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EDITED BY  
Nicola Maria Pugno,  
University of Trento, Italy

REVIEWED BY  
Priya Varshney,  
National Institute of Technology  
Rourkela, India  
Shabi Thankaraj Salammal,  
Advanced Materials and Processes  
Research Institute (CSIR), India

\*CORRESPONDENCE  
Aditya Kumar,  
aditya@iitism.ac.in,  
adityaku43@gmail.com  
Kiran Kumar Bokara,  
bokarakiran@ccmb.res.in

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# COVID-19 repellent cloth

Sapan Kumar Pandit<sup>1</sup>, Poonam Chauhan<sup>1</sup>,  
Apurba Sinhamahapatra<sup>1</sup>, Yash Parekh<sup>2</sup>,  
M. Ghalib Enayathullah<sup>2</sup>, Kiran Kumar Bokara<sup>2\*</sup> and  
Aditya Kumar<sup>1\*</sup>

<sup>1</sup>Department of Chemical Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Dhanbad, India, <sup>2</sup>CSIR-Center for Cellular and Molecular Biology, Hyderabad, India

In this research work, for the first time, we have developed and demonstrated a COVID-19 repellent coating on cotton cloth that not only repels the virus but also most of the human body fluids (superhemophobic). The coating was tested in the BSL3 lab. The controlled experiments revealed no significant increase in the log viral particles on coated fabric compared to the uncoated surface, evidence that the coated fabric resisted the SARS-CoV-2 inoculum. Further, the coated cloth exhibited excellent dust-free nature and stain resistance against body fluids (blood, urine, bovine serum, water, and saliva aerosol). It also shows sufficient robustness for repetitive usage. The fabrication process for the developed COVID-19 repellent cloth is simple and affordable and can be easily scaled up for mass production. Such coating could be applied on various surfaces, including daily clothes, masks, medical clothes, curtains, etc. The present finding could be a mammoth step towards controlling infection spread, including COVID-19.

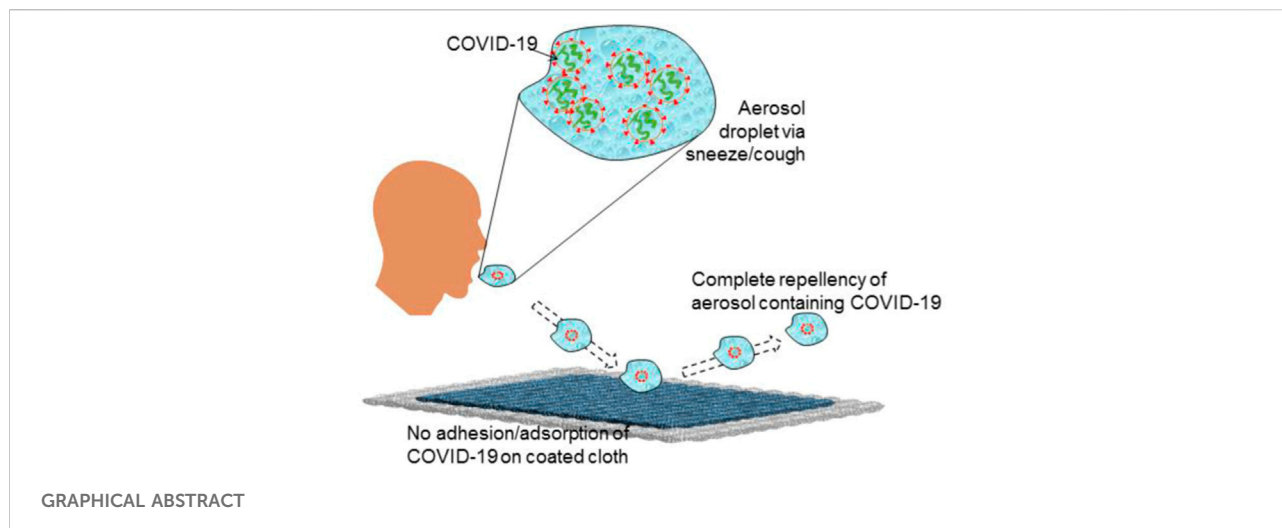
## KEYWORDS

COVID-19, SARS-CoV-2, anti-viral, superhemophobic, virucidal

## Introduction

In late 2019, a new virus, SARS-CoV-2 (also known as COVID-19) emerged. Within a few months of emerging, it created a havoc situation worldwide, and eventually, WHO declared it a pandemic in March 2020 (Cucinotta and Vanelli, 2020). Due to its highly transmissible nature, nearly all nations reported infection cases from COVID-19. Most infected patients experience mild to moderate respiratory illness, mainly common flu symptoms, and recover with standard flu treatment. However, some people with medical history such as diabetes, chronic respiratory disease, and cardiovascular disease may also experience severe illness or death. It is estimated that COVID-19 has resulted in more than 6.5 million deaths and billions of dollars in losses (Who, 2020b). Infection of the virus occurs through the respiratory system *via* the direct transmission of airborne droplets (sneeze, cough), direct contact transmission (blood or other liquid, skin), indirect transmission from a surface (respirator mask, cloth, carpet, handles, switches, and table).

PPEs are not 100% safe as the virus remains alive on them for many days and requires very careful disposal practices to avoid further infection spread. Besides this, people face a tough time working with wearing these single-use multilayer full-body cover PPEs. As these PPEs are uncomfortable and expensive, most people bypass the protocols.



Therefore, if COVID-19-repellent affordable PPEs are developed, which can be used multiple times, this will help to control the spread of infection to a huge extent.

The viral-repellent coating can be done by designing a surface with an excellent anti-wetting state that comprises a high static contact angle and low tilt angle with body fluid (blood, urine, protein, saliva aerosol, and water) (Galante et al., 2020). Typically, such a surface comprises nano and micro rough structures trapping air which makes a liquid-air interface and leads to superhemophobicity (blood static contact angle greater than  $150^\circ$  and tilt angle less than  $10^\circ$ ). Designing a superhemophobic surface is more challenging as blood has a much lower surface tension (about 54 mN/m) (Tang and Hu, 2005; Leszczak et al., 2013). Body fluid is a direct carrier of transport viruses, microbes, and pathogens that lead to people associated with infected patients.

In view of the above findings, we have developed a novel COVID-19 repellent coating on cloth *via* an easy and economical surface modification method. This coated cloth is COVID-19 repellent in nature and was tested against COVID-19 virus in BSL-3, which confirmed excellent COVID-19 repellency. There are proposals on COVID-19 repellency earlier; however, the present study is the first to demonstrate it in reality.

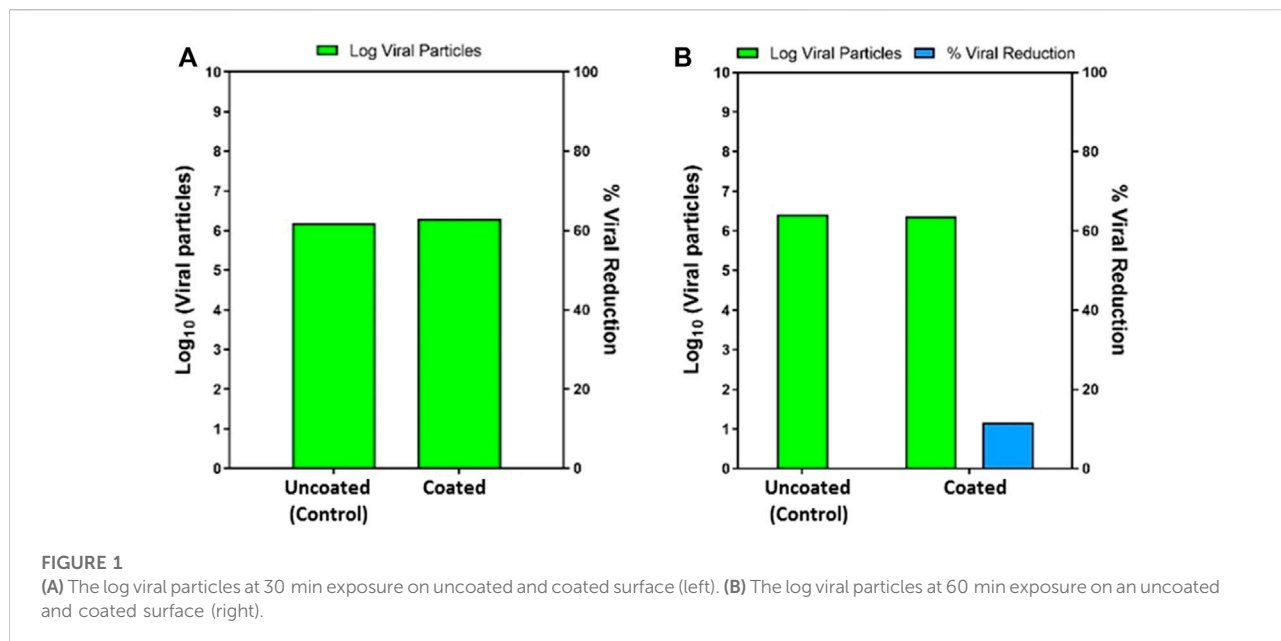
## Experimental details

To develop COVID-19-repellent coated cloth, modification of the cloth surface was done by using an immersion technique. Before coating, the as-received cloth was cleaned in water and acetone mixture solution in ultrasonication for 30 min and dried in a hot air oven at a temperature of  $60^\circ\text{C}$ . Later on, the coating solution was prepared by adding a 1% w/v of pfluorodecltriethoxysilane (PFDTES, > 97%, procured from

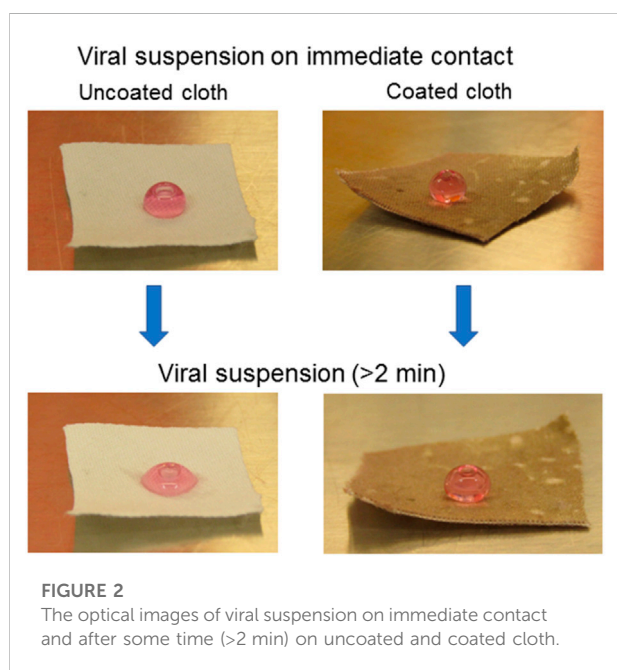
Sigma-Aldrich Co., Ltd) into 40 ml ethanol (procured from Changshu Hongsheng Fine Chemical Co. Ltd.) and stirred for 2 h at the room temperature. The clean and dried cloth was immersed in the prepared coating solution for 24 h. Then, the sample was taken out and dried in a hot air oven at  $90^\circ\text{C}$  for 2 h.

The coated and uncoated surfaces were tested against the SARS-CoV2 virus (Indian/a3i clade/2020 isolate) in the BSL3 lab of CSIR-CCMB (ASTM E1052-20, 2020) for 30 and 60 min of contact with the virus. Briefly, the coated and uncoated cloth surface was co-incubated with the virus inoculum for 30 and 60 min, respectively. After the specified incubation time, the virus inoculum (0.1 MOI) from both surfaces was added to the Vero cells and left for 3 h post-infection, the viral inoculum was replaced with fresh media containing 10% FBS and was maintained at  $37^\circ\text{C}$ , 5%  $\text{CO}_2$ , until 72 h. After 72 h, the cell supernatant was collected and spun for 10 min at 6,000 g to remove cell debris, and the supernatant was transferred to fresh collection tubes. The viral RNA was extracted using MagMAX™ Viral/Pathogen Extraction Kit (Applied Biosystems, Thermofisher Scientific), and an automated RNA extraction machine (KingFisher Flex (version 1.01, Thermofisher Scientific) was used as instructed by the manufacturer. The SARS-CoV2 viral copies were detected using COVID-19 RT-qPCR Detection Kit (Fosun 2019-nCoV qPCR, Shanghai Fosun Long March Medical Science Co. Ltd.) following the manufacturer's instructions (Baller et al., 2020). The  $C_t$  values of the N gene, E gene, and ORF 1 ab were considered to estimate the % viral reduction and log viral particles.

The liquid (blood, urine, protein, water) contact angle measurements were performed using Tensiometer (DSA 25, Kruss, Germany) by placing a droplet of 3–5  $\mu\text{l}$  on uncoated and coated samples at room temperature. The experiment was repeated at five different locations with each sample to calculate the average value. The surface morphology of the samples was



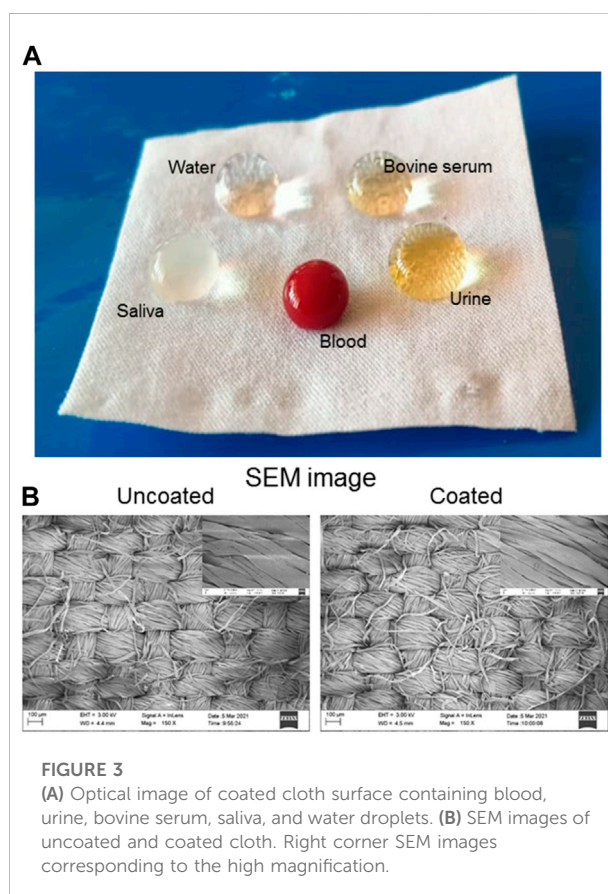
**FIGURE 1** (A) The log viral particles at 30 min exposure on uncoated and coated surface (left). (B) The log viral particles at 60 min exposure on an uncoated and coated surface (right).



**FIGURE 2** The optical images of viral suspension on immediate contact and after some time (>2 min) on uncoated and coated cloth.

carried out using a scanning electron microscope (SEM, JEOL, JSM-6480LV). The elemental analysis of the samples was performed using X-ray Photo-Electron Spectroscopy (XPS) with Auger Electron Spectroscopy (AES) module and C60 sputter gun (PHI 5000 Versa Probe II, FEI Inc.).

In the self-cleaning experiment, uncoated and coated samples were forcefully dipped into the muddy water for 10 min using the tweezers. Later, the samples were removed



**FIGURE 3** (A) Optical image of coated cloth surface containing blood, urine, bovine serum, saliva, and water droplets. (B) SEM images of uncoated and coated cloth. Right corner SEM images corresponding to the high magnification.

from the muddy water, and the behavior of the muddy water droplets was studied on the surfaces. The stain resistance

TABLE 1 The contact angle of body fluid for uncoated and coated cloth surfaces and their images.

| Body fluid     | Surface tension (mN/m)                 | Contact angle (°) |        | Droplet image showing contact angle of coated cloth                                 |
|----------------|--|-------------------|--------|---|
|                |  | Uncoated          | Coated |   |
| Blood          | 55.89 ± 3.57 (Hrncir and Rosina, 1997) | ~0                | 155    |  |
| Urine          | 50–60 (Thomas et al., 2009)            | ~0                | 154    |  |
| Bovine serum   | <72 (Le et al., 2022)                  | ~0                | 162    |  |
| Saliva aerosol | 55–65 (Gittings et al., 2015)          | ~0                | 157    |  |
| Water          | 72 (Le et al., 2022)                   | ~0                | 155    |  |

experiment was performed by placing the liquid (urine and blood) droplets on uncoated and coated samples and later drying them by keeping the samples on the heating plate at 60°C for a few minutes. The urine and bloodstains left on the coated and uncoated surfaces were studied later.

The water absorption capacity of the uncoated and coated samples was measured. Initially, all the samples were immersed in water for 10 min. After draining the excess water, the weight of the samples ( $w_a$ ) was measured and compared with the weight of the sample before immersion in water ( $w_d$ ). The absorption capacity of the samples was calculated using Eq. 1.

$$\text{Water absorption capacity (\%)} = \frac{w_a - w_d}{w_d} \times 100 \quad (1)$$

## Results and discussion

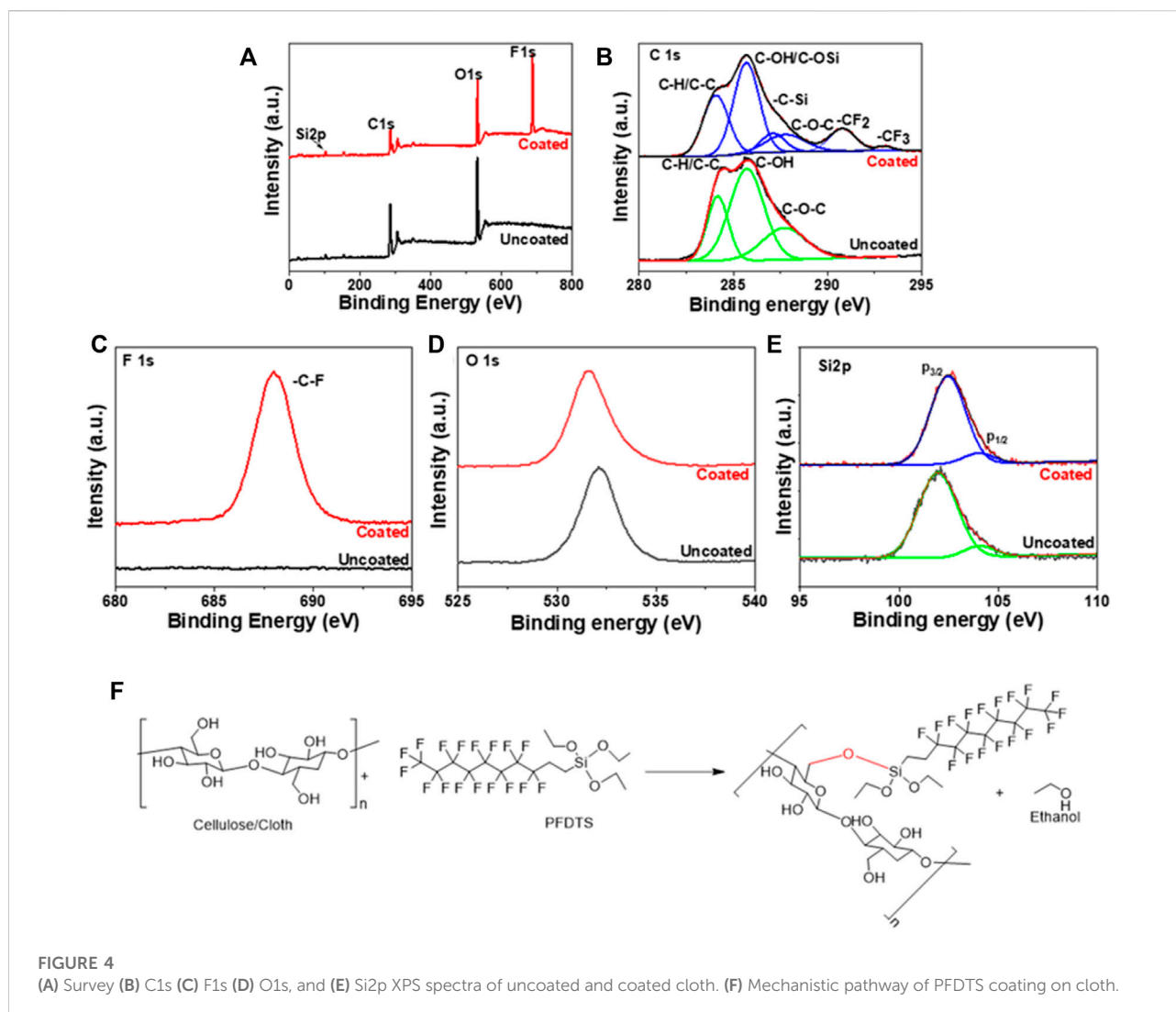
In this study, COVID-19 repellent cloth was developed by immersing cloth samples in PFDTES solution.

In virus testing, there was no significant reduction observed in the log viral number on exposing the viral inoculum on the coated and uncoated surface for 30 and 60 min (Figure 1). This may be due to the liquid-repellent nature of the coated surface. The contact of viral particles on the coated material was eliminated, and no viral increase was observed. This data proves the repellent nature of the test surface's viral suspension repellent nature and supports the intactness of

the droplet containing viral particles over the tested time (Figure 2).

The surface wettability of coated cloth was further measured and compared with the uncoated cloth. The cotton fabric exhibits superhemophilic behavior with a blood static contact angle of ~0°. The blood repellency of coated cloth is measured at a static contact angle of 155°, indicating that the fabric has attained superhemophobicity. Additionally, body fluids (urine, protein, saliva aerosol, and water) also show good repellency with contact angles of more than 150° (Figure 3A, Table 1). The Supplementary Video shows the body fluid's behavior on the coated surface (Supplementary Video S1).

The surface morphology of the cloth surface after coating was examined by SEM analysis, as shown in Figure 3B. After coating, no change in morphology is observed due to the formation of a monolayer on its surface. The XPS results in Figure 4 confirm the chemical compositions of uncoated and coated samples. The XPS survey (Figure 4A) scan of uncoated samples confirms C, O, and Si of cellulosic structure and SiO<sub>2</sub> as textile impurities. For coated cloth, C, O, and Si of cloth and PFDTS, and F of PFDTS are identified. The high-resolution core-level C 1s spectra (Figure 4B) of the coated and uncoated samples are easily distinguishable. The uncoated cloth's C1s spectra exhibits three major peaks at 284.2, 285.7, and 287.7 eV corresponding -C-H/C-C, C-OH, and C-O-C functionalities confirm the cellulosic structure (Wang et al., 2020). The C 1s spectrum of coated cloth exhibit six major peaks at 284.1, 285.7, 287.1, 287.8, 290.8, and 293.1 eV corresponding to C-H/C-C, C-OH/C-O-Si, C-Si, C-OC, -CF<sub>2</sub>, and -CF<sub>3</sub> functionalities confirms



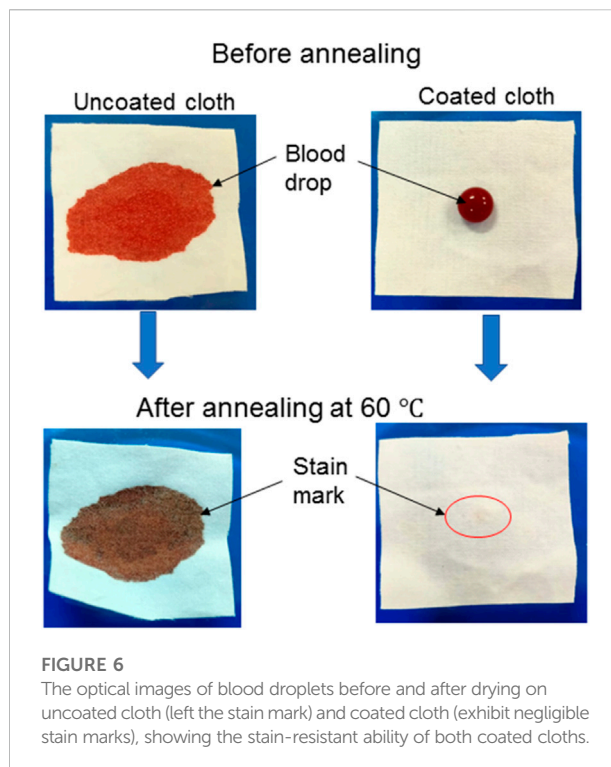
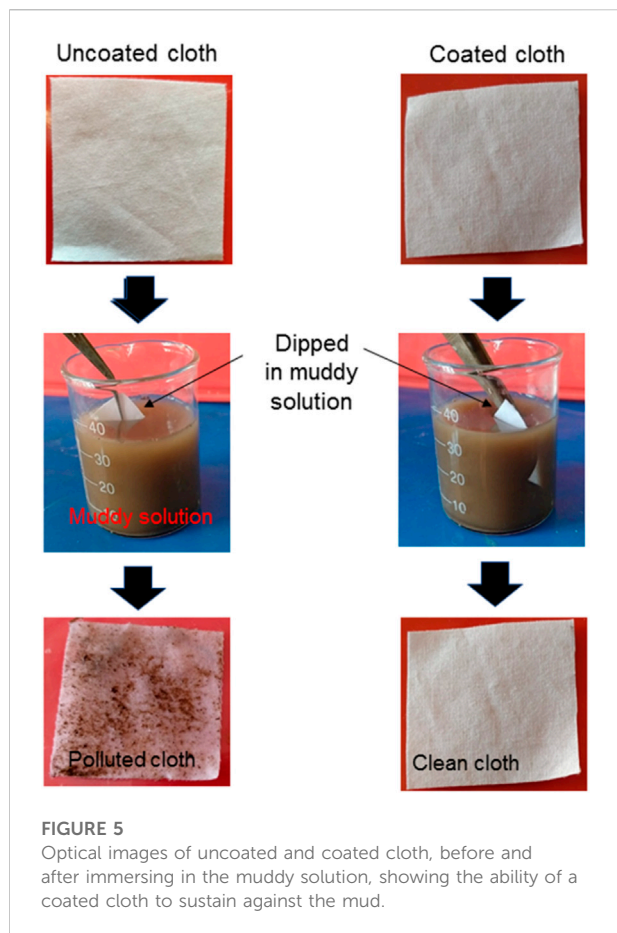
the presence of PFDTs and cellulosic structure (Korolkov et al., 2020). The high-resolution F1s spectra (Figure 4C) of coated cloth exhibits a peak at 688.0 eV corresponding to C-F functionality (Korolkov et al., 2020). The high-resolution O1s (Figure 4D) reveals a prominent peak shifting for coated (531.6 eV) and uncoated (532.2 eV) samples indicating a significant change in the oxygen chemical environment (Korolkov et al., 2020; Wang et al., 2020). Besides the carbon-oxygen bond of cellulose in the coated sample, oxygen is also bonded with silicon. The high-resolution Si 2p spectra of samples are presented in Figure 4E. The spectrum of uncoated cloth reveals peaks at 101.9 and 104.0 eV for 2p<sub>3/2</sub> and 2p<sub>1/2</sub> electrons corresponding to SiO<sub>2</sub> impurities often found in textiles. The spectrum of coated cloth exhibits peaks at 102.4 and 104.0 eV for 2p<sub>3/2</sub> and 2p<sub>1/2</sub> electrons corresponding to the silane group of PFDTs (Korolkov et al., 2020). It is also observed that the Si content increases in coated cloth compared to uncoated cloth. The observed XPS data not only confirms the PFDTs but also

indicates the (PFDTs) Si-O-C (cellulose) interaction leading to a stable PFDTs coating on the cloth surface. A probable scheme is presented in Figure 2F displaying the coating formation mechanism.

The ability of a coated cloth to sustain against the dirt is demonstrated in Figure 5. For the experiment, uncoated and coated samples were immersed in a mud water solution for 10 min. It is noted that the coated fabric floats over the muddy solution due to its water repellency and is difficult to immerse; so, it is forcefully immersed in the solution. After 10 min immersion, the uncoated surfaces were soaked with muddy water, whereas coated cloth remained clean, indicating that mud particles do not adhere to the coated surface due to the air-solid interface present on the surface.

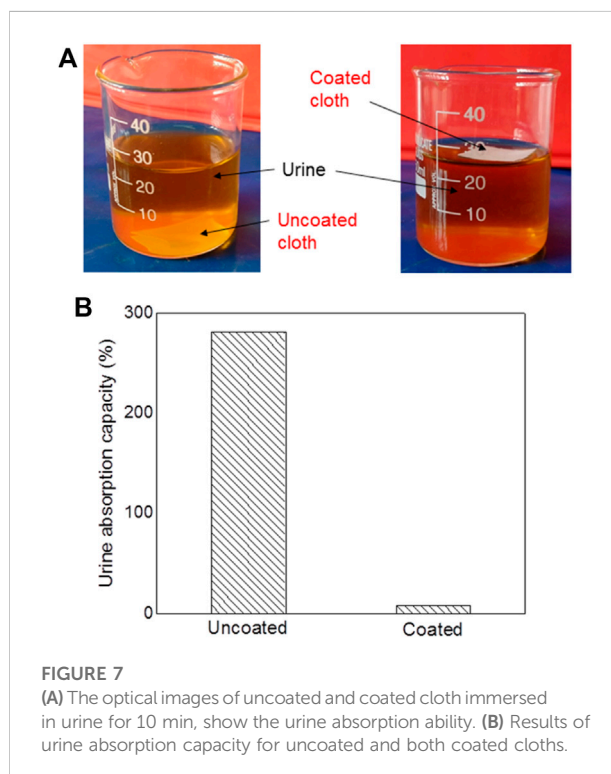
Body fluid (mainly blood and urine) leaves stain marks on the medical clothes/devices, including the apron, masks, bedsheets, and covers due to the inherent hydrophilic nature of the cloth fabric surface. In most cases, these stain marks do not





fade away even after rigorous washing. In consideration of this, we have performed anti-stain and liquid absorption tests. Results of the anti-stain property of cloth before and after coating demonstrated that the blood droplets are entirely absorbed by uncoated cloth and spread over it, whereas these droplets make spherical shapes, as shown in Figure 6. A similar observation was seen for colored water and urine. Later these droplets containing samples were kept in a hot air oven at 50°C. After evaporation, these fluids leave stain marks on the uncoated cloth surface. Whereas there are negligible stain marks on a coated cloth surface, showing its anti-stain property.

In the liquid absorption test, the uncoated and coated cloth was immersed in urine, as shown Figure 7. Initially, the weight of all samples was 0.043 g. After immersion, it was 0.167 and 0.047 g for uncoated and coated cloth, respectively. The calculated urine absorption capacity of cloth is shown in Figure 7. The uncoated cloth shows high urine absorption of 281% which is attributed to the cloth's inherent superhydrophilic characteristic. The coated cloth exhibits a urine absorption of 8%, which is only 2.8% of the uncoated cloth. This result reveals that the urine absorbing capability is higher in uncoated samples compared to coated



samples. The coated samples also show small urine absorption due to the non-homogeneity coating on its edges side.

The global supplies for PPEs and masks due to their regular use are a constraint and make it harder for industries to meet the requirements. Incorporating thermal disinfection, UV-Illumination, or hydrogen peroxide vapor exposure (Celina et al., 2020) is a known time-consuming disinfection method. The present coating reduces the need for the aforementioned sanitization processes to a simple one, such as cleaning with a non-reactive disinfectant to the coating for 99% elimination of the viral particles.

## Conclusion

In this paper, we have demonstrated a facile and durable COVID-19 repellent coating on cloth fabric. Results of the coated cloth showed the complete repellency of body fluid (blood, urine, bovine serum, water, saliva aerosol) with a static contact angle greater than 150°. Coated cloth showed non-adherence to dirt, stains from the body fluid, and negligible body fluid adsorption. The interaction of COVID-19 viruses with uncoated and coated was examined at BSL-3 research facilities, and it was found that coated cloth showed complete repellency to the viruses. Experimentally coated cloth showed good washing durability, i.e., it can be used multiple times. Since this COVID-19 repellent-coated cloth is made by a straightforward immersion technique, scaling up at the industrial level will be easily feasible. Commercializing such a product for general public use at economical rates will really help fight against the COVID-19 pandemic.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

## Ethics statement

The SARS CoV2 study was approved by the Institutional Biosafety Committee of CSIR Center for Cellular and Molecular Biology, Hyderabad, India.

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## Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fceng.2022.1066184/full#supplementary-material>

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