ORIGINAL ARTICLE

Microscopic study of materials used to make masks to protect against COVID-19

Estudo microscópico dos materiais utilizados para confecção de máscaras para proteção contra a COVID-19

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ABSTRACT

Objective: to analyze the materials used to make masks to protect against COVID-19 for use by the general population in relation to the surface, size, shape and distribution of pores by means of a microscopic study. **Method:** analytical study. Analyzes of fabric samples and other materials used to make masks to protect the community in general against COVID-19 were performed in an Electron Microscopy and Microanalysis Laboratory. **Results:** the analysis of 100% cotton and twill samples showed these two types of fabrics are an effective microbial barrier. On the other hand, tricoline and the other fabrics and materials analyzed do not offer effective barriers to protect against COVID-19. **Conclusion:** among the analyzed fabrics, 100% cotton has a denser weft with thicker threads and little porosity, thereby being an effective barrier to protect against infections.

Descriptors: Coronavirus Infections; Pandemic; Personal Protective Equipment; Masks; Aerosols.

RESUMO

Objetivo: analisar, por meio de um estudo microscópico, os materiais utilizados para confecção das máscaras de uso da população em geral para a proteção contra a COVID-19, em relação à superfície, o tamanho, a forma e a distribuição dos poros dos mesmos. **Método:** estudo analítico. Foram realizadas análises de amostras de tecidos e outros materiais utilizados para confecções de máscaras para proteção da comunidade em geral contra a COVID-19 em um Laboratório de Microscopia Eletrônica e Microanálise. **Resultados:** a análise do tecido de algodão 100% e da sarja evidenciou esses dois tipos de tecidos como efetiva barreira microbiana. Em contrapartida, o tricoline e os demais tecidos e materiais analisados, não se apresentam como barreiras eficazes na proteção a COVID-19. **Conclusão:** entre os tecidos analisados, o algodão 100%, fornece uma trama mais densa, com fios mais grossos e pouca porosidade, sendo uma barreira eficaz na proteção contra infecções.

Descritores: Infecções por Coronavírus; Pandemia; Equipamento de Proteção Individual; Máscaras; Aerossóis.

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INTRODUCTION

The disease outbreak caused by coronavirus infection (COVID-19) was characterized as a pandemic by the World Health Organization (WHO) on March 11, 2020[1]. Since then, the number of infected people worldwide has grown substantially and the severe acute respiratory syndrome caused by the coronavirus (SARS-CoV-2) has become one of the main causes of morbidity and mortality worldwide.

COVID-19 is spread and suspended in the air through respiratory droplets containing the virus, thus, the main modes of infection involve respiratory droplets with an aerodynamic diameter of less than 5mm. These fine particles can be transported by air or by particles larger than 5mm that fall quickly from an infected person[2].

Given the concern with contamination among people, international and national agencies recommend prevention measures, including the use of masks in public environments, as this contamination can occur through droplets expelled during speech, sneezing and coughing[1-3].

Masks can help prevent people infected with COVID-19 from spreading the virus to others around them. When used in public environments, masks are more likely to reduce the spread of the virus[3]. They are considered simple barriers that prevent respiratory droplets from coughing, sneezing and speech from propagating in the air[3]. Thus, face masks are advocated as a source of collective benefit.

Homemade fabric masks have gained significant importance in everyday life in the last year, as they play a very important role in the contamination barrier by preventing the spread of aerosols in the environment when the user sneezes and coughs and by preventing the user's nasopharyngeal region from entering into contact with contaminated aerosols. Thus, the role of the mask to act as a barrier to the entry of aerosols into the respiratory system depends on the conditions of its use, its type, the material used and the mask adjustment[2].

The WHO and Centers for Disease Control and Prevention (CDC) advised the use of cloth masks by the general population prepared with at least three layers. This way, the quantity of particles emitted to the environment is reduced when the user's mouth is covered. The use of these multilayer masks effectively blocks respiratory droplets between 1-10mm. However, there is no guarantee that a homemade mask can prevent contact with the viral load and efficiently protect the user, since many of them are made with common fabrics, do not have quality control nor fixed standards to choose the material[2].

The efficiency of filtration of various fabrics used to make homemade masks was verified, although it depends on the combination and arrangement between them so that they can be more effective in protecting users[4].

A study indicates that some fabrics used to manufacture homemade masks can act as a partial barrier to contain droplets, if materials are inappropriate[5]. As many types of fabrics are being used to make homemade masks, this group that studies personal protective equipment, specifically masks, raised concerns about the types of fabric chosen by the general population for making them. A microscopic study was developed to evaluate the weave of the fabrics used and guide the population to make masks using appropriate and effective materials that block the passage of the virus through the fabric.

Thus, the aim of this study was to analyze through a microscopic study, the materials used to make masks to protect against COVID-19 for use by the general population, in relation to surface, size, shape and distribution of the pores.

METHOD

This is an analytical study conducted at the Electron Microscopy and Microanalysis Laboratory (Portuguese acronym: LMEM) of a state university in the north of Paraná, in April 2020. The choice of fabric type for analysis resulted from doubts of the population presented in the media, research in local shops regarding the fabrics purchased for the manufacture of masks and from other published studies on fabrics of homemade masks[5]. Masks made of various fabrics were purchased from the local trade. Samples of 100% cotton, light twill, tricoline, non-woven fabric (TNT), mesh and a material used for general cleaning were taken from these masks. Samples are equivalent to one layer of cloth mask.

Samples were cut to a maximum size of $9mm^2$ and evaluated by Scanning Electron Microscopy (SEM) using the FEI Quanta 200 (FEI Company, Netherlands) equipment with a vacuum atmosphere of 10^6 torr.

Then, samples were mounted on aluminum supports with carbon tape, gold film coated (BALTEC SDC 050, Sputter Coater, Germany) and observed in SEM. Electron micrographs given by SEM were generated in topographic mode (secondary electrons) at 20 kV in high vacuum.

To determine the chemical composition of the materials analyzed, the technique of Energy Dispersive Spectroscopy (EDS) in SEM was used. The samples were mounted on aluminum supports with carbon tape, carbon film coated (BALTEC SDC 050, Sputter Coater, Germany) and observed by SEM in the EDS. Spectra were generated in quantitative and mapping mode. The analyzes were obtained from 10 points for each sample, which allowed a better determination of the chemical composition.

RESULTS

The analyzes of the fabrics/materials with the use of SEM showed that the 100% cotton fabric offers an effective microbial barrier, given its layer of thick threads (~350µm diameter) homogeneously interwoven. Each thread is made up of many thin threads with 10-15µm diameter. The weight of the fabric varies between 140-240g/m^2.

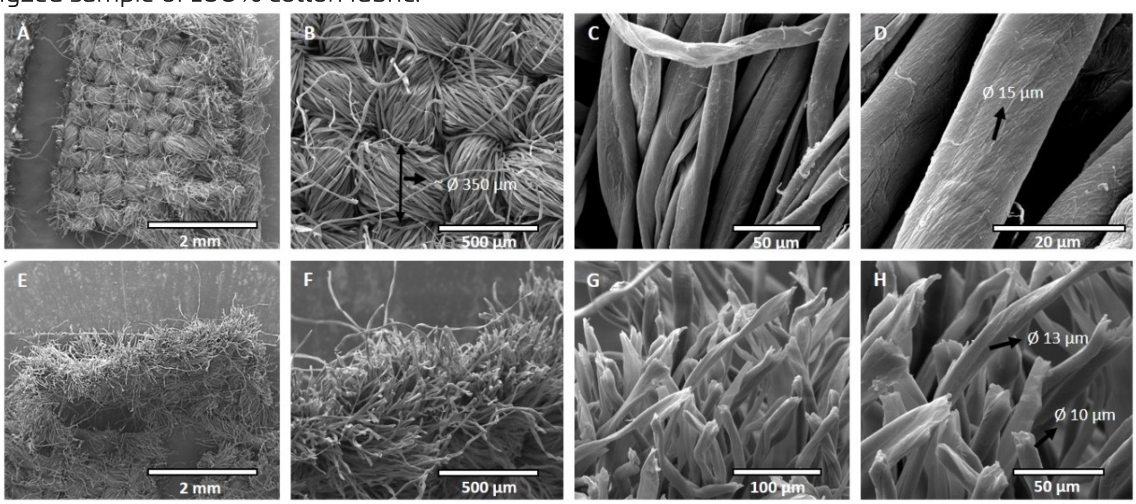
Figure 1 shows the filaments next to each other. This detail makes this type of fabric used to make triple layer masks for general use by the community effective for prevention against COVID-19. The distance between the filaments is approximately 5µm, which favors the reduction of contact between the droplets expelled by an individual and the external environment.

The lightweight twill fabric shown in Figure 2 has a weight of 190g/m^2 and the SEM analysis showed a closed material with the composition of microfilaments of each fine fiber (~15µm). The filaments are very close to each other, resembling 100% cotton, and the fabric has a high warp quality and consequently, good quality in droplet retention. Therefore, the use of this fabric is recommended for triple layered homemade masks.

In relation to the tricoline fabric, the following samples were analyzed: a blue color sample and a white color sample, with a weight of 109g/m^2 and a printed tricoline sample with a weight of 157g/m^2.

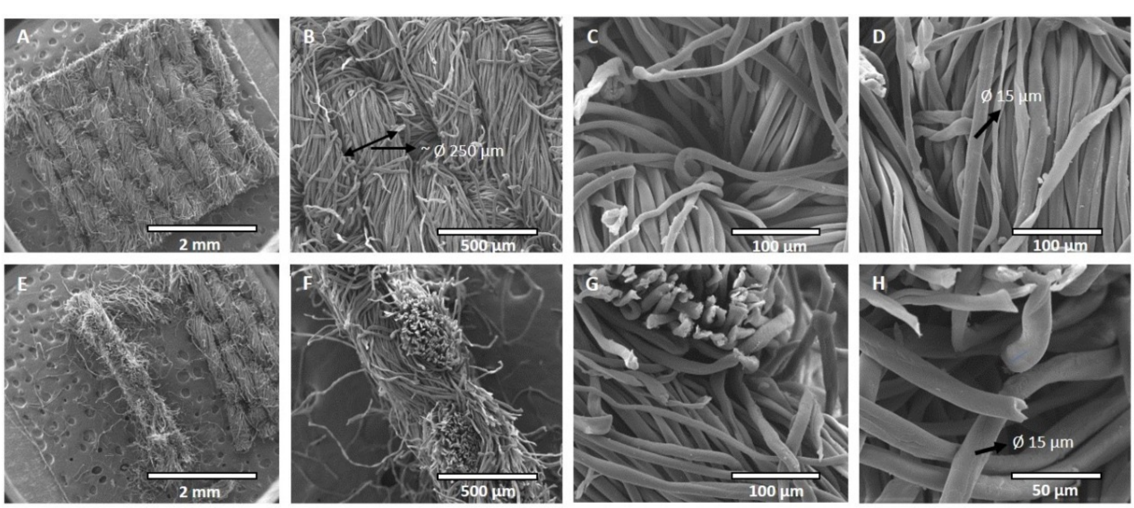
The structure of the three samples is similar, composed of microfilaments with fine characteristics, larger spaces and openings between the wefts (~25 a 70µm). These spaces can facilitate the passage of droplets, even when masks are multilayered. Thus, they do not offer appropriate protection compared to masks made with 100% cotton and light twill fabric. A negative point identified in the printed sample was the presence of a "glue" or "gum" in its texture due to the dye

Figure 1. Electron micrographs and Energy Dispersive Spectroscopy given by Scanning Electron Microscopy of the analyzed sample of 100% cotton fabric.



Source: Electron Microscopy and Microanalysis Laboratory - Universidade Estadual de Londrina.

Figure 2. Electron micrographs and Energy Dispersive Spectroscopy given by Scanning Electron Microscopy of the analyzed sample of light twill.



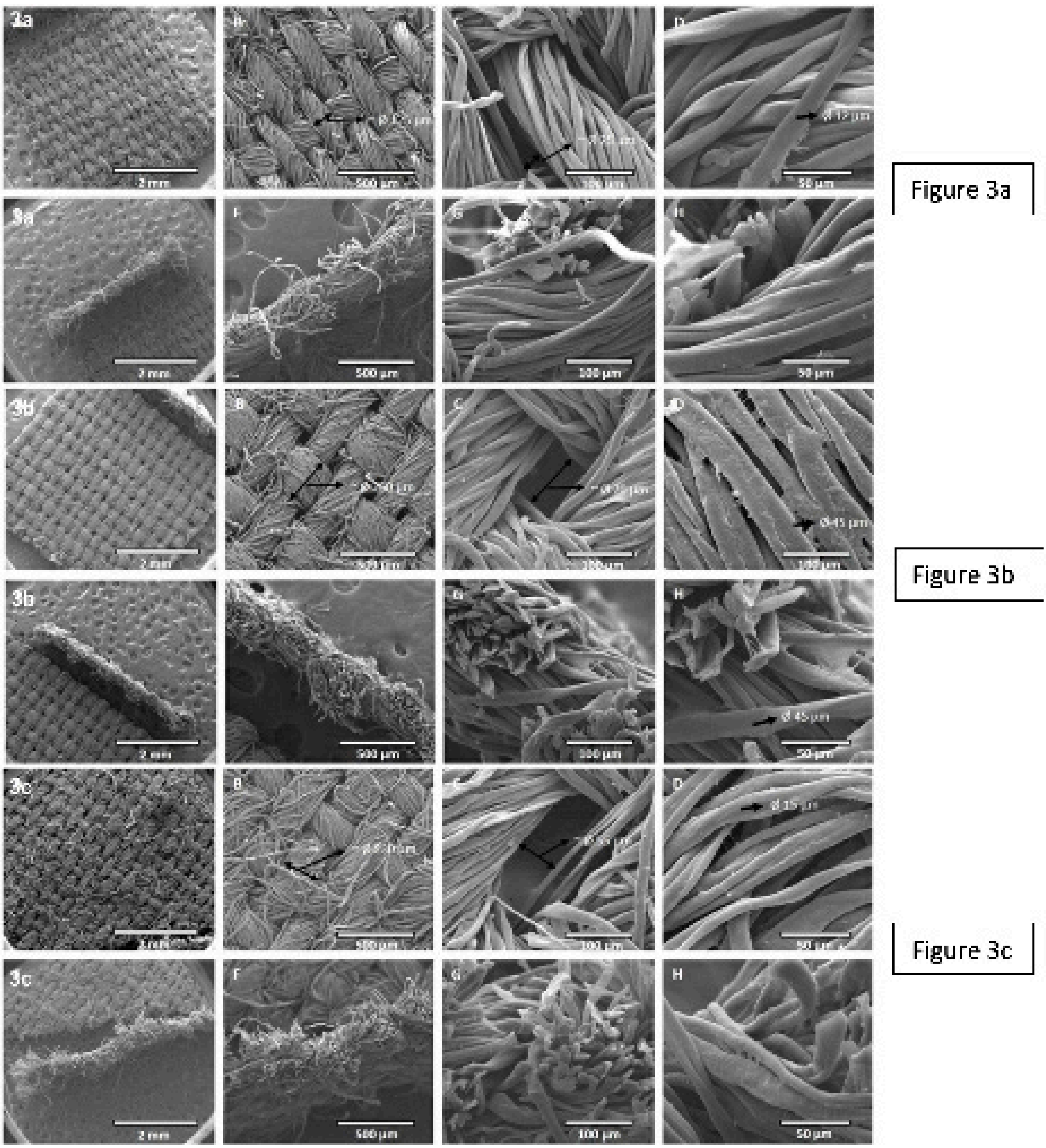
Source: Electron Microscopy and Microanalysis Laboratory - Universidade Estadual de Londrina.

layers, which can be a difficult factor for the passage of air and make the use of this mask a little more uncomfortable than the other samples analyzed.

In Figure 3a is the blue tricoline, in Figure 3b is the white tricoline, and in Figure 3c the printed tricoline fabric.

The non-fabric TNT, shown in Figure 4, has thick fibers, around 40-50μm, but the spaces between fibers are larger, ranging from 115 to 300μm, which means that this material does not offer adequate protection against COVID-19 contamination through droplets, even if it is a triple layer mask. Therefore, this material is not recommended for the manufacture of protective masks for use by the general population.

Figure 3. Electron micrographs and Energy Dispersive Spectroscopy given by Scanning Electron Microscopy of the analyzed sample of tricoline.



Source: Electron Microscopy and Microanalysis Laboratory - Universidade Estadual de Londrina.

The mesh, shown in Figure 5, is a fabric composed of 35% viscose and 65% polyester with a weight of 165g/m^2. It has large amounts of pores between its fibers (above 100μm). Despite appearing to be a thick fabric, these large pores make this type of fabric not recommended for the manufacture of masks for use by the general population, when it comes to protecting against COVID-19 contamination.

The material used for cleaning, known as multipurpose cloths, is composed of 70% viscose and 30% polyester and has spaces greater than 500μm. Therefore, this type of material should not be chosen to make protective masks for the general population either, as the holes between wefts are large enough to allow the passage of contaminated droplets, facilitating the transmission of COVID-19 between people, as shown in Figure 6.

Another point to be addressed is the mask that has a seam in front of the nose of the person who will use it, as shown in Figure 7. This type of mask is also not recommended for use in protection against COVID-19. In the analyzed material, there is a hole at the seam site that facilitates contamination between people.

The results of this study have been disseminated to the general population through local and state communication networks, and on social media.

DISCUSSION

The COVID-19 virus can be spread between people through droplets or airborne aerosols when infected people talk, cough or sneeze. When entering contaminated environments, they may be exposed to these agents(6).

The great challenge for the control of this pandemic is that people infected by COVID-19 may be asymptomatic, that is, not show any symptoms, and thus, infect other people, without even being aware of this fact.

Contaminated droplets can have various sizes and are classified as aerosols when they are smaller than 5μm. The droplets reach the upper airway (nasal fossa and oral cavity mucosa), as they are heavier particles and not airborne. Aerosols remain suspended in the air for long periods because of their size and play a fundamental role in the spread of the infection, as when inhaled they can penetrate deeper into the respiratory tract(6).

COVID-19 is caused by a virus measuring approximately 120nm (0.12μm). When inserted in droplets and in contact with the mask, the critical role of its transmissibility is reduced, as it adheres to the fabric of the mask(7). Therefore, the less porous and better structured the fibers of the fabric used for making the masks, the better the effectiveness of protection against the COVID-19 virus.

In a recent study, the filtration efficiency of fabrics for particles between 10nm and 10μm was evaluated. It showed that denser fabrics with tighter weaves and low porosity in their structure, as is the case of cotton, had best performance during the filtration test with aerosol particles(4), as also demonstrated in the present study.

The fabrics combined with cotton also showed effective filtration, as the joining of layers makes the mask hybrid with mechanical and electrostatic filtration(4).

Cotton fabric has shown a filtration rate of 5-80% for particles smaller than 300nm, and the effectiveness of this filtration is better when several layers of fabric are used(4). Thus, in this study, we recommended the manufacture of masks with triple layers of fabric.

In addition to choosing the fabric, no holes with needles for sewing or embroidery should be made in the wefts. This avoids the appearance of pores that can cause leaks in the masks and reduce their effectiveness of protection.

Comfort is another point that must be taken into account when making cloth masks. This is an important factor, as a mask that offers resistance to breathing and imposes an extra respiratory load on the user contributes to non-adherence to the proper use(8).

In this study, a fabric with gums or glues in its wefts due to the dye layers was evaluated, and this can hinder the passage of air during breathing. This inconvenience can be reduced by making a double layer mask, where the outer layer can be made of printed fabric and the inner layer of plain fabric.

When the mask is made with elastics that fit the user's ear, it can provide comfort during its placement and removal, thereby reducing the incidence of self-contamination during manipulation, as in the case of masks with ribbons tied to the head of users.

International and national agencies recommend the use of a cloth mask to reduce the transmission of the virus, as it works as a barrier. It must be made according to standards established by health agencies and the Brazilian Association of Technical Standards (Portuguese acronym: ABNT), in correct measurements for the user, completely covering the mouth and nose, without leaving spaces on the sides, since if not well-fitted to the face, it will not present efficient results(1,2,9).

Washing the masks may damage the fabric fibers, compromising the efficiency of filtration, as the fibers that make up the fabric can be damaged with each wash.

In a study, it was proven that after the fourth washing cycle, there is a drop of approximately 20% in the filtering efficiency of the mask, because of small changes in the morphology of the fabric surface often invisible to the eyes, increasing the size and shapes of pores(10).

Masks should be changed whenever they are damp, and discarded when the fabric or elastic that holds the face is damaged.

Masks reduce the exposure to droplets contaminated with COVID-19 through fabric filtration and sealing between

Figures 4, 5 and 6. Electron micrographs and Energy Dispersive Spectroscopy given by Scanning Electron Microscopy of the analyzed sample of TNT material (4), sample of PV mesh (5) and sample of material used for cleaning (6).

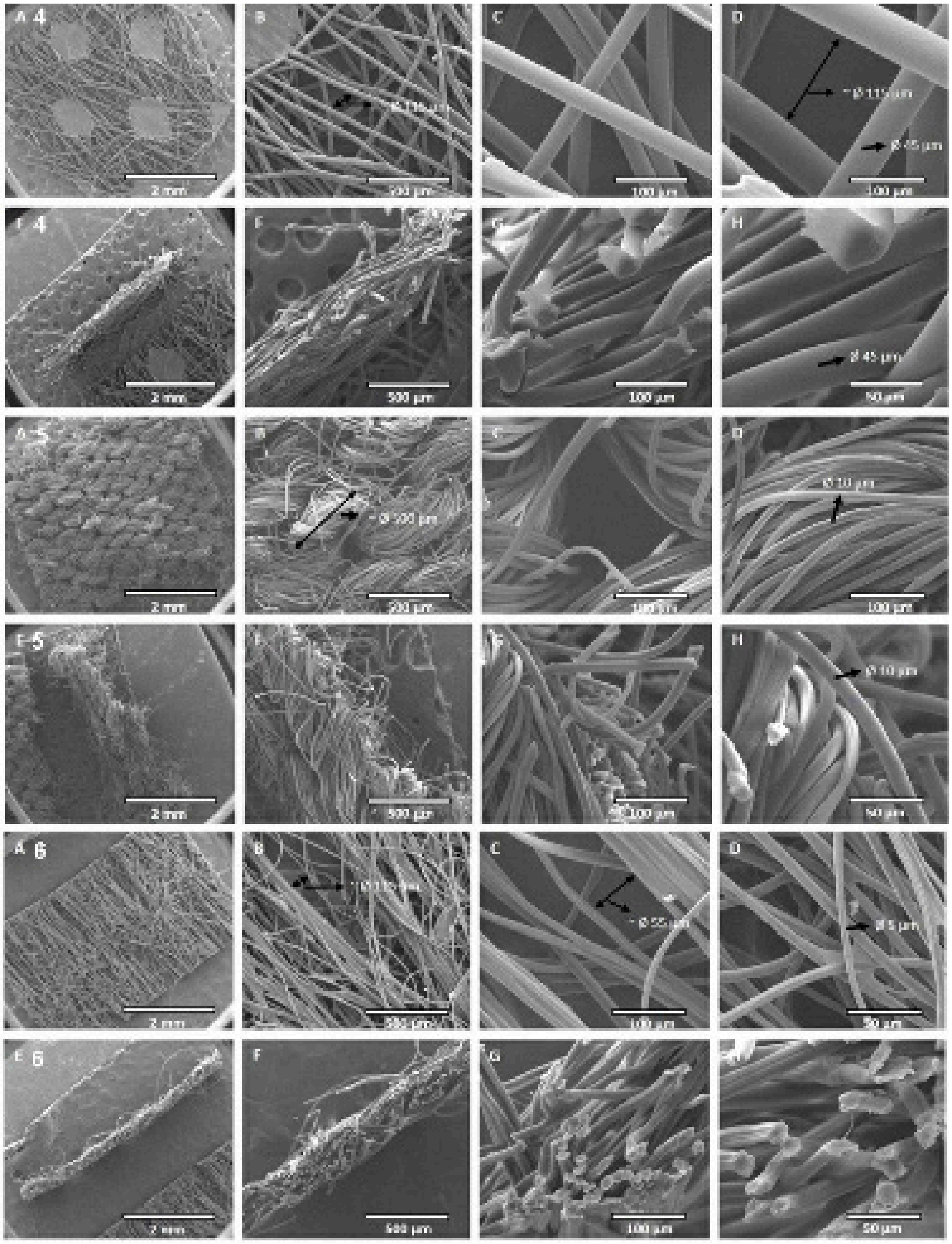


Figure 4

Figure 5

Figure 6

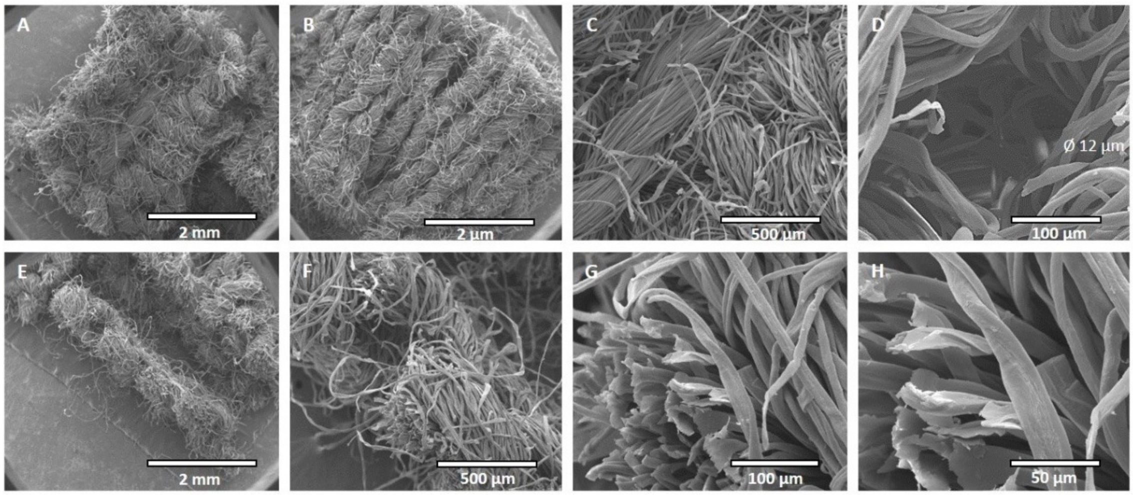
Source: Electron Microscopy and Microanalysis Laboratory - Universidade Estadual de Londrina.

the mask and wearer's face. However, the adoption of this measure must be implemented together with other measures recommended by the Ministry of Health, such as social distancing, hand hygiene and respiratory etiquette[11].

The limitation of this study was not including the performance of the particles filtration test in order to ensure the efficacy of the fabric filtration. However, it has potential in the results, as in fabrics analyzed, it was found that well-elaborated, dense and non-porous weaves have a protective effect against the dissemination of the COVID-19 virus.

In addition, this study provides subsidies for a larger project, which is the ongoing development of a prototype of a mask for the protection of hospital workers. It is under development by the research group to which these researchers

Figure 7. Electron micrographs and Energy Dispersive Spectroscopy given by Scanning Electron Microscopy of the analyzed sample of masks with seams in front of the nose.



Source: Electron Microscopy and Microanalysis Laboratory - Universidade Estadual de Londrina.

belong, thus, the need to continue this study in relation to knowledge on the filters used in the masks.

CONCLUSION

The results of the study allow the conclusion that the size, shape and distribution of the pores in the fabrics of homemade masks for use by the general population must be taken into account for their manufacture, so they provide significant protection against the transmission of particles contaminated with the COVID-19 virus.

Among the fabrics analyzed using electron microscopy, 100% cotton has a denser weft with thicker threads and little porosity. It offers an effective barrier to protect against infections for use by the general population. This type of fabric can be combined with other fabrics, such as water-repellent fabrics in order to make it a more effective mask.

The protection of the general population with the use of homemade masks must be combined with other prevention measures such as hand hygiene, respiratory etiquette and social distancing.

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