moisture management test

According to the AATCC (American Association of Textile Chemists and Colorists) 195 test method, the tester assesses the fabric's ability to manage liquids in a standard environment of 70°F and 65% RH. The moisture management tester measures variations in electric conductivity to assess the fabric's absorption capabilities.

4.2 Fourier-transform infrared spectroscopy analysis

Both the raw fiber and the coated nonwoven fabric underwent an investigation using Fourier transform infrared

Fig. 4 *V. negundo* L. dried leaves and leaves powder

Fig. 5 Methonylic extractions of *V. negudo* extract

spectroscopy (FTIR). This technique identified and analyzed major functional groups responsible for antibacterial activity. The chemical composition present in the fibers was assessed through Jasco FT/IR-6300 (type A) spectrometer. Powder of plant specimen and potassium bromide (KBr) mixture in thin plating are used to transmit infrared light, and the transmittance percentage was measured as a function of wave number from 4000 to 500 cm^{-1}.

4.3 Surface morphological study

A scanning electron microscope (SEM) with an energy dispersive X-ray spectroscope was used to analyze the exterior surfaces of the *H. sabdariffa* L. fiber (SIGMAHV—Carl Zeiss with Bruker Quantax 200—Z10 EDS Detector). The pictures were captured at 5kV of accelerating voltage. A tiny layer of gold is applied to the surface of the fiber in order to increase conductivity. At a 20-kV accelerating voltage, the samples were analyzed in the SEM.

4.4 Minimum inhibitory concentration assay

MIC determines the lowest concentration of an antimicrobial agent that prevents the visible growth of a microorganism. Microbes such as *E. coli* and *Staphylococcus aureus* were used for antimicrobial analysis. Similarly, microbes such as *Candida albicans* and *Candida tropicalis* were used for antifungal analysis. Bacterial cultures were grown on nutrient agar. During the initial incubation, microorganisms were suspended in 10 ml of physiological saline solution. For the MIC, determination and bacterial solutions of 5×10^5 ml colony-forming units were employed. The antibacterial activity of the plant extracts was determined using sterile 2-ml 96-well plates. The 8 wells of each row were filled with 0.5-ml sterilized Mueller Hinton agar. Well-1 was filled with a control sample and the rest of the seven wells were filled with different concentrated *V. negudo* plant extracts (1 to 10 μl). These deep wells were incubated for 24h at 37°C. The turbidity value was observed for all 8 wells after 24h. MIC was determined at the optical density readings at 600 nm with a Labman UV-Vis spectrophotometer. At least three repetitions were run for each assay.

4.5 Disc diffusion method

The antibacterial activity and antifungal activity of *V. negudo* L–treated nonwoven fabric were assessed through the disc diffusion method. MHA (Mueller Hinton agar) plates were prepared by pouring 20 ml of molten media into sterile petri plates. After solidification of the media, 20–25 μl suspension of bacterial and fungal inoculums was swabbed uniformly. The sterile paper discs were dipped into the required solvents and then placed in agar plates. The treated fabric was placed inside the respective well. After that, the plates were incubated at 37°C for 24 h. The assay was carried into triplicates, and control plates were also maintained. The zone of inhibition was measured from the edge of the disc to the zone in mm.

5 Results and discussion

5.1 FTIR

The FTIR spectra of raw and *V. negundo* L–treated *H. sabdariffa* L. fiber are shown in Fig. 6. While comparing the raw *H. sabdariffa* L. fiber to *V. negundo* L–treated fiber found significant changes in the FTIR peak. In the raw *H. sabdariffa* L. fiber (pulp), the broadband at 3103 cm^{-1} corresponds to OH stretching of *H. sabdariffa* L. fiber due to the presence

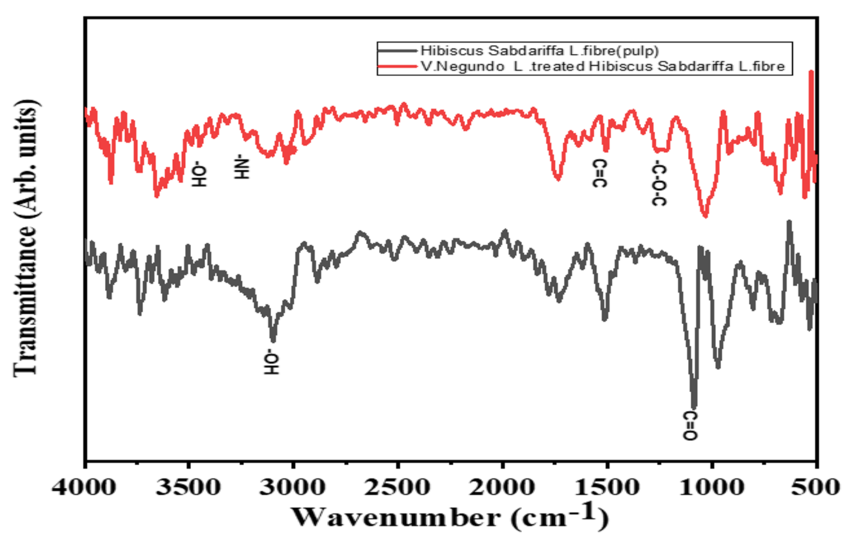

Fig. 6 FTIR spectra of *H. sabdariffa* L. (raw and treated with *V. negundo* L.)

of cellulose. Around 2300 to 2400 cm^{-1}, a peak was eliminated ($-CH_2$ and $-CH_3$ stretching) due to the removal of hemicelluloses, wax, and other natural impurities by the alkali treatment). Subsequently, the absorbance at 1089 cm^{-1} was C-O stretching of phenolic hydroxyl groups in the lignin [28]. The extending vibrations of ester and carboxyl groups in microcrystalline celluloses are attributed to the small band at 1000 and 1500 cm^{-1}[29]. The *V. negundo* L. treated fiber shows some changes from the raw structure. Those are as follows. The broad band at 3450 cm^{-1} corresponded to the alcohols and the phenols; the peak at 3234 cm^{-1} was caused by N-H stretching which showed the presence of primary and secondary amines, The band at 1273 cm^{-1} was due to C-O-C groups, The absorbance of the sharp band at 1508 cm^{-1} was due to C=C stretching between the extract and fiber [30]. Further, 3103 cm^{-1} corresponds to OH stretching was removed in the *V. negundo* L.–treated structure due to the formation of chemical bonding with the fiber. Similarly, the ether bond of untreated fiber at 1089 cm^{-1} was also removed due to the treatment with *V. negundo* L. [31].

5.2 SEM

The SEM images in Fig. 7A and B show the extracted *H. sabdariffa* L. fiber nonwoven samples without any surface coating. Figure 7C and D shows the *H. sabdariffa* L. fiber surface coated with *V. negundo* L. extract. It is evident in Fig. 8D that the surface coating was discovered in a homogenous distribution which is responsible for the antimicrobial activity.

5.3 Moisture management test

The treated *H. sabdariffa* L. fiber non-woven fabric was tested for its liquid absorbency by moisture management test. The details are shown in Table 1.

Due to the higher cellulosic content of *H. sabdariffa* L. fabric, the moisture management indices are very positive for this nonwoven fabric. The maximum wetted radius, AOTI, and OMMC values are significantly higher for *V. negudo* L.–treated rose fabric. More specifically, the OMMC value of this nonwoven fabric is 0.63, which falls under the category of "very good" category. According to Hada Masayu et al., the moisture regain of *V. negudo* L. leaves possessed 69% of its weight. This phenomenon is supported by increasing the moisture regain of this treated nonwoven fabric [32]. Further to this, the structure of the nonwoven fabric increases the capillary action, which is supported by the moisture wick ability of the fabric [33]. The following are the moisture properties of various research activities undertaken to compare these diaper features. Fenye Meng et al. studied the moisture management properties of two different commercially successful diapers and found that the average absorption rate in (%/s) was 7.81, the maximum wetting radius was 8 mm, the spreading speed mm/s was 0.22, and the OMMC value was 0.41 [34]. Similarly, Hande Gül and Sukran studied

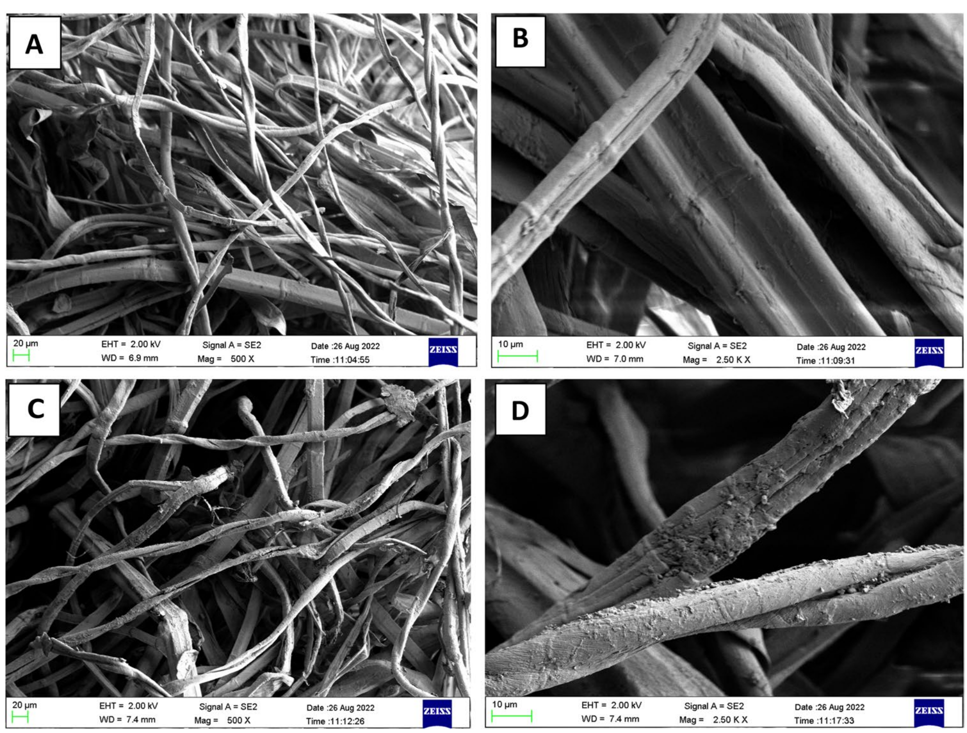

Fig. 7 **A**, **B** The SEM images of uncoated *H. sabdariffa* L. fiber nonwoven samples. **C**, **D** The SEM images of *H. sabdariffa* L. fiber nonwoven Coated with *V. negundo* L. extract

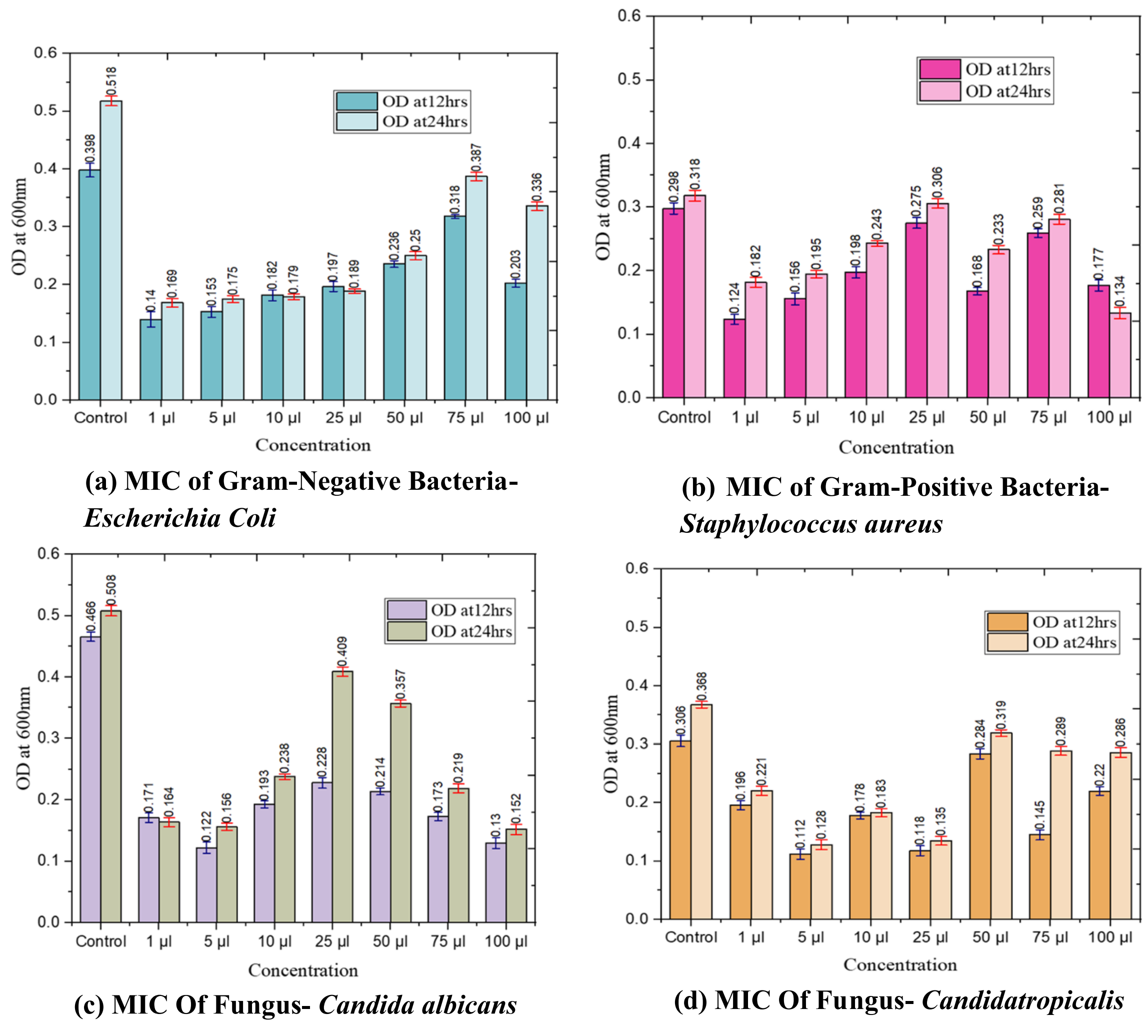

Fig. 8 MIC Assay of *V. negundo* L. extract against different microbes

Table 1 MMT of non-woven spunlace fabric

S. No	Characteristics	Top layer	Bottom layer
1.	Wetting time in seconds	35.349	4.118
2.	Absorption rate %/s	4.238	14.264
3.	Maximum wetted radius in mm	13.334	15.0
4.	Spreading speed mm/s	0.368	1.707
5.	Average one-way transport index % (AOTI)	641.645	641.645
6.	Overall moisture management capability (OMMC)	0.63	0.63

OMMC values, 0–0.2—very poor, 0.2–0.4—poor, 0.4–0.6—good, 0.6–0.8—very good

the moisture management properties of spun bonded/airlaid PP and wood pulp-based nonwoven fabric with diaper application and found the average wetting time was 14 s, maximum wetted radius was 22 mm, spreading speed mm/s was 2.5, and OMMC was 0.56 [35]. Through this observation, it is found that this treated nonwoven fabric is highly suitable for hydrophilic diaper product–based applications.

5.4 Minimum inhibitory concentration assay

In the present investigation, the crude extracts were derived from *V. negundo* L., and their efficacy to inhibit the growth of certain microorganisms was studied through in vitro mode for the application of hygiene textiles. This investigation was carried out against four microbes such

Table 2 MIC against bacteria

S. No	Concentration	*E. coli*		*S. aureus*	
		OD at 12h	OD at 24h	OD at 12h	OD at 24h
1	Control	0.398	0.518	0.298	0.318
2	1 µl	0.140	0.169	0.124	0.182
3	5 µl	0.153	0.175	0.156	0.195
4	10 µl	0.182	0.179	0.198	0.243
5	25 µl	0.197	0.189	0.275	0.306
6	50 µl	0.236	0.250	0.168	0.233
7	75 µl	0.318	0.387	0.259	0.281
8	100 µl	0.203	0.336	0.177	0.134

Table 3 MIC against fungus

S. No	Concentration	*Candida albicans*		*Candida tropicalis*	
		OD at 12h	OD at 24h	OD at 12h	OD at 24h
1	Control	0.466	0.508	0.306	0.368
2	1 µl	0.171	0.164	0.196	0.221
3	5 µl	0.122	0.156	0.112	0.128
4	10 µl	0.193	0.238	0.178	0.183
5	25 µl	0.228	0.409	0.118	0.135
6	50 µl	0.214	0.357	0.284	0.319
7	75 µl	0.173	0.219	0.145	0.289
8	100 µl	0.130	0.152	0.220	0.286

as *E. coli*, *S. aureus*, *C. albicans*, and *C. tropicalis*. The results are presented in Tables 2 and 3.

Figure 8 represents the graphical format of MIC assay against the bacteria and funguses.

According to Fig. 8, it was found that the herbal extract concentration has great potential against *E. coli* at 1µl, *S. aureus* at 1µl, *C. albicans* at 5µl and *C. tropicalis* at 5µl shows antimicrobial and antifungal components against microorganisms. The MIC, namely the lowest concentration of *V. negundo* L. extract at which minimum growth was observed after the incubation of the samples against the tested bacterial strain, was found to be 1µl against *E. coli* and *S. aureus*, 5µl against *C. albicans* and *C. tropicalis* since its corresponding optical density (OD) values are very less. Further, an increase in the concentration of the extract has not improved the antimicrobial activity significantly. According to Jayasree et al., the antimicrobial and antifungal activity *V. negundo* leaves extract is highly significant, and due to that reason the treated structure possessed higher antimicrobial and antifungal values [36].

5.5 Antimicrobial analysis of herbal finished fabric

Antimicrobial activity was performed by the disc diffusion method. The stock culture of bacteria (*E. coli*, *S. aureus*) and fungus (*C. albicans*, *C. tropicalis*) were received by inoculating in nutrient broth media and grown at 37% for 18 h. The agar plates of the above media were prepared and the treated nonwoven fabric was kept in the medium. Each plate was inoculated with 18 h old cultures, the bacteria, and fungus was spotted in the sterile plates. Cut the 4 wells and pour the extract 100 µl. All the plates were incubated at 37°C for 24 h, and the diameter of the inhibition zone was noted in cm. In this assessment, two standard samples were produced with commercially treated chemicals such as chloramphenicol and fluconazole for bacteria and fungus respectively. Table 4 indicated the zone of inhibition (ZOI) of *V. negundo* L.–treated fabric against different microbes. Figs. 9 and 10 indicted the graphical representation of antibacterial and antifungal properties of raw and *V. negundo* L.–treated fabric.

According to Fig. 10, the zone of inhibition measures 0.7 cm against gram-positive *S. aureus* and 0.8 cm against gram-negative *E. coli* bacteria, which are very close to the standard samples. Similarly, the zone of inhibition measures 2.7 cm against *C. albicans* and 2.5 cm against *C. tropicalis* fungus, and these results are also very close to the standard samples. Hence it is interpreted that the *V. negundo* L.–treated *H. sabdariffa* L. non-woven fabric possessed sufficient antibacterial and antifungal properties against different microbes. Through the disc diffusion method, it is found that the aqueous extracts of *V. negundo* L. exhibited strong antimicrobial and antifungal activities against tested microorganisms.

6 Conclusion

Micro-fibrillated cellulose (MFC) was extracted from the non-wood plant fiber used in this study. The *H. sabdariffa* L. fiber was extracted and underwent surface modification through the kraft pulping procedure to improve its

Table 4 Zone of inhibition of *V. negundo* L.–treated fabric against microbes

Organisms	*S. aureus*	*E. coli*	*C. albicans*	*C. tropicalis*
Control fabric	No zone	No zone	No zone	No zone
V. negundo L.–treated *H. sabdariffa* L. nonwoven fabric	0.7 cm	0.8 cm	2.7 cm	2.5 cm
Standard (chloramphenicol/fluconazole))	1.2 cm	1.2 cm	2.8 cm	2.8 cm

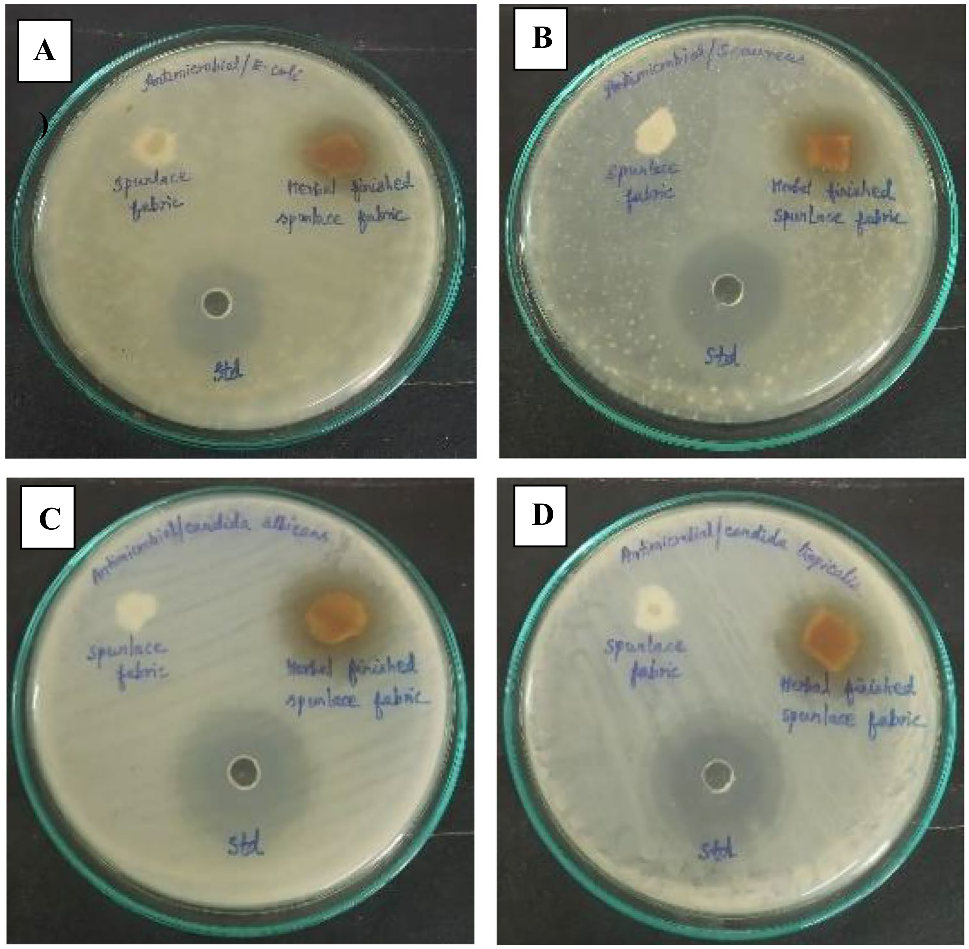

Fig. 9 Antibacterial and antifungal assessments of *V. negundo* L. and *H. sabdariffa* L. nonwoven fabric (**A** test against *E. coli*, **B** test against *S. aureus*, **C** test against *C. albicans*, **D** test against *C. tropicalis*)

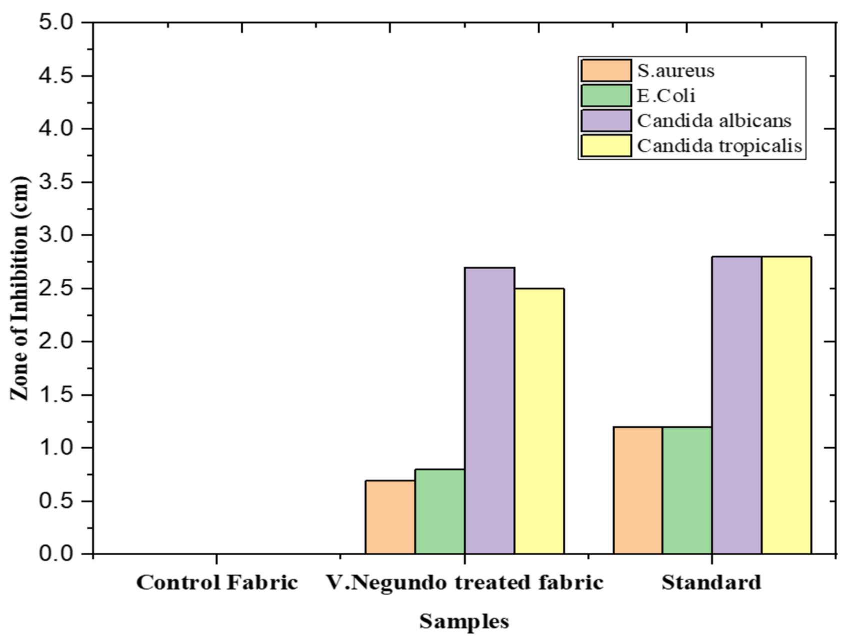

Fig 10 Antibacterial analysis of different nonwoven fabric samples

properties. The fiber tends to acquire fineness, elasticity, and liquid absorption qualities as a result of the de-lignifying process. Through FTIR analysis, it was determined that a significant amount of inorganic constituents, such as lignin, wax, and ash has been removed. To create nonwoven spunlace textile material, the finished fiber pulp was fluffed, carded, and then formed into a lap. The density, thickness, and tearing strength of *H. sabdariffa* L. fiber is 15.22 g/sq.m, 0.50 mm, and 5.78 kg.f. It was finished with *V. negundo* L. extract to make it a useful cloth against hazardous skin infections by bacteria and fungus. Through this experiment, it was discovered that the *V. negundo* L. extract has improved the antimicrobial activity and moisture management properties of *H. sabdariffa* L. nonwoven fabric. The moisture management study reported on the *V. negundo* L.–treated *H. sabdariffa* L. fiber nonwoven fabric was about 0.63, which is a significant index when compared to commercially available diaper goods. Similarly, The antimicrobial activity of *V. negundo* L.–treated *H. sabdariffa* L. fiber nonwoven fabric was found as 0.7 cm, 0.8 cm, 2.7 cm, and 2.5 cm against *S. aureus*, *E. coli*, *C. albicans*, and *C. tropicalis* microorganisms which were fairly good versus the commercial samples, and it is reconfirmed the research work of Bevan et al. [37]. It is concluded that the *H. sabdariffa* L. bast fiber fabric can effectively be utilized as non-implantable feminine hygiene textile product.

Author contribution T.R. Indumathi: experimental work, sample preparation, visualization. R. Divya: guidance, literature work, supervision, characterization, material sourcing, writing support. B. Senthil Kumar: manuscript writing, editing, coordination. A. Selvakumar: manuscript revision, language editing.

Data availability There is no dataset provided with this submission.

Declarations

Ethics approval Not applicable.

Competing interests The authors declare no competing interests.

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