



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



## Development of a microbial coating for cellulosic surface using aloe vera and silane

Poonam Chauhan, Aditya Kumar\*

Department of Chemical Engineering, Indian Institute of Technology, Indian School of Mines Dhanbad, Jharkhand 826004, India



### ARTICLE INFO

#### Keywords:

COVID-19  
Aloe vera  
Antibacterial  
Antifungal  
Stain-resistant

### ABSTRACT

The highly contagious nature of SARS-CoV-2 (COVID-19) virus has created a havoc effect all over the world in a very short period. The most effective method for precaution of this virus as suggested by WHO is use of PPEs (triple layered face mask, body suits) and social distancing. However, the frontline doctors and medical staff have high risk of exposure to the virus during treatments and removal and discarding of the PPEs. Also the PPEs are of the onetime use and wearing these PPEs in hot and humid seasons is very uncomfortable. A possible solution of this problem is if clothes are anti-bacterial and anti-viral in nature, one single-layered will be sufficient and the spread of virus will also be minimized. Considering this, we have designed a facile and durable anti-wash antimicrobial coating on cloth by aloe vera and hexadecyltrimethoxysilane (HDTMS). In lab scale study, present coating shows good chemical and thermal stability making it reusable multiple times even after repeated washing. The coated cloth reveals the excellent anti-dirt and stain resistance properties leading to complete non-adherence of dirt and stain (e.g. Color, food, ink) on it. Anti-bacterial and anti-fungi properties of the coated cloth were confirmed by doing *E. coli* (bacteria) and *A. Niger* (fungus) culture studies, respectively. This coating is imbued with well-known anti-viral agent aloe vera which inhibits the attachment of the virus on the surface. The water-repellent nature of the coating combined with the use anti-viral agent, aloe vera makes it a potential anti-COVID-19 coating.

### 1. Introduction

Recently, SARS-CoV-2 or COVID-19 virus has been spreading rapidly all over the world within a short span of time interval. The transmission of viruses such as COVID-19 occurs by two principal means: (1) airborne droplets containing virus (a sneeze or cough); and (2) contact transmission, that is, the physical transfer of virus from a biological source (blood or other liquid, skin) to another person (from a person's hand to another person) or from a surface (counter, table, respirator mask, clothing, carpet or hospital curtain) to another surface (a person's skin, mouth or eye). This fast spreading of COVID-19 is due to its stability for several hours to days in aerosols and on surfaces (Doremalen et al., 2020).

It is recently noticed that COVID-19 can readily undergo in mutation or genetic changes which is making the situation more difficult. Since this virus is a new type of corona virus, the details of COVID-19 are yet under study by people throughout the world and its vaccine and medications have not been established yet. Therefore, many collective measures (washing or sanitizing hands, maintain social distancing, quarantining suspected people, complete or partial lockdown of the cities, closing

schools and other public gathering places, cancelling sports and public events, and disinfecting public places and use of respiratory mask) are needed to decrease infection rates in the whole world. The doctors and the health care staff are at extreme risk of getting infection and hence have to wear proper personal protective equipment (PPE) such as respirator masks to minimize contact transmission onto facial skin or airborne inhalation of COVID-19. Although respiratory mask helps trap larger respiratory droplets and protect from contracting the COVID-19, but these masks are presently of one time use as pathogens on their outer layer. Single use of these masks is increasing the problem. Therefore, if their surfaces can be made of anti-viral, these masks can be re-used. Additionally, working while wearing PPE kits by health workers is not easy, particularly, in hot and humid seasons. Therefore, if their clothes are bactericidal and virucidal in nature, then PPE will not be needed and extent of virus spread can be reduced.

Although there are several antimicrobial N95 masks and clothes in the market utilizing iodine, silver or tryclocan, but none of them is efficient of killing or inactivating viruses. The size of microbes and COVID-19 are different. Recent study has been confirmed the structure

\* Corresponding author.

E-mail address: [adityaku43@gmail.com](mailto:adityaku43@gmail.com) (A. Kumar).

of COVID-19 (Holbrook et al., 2020) and the average size of this virus is 70–80 nm. Therefore it is required to develop new specialized anti-viral coating on cloth surface especially for COVID-19.

To overcome the above mentioned issues, the work has been devoted to design the artificially protective cloth (antibacterial, antiviral) to reduce the transmission of infection with body fluid repellency properties from its surfaces. Antimicrobial and antiviral cloth does not only protect the health care worker from of disease but also prevents the growth of fungus on its surface. If cloth is itself anti-wash in nature, then it can also reduce the risk of spread the disease by repelling the body fluid (Galante, Haghanifar, Romanowski, Shanks & Leu., 2020; Tudu, Sinhamahapatra & Kumar, 2020).

Several other studies have been done in the preparation of anti-wash and antimicrobial cloth by using nanoparticles (Ag, ZnO and Cu) (Hong, Kim & Park, 2018; Perera et al., 2013; Shaban, Mohamed & Abdallah, 2018; Yazdanshenas & Khalilabad, 2013). Aforesaid these surfaces have some drawbacks such as low durability, poor bonding, high cost, and complex preparation. The nanoparticles are incorporated into the woven fabric matrix by either physical or chemical method. Thus, due to the poor bonding with the fabric, the nanoparticles may gradually detach from the cotton fabric after a period of use and come in contact of human skin, causing serious health problem (Kulthong, Srisung, Boonpavanitchakul, Kangwansupamonkon & Maniratanachote, 2010; Windler et al., 2012). Additionally, some nanoparticles (e.g., TiO<sub>2</sub>) are toxic in nature after exposure to sunlight (El-Naggar, Shaheen, Zaghoul, El-Rafie & Hebeish, 2016).

Nowadays, the variety of green approaches has been carried out in developing the antimicrobial and antiviral cotton fabric. From the literature, the antimicrobial cotton clothes have been produced using plant leaves extract such as aloe vera (Ali, Purwar, Joshi & Rajendran, 2014), Azadirachta indica (neem) (El Aty., Bassyouni, Zaher & Guirguis, 2018; Rajendran et al., 2012), lotus (Oh & Na, 2014), ginger, and curry leaves (Jaswal, Preet & Goal, 2017). Plant leaves extract has been chosen as a coating material because it is economical, eco-friendly and bioactive in nature with antifungal, antibacterial and anti-viral activity. at (Guo X. & Mei, 2016; Kawai et al., 1998). Among these, aloe vera or aloe barbadense has been used as a curative agent. Its gel consists of 99.3% water and remaining 0.7% solids part (Grindlay & Reynolds, 1986). It has 75 active ingredients such as aloesin, anthraquinones (aloin and aloe emodin), aloemannan, acemannan (gel polysaccharides), aloeride, verectin, giberellinlike substance, aloeresin I, 5-methylchromone, flavonoids, glycoprotein fraction, anthraglycosides, reducing sugars, cardiotoxic glycosides, saponins, naftoquinones, sterols, triterpenoids, amino acids, vitamins and others (Grindlay & Reynolds, 1986; Sánchez, Burgos, Iglesias & Serranillos, 2020).

Due to presence of several active ingredients, aloe vera possesses antibacterial, antiviral, antifungal, antioxidant, angiogenic, immune system modulator, antidiabetic, antihypertensive, cathartics, analgesic, anti-inflammatory, wound healing, antihepatitis, anti-gastric ulcer, and antineoplastic activities (Sánchez et al., 2020; Stanić, 2007). Presence of anthraquinones and polysaccharides in aloe vera make it useful as antiviral activities for human cytomegalovirus, herpes simplex virus type 1 (HSV-1), herpes simplex virus type 2 (HSV-2), H1N1 subtype influenza, and poliovirus (Bernard et al., 1992; Rezazadeh, Moshaverinia, Motamedifar & Alyaseri, 2016, 2016; Semple, Pyke, Reynolds & Flower, 2001; Sun et al., 2018; Zandi, Zadeh, Sartavi & Rastian, 2007). In all studies, anti-viral mechanism of aloe vera is likely the physical inhibition of binding between the virus and host cell. This property of aloe vera holds promise that anti-microbial coatings based on cotton fabric will be effective against many types of bacteria, fungi, and viruses.

In the past studied, it has been found that the various anti-viral and anti-bacterial polymeric and nanoparticles (copper, silver) based coatings are available on the fabric surface. But no anti-viral, anti-dirt and anti-stain coating is produced using green approach. In this work, the simple and low-cost technique (green approach) was used to fabricate the aloe vera based anti-wash coating on cloth. Durability, anti-dirt,

stain-resistance ability of prepared coating was examined. Anti-bacterial and anti-fungal properties of coating have been examined in details using *E. coli* and *A. Niger*, respectively. Additionally, anti-viral mechanism of coating for COVID-19 has been proposed in this paper.

## 2. Experimental details

### 2.1. Materials

Commercially available cotton fabric was purchased from Asia Hosiery Mills Private Limited, India. Aloe vera powder was purchased from Axi Rejuvenate Life Care Products, India. HDTMS was purchased from Sigma-Aldrich. Ethanol was purchased from Merck Life Science Private Ltd., India. All chemicals were used as received.

### 2.2. Preparation of aloe vera extract

The aloe vera extract was prepared by extraction process from the aloe vera powder. The powder was prepared from the dried leaves of aloe vera. One g of aloe vera powder was poured in a conical flask containing 10 ml ethanol, and kept for 12 h at room temperature for extraction. Here, ethanol was used as a solvent for the extraction. The aloe vera extract was filtered by using Whatman filter paper grade-1 to remove particulate matter from the extract solution. An obtained yellow-brownish color clear solution (extract) was used for further experiment.

### 2.3. Preparation of superhydrophobic cotton fabric

The cotton fabric was cut into a square shape with a dimension of 3 cm × 3 cm. The Cotton fabric was washed several times with ethanol and water mixture using ultrasonication for 30 min to remove the wax and other impurities on its surface and dried in the hot air oven for 1 h at 80 °C. Fig. 1 shows the schematic representation of superhydrophobic cotton fabric. The coating solution was prepared by mixing HDTMS (5%, v/v) and aloe vera extract followed by stirring for 2 h at room temperature. Cleaned cotton fabric was immersed in the prepared coating solution for 24 h. Afterward, fabric sample was dried in the hot air oven at 120 °C for 2 h for complete removal of solvent.

### 2.4. Characterizations

Scanning electron microscope (SEM, Supra 55 V, Carl Zeiss, Germany) was used to examine the surface morphology of cotton fabric before and after modification. To examine the wettability of cotton fabric, a contact angle measurement (DSA 25, Krüss, Germany) was performed on its surface at the room temperature with 3–5 µL droplet of water. Water contact angles (WCA) were measured four times at different positions on each sample and mean value of them were reported. Functionality of the cotton fabric sample was recorded using a Fourier-transform infrared spectroscopy (FTIR, Cary 660, Agilent Technologies, USA) in the wavelength range of 400–4000 cm<sup>-1</sup>. The FTIR spectra was recorded at the scan number of 16. The resolution of the FTIR analysis was maintained at 4 cm<sup>-1</sup>.

The antibacterial activity of uncoated and coated sample was measured against *E. coli* bacteria using disk diffusion method (Tudu, Kumar & Bhushan, 2019). Initially, both uncoated and coated cotton fabric were cut into the circular shape with diameter 7 mm. Subsequently, approximate 25 ml prepared Muller Hinton agar was poured onto the sterilized petri dishes and left for 30 min to get solidified before inoculating. 1 ml of bacteria culture with a concentration of 1 × 10<sup>-5</sup> colony forming unit (CFU)/ml was spread onto the Muller Hinton agar plate and then a hole was punched into the each plate and sample was kept in it. After that, the petri dishes were incubated at 37 °C. The clear zones were recorded around the coated fabric at different time intervals (24 h, 48 h, and 72 h), and measured with a caliper in mm.

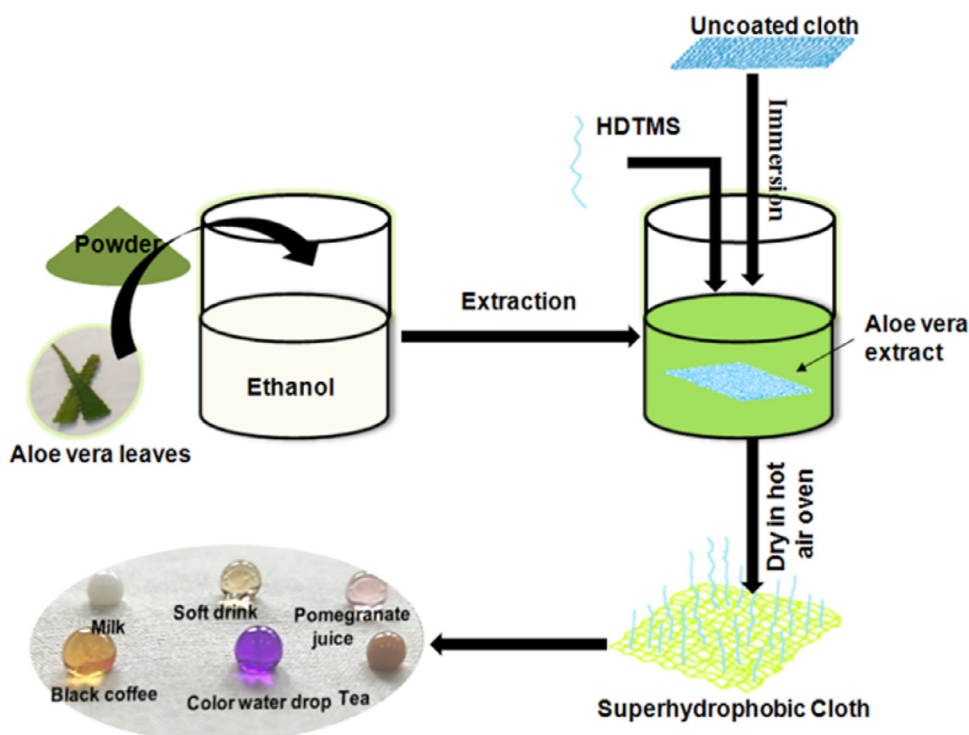


Fig. 1. Schematic diagram of the preparation process of superhydrophobic cotton fabric using HDTMS and aloe vera extract.

The antifungal assay of uncoated and coated samples was performed using agar disc diffusion method against *Aspergillus niger*. Sabouraud dextrose agar media was prepared in autoclave and poured into the sterile petri plates. The fungal isolate was inoculated on the solidified culture media plates. The samples were cut in the disc (7 mm) and were placed on the media with the help of sterile forceps. The plate was incubated at 27 °C, and then the zone of inhibition was measured at different time intervals (24 h, 48 h).

In self-cleaning experiment, the dust particles were spread over the both uncoated and coated surfaces. Later, the water was dropped on the dusted clothes using dropper. Behavior of the water on both dusted samples was observed by capturing the optical images using camera (Oneplus A6000, f/1.7). In stain resistant experiment, blue color water droplets were kept on both uncoated and coated cotton fabric. After that, both samples were dried for complete vaporization of the water droplets from its surfaces, and the stained on both coated and uncoated samples were observed before and after drying at room temperature.

In thermal stability test, coated sample was annealed in the hot air oven (120 °C to 170 °C) for 1 h. After that, the WCA of annealed sample was measured to examine the wettability of its surface. In washing durability test, coated sample was immersed in the water containing detergent and placed into the ultrasonication bath at 40 °C. After 1 h, the washed fabric sample was rinsed with water to remove the excess detergent solution from its surface and dried at 80 °C. Finally, the WAC was measured after washing to check its superhydrophobicity.

### 3. Results and discussion

An antimicrobial cotton fabric was fabricated using aloe vera extract and fluorine free silane by a simple immersion process. An aloe vera extract shows antibacterial and antifungal properties. The main bioactive components present in aloe vera such as flavonoid compounds, have been identified. So, alkali reagent test was performed to identify the flavonoid compounds. In this test, natural color of aloe vera extract (reddish) was changed into yellowish-brown color by adding the dilute NaOH (0.1 N) dropwise into the extract and became colorless after adding drop of dilute acid in the mixture, found the similar observation from literature

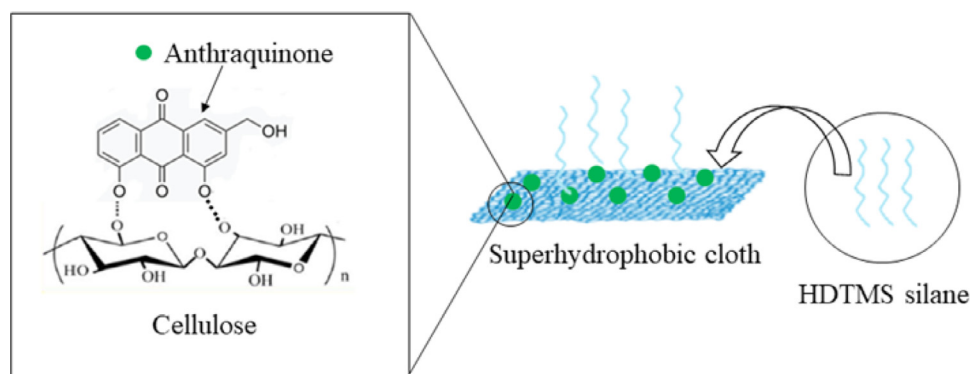
(Gul, Jan, Faridullah, Sherani & Jahan, 2017). Modify cloth shows the same property of cotton cloth like before while the color of its surface was slightly changed because of the aloe vera extract natural color. Fig. 2 illustrates mechanism of HDTMS and aloe vera based coating on the cotton fabric in the details. The inherent (-OH) groups on the cotton cloth react with the anthraquinone (major antimicrobial components present in the aloe vera and contains reactive -OH or phenolic groups). Subsequently, the cloth was immersed in the HDTMS solution, the reactive molecules (polar groups) of the silane react with some (-OH) groups as well as with the anthraquinone reactive groups and participates in a complex reaction. The presence of abundant hydrophobic long alkyl chain of HDTMS, it shows the superhydrophobic nature.

The surface energy calculation is expressed as  $\gamma = \gamma^d + \gamma^p$ , where d and p mean dispersion and polar component, respectively. Here, the Owens and Wendt (1969) approach, the surface energy of the modify surface was calculated using geometric mean method according to this Eq. (1).

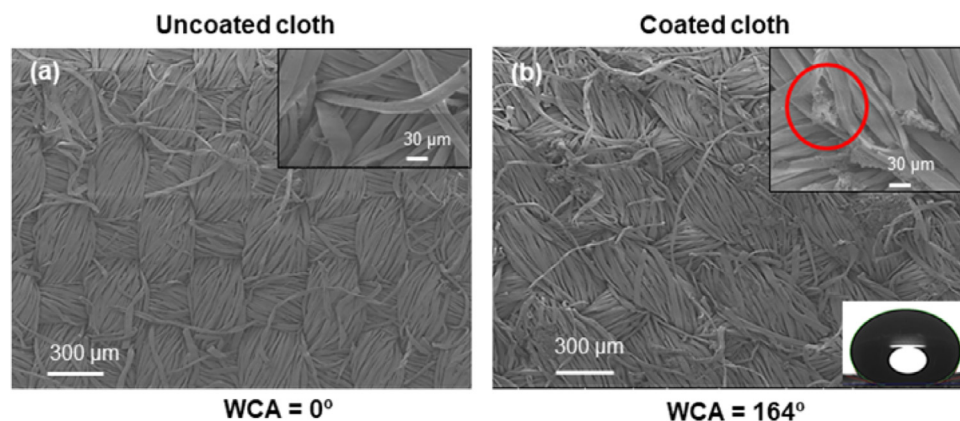
$$(1 + \cos \theta_i) \gamma_{ii} = 2 \left( \sqrt{\gamma_{ii}^d \gamma_s^d} + \sqrt{\gamma_{ii}^p \gamma_s^p} \right) \quad (1)$$

Two liquids ( $i = 1, 2$ ), ethylene glycol ( $\gamma_{11} = 47.7 \text{ mN/m}$ ,  $\gamma_{12}^d = 26.4 \text{ mN/m}$ ,  $\gamma_{12}^p = 21.3 \text{ mN/m}$ , ethylene contact angle ( $\theta_1$ ) = 138°) and water ( $\gamma_{12} = 72.8 \text{ mN/m}$ ,  $\gamma_{12}^d = 26.4 \text{ mN/m}$ ,  $\gamma_{12}^p = 46.4 \text{ mN/m}$ , water contact angle ( $\theta_2$ ) = 164°) were used to calculate the surface energy of coated cloth which is determined equal to 14.4 mN/m.

Surface wettability of uncoated and coated samples was evaluated by the measurement of WCA. The water was absorbed quickly on the uncoated surface due to its hydrophilic/ superoleophilic nature (WCA ≈ 0°). The WCA for uncoated and aloe vera extract coated fabric were measured 0°. After coating with HDTMS of aloe vera extract coated sample, the WAC of was increased to 164° because the active hydroxyl groups (presence on the fabric surface) are attached chemically with silane (low surface energy material) and flavonoid (by cross-linking). The WCA captured image of the coated surface is shown in Fig. 3, which exhibits superhydrophobicity. The contact angle for water-based products and oils are found to be more than 150° as shown in Table 1.



**Fig. 2.** Mechanism of the preparation of superhydrophobic surface based on HDTMS and aloe vera extract.



**Fig. 3.** SEM images of (a) uncoated and (b) coated cotton fabric. The image of the water contact angle on the right bottom was captured using high resolution camera. Images on the both top right corners are of high magnified SEM. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

**Table 1**  
Contact angle of water based products on uncoated and coated samples.

Liquid	Contact angle (°)	
	Uncoated cloth	Coated cloth
Water	0	164
Tea	0	160
Black coffee	0	158
Soft drink	0	163
Pomegranate juice	0	164
Milk	0	159

Scanning electron microscopy was used to study of the surface morphology of both uncoated and coated cotton fabric. It is found that the cotton fabric is tightly woven with dozens of threads. SEM images reveal that a pristine cotton fabric has an inherent surface roughness consisting of micro-structures as shown in the Fig. 3(a). The morphology of coated sample reveals the microstructures of the surface with the in-homogenously distribution of coating material (aloe vera extract) or the aggregation of the flavonoid's molecules (enclosed in red circle) as shown in Fig. 3(b). Increase of the contact angle is because of roughness on the surface and the long chain alkyl molecules which is hydrophobic in nature. As explained by Cassie-Baxter wetting state, these rough microstructures present on coated surface contains air pockets beneath the water droplet and these air pockets enhance the water contact angle, making the surface superhydrophobic (Cassie & Baxter, 1944).

To further confirm that cotton fabric was successfully modified by HDTMS and aloe vera extract, FTIR study was done to understand the chemical bonding. The existence of all signature peaks on uncoated, coated cotton surface, and the aloe vera extract solution were shown in Fig. 4.

In Fig. 4(a), peaks at  $1458\text{ cm}^{-1}$  and  $1656\text{ cm}^{-1}$  correspond to the C = C (aromatic ring) and C = O (flavonoids groups), respectively

(Mot, Dumitrescu & Sarbu, 2011). Commonly, the peaks at  $3336\text{ cm}^{-1}$  and  $2901\text{ cm}^{-1}$  in uncoated cloth are attribute to -OH stretching groups (Beroual et al., 2020a, 2020b). The C-H bond is stretching vibration of  $\text{CH}_2$  group. Furthermore, the band appeared at  $1162\text{ cm}^{-1}$  and  $1054\text{ cm}^{-1}$  are attribute to the C-O-C and C-O, related to the asymmetric vibration of the beta-glycosidic linkage in cellulose (Tarchoun, Trache & Klapotke, 2019; Tarchoun, Trache, Klapotke, Derradji, & Bessa, 2019) as shown in Fig. 4(b). The presence of the absorption peak at  $1650\text{ cm}^{-1}$ , which is assigned to the C = O stretching vibration, demonstrates that flavonoid compounds have been successfully attached onto the cotton fabric. At this peak, it shows the strong antioxidant compound (Mot et al., 2011). The peaks at  $2916\text{ cm}^{-1}$  due to the C-H asymmetric shows the presence of long chain alkyl groups (Zhang, Wang, Wang, Shi & Li, 2012), indicating that the cotton fabric was well coated with HDTMS and flavonoid compounds as shown in Fig. 4(b).

### 3.1. Bacterial and fungal activities

In general, chance of bacteria growth is high in humid environment, and cotton works as a resource of nutrient for bacteria due to the presence of cellulose materials. So, the large number of bacteria could easily adhere on the cotton fabric. In this paper, antibacterial activity of both uncoated and coated fabric was evaluated against the gram negative bacteria (*E. coli*). Fig. 5(a-c) shows that the bacteria are adhere to the uncoated sample at the different time intervals (24 h, 48 h, 72 h) due to its water absorption property. On the other hand, coated cotton fabric has the tendency to repel water from its surface, making difficult to adhere and penetrate into the cotton fabric matrix. So, the coated sample shows the inhabitation zone surrounding it as clearly shown in Fig. 5(d-f). Here, two reasons play the significant role to display the antibacterial property on the coated cotton fabric. HDTMS silane is used as a coating material which has long alkyl chain and creates a barrier to reach bacteria. The aloe vera extract consists of bioactive compounds; after add-on the extract, it increases the antibacterial and antifungal activities on the

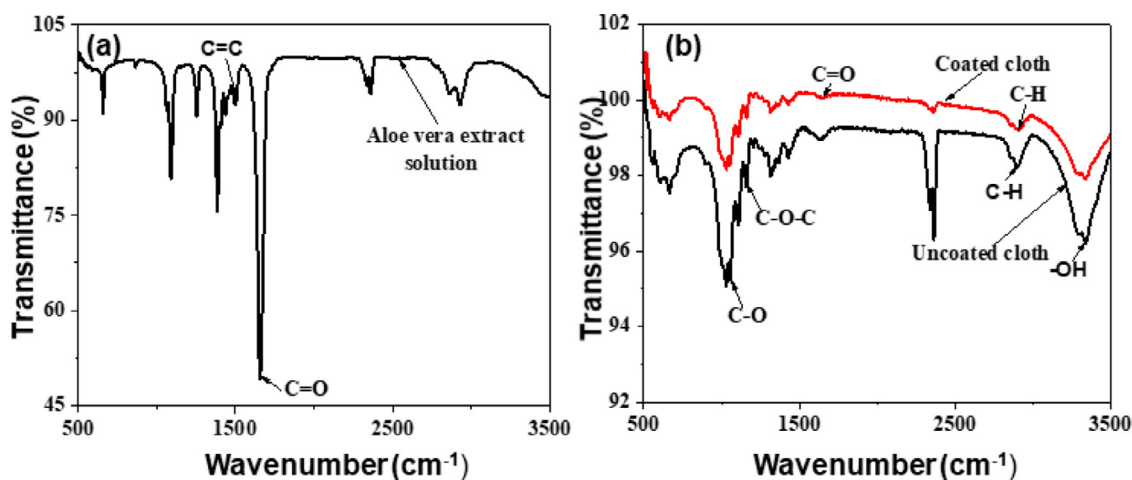


Fig. 4. (a) FTIR spectra of aloe vera extract solution, C = C and C = O, indicates the presence of aromatic ring and flavonoid, respectively. (b) FTIR spectrum of uncoated and coated cotton fabric. The -OH stretching at 3343 cm<sup>-1</sup> indicates the presence of hydroxyl groups. While in coated fabric, the presence of absorption peak at 2916 cm<sup>-1</sup> indicates the C-H group (long chain hydrocarbons). The absorption peak at 1650 cm<sup>-1</sup> indicates the presence of flavonoid compounds.

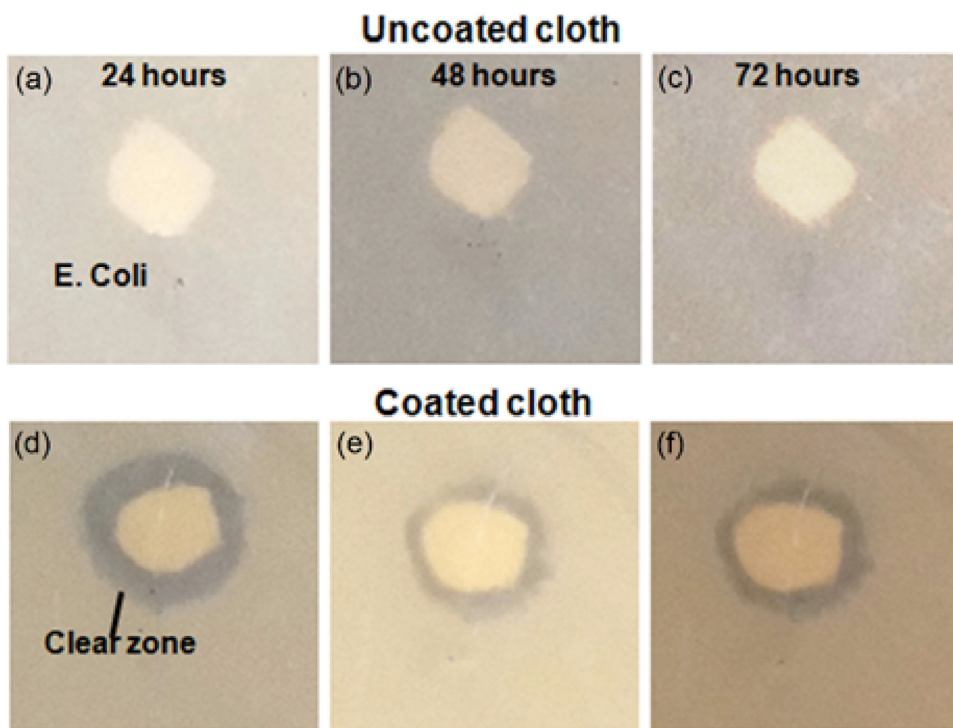


Fig. 5. The optical images of bacteria adhered on (a-c) uncoated and (d-f) coated cotton fabric. Clear zone (no bacteria growth) is seen around the coated sample. Antibacterial activity is observed against the E. coli bacteria after incubation for 24, 48, and 72 h.

**Table 2**  
Zone of inhibition of uncoated and coated samples against E. coli bacteria after different time intervals.

Incubation time (h)	Inhabitation zone (mm)	
	Uncoated cotton fabric	Coated cotton fabric
24	—	9
48	—	7
72	—	7

coated cotton fabric. Initially, the antibacterial activity is high because of the diffusion of the antibacterial agent which are attached physically on its surface into the agar plate. Later, it is observed that the antibacterial activity is not affected much, even after 72 h. The antibacterial activity of the coated fabric with time is shown in Table 2. It is concluded that the coated cotton fabric shows the excellent antibacterial activity for a long time against the E. coli bacteria.

The anti-fungal activity of both uncoated and coated cotton fabric was calculated against the A. Niger fungus. The uncoated cloth was wetted quickly, and visible spore is seen near the sample, implies the growth of fungal as shown in Fig. 6(a-b) while the coated cloth when exposed to fungal shows no growth over its surface as well as around the sample as shown in Fig. 6(c-d). Even after 48 h it exhibits the antifungal activity. The antifungal activity on the coated surface is observed due to its moisture control ability along with aloe vera extract (antifungal agent). As illustrated in Table 3, the coated cotton fabric exhibits the antifungal activity over time.

### 3.2. Viral activities

With the help of primarily results of antibacterial and antifungal activities of aloe vera coating and its antimicrobial and antiviral mechanism given in literature, we have been proposed the antiviral mechanism of aloe vera coating for COVID-19 virus. The main mode of trans-

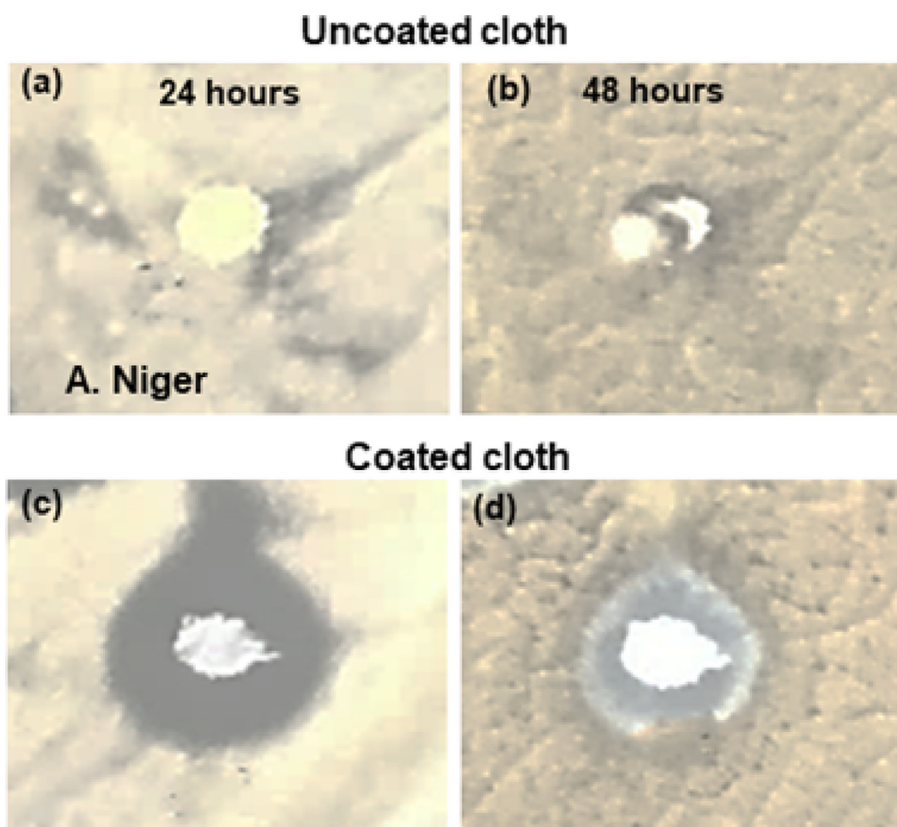


Fig. 6. The optical images of fungus adhered on (a-b) uncoated cloth and (c-d) coated cotton fabric. Clear zone (no fungi growth) is seen around the coated sample. Antifungal activity is observed against the *A. Niger* fungus after incubation for 24 and 48 h.

**Table 3**  
Zone of inhibition of uncoated and coated samples against *A. niger* fungi species after different time intervals.

Incubation time (h)	Inhabitation zone (mm)	
	Uncoated cotton fabric	Coated cotton fabric
24	—	17
48	—	13

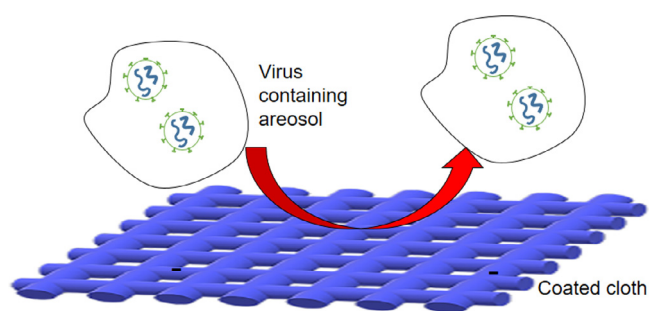


Fig. 7. A schematic representation of proposed mechanism of aerosol (containing virus) droplets rebound from the coated cloth.

mission of virus is aerosol droplets containing COVID-19 (a sneeze or cough) which is water based and present coated cloth surface exhibits extremely good water-repellent nature. Therefore, inhibition of virus from the cloth is by repelling aerosol droplets from the surface (Fig. 7).

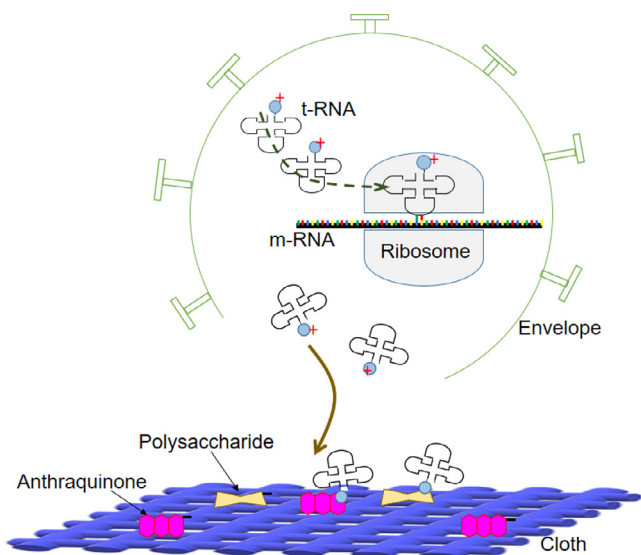
Virus can also reach to the surface by physically contact mode. Once the virus reach to the surface, aloe vera plays an important role antiviral activities. Aloe vera inhibits the bacterial protein synthesis by preventing aminoacyl-transfer-ribonucleic acid (aa-t-RNA) with bacterial ribosome. In general t-RNA participates in protein synthesis by decoding a messenger ribonucleic acid (m-RNA) at specific sites in the ribosome

present in virus cell. In aa-t-RNA, t-RNA is connected with amino acid and making it chemically charged (positive) and this amino acid is later delivered in ribosome in protein synthesis.

Aloe vera has 75 bioactive agents such as anthraquinones (aloin and aloe-emodin), aloemannan, acemannan (polysaccharides), aloeride, verectin, gibberellinlike substance, flavonoids, glycoprotein fraction, anthraglycosides, reducing sugars, cardiotoxic glycosides, saponins, naftoquinones, sterols, triterpenoids, amino acids, vitamins and others (Grindlay & Reynolds, 1986; Sánchez et al., 2020). Recent studies have been discussed that anthraquinone and its derivatives (polyphenolic structures analogue of tetracycline) inhibit the protein synthesis by preventing the association of aa-t-RNA with the ribosome (Rezazadeh et al., 2016; Sánchez et al., 2020; Sydiskis, Owen, Lohr, Rosler & Blomster, 1991). It is because of negative charge present on anthraquinone and its derivatives which can attract the positive charged aa-t-RNA as shown in Fig. 8.

On the other hand, in vitro studies have demonstrated that polysaccharides decrease virus replication and viral adsorption period by interacting with virus particles (Cataldi et al., 2015; Sánchez et al., 2020; Sun et al., 2018; Xu, Ruan & Li, 2010). Polysaccharides are carbohydrates and main component in aloe vera for biological activities. It is reported that acidic polysaccharides (negative charge) with high uronic acid content can associate with their anti-adhesive. The negative charge present in polysaccharides (uronic acid) attract the t-RNA and inhibit the protein synthesis by preventing the association of aa-t-RNA with the ribosome as shown in Fig. 8.

It can be concluded that the water-repellent nature of the coating combined with the use of anti-viral agent aloe vera makes it a potential anti-COVID-19 coating. Further viral testing is required to demonstrate the concepts discussed herein. Therefore authors are in the process of carrying out the viral testing of present coating and the findings will be content of a future publication. After aloe vera based coating on cloth, multi-layered clothing and full body cover PPE kits will not be needed and virus transmission will also be reduced.



**Fig. 8.** A schematic representation of proposed mechanism of suppression of virus by association of t-RNA with anthraquinone and polysaccharide on aloe vera coated cloth.

**3.3. Anti-washing and durability tests**

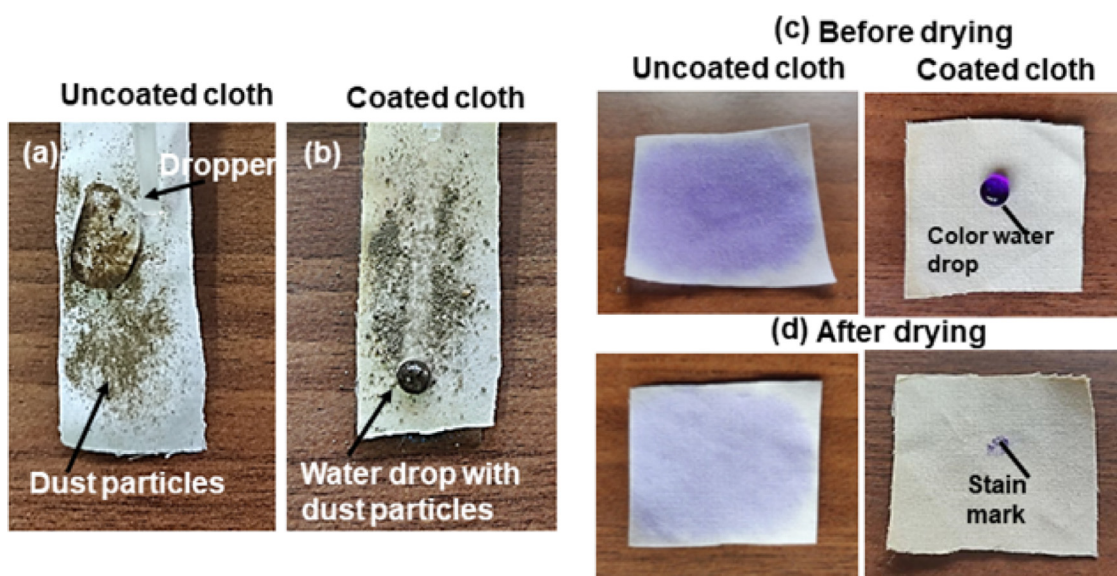
The clothes need regular washing to remove the dirt, contamination and stain. Due to daily washing, cotton fabric does not lead permanent effect, and degrades its quality. So, to avoid this problem, the anti-washing properties have been developed on the cloth surface in this paper. To demonstrate the anti-dirt property of coating, the hydrophilic dust particles were placed on both uncoated and coated surfaces. When water droplet is dropped on the uncoated cloth, it becomes completely wet with the dust particles, and spread over the sample surface as shown in Fig. 9(a). In case of coated sample, spherical drop is formed with the dust particles and roll-off from its surface and turning the cotton fabric dust free (Fig. 9(b)). The above observation clearly indicates the excel-

lent anti-dirt ability of coating which is due to its high water repellence property.

Nowadays, stains are growing concern in clothes related to many purposes such as wearing, household, and medical. Stain comes from food, liquid, detergents, and disinfectant. The uncoated fabric has the ability to absorb all water and oil based products, is stained immediately. Some stains are very difficult to remove from the clothes. Even, it could actually cause permanent damage the clothes. Since after coating cloth can easily repel water, water based liquid (cold drink, tea, coffee, etc.), and other liquid, therefore it should also show the stain resistance property. In stain resistance experiment, the color water droplets are placed on both coated and uncoated samples as shown in Fig. 9(c), the coated fabric does not get wetted by the colored water and forms the spherical drop on it while the uncoated cotton fabric becomes quickly wet. Later, both uncoated and coated samples are dried at room temperature. Color stained marks are seen on the uncoated whereas a little stain is observed on the coated sample (Fig. 9(d)) because of a small area of the spherical drop is touched on its surface, and left the small stain due to the diffusion of color in the fiber present on the surface. The above results confirm the stain-resistant property of cloth after coating.

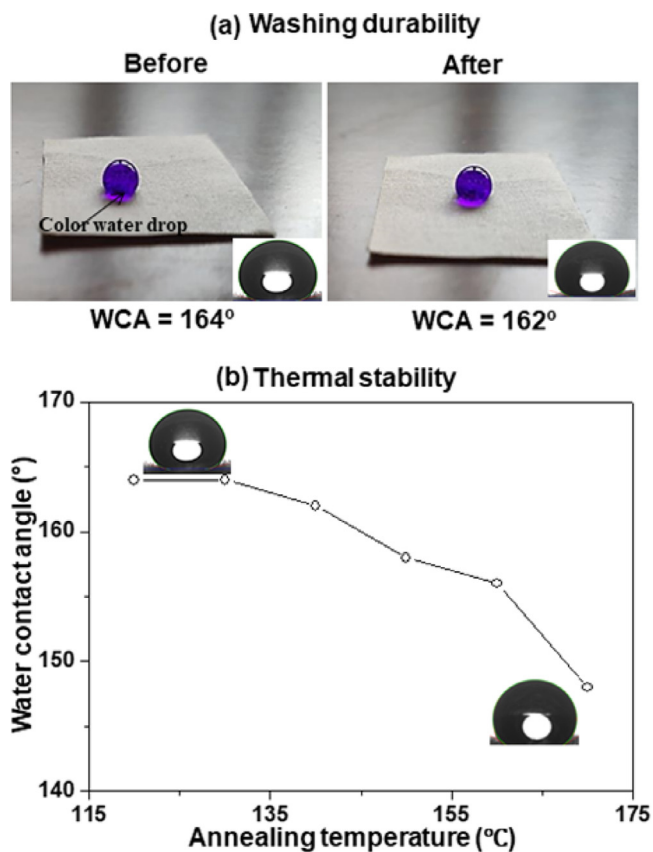
The chances of damage of coating are more likely from gentle uses. In practical application, the laundry durability should be good for reuse of coated cloth. The laundry durability experiment of coated sample was carried out by the ultrasonication bath. The coated sample was kept into the beaker containing detergent solution in the ultrasonication bath for 1 h at 40 °C. Although, the coated sample has the high water repellency, but due to the addition of detergent, the surface tension of water decreases. It was immersed into the water detergent solution without applying any external force. The optical images of water droplet on coated cotton fabric before and after laundry with WCA are shown in the Fig. 10(a). There is no change in the WCA of coating. The above observation clearly indicates the excellent washing durability without losing its wetting property.

To study the effect of elevated temperature on coating, the coated sample was annealed at high temperature of 120 °C to 170 °C for 1 h in hot air oven. It is found that after annealing up to 160 °C it maintains its color along with superhydrophobicity (WCA ≈ 156°) and losses its superhydrophobicity above 160 °C with WCA ≈ 148° due to the decomposition of HDTMS (boiling point =155 °C) from its surface (Chauhan, Ku-



**Fig. 9.** The optical images of after pouring the water (a) uncoated fabric became contaminated with the dust particles (b) spherical drop was formed with dust particles and roll-off from coated surface, showing the self-cleaning property. The optical images of the color water drop on uncoated and coated surfaces (c) before drying (d) after drying. Visible stain marks are seen on uncoated whereas little stain marks are seen on the coated surface, showing the stain-resistant property of coating.





**Fig. 10.** (a) Optical images of water drop on coated cloth before and after 1 h washing in detergent, showing the washing durability of coating. (b) Water contact angle as a function of annealing temperature. Changes in WCA after annealing 1 h at 160 °C due to the decomposition of the coating materials (HDTMS, BP=155 °C).

mar & Bhushan, 2019) as shown in Fig. 10(b). No change is observed in its color even after annealing at 180 °C. In comparison, the uncoated cotton fabric starts to decompose gradually at 149 °C after exposing the heat. This test implies that coating is thermally stable and provides the protection to the cloth from the heat.

#### 4. Conclusions

In this work, a simple green approach has been used to prepare the anti-wash and antimicrobial cloth using HDTMS and aloe vera extract. Aloe vera acts as an antimicrobial and antiviral agent and HDTMS reduces the contact of the water and other liquids from surface by lowering the surface energy. The coated cloth shows the excellent water repellency with a WCA of 164°. It also shows that the coated cotton fabric possesses remarkable washing durability in detergent solution. Coated cloth is also able to survive upto 160 °C. Moreover, coated cloth exhibits the excellent anti-dirt and stain-resistant properties. The coated cloth surface shows the antibacterial and antifungal activity against the *E. coli* and *A. niger*, respectively over a long time period (≈72 h). In this paper, we have demonstrated two antiviral mechanisms: repellency of aerosol containing viruses due its superhydrophobic nature and inhibition of protein synthesis of virus due to presence of aloe vera on the coated surface. The water-repellent nature of the coating combined with the use of anti-viral agent aloe vera makes it a potential anti-COVID-19 coating. Further viral testing is required to demonstrate the concepts discussed herein, which has yet to be reported. Therefore, authors are in the process of carrying out the viral testing of present coating and the findings will be content of a future publication. Importantly, after aloe

vera based coating on cloth, multi-layered clothing and full body cover PPE kits will not be needed and virus transmission will also be reduced.

#### Declaration of Competing Interest

There is no conflict to declare.

#### References

- Ali, S. W., Purwar, R., Joshi, M., & Rajendran, S. (2014). Antibacterial properties of aloe vera gel-finished cotton fabric. *Cellulose (London, England)*, 21, 2063.
- Bernard, D. L., Huffman, J. H., Morris, J. L., Wood, S. G., Hughes, B. G., & Sidwell, R. W. (1992). Evaluation of the antiviral activity of anthraquinones, anthrones and anthraquinone derivatives against human cytomegalovirus. *Antiviral Research*, 35, 2463–2466.
- Beroual, M., Boumaza, L., Mehelli, O., Trache, D., Tarchoun, A. F., & Khimeche, K. (2020a). Physicochemical properties and thermal stability of microcrystalline cellulose isolated from esparto grass using different delignification approaches. *Journal of Polymers and the Environment*. 10.1007/s10924-020-01858-w.
- Beroual, M., Trache, D., Mehelli, O., Boumaza, L., Tarchoun, A. F., Derradji, M., et al. (2020b). Effect of the delignification process on the physicochemical properties and thermal stability of microcrystalline cellulose extracted from date palm fronds. *Waste and Biomass Valorization*. 10.1007/s12649-020-01198-9.
- Cassie, A. B. D., & Baxter, S. (1944). Wettability of porous surfaces. *Transactions of the Faraday Society*, 40, 546.
- Cataldi, V., Bartolomeo, S. D., Campli, E. D., Nostro, A., Cellini, L., & Giulio, M. D. (2015). In vitro activity of aloe vera inner gel against microorganisms grown in planktonic and sessile phases. *International Journal of Immunopathology and Pharmacology*, 28, 595–602.
- Chauhan, P., Kumar, A., & Bhushan, B. (2019). Self-cleaning, stain-resistant and anti-bacterial superhydrophobic cotton fabric prepared by simple immersion technique. *Journal of Colloid and Interface Science*, 535, 66.
- Doremalen, N., Bushmaker, T., Morris, D. H., Holbrook, M. G., Gamble, A., Williamson, B. N., et al. (2020). Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. *The New England Journal of Medicine*, 382, 1564–1567.
- El Aty, A. A. A., Bassyouni, G. T. E., Zaher, N. A. A., & Guirguis, O. W. (2018). Experimental study on antimicrobial activity of silk fabric treated with natural dye extract from neem (*Azadirachta indica*) leaves. *Fibers and Polymers*, 19, 1880.
- El-Naggar, M. E., Shaheen, T. I., Zaghoul, S., El-Rafie, M. H., & Hebeish, A. (2016). Antibacterial activities and UV protection of the in situ synthesized titanium oxide nanoparticles on cotton fabrics. *Industrial and Engineering Chemistry Research*, 55, 2661.
- Galante, A. J., Haghanifar, S., Romanowski, E. G., Shanks, R. M. Q., & Leu, P. W. (2020). Superhydrophobic and anti-virofouling coating for mechanically durable and wash-stable medical textiles. *ACS Applied Materials & Interfaces*, 12, 22120–22128.
- Grindlay, D., & Reynolds, T. (1986). The aloe vera phenomenon: A review of the properties and modern uses of the leaf parenchyma gel. *Journal of Ethnopharmacology*, 16, 117–151.
- Gul, R., Jan, S. U., Faridullah, S., Sherani, S., & Jahan, N. (2017). Preliminary phytochemical screening, quantitative analysis of alkaloids, and antioxidant activity of crude plant extracts from ephedra intermedia indigenous to Balochistan. *The Scientific World Journal*, 1, Article 5873648.
- Guo X., X., & Mei, N. (2016). Aloe vera: A review of toxicity and adverse clinical effects. *Journal of Environmental Science and Health Part C: Environmental Carcinogenesis and Ecotoxicology Reviews*, 34, 77.
- Holbrook, M. G., Gamble, A., Williamson, B. N., Tamin, A., Harcourt, J. L., Thornburg, N. J., et al. (2020). Transmission electron microscopy imaging of SARS-CoV-2. *Indian Journal of Medical Research*, 151, 241–243.
- Hong, H. R., Kim, J., & Park, C. H. (2018). Facile fabrication of multifunctional fabrics: Use of copper and silver nanoparticles for antibacterial, superhydrophobic, conductive fabric. *RSC Advances*, 8, 41782.
- Jaswal, P., Preet, A., & Goal, G. (2017). Antibacterial activity of herbal treated cotton fabric. *International Research Journal of Engineering and Technology*, 4, 39.
- Kawai, K., Beppu, H., Simpo, K., Chihara, T., Yamamoto, N., Aggatus, T., et al. (1998). In-vivo effects of aloe arborescens miller varnataleensis Berger (Kidachi aloe) on experimental tinea pedis in guinea pig feet. *Phytotherapy Research*, 12, 178.
- Kulthong, K., Srisung, S., Boonpavanitchakul, K., Kangwansupamonkon, W., & Maniratanachote, R. (2010). Determination of silver nanoparticle release from antibacterial fabrics into artificial sweat. *Particle and Fibre Toxicology*, 7, 8.
- Mot, A. C., Dumitrescu, R. S., & Sarbu, C. (2011). Rapid and effective evaluation of the antioxidant capacity of propolis extracts using DPPH bleaching kinetic profiles, FT-IR and UV-vis spectroscopic data. *Journal of Food Composition and Analysis*, 24, 516.
- Oh, K. W., & Na, Y. J. (2014). Antibacterial activity of cotton fabric treated with extracts from the lotus plant. *Textile Research Journal*, 84, 1650.
- Perera, S., Bhushan, B., Bandara, R., Rajapakse, G., Rajapakse, S., & Bandara, C. (2013). Morphological, antimicrobial, durability, and physical properties of untreated and treated textiles using silver-nanoparticles. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 436, 975.
- Rajendran, R., Radhai, R., Balakumar, C., Ahamed, H. A. M., Vigneswaran C., C., & Vaideki, K. (2012). Synthesis and characterization of neem chitosan nanocomposites for development of antimicrobial cotton textiles. *Journal of Engineered Fibers and Fabrics*, 7 155892501200700.

- Rezazadeh, F., Moshaverinia, M., Motamedifar, M., & Alyaseri, M. (2016a). Assessment of anti HSV-1 activity of aloe vera gel extract: an in vitro study. *Journal of Dentistry*, *17*, 49–54.
- Rezazadeh, F., Moshaverinia, M., Motamedifar, M., & Alyaseri, M. (2016b). Assessment of anti HSV-1 activity of aloe vera gel extract: an in vitro study. *Journal of Dentistry Shiraz University of Medical Sciences*, *17*, 49–54.
- Sánchez, M., Burgos, E. G., Iglesias, I., & Serranillos, M. P. G. (2020). Pharmacological update properties of aloe vera and its major active constituents. *Molecules (Basel, Switzerland)*, *25*, 1324.
- Semple, S. J., Pyke, S. M., Reynolds, G. D., & Flower, R. L. (2001). In vitro antiviral activity of the anthraquinone chrysophanic acid against poliovirus. *Antiviral Research*, *49*, 169–178.
- Shaban, M., Mohamed, F., & Abdallah, S. (2018). Production and characterization of superhydrophobic and antibacterial coated fabrics utilizing ZnO nanocatalyst. *Scientific Reports*, *8*, 3925.
- Stanić, S. (2007). Anti-genotoxic effect of aloe vera gelR on the mutagenic action of ethyl methanesulfonate. *Archives of Biological Sciences (Belgrade)*, *59*, 223–226. 10.2298/ABS0703223S.
- Sun, Z., Yu, C., Wang, W., Yu, G., Zhang, T., Zhang, L., et al. (2018). Aloe polysaccharides inhibit influenza A virus infection: A promising natural anti-flu, drug. *Frontiers in Microbiology*, *9*, 2338.
- Sydiskis, R. J., Owen, D. G., Lohr, J. L., Rosler, K.-H. A., & Blomster, R. N. (1991). Inactivation of enveloped viruses by anthraquinones extracted from plants. *Antimicrobial Agents and Chemotherapy*, *35*, 2463–2466.
- Tarchoun, A. F., Trache, D., & Klapotke, T. M. (2019). Microcrystalline cellulose from *Posidonia oceanica* brown algae: Extraction and characterization. *International Journal of Biological Macromolecules*, *138*, 837–845.
- Tarchoun, A. F., Trache, D., Klapotke, T. M., Derradji, M., & Bessa, W. (2019). Ecofriendly isolation and characterization of microcrystalline cellulose from giant reed using various acidic media. *Cellulose (London, England)*, *26*, 7635–7651.
- Tudu, B. K., Kumar, A., & Bhushan, B. (2019). Fabrication of superoleophobic cotton fabric for multi-purpose applications. *Philosophical Transactions of the Royal Society A*, *377*, Article 20190129.
- Tudu, B. K., Sinhamahapatra, A., & Kumar, A. (2020). Surface modification of cotton fabric using TiO<sub>2</sub> nanoparticles for self-cleaning, oil-water separation, anti-stain, anti-water absorption, and anti-bacterial properties. *ACS Omega*, *5*, 7850–7860.
- Windler, L., Lorenz, C., Goetz, N., Hungerbühler, K., Amberg, M., Heuberger, M., et al. (2012). Release of titanium dioxide from textiles during washing. *Environmental Science & Technology*, *46*, 8181.
- Xu, C., Ruan, X. M., & Li, H. S. (2010). Anti-adhesive effect of an acidic polysaccharide from aloe vera L. var. chinensis (Haw.) Berger on the binding of *Helicobacter pylori* to the MKN-45 cell line. *Journal of Pharmacy and Pharmacology*, *62*, 1753–1759.
- Yazdandehnas, M. E., & Khalilabad, M. S. (2013). One-step synthesis of superhydrophobic coating on cotton fabric by ultrasound irradiation. *Industrial & Engineering Chemistry Research*, *52*, 12846.
- Zandi, K., Zadeh, M. A., Sartavi, K., & Rastian, Z. (2007). Antiviral activity of aloe vera against herpes simplex virus type 2: An in vitro study. *African Journal of Biotechnology*, *6*, 1770–1773.
- Zhang, M., Wang, C., Wang, S., Shi, Y., & Li, J. (2012). Fabrication of coral-like superhydrophobic coating on filter paper for oil-water separation. *Applied Surface Science*, *261*, 764.